

WISE | annual report

Waterloo Institute for Sustainable Energy

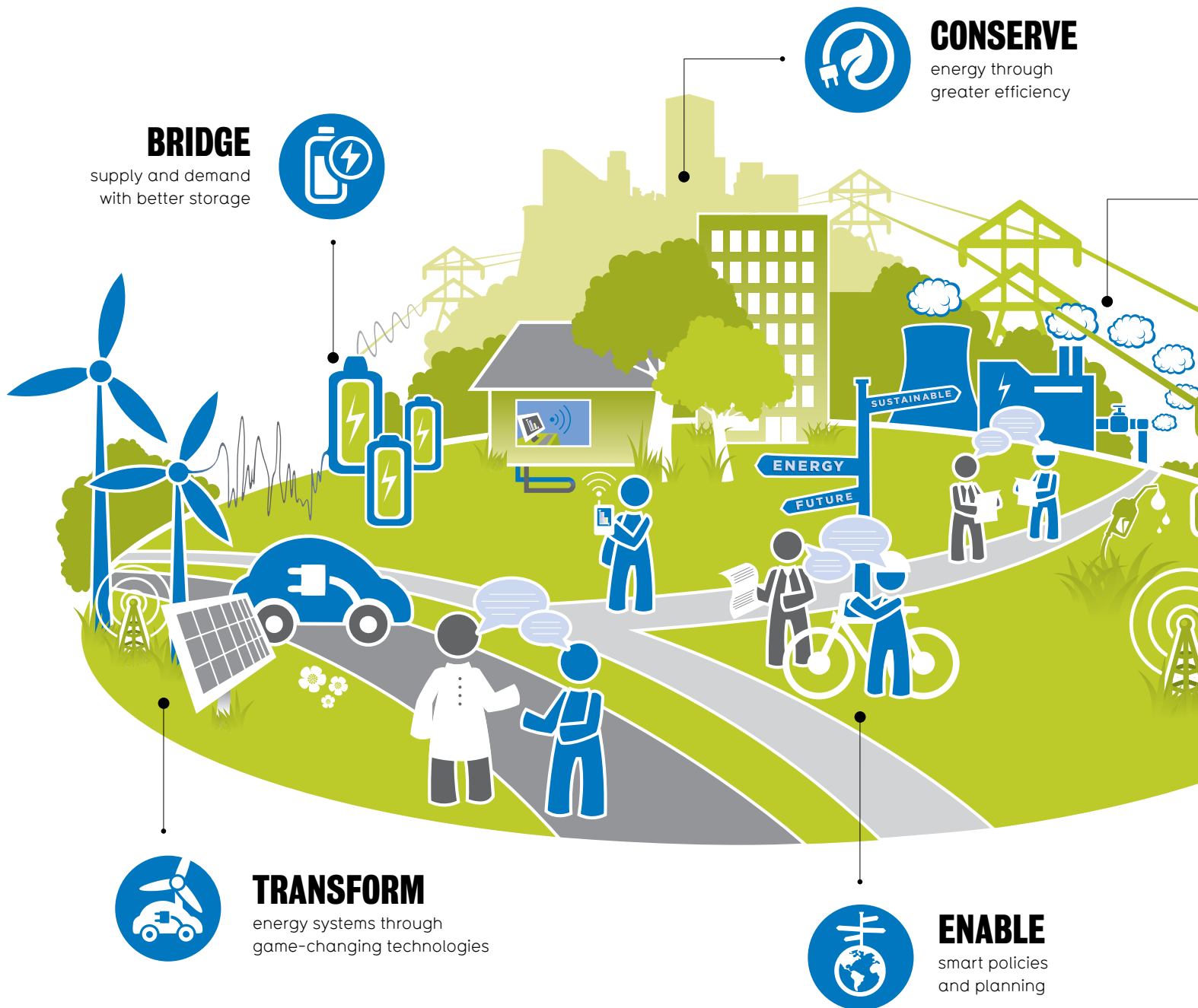
2016-2017



UNIVERSITY OF
WATERLOO



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 refashion 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.





TABLE OF CONTENTS

INTRODUCTION

Mission and Strategic Objectives	2
A Note from the Executive Director	3
Explore WISE	4

COLLABORATE

Energy Initiatives	8
Education and Training	8

REACH OUT

Energy Research Themes	10
1. Affordable Energy for Humanity (AE4H) - A Global Change Initiative	12
2. Energy Storage	17
3. Bioenergy	20
4. Solar Energy	22
5. Low Carbon Energy Futures	24
6. Healthy Grid	25
Events	26
WISE Participation	27

INFLUENCE

Informing Public Dialogue	31
Public Lecture Series	31
Research Spotlights	32
Publications and Invited Presentations	34
Awards and Recognition	37

WISE BY THE NUMBERS

OUR PEOPLE

Advisory Council	40
Internal Board of Management	40
WISE Members	41
Senior Executive Fellows	41
Staff	41
AE4H Participants	42

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 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

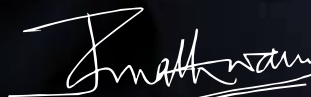
Establish WISE as the authoritative source of energy insights and analysis, and translate important scientific discoveries for a wide audience, informing energy policy both here and around the globe.

A NOTE FROM THE EXECUTIVE DIRECTOR

We remain committed to advancing the research efforts of our members and help amplify the scope and recognition of their contributions. Our faculty members and graduate students remain fully engaged in research projects working with businesses, utilities, government agencies and the 'not-for-profit' entities.

During the past year, we have made important strides in several areas of energy research relevant to the development of a cleaner energy system that meets the changing requirements of our national aspirations. Canada is fully committed to lowering our carbon footprint, and even though the aspirational targets are challenging, we strongly believe that we can get to a low carbon economy without jeopardizing our economic well-being.

Our vision is the advancement of clean energy solutions, accessible and affordable for all.



JATIN NATHWANI, Executive Director

RESEARCH LABS



BRIDGE

Applied Nanomaterials
and Clean Energy Lab
Carbon Nanomaterials Lab
Fuel Cell and Green
Energy Lab
Giga to Nano Center
Nazar Research Group



CONSERVE

Advanced Systems
Glazing Lab
Information Systems
and Science for
Energy Lab (ISS4E)
Sustainable Energy
Policy Group



DELIVER

Electricity Market Simulation
and Optimization Lab
High Voltage Energy Lab
Information Systems and
Science for Energy Lab
Non-destructive Testing Lab





ENABLE

Sustainable Energy
Policy Group



IMPROVE

Center for Pavement and
Transportation Technology Lab
Mechatronics Vehicle Lab
Non-destructive Testing Lab
Qing-Bin Lu's Lab
Solar Thermal Research Center



TRANSFORM

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 2 Nano Centre
Mechatronics Vehicle Lab
Solar Thermal
Research Center
Advanced Glazing
System Lab
Laboratory for Research
in Thermochemical
Process and Green Energy
Sustainable Reaction
Engineering 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.

However, we're not content to simply gather great minds under the WISE umbrella. Rather, we actively work to foster connections amongst our members and promote the kind of multidisciplinary projects required to solve complex, global problems.

PHOTO CREDIT: Michael Bennett & the Waterloo Global Science Initiative. This work is licensed under the Creative Commons Attribution-NonCommercial 2.0 Generic License. To view a copy of this license, visit <http://creativecommons.org/licenses/by-nc/2.0/> or send a letter to Creative Commons, PO Box 1866, Mountain View, CA 94042, USA.

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.

However, we're not content to simply gather great minds under the WISE umbrella. Rather, we actively work to foster connections amongst our members and promote the kind of multidisciplinary projects required to solve complex, global problems.

PHOTO CREDIT: Michael Bennett & the Waterloo Global Science Initiative. This work is licensed under the Creative Commons Attribution-NonCommercial 2.0 Generic License. To view a copy of this license, visit <http://creativecommons.org/licenses/by-nc/2.0/> or send a letter to Creative Commons, PO Box 1866, Mountain View, CA 94042, USA.

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.

However, we're not content to simply gather great minds under the WISE umbrella. Rather, we actively work to foster connections amongst our members and promote the kind of multidisciplinary projects required to solve complex, global problems.

PHOTO CREDIT: Michael Bennett & the Waterloo Global Science Initiative. This work is licensed under the Creative Commons Attribution-NonCommercial 2.0 Generic License. To view a copy of this license, visit <http://creativecommons.org/licenses/by-nc/2.0/> or send a letter to Creative Commons, PO Box 1866, Mountain View, CA 94042, USA.

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.

However, we're not content to simply gather great minds under the WISE umbrella. Rather, we actively work to foster connections amongst our members and promote the kind of multidisciplinary projects required to solve complex, global problems.

PHOTO CREDIT: Michael Bennett & the Waterloo Global Science Initiative. This work is licensed under the Creative Commons Attribution-NonCommercial 2.0 Generic License. To view a copy of this license, visit <http://creativecommons.org/licenses/by-nc/2.0/> or send a letter to Creative Commons, PO Box 1866, Mountain View, CA 94042, USA.



ENERGY INITIATIVES

The Waterloo Institute for Sustainable Energy (WISE) is currently involved in multiple R&D initiatives with industry leaders in the energy sector. We explore boundaries of scientific knowledge to bring a critical mass of expertise to develop solutions that integrate experience and challenges from the outside world into our internal academic perspectives. Data driven strategic research, modeling and planning helps advance basic and applied research for subsequent commercialization. Addressing the technical and economic issues of low carbon energy technologies is a priority for WISE. The research activities include convergence of Information and Communication Technology (ICT) within the existing and emerging energy systems. Many ICT-enabled prototypes developed in our labs have already proved that ICT can contribute to large-scale improvements in the power and energy sector leading to increased efficiency and a decrease in greenhouse gas (GHG) emissions.

EDUCATION AND TRAINING

ENERGY COUNCIL OF CANADA

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 FELLOWSHIP

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.

In February 2017 WISE Fellows were invited to give poster presentations at the 2017 Canadian Energy Industry – Updates and Insights held in Ottawa. Three students gave presentations at the conference with the theme “Reducing Emissions from Energy Use: Policies, New Initiatives, What’s Needed”. It was an important opportunity for the students to meet and network with Energy Council of Canada members. As a result, valuable sources of data collection and mentoring connections were identified.



BENJAMIN SANCHEZ

“Methodology for improving the net environmental impacts of new buildings through Product Recovery Management”

This event was the link between the academic world and the field for Ben. He had the opportunity to learn the current policy initiatives and needs related to his research topic and to hear the opinion of stakeholders in industry and government which directly impacts how he will be able to continuously shape the approach and scope of his research.

... This was a unique opportunity to understand the relevance of my research and the aspects that matter for the general public.



BRONWYN LAZOWSKI

“Engaging Residential Consumers Using Smart Grid Tools”

The event gave Bronwyn the opportunity to hear insights on Canada’s energy transition from the Minister of Natural Resources, the Honourable James Carr and to network with insightful actors across the energy sector.

A variety of useful exchanges gave her the opportunity to receive informative and valuable feedback on her research and hear first-hand whether her research is valuable outside of academia – in which it sounded like it was!

... The poster presentation provided a valuable format, which allowed me to make meaningful connections with insightful actors within the energy sector.



STEPHANIE WHITNEY

“Applying social theories to conservation initiatives”

Stephanie was pleased to be able to engage with other participants through her presentation, mingling and deeper conversations.

... I was pleased with the level of interest from and engagement with the attendees at the recent ECC event.

**18 FELLOWSHIPS
\$247,000**

have been awarded since 2013

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 6 ENERGY RESEARCH THEMES:

1. Affordable Energy for Humanity (AE4H) – A Global Change Initiative
2. Energy Storage
3. Bioenergy
4. Solar Energy
5. Low Carbon Energy Futures
6. Healthy Grid





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



Having reliable access to electricity is essential to decent quality health centres, schools, and homes. Using electricity to pump water or light up a shop at night opens up economic opportunities that can allow individuals and families to climb out of poverty for the first time.

In addition, achieving universal access to affordable, reliable, sustainable and modern energy – enshrined by the United Nations as Sustainable Development Goal 7 – will help determine whether or not the global community will reach its climate change targets.

These twin objectives of: a) providing energy for an additional billion people so that they can live better lives; and b) doing so with energy sources that do not exacerbate environmental problems – make SDG 7 the quintessential sustainable development challenge of this century. If we do not tackle this, it's hard to imagine a future where we achieve the rest of our global goals.

This is why in September 2015 the Waterloo Institute for Sustainable Energy, in partnership with a global consortium of partners, launched the Affordable Energy for Humanity Initiative. This platform for collaboration aims to bring Waterloo innovation to the global fight against energy poverty.

One of our first major activities, in April 2016, was to work with the Waterloo Global Science Initiative to host a global summit on the topic, bringing leading innovators and practitioners from all over the world to Waterloo. In March 2017 we released the final report from this process, the 'OpenAccess Energy Blueprint'. This document lays out a number of concrete steps that decision-makers can take in the areas of policy, finance, entrepreneurship support, education and skills training to move this agenda forward. The document has since received support from, amongst others, the Offices of the Ontario Premier and Governor General of Canada, as well as from the World Bank and the Enel Foundation.

Moving forward, we are excited to announce that we will be hosting the 'AE4H Innovation Lab' in Germany in June 2017. This event will bring together many of our partners to develop proposals for concrete actions to operationalize the recommendations of the blueprint report.

An overview of some of our activities and accomplishments over the past year are on the following pages.

OPENACCESS ENERGY BLUEPRINT PUBLICATION

Together with the Waterloo Global Science Initiative (WGSi), AE4H has developed the OpenAccess Energy Blueprint to achieving universal electricity access. This document is the result of multinational, multidisciplinary and multigenerational collaboration at

WGSi's OpenAccess Energy Advisory Workshop (October 18–20, 2015), Summit (April 24–27, 2016) and further engagement with energy sector researchers, leaders and advisors. AE4H Manager Nigel Moore co-authored the report alongside New Scientist writer Michael Brooks.



The OpenAccess Energy Blueprint features:

- › insight into proactive governance, creating a fair marketplace, empowering people, and effective entrepreneurship for energy access;
- › a feature section on energy access challenges in Canada's remote Indigenous communities;
- › Solutions Spotlights featuring innovative technologies, business and finance models;
- › a commitment to establishing and nurturing partnerships on the road to establishing energy access.

The pathway we recommend involves four clear steps, each of which requires the implementation of a number of strategies:

1. **Enable** – Establish national energy plans, and a policy and regulatory environment conducive to the creation of off-grid electricity services;
2. **Align** – Facilitate creative alliances between those seeking to provide electricity services and those who can finance the projects;

3. **Empower** – Build the human capacity to allow the sector to thrive – especially drawing on the strength of women and community members to deliver solutions at the ‘last mile’ through education, training and networking;
4. **Incubate** – Create financially sustainable platforms to help energy entrepreneurs succeed in creating sustainable energy businesses that can serve even the most difficult and impoverished markets.

Energy access – the Canadian context, a special section in the OpenAccess Energy Blueprint, acknowledges the role of energy as the backbone of a better quality of life for Canada's remote and Indigenous communities and our responsibility to provide the supportive resources these communities need to not only meet their current minimum energy needs but to plan for plenty.

Four steps are required to establish this as an area of national priority:

1. **Commit to a step change in investment** – Canada's federal government should increase its overall funding commitments for energy in remote communities from the tens of millions to the billions in the immediate future. This funding should be seen as a priority area for ongoing green infrastructure spending programs.
2. **Recognize Indigenous leadership and support capacity building** – In order to ensure long-term economic and social benefits, Indigenous clean energy leadership must be recognized and supported through capacity building programs.
3. **Create a single, intergovernmental point of contact** – A single point of contact within government – whose responsibility is to ensure those initiating and managing energy projects can navigate regulations, funding and reporting at the federal and provincial/territorial level and across relevant departments – is essential.
4. **Connect people, technologies and information** – Knowledge sharing between communities and innovative institutions is critical to success. Private and public sectors should be encouraged to utilize up-to-date information and innovative technologies to seek new arrangements for energy projects in remote communities that are financially sustainable over the long term.



Uche Onuora, co-founder of Hitch, speaking at IoT Waterloo Region event in April 2017

ENERGY ACCESS VENTURES AND ENTREPRENEURSHIP

AE4H is supporting two entrepreneurs at the Velocity incubator who are working on energy access ventures. The first is Orbit, founded by solar technology expert Michael Sinclair, who is in the process of writing a report for AE4H on the challenges and opportunities that western entrepreneurs face in trying to set up renewable energy enterprises in the developing world. The other is Hitch, founded by ICT expert and native Nigerian Uche Onuora. AE4H has supported Hitch in hiring a co-op student programmer to refine their prototype technology, which enables off-grid internet access and content caching in remote regions, powered by solar energy. Hitch's technology will be field tested in Nigeria in May 2017. Both Uche and Michael will also be participating at the AE4H innovation Lab in June 2017.

STUDENT INTERNSHIPS AND FIELD PLACEMENTS

AE4H has developed relationships with approximately 20 small and medium private enterprises delivering energy access solutions in Sub-Saharan Africa, South East Asia and the Caribbean. A select number of internship opportunities with these organizations is being actively advertised to UWaterloo students in partnership with UWaterloo's MDP Program (SEED, Environment). AE4H is also in the process of building a web-based platform that acts as a one-stop shop for students to find internship opportunities in energy access enterprises.



APPLICATION TO MacARTHUR FOUNDATION'S 100 & CHANGE COMPETITION

In October 2016 AE4H submitted a major grant application for \$100 Million to pursue the creation of a global fellowship and research program that aims to develop the next generation of energy access innovators and practitioners and provide them with a pathway to test their ideas and launch ventures across the developing world. The application was a major effort submitted with the support of 29 partner institutions across the world. Though not selected as one of the 9 finalists, the AE4H application was ranked in the top 200 out of 2000 applications and is now featured on the MacArthur Foundation 100 & Change website alongside the other top 200 proposals.

NEXT STEPS: ENERGY ACCESS INNOVATION LAB EVENT

In June 2016 AE4H was awarded an International Research Partnership Grant from the University of Waterloo's International Office with matching funds from partners at the Karlsruhe Institute of Technology (Germany) and Waterloo Global Science Initiative. AE4H will use these funds to host a 2.5 day 'Innovation Lab' at the Institute for Advanced Sustainability Studies in Potsdam, Germany in June 2017.

The event will bring together 54 AE4H members from academia, civil society and the private and public sectors to define and shape key pathways for technology innovation and capacity building to support universal energy access. The forum will develop funding strategies, develop best practices for research in the field and the lab and launch new collaborative projects.

2 ENERGY STORAGE

Energy storage technologies provide valuable support to power grids as backup power, load leveling, frequency regulation, voltage support, grid stabilization, and energy management services. Rapid development of variable renewable energy resources (wind and solar) suggests a growing role for storage to accommodate the intermittency of the generation. The need for balancing services, rapid generation ramping, and moving energy from times of excess to times of high demand are expected to increase with high levels of wind and solar energy penetration – exactly the types of services that energy storage can provide.

i) Distributed Battery Storage

Batteries can play a significant role in managing variability and support the decentralized nature of renewable energy technologies to ensure a reliable electricity supply. At high levels of penetration, the fluctuations of energy output increases the risk for reliable operation of the grid. The physics of power flows requires supply and demand of electricity must be balanced at all times. The battery is charged when excess power is available and later discharged as needed. This storage technology can be used for both short (seconds-minutes) and long-term (hours-seasons) applications (i.e. both power and energy services) and benefits from being highly scalable and efficient.

Battery storage in the power sector needs to overcome several barriers before it can be integrated as a mainstream option. One barrier is the lack of monetary compensation schemes available for the benefits of battery storage systems. Cost-competitiveness, validated performance and safety are others. The regulatory construct built around a legacy system of centralised generation and load-driven system planning is another factor.



LINDA NAZAR
Professor, Chemistry

Professor Nazar (Chemistry) has developed the concept of aqueous batteries to provide cost-effective, durable, and safe options to battery storage applications. In this battery storage technology, using zinc as the negative electrode, addresses the issues of low energy density, slow charge and discharge speeds and inability to hold a charge over many cycles. The other issues have been tackled by building a better positive electrode. Professor Nazar and her team has created nanobelts of vanadium oxide bronze ($\text{Zn}_0.25\text{V}_2\text{O}_5 \cdot n\text{H}_2\text{O}$), with metal ions and structural water sandwiched between sheets of oxide. The result is a compact electrode structure that allows aqueous batteries to charge and discharge quickly and this technology retains more than 80 per cent of its capacity over 1,000 cycles. The nanobelts are also easy to fabricate on a large scale. At a cost of less than US\$65 per kilowatt-hour, these batteries offer a highly affordable solution for grid-scale storage.



ZHONGWEI CHEN
Professor, Chemical Engineering

Professor Chen's (Chemical Engineering) work is on a specific anode material that can maximize the performance of a lithium ion battery (LIB) in energy storage options. LIB can play a vital role as renewable energy storage devices for applications in electric vehicles and portable electronics. Commercial LIBs employ graphite as the anode material with a low capacity unable to satisfy the energy demand of emergent systems. There is a need to develop new anode materials with high capacity and reliability as well as low fabrication cost for practical applications. The LIB using the innovatively developed anode material by Prof. Chen and his team can deliver a high volumetric capacity of $2350 \text{ mA h cm}^{-3}$ and exhibit superior cycle stability over 1500 cycles as well as a high capacity retention of 85% at a 1 C rate. The excellent battery performance combined with the simplistic, scalable, and green chemistry approach makes this material a promising candidate for LIB applications.

ii) Flywheels

Flywheel energy storage systems (FESS) offer several unique advantages as an energy storage solution with attributes of a high cycle life, long operational life, high round-trip efficiency, high power density, low environmental impact, and ability to store megajoule (MJ) levels of energy with no upper limits when configured in banks.

Flywheels are mechanical devices that spin at high speeds, storing electricity as rotational energy. This energy is later released by slowing down the flywheel's rotor, releasing quick bursts of energy (i.e. releases of high power and short duration).

Professor Salama (Electrical and Computer Engineering) and his team have proposed a unique approach, using a flywheel to store excess electricity during off-peak periods and also reduce voltage fluctuations. The system consists of a flywheel, a permanent magnet synchronous machine and three-phase back-to-back converters. The researchers put it to the test in a simulation of a residential distribution network that includes photovoltaic panels. The results show that incorporating a flywheel energy storage system can compensate for the fluctuations in output power, thus reducing the need for an automatic voltage regulator. Thus, more electricity produced by solar panels is actually used, extracting maximum benefit from each ray of sunshine.

iii) Compressed Air Energy Storage (CAES) in Salt Caverns

Compressed air energy storage (CAES) in salt caverns represent an innovative concept for storing very large amount of energy below the ground. It is a highly flexible energy storage system that can provide storage at any scale, up to large grid scale if conditions are suitable. This technology has a huge potential in balancing energy on transmission networks, owing to its use of mature technologies and low cost per unit of storage capacity.

Professor Dusseault (Earth and Environmental Sciences), Professors Canizares and Bhattacharya (Electrical and Computer Engineering), Professor Fraser (Mechanical and Mechatronics Engineering), Professor Basu (Civil and Environmental Engineering), and Professor Nathwani (Management Sciences) have initiated this project with Ontario Power Generation (OPG), Union Gas, NRStor, Compass Minerals, and Rocky Mountain Power (RMP). The preliminary assessment has shown the CAES in salt caverns is a technically feasible and financially viable technology. In addition, it is concluded that CAES integrates well with battery energy storage because they occupy different response-time regions and are of different scales of output over demand times (seconds to days). A CAES grid-scale facility combined with on-site battery storage capability is an excellent combination for large-scale grid management.

3 BIOENERGY

Bioenergy has the potential to make an important contribution to meeting growth in energy demand. This contribution can be expanded very significantly in the future, providing greenhouse gas savings and other environmental benefits including opportunities for social and economic development in rural communities. Biomass energy conversion technologies include:

i) Thermal and Thermochemical Technologies

A thermal conversion is the use of heat, with or without the presence of oxygen, to convert biomass materials or feedstocks into other forms of energy. Thermal conversion technologies include direct combustion, pyrolysis, and torrefaction. Thermochemical conversion is the application of heat and chemical processes in the production of energy products from biomass. A key thermochemical conversion process is gasification.



ALI ELKAMEL
Professor, Chemical Engineering

Professors Elkamel and Anderson's (Chemical Engineering) work is on a conceptual design of a peat gasification process to produce electricity and methanol. Two types of gasifiers (i.e., updraft fixed-bed and dual fluidized-bed) and two types of methanol synthesis reactors (i.e., gas-phase and liquid-phase) are paired to create four design alternatives that are modeled in Aspen Plus software. The chosen design is then refined with detailed modeling of the power generation section and energy integration. The final design consumes 1,000 tonne peat/day, produces 214 tonne methanol/day, and generates 56 MW of electricity with GHG emissions reduced by 22 per cent.



BILL ANDERSON
Professor, Chemical Engineering

ii) **Biological and Biochemical Technologies**

Micro-organisms can be regarded as biochemical “factories” for the treatment and conversion of biological materials. Fermentation technologies, with the assistance of biological engineering, are leading to breakthrough processes for creating fuels and fertilizer, and other products useful in agriculture and energy sector. Anaerobic digestion and fermentation are key biochemical conversion technologies.

Professor Lee’s (Civil and Environmental Engineering) work involves production of hydrogen from sugar beet juice using an integrated biohydrogen process of dark fermentation and microbial electrolysis cell. The overall hydrogen production from the integrated biohydrogen process was 25% of initial chemical oxygen demand (COD) and the energy recovery from sugar beet juice was 57 per cent using the combined biohydrogen.

Professor Lee is also focusing on the concept of microbial fuel cells with emphasis on three key areas i.e. (i) Adding an electron scavenger to the system to prevent the efficiency drop that occurs when the electrons produced from bacteria are grabbed on route to the anode, (ii) Using large quantities of *Geobactersp.* to increase the current density within the tiny fuel cells, and (iii) Reducing the internal resistance within MFCs by designing fuel cells with a high surface-to-volume ratio and adjusting the distance between electrodes.



FLORA NG
Professor, Chemical Engineering

Professor Ng (Chemical Engineering) has turned to acid catalysts to create a cost-effective and green alternative. She is performing several analytical studies to evaluate the feasibility of producing biodiesel from high-FFA (free fatty acids) feedstock without the problem of soap by-products by using a novel solid acid catalyst and converting the oil's triglycerides and FFAs into biodiesel in a single-step process. One of her key focused areas is to produce biodiesel with glyceride levels and acid numbers that met international biodiesel standards by adding a water-stripping step.

4 SOLAR ENERGY

The growth in the solar sector is helping pave the way to a cleaner, more sustainable energy future. Over the past few years, the cost of a solar energy system has dropped significantly resulting in increased solar energy deployment across Canada. As a clean energy resource, solar supports broader national priorities with respect to climate change mitigation.

i) Quantum Dots for Next Generation Solar Photovoltaics (PVs)

Quantum dots (QDs) are semi-conductors on a nanometer scale described as colloidal quantum-confined semiconductor nanostructures. They are an emerging class of functional material being developed for novel solar energy conversion strategies. First and second generation photovoltaic (PV) cells have best-cell power conversion efficiencies (PCE) that are asymptotically approaching the Shockley-Queisser (SQ) limit; for example, the record for c-Si based solar

cells is currently at 25 per cent, while for GaAs the record is 28.3 per cent. Third generation PV can have a higher limiting conversion efficiency by bypassing one of the assumptions of the SQ analysis and recovering either some of the energy lost via thermalization or providing pathways to harvest those photons not absorbed in a standard solar cell. In addition to the efficiency considerations, third generation solar cells promise low manufacturing costs.

Professor Sivoththaman's (Electrical and Computer Engineering) team has examined the toxicity and safety aspects of nanoparticle spread in third generation photovoltaic device processing environments. Detection strategies for analysis of the nanomaterials toxicity has been evaluated. Detection of aerosolized nanoparticles was experimentally verified using gold nanoparticle adsorbent, followed by spectroscopic measurements. Results from in-vitro cytotoxicity study with HeLa cell cultures and fluorescent plate reading confirms that core/shell 'CdSe/ZnS' QDs are responsible for cell death following exposure.

ii) Solar Roadways

Professor Tighe (Civil and Environmental Engineering) has conducted a finite element analysis to predict how her solar road based prototype would perform in real-world

conditions. Using modelling software, her team tested the panel's

durability on four structural bases typically used in Ontario

pavement: concrete, asphalt, granular and subgrade. For each,

they applied the maximum wheel and axle loads allowed

under Canadian regulations to different areas on the panels,

checking whether they would crack or fail under the pressure.



In all cases, there were no cracks and the strain put on the

transparent and base layers of the panels fell well below their

endurance limits, demonstrating that the prototype is road-worthy.

Additional reinforcement provided by the solar panels helped distribute tire loads,

actually maintaining or improving the structural performance of the base they're

installed on. The results suggest that researchers can move their trials out of the

lab and into the field – paving the way for a network of solar highways.

iii) Solar Thermal

Solar thermal technology uses the sun's energy to generate low-cost, environmentally friendly thermal energy.

Professors Collins and Wright's (Mechanical and Mechatronics Engineering) current

work is on solar thermal technologies with a focus on efficient design of the building

envelope and providing accurate estimates of glass-to-shade heat transfer

coefficient for intermediate spacing.

They have developed shading devices attached to windows that can be used

to control solar gain and hence reduce building peak load and annual energy

consumption. The performance of a shading device in this regard is strongly

dependent on its solar optical properties. Unique measurement techniques have been

developed to obtain off-normal solar optical properties of flat shading materials.

The off-normal properties are needed in order to develop solar optical property

models both for shading materials and shading devices. These models provide

useful input to building peak load calculation and annual energy simulation tools.

5 LOW CARBON ENERGY FUTURES

i) Waterloo Regional Decarbonization Forum

Professor Douglas (Philosophy) in collaboration with Balsillie School of International Affairs (BSIA) launched the Decarbonization Forum: Charting Waterloo's Energy Future, with the aim to envision a carbon free Waterloo Region working with 50 experts, drawn from academia, local institutions, government, businesses, and local NGOs explored options for replacing our dependence on fossil fuels with a sustainable energy system.



HEATHER DOUGLAS
Professor, Philosophy

The goal of the forum was to allow local stakeholders to incorporate a holistic view of our energy system and identify major decarbonization challenges. **The challenges identified to be met prior to 2050 include:**

1. Dramatically reducing energy needs of the build environment
2. Maximize local renewable power generation
3. Eliminating fossil fuels based transportation
4. Replacing natural gas as a source of energy for heating

ii) Green Infrastructure

Professors Fowler and Elkamel's (Chemical Engineering) strategy is to decarbonize transportation through the use of power-to-gas for oil refining operations. Power-to-Gas is a technology that generates hydrogen by electrolysis. It can be used to provide a number of energy services including energy storage, ancillary services for the electrical grid and, the production of hydrogen for industrial processes and transportation fuel. The purpose of this work is to provide an incentive for using power-to-gas technology for oil refining processes in an effort to reduce the carbon footprint in refining industry and ultimately the transportation sector.

It also highlights the optimal size and operation of the hydrogen production facility that include polymer electrolyte membrane (PEM) electrolyzers to meet the proposed refinery demand. One of the advantages of providing green hydrogen to oil refining is that it is an opportunity to reduce the carbon footprint of the transportation sector and emissions on a life cycle basis. The researchers note that power-to-gas is an economically feasible approach to produce hydrogen. The use of PEM electrolysis to provide hydrogen results in a significant reduction.



6 HEALTHY GRID

The growth of analytics for monitoring electric distribution assets is transforming utility management strategies. New innovative solutions help utilities prevent equipment failure while optimizing management strategies for critical distribution infrastructure.

i) Non-Destructive Testing of Wood Poles

Dr. Tallavo (Research Associate), Professors Cascante and Pandey (Civil and Environmental Engineering) have developed a prototype to do non-destructive testing (NDT) condition assessment of wood poles. To avoid failures and to ensure the reliability of the electrical network, the internal condition of wood poles must be assessed on an ongoing basis as part of an active maintenance strategy. The prototype in discussion has the ability to give quantitative measurement of the internal condition of wood poles with high accuracy, detects early decay and estimates the remaining strength of the poles with precision, and reduces the time required to perform reliable inspection.

EVENTS

- › Energy Day 2017 | **30 Mar 2017**
- › Resource Recovery Partnership Webinar: Energy from Waste | **8 Feb 2017**
- › The first annual Technology Innovation and Policy Forum 2016 – Microgrids & Distributed Energy: Is there a revolution in the making? | **24 Nov 2016**
- › Decarbonization Forum | **17-18 Nov 2016**
- › Sustainable Development Technology Canada Workshop | **28 Oct 2016**
- › Compressed Air Energy Storage Student presentations | **17 Oct 2016**
- › University of Waterloo Academic – Industry Networking Forum on Greenhouse Gases | **12 Oct 2016**
- › Resource Recovery Partnership Workshop | **23 Jun 2016**
- › The Open Access Energy Summit | **24-27 April 2016**
- › 2016 Council for Clean and Reliable Energy Energy Leaders Roundtable | **13-15 Apr 2016**
- › Sarnia-Lambton Energy Symposium | **11 Feb 2016**
- › Power Shift Design for Development Event | **25 Feb 2016**

ACM E-ENERGY 2016

Hosted this year by Lukasz Golab and Srinivasan Keshav et al.

21-24 June 2016 held at the Delta Hotel, Waterloo

conferences.sigcomm.org/eenergy/2016

The seventh ACM International Conference on Future Energy Systems (ACM e-Energy) aims to be the premier venue for researchers working in the broad areas of computing and communication for smart energy systems, and in energy-efficient computing and communication systems.

By bringing together researchers in a high-quality single-track conference with significant opportunities for individual and small-group interaction. This event served as a major forum for presentations and discussions to shape the future of this area.

EXECUTIVE DIRECTOR - INVITED SPEAKER

- › TD Walter Bean Lecture in Environment | **28 March 2017**
- › Energy Storage Symposium – University of Waterloo | **27 Feb 2017**
- › Canadian Nuclear Association Conference and Trade Show | **23 Feb 2017**
- › Canadian Electricity Association Seminar | **16 Nov 2016**
- › Faculty of Environment Knowledge Integration Seminar-UW | **4 Nov 2016**
- › Royal Canadian Institute for Science | **30 Oct 2016**
- › EUCI Aboriginal Energy Challenge | **26 Oct 2016**
- › Toronto Region Board of Trade Energy Roundtable | **5 Oct 2016**
- › International Economic Forum of the Americas – Toronto Global Forum | **13 Sept 2016**
- › Ministry of Energy Roundtable | **31 May 2016**
- › Waterloo Unlimited Grade 10 Math Class | **17 May 2016**

WISE PARTICIPATION

- › ACM E-Energy 2016: The 7th International Conference on Future Energy Systems | **21-24 June 2016**
- › Conference on Electrical Insulation and Dielectric Phenomena Workshop: Information High Frequency Transients in Insulation Systems (Prof. Shesha Jayaram) | **16 Oct 2016**
- › ECOLOO (University of Waterloo) | **25 Oct 2016**
- › Eco-Summit 2016 (University of Waterloo) | **6 Jul 2016**
- › Karlsruhe Institute of Technology (Prof. Kankar Bhattacharya et al.) | **23-27 May 2016**
- › International Conference on Solar Technologies and Hybrid Mini Grids to Improve Energy Access – Bad Hersfeld Germany. Nigel Moore | **21-23 Sept 2016**
- › The Science of Scaling: Building Evidence to Advance Anti-Poverty Innovations – UC Berkeley Development Impact Lab. Nigel Moore | **26 Sept 2016**
- › Taiyuan China Summit (Prof. Roydon Fraser) | **7-9 Sept 2016**

ROYDON FRASER

Prof. Roydon Fraser, Department of Mechanical and Mechatronics Engineering, was invited to present his research relating to low-carbon energy development and the applications in the area of transportation. Prof. Fraser also presented the role and vision of WISE to help transform our energy future through partnership.



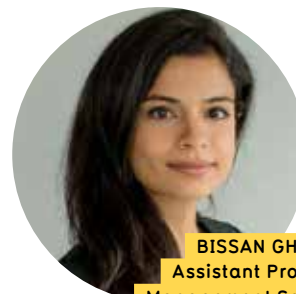
ROYDON FRASER
Professor, Department of Mechanical
and Mechatronics Engineering

- › ECC Ottawa event (Energy Council of Canada Energy Policy Research Fellows) | **6 Feb 2017**
- › Mathematical Optimization Conference (Prof. Bissan Ghaddar) | **29-31 Mar 2017**

BISSAN GHADDAR

Assistant Professor Bissan Ghaddar, Management Sciences, presented a talk on energy transmission and distribution at the Conference on Mathematical Optimization in the Decision Support Systems for Efficient and Robust Energy Networks held 29-31 March 17 in Modena, Italy with travel support from WISE. Prof. Ghaddar also provided promotional material about WISE to participants.

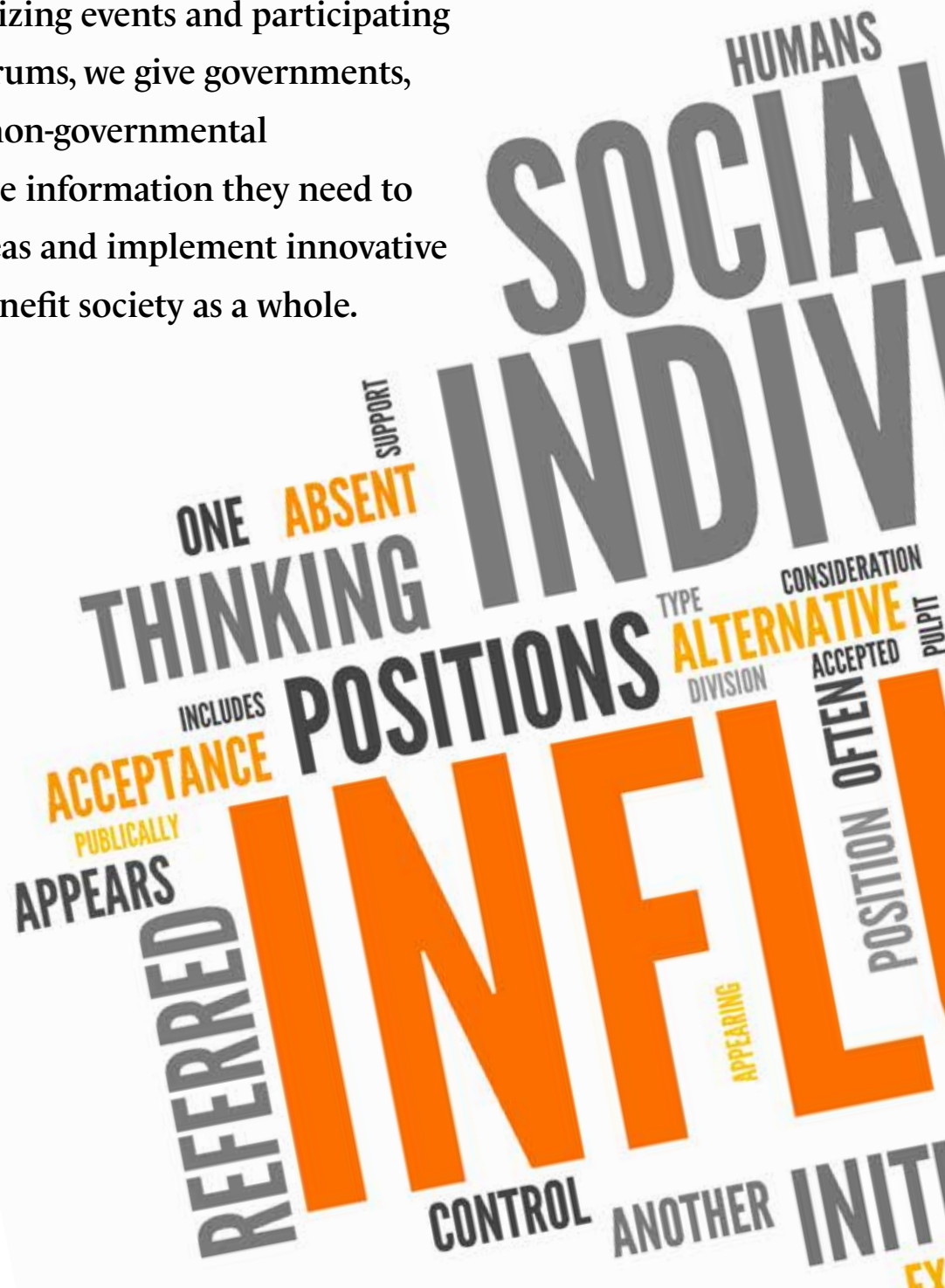
With increasing demand, power networks have rapidly increased their size and complexity which requires systems supporting the operational, regulatory and design decisions and appropriate mathematical models. Prof. Ghaddar presented a new mathematical model for transmission network expansion planning to find the optimal plan for power system expansion so that the system can operate at a minimum cost and provides forecasted system loads over a given horizon.



BISSAN GHADDAR
Assistant Professor,
Management Sciences

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.



A word cloud centered around the concept of social psychology, featuring the following terms:

- CONFORMITY** (largest)
- GROUP**
- PERCEIVED**
- CONGRUENCE**
- INDIVIDUAL**
- PUBLIC**
- BEHAVIOR**
- PRIVATELY**
- NEED**
- STUDENTS**
- MEMBERS**
- ANTI-CONFORMITY**
- POWERFUL**
- ORIGINAL**
- COUNTER-CONFORMITY**
- INVOLVES**
- CONVERSION**
- EXPERTISE**
- LIKED**
- STANDARDS**
- EITHER**
- INACTIONS**
- POSITIVE**
- KNOWN**
- ONE'S**
- NORMS**
- BELIEVED USUALLY**
- AUTHORITY**
- POWER**
- ATTRACTIVENESS**
- POSSESS**
- CITIZENS**
- PERSONAL**
- MAJORITY**
- ACCESS**
- MANY**
- INDEPENDENCE**
- NORMATIVE**
- PUBLICLY**
- SOMEONE**
- NORM**
- BELIEF**
- ALIGNED**
- ACTIONS**
- WELL**
- WHEREAS**
- DIFFERENCES**
- DEMONSTRATE**
- ARM**
- SENT**
- AMPLE**
- TIONAL**



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 2016

B. Paul Mertes

President and CEO, CircuitMeter Inc.

Forensic Energy Management

JUNE 2016

Dr. Julian Cleary

Expert in Environmental
Life Cycle Assessment

Forest Bioenergy in Ontario: Examining
the Life Cycle Impacts and Costs of Using
Harvest Residue as Feedstock for Small-
and Large-Scale Bioenergy Systems

JULY 2016

Jeff Lloyd

President, Almita Piling

Helical Piling Applications in Canada

AUGUST 2016

Dr. Madjid Soltani

Director, HVAC & Energy Lab, K.N.Toosi
University of Technology

Natural Ventilation of Buildings Using a
New Design of Wind-Catcher to Decrease
Energy Consumption in Windy Regions

AUGUST 2016

Dr. Kobra Gharali

Assistant Professor,
Mechanical Engineering,
University of Tehran, Iran

Wind Turbine Aerodynamics and
Solar Car Cooling Systems

SEPTEMBER 2016

Dr. Claudio Vergara

Postdoctoral Associate, MIT Tata
Center for Technology and Design

How Can We Help Electricity Access Scale-up
Faster? *Presented by WISE and AE4H

NOVEMBER 2016

Paul M. Grod

President and CEO,
Rodan Energy Solutions

Demand-Side Management, Micro-Grids,
Demand Response and Reducing the
Need to Overbuild Capacity

NOVEMBER 2016

Tariq Qurashi

NGT Sales Consultant,
Enbridge Gas Distribution Inc.

Natural Gas – an Important
Transportation Fuel as Part of
a Low Emission Logistics Strategy

DECEMBER 2016

Daniela Roeper

Founder, Borealis Wind

Experimental and Computational Optimization
of a Wind Turbine Blade De-Icing System

DECEMBER 2016

Sankaran Ramalingam

President, Energy and Fuel Users
Association of India (ENFUSE)

Energy Economics – Towards Sustainable
Development and a 'Green GDP'

JANUARY 2017

Benjamin Grunfeld

Managing Director, Navigant

Electricity, an Industry in Transition

FEBRUARY 2017

Dr. Srinivasan Keshav

Professor, Cheriton School of
Computer Science, UWaterloo

Solar + Storage + IOT + LED = \$30 Trillion

APRIL 2017

S. Eswar Prasad

Chairman, Piemades, Inc and
Adjunct Professor, Dept of
Mechanical and Industrial
Engineering, University of Toronto

Piezoelectric Materials and
Their Applications

APRIL 2017

Peter Russell

President, RESTCo

Energy-Secure, Adaptable Housing
and Infrastructure for Remote and
Northern Communities

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.



AN EXPENSIVE WAY TO TACKLE PEAK POWER PROBLEMS

Researcher: ANINDYA SEN

According to his analysis, the High-5 program has added an average of \$34 to the annual electricity bill of Ontario households. Meanwhile, the program fails to help sectors such as manufacturing that can't easily shift their production to non-peak hours.

That's why Sen recommends the Ontario government phase out High-5 and instead rely on the capacity system currently being developed to reduce peak demand and help lower electricity costs for everyone while giving industry real-time data to help them cut their consumption.



HELPING HOUSEHOLDS SAVE ELECTRICITY

Researchers: IAN ROWLANDS, PAUL PARKER AND IVAN KANTOR

Around the world, governments, utility companies and environmental organizations alike are encouraging consumers to use electricity more wisely. And with good reason. Reducing electricity consumption or shifting it to off-peak hours can cut greenhouse gas emissions, postpone the need for new generating stations and reduce the pressure on electricity grids.

What exactly does that look like at the household level? Three WISE researchers decided to find out.



OPTIMIZING POWER FLOW

Researcher: BISSAN GHADDAR

The better you can optimize the flow of electricity in a power grid, the more energy you save and the fewer planet-warming greenhouse gases you generate but supply and demand fluctuate month by month, day by day and hour by hour. On top of that, there are a host of constraints to take into account.

Ghaddar and her team are treating the issue as a sparse polynomial optimization problem and use convexifications to find the optimal solution while making the calculations more manageable. Their approach produces significantly better results to accurate answers every time. These improvements mean very significant savings for a billion-dollar problem.

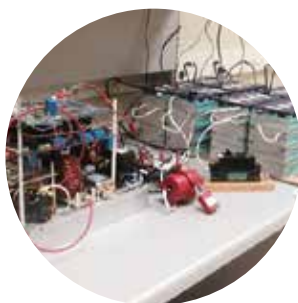


PUTTING FLYWHEELS TO WORK IN SOLAR ENERGY SYSTEMS

Researchers: AYMAN ELTANTAWY, MAGDY SALAMA, TAREK EL-FOULY AND GLENN ALLEN

From steam engines to spaceships, humans have been using flywheels for centuries. These simple wheels serve as batteries by stockpiling excess energy as mechanical motion, spinning faster the more energy they store.

WISE researchers suggest this tried-and-true technology could give photovoltaic systems a boost, addressing two of the key challenges involved in tapping the sun's energy.



A MODEL FOR SMART EV CHARGING

Researchers: MEHRDAD KAZERANI, CLAUDIO CAÑIZARES

Mass adoption of plug-in electric vehicles (EVs) would put a big dent in global carbon emissions but could pose challenges for distribution systems. When thousands of commuters arrive at work and plug in their vehicle, the surge in demand could overload local feeders and transformers.

Bidirectional smart chargers could serve as important buffers between electricity supply and demand by giving drivers the option of charging when power is plentiful (and rates are cheaper) and earning discounts or rebates by supplying electricity from their vehicles back to the grid. WISE researchers are helping to make that vision a reality.



MAKING MICROGRIDS MORE STABLE

Researchers: JOHN SIMPSON-PORCO, EMMA TEGLING, MARTIN ANDREASSON, HENRIK SANDBERG

In an ideal electrical grid, the frequency and voltage stay constant. However, when you have several sources of power, the variations in the amount of power generated create shifts in voltage and frequency.

In a traditional grid where the electricity flows in a single direction from generator to consumer, that's relatively simple to achieve with a centralized control system of primary and secondary controls.

PUBLICATIONS AND INVITED PRESENTATIONS

AE4H was featured as the cover story in the spring 2016 issue of Waterloo Magazine. The article entitled, *Power to the People: Driving a Revolution in Affordable Energy for Humanity* outlined the importance of the research contributions of the WISE Global Change Initiative – Affordable Energy for Humanity (AE4H).

SELECTED MEMBER PUBLICATIONS

- Fu, J., Cano, Z. P., Park, M. G., Yu, A., **Fowler, M.**, & **Chen, Z.** (2016). Electrically Rechargeable Zinc–Air Batteries: Progress, Challenges, and Perspectives. *Advanced Materials*, 29(7), 1604685.
- Salkuyeh, Y.K., **Elkamel, A.**, Thé, J., & **Fowler, M.** (2016). Development and techno-economic analysis of an integrated petroleum coke, biomass, and natural gas polygeneration process. *Energy*, 113, 861–874.
- Elsholkami, M., Warren, M., Huang, C., Peters, S., Tu, Z., **Elkamel, A.**, & **Anderson, W.A.** (2016). Techno-economic analysis of a peatland gasification process for methanol synthesis and power production. *Proceedings of the 2016 International Conference on Industrial Engineering and Operations Management*. Detroit, Michigan, USA, September 23–25, 2016.
- Yu, H., Tan, Z., Thé, J., Feng, X., **Croiset, E.** & **Anderson, W.A.** (2016). Kinetics of the absorption of carbon dioxide into aqueous ammonia solutions. *AIChE Journal*, 62(10), 3673–3684.
- Zamani, P., Higgins, D. C., Hassan, F. M., Fu, X., Choi, J. Y., Hoque, M. A., Jiang, G., & **Chen, Z.** (2016). Highly active and porous graphene encapsulating carbon nanotubes as a non-precious oxygen reduction electrocatalyst for hydrogen-air fuel cells. *Nano Energy*, 26, 267–275.
- Eftekhari, A., Liu, Y., & **Chen, P.** (2016). Different roles of ionic liquids in lithium batteries. *Journal of Power Sources*, 334, 221–239.
- Srirangan, K., Bruder, M., Akawi, L., Miscevic, D., Kilpatrick, S., Moo-Young, M., & **Chou, C.P.** (2016). Recent advances in engineering propionyl-CoA metabolism for microbial production of value-added chemicals and biofuels. *Critical Reviews in Biotechnology*, 37(6), 701–722.
- Kundu, D., Adams, B., Duffort, V., Vajargah, S., & **Nazar, L.** (2016). A high capacity and long-life aqueous rechargeable zinc battery using a metal oxide intercalation cathode. *Nature Energy*, 1(10), 1–8.
- Sindi, H., Shaaban, M., & **El-Saadany, E.** (2016). Distributed generation long-term planning for voltage profile enhancements using optimal hourly operation conditions. *2016 IEEE Canadian Conference on Electrical and Computer Engineering, CCECE 2016*; Vancouver; Canada; 14 May 2016 through 18 May 2016; Category number CFP16758-ART; Code 124690.

Tahir, M., Nassar, M. E., **El-Shatshat, R.**, & **Salama, M.M.A.** (2016). A review of Volt/Var control techniques in passive and active power distribution networks. *4th IEEE International Conference on Smart Energy Grid Engineering*, SEGE 2016; Oshawa; Canada; 21 August 2016 through 24 August 2016; Category number CFP16SEJ-ART; Code 124272.

Jiang, Y. H., Levman, R., **Golab, L.**, & **Nathwani, J.** (2016). *Analyzing the impact of the 5CP Ontario peak reduction program on large consumers*. *Energy Policy*, 93, 96-100.

Liu, X., **Golab, L.**, **Golab, W.**, **Ilyas, I.F.**, & Jin, S. (2016). Smart Meter Data Analytics: Systems, Algorithms, and Benchmarking. *ACM Transactions on Database Systems (TODS)*, 42(1), 2.

Ladubec, C., and **Gracie, R.** (2017). Stabilized finite element methods for vertically averaged multiphase flow for carbon sequestration. *International Journal for Numerical Methods in Engineering*, 111(8), 724-752.

Johnson, D.A., Gu, M., & Gaunt, B. (2016). Wind Turbine Performance in Controlled Conditions: BEM Modeling and Comparison with Experimental Results. *International Journal of Rotating Machinery*, 2016(3), 1-11.

Joshi, A., Gangadharan, S., & **Leonenko, Y.** (2016). Modeling of pressure evolution during multiple well injection of CO₂ in saline aquifers. *Journal of Natural Gas Science and Engineering*, 36, 1070-1079.

Karanasios, K., & **Parker, P.** (2016). Recent Developments in Renewable Energy in Remote Aboriginal Communities, Quebec, Canada. *Papers in Canadian Economic Development*, 16, 98-108.

Simpson-Porco, J.W., Dörfler, F., & Bullo, F. (2017). Voltage stabilization in microgrids via quadratic droop control. *IEEE Transactions on Automatic Control*, 62(3), 1239-1253.

Alharbi, W., & **Bhattacharya, K.** (2017). Electric Vehicle Charging Facility as a Smart Energy Microhub. *IEEE Transactions on Sustainable Energy*, 8 (2), 616-628.

Tamimi, B., **Cañizares, C.**, & Battistelli, C. (2017). Hybrid Power Flow Controller Steady-State Modeling, Control, and Practical Application. *IEEE Transactions on Power Systems*, 32(2), 1483-1492.

Ahmadi, L., **Young, S.B.**, **Fowler, M.**, **Fraser, R.A.**, & Achachlouei, M.A. (2017). A cascaded life cycle: reuse of electric vehicle lithium-ion battery packs in energy storage systems. *International Journal of Life Cycle Assessment*, 22(1), 111-124.

Ozden, A., Ercelik, M., Ouellette, D., Colpan, C.O., Ganjehsarabi, H., & **Hamdullahpur, F.** (2017). Designing, modeling and performance investigation of bio-inspired flow field based DMFCs. *International Journal of Hydrogen Energy*, 42(33), 21546–21558.

He, S., Kilgour, D. M., & **Hipel, K.W.** (2017). A general hierarchical graph model for conflict resolution with application to greenhouse gas emission disputes between USA and China. *European Journal of Operational Research*, 257(3), 919–932.

Khanali, M., Hayati-Soloot, A., Høidalen, H.K., & **Jayaram, S.** (2017). Study on locating transformer internal faults using sweep frequency response analysis. *Electric Power Systems Research*, 145, 55–62.

Abuaish, A., & **Kazerani, M.** (2017). Single-phase bidirectional integrated onboard battery charger for EVs featuring a battery-supercapacitor hybrid energy storage system. *2017 IEEE International Conference on Industrial Technology, ICIT 2017*; Hilton Toronto; Canada; 23 March 2017 through 25 March 2017; Category number CFP17CIT-ART; Code 127554.

Adepetu, A., & **Keshav, S.** (2017). The relative importance of price and driving range on electric vehicle adoption: Los Angeles case study. *Transportation*, 44(2), 353–373.

Askari, H., Asadi, E., Saadatnia, Z., Khajepour, A., **Khamesee, M.B.**, & Zu, J. (2017). A hybridized electromagnetic-triboelectric self-powered sensor for traffic monitoring: concept, modelling, and optimization. *Nano Energy*, 32, 105–116.

Delkhosh, M., Foumani, M.S., & **Azad, N.L.** (2017). Optimisation and comparison of different powertrain layouts for parallel hybrid electric vehicles equipped with continuous transmission. *International Journal of Heavy Vehicle Systems*, 24(1), 45–64.

Yan, L., Han, D., Xiao, M., Ren, S., **Li, Y.**, Wang, S., & Meng, Y. (2017). Instantaneous carbonization of an acetylenic polymer into highly conductive graphene-like carbon and its application in lithium-sulfur batteries. *Journal of Materials Chemistry A*, 5(15), 7015–7025.

Lipka, P.A., Campaigne, C., **Pirnia, M.**, O'Neill, R.P., & Oren, S.S. (2017). Constructing transmission line current constraints for the IEEE and polish systems. *Energy Systems*, 8(1), 199–216.

Sen, A. (2017). Peak power problems: How Ontario's industrial electricity pricing system hurts consumers. *The Electricity Journal*, 30(1), 62–67.

Greene, M., & **Rowlands, I.** (Eds.). (2016). *Global environmental change and international relations*. Springer.



AWARDS AND RECOGNITION

uwaterloo.ca/electrical-computer-engineering/news/ece-professor-sherman-shen-named-university-professor

Electrical and Computing Engineering Prof. Sherman Shen has been designated “University Professor” by the University of Waterloo’s Tenure and Promotion Committee. Prof. Shen is the first in ECC to be honoured with this distinction.

The University of Waterloo owes much of its international reputation and stature to the quality of its eminent professors. The designation “University Professor” is the way Waterloo recognizes exceptional scholarly achievement and international pre-eminence. Once appointed, a faculty member retains the designation until retirement.

Zhongwei Chen, Chemical Engineering professor and the Canada Research Chair in Advanced Materials for Clean Energy, has been awarded the E.W.R. Steacie Memorial Fellowship from the Natural Sciences and Engineering Research Council of Canada (NSERC). The fellowship grant of \$250,000 was awarded to **Chen** in recognition of his work in developing new nanomaterials that make batteries and fuel cells smaller, lighter and longer-lasting.

To further Prof. **Chen's** work on developing these silicon based lithium-ion batteries, Vancouver's Newtech Power Inc. has pledged \$3 million in funding. This new technology promises a 40 to 60 percent boost to energy density and could increase the efficiency of an electric vehicle's battery so dramatically it would allow for 500 kilometers of travel per charge.

September saw the official opening of GAIA, the Green and Intelligent Automotive research facility headed by Systems Design Engineering professor and the Canada Research Chair in System Dynamics, **John McPhee**. Part of the Waterloo Centre for Automotive Research (WatCAR), the \$10-million GAIA facility consists of three labs: one focusing on powertrain efficiency, another on longer-lasting batteries for hybrid and electric cars, and a third for testing research-modified hybrid electric vehicles on rolling dynamometers in real-world conditions. The GAIA lab is the first of its kind in Canada and will allow for unique innovative development and testing on hybrid and electric vehicles.

Prof. **John McPhee** has teamed up with fellow Systems Design Engineering Prof. **Nasser Azad** to develop more intelligent control systems for electric and hybrid vehicles by improving fuel economy and driving range in a collaboration with Toyota. To achieve this Profs. **McPhee** and **Azad** are using existing intelligent technologies such as GPS that capture, store and check the data of everything the vehicle does. With this data they determine how best to use the vehicle's energy sources to achieve maximum efficiency.

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 here 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. Undergraduate students Mohamed Elsholkami, Matthew Warren, Chu Huang, Sheryl Peters and Zhengkai Tu teamed up with Profs. **Ali Elkamel** and **William Anderson** to cut air pollution and convert that peat into power. Their project, "Biomass Utilization via Syngas Generation" was awarded first place in March's Shell Canada Chemical Engineering Capstone Symposium 2016.

WISE BY THE NUMBERS

OUR PEOPLE

114
members

28 distinguished
awards and
honours

29
labs

11 research
chairholders

21
areas of
expertise

SCHOLARLY OUTPUT

520+ member
publications
(2016-2017)

WISE hosted
24 VISITORS

9 Cisco System Smart Grid
Research Awards totaling

18 Energy Council of Canada
Fellowships totaling

\$160,000

\$247,000

OUR PEOPLE

ADVISORY COUNCIL

Members of the Council comprise senior leaders from the business community engaged in the development of the energy sector and shaping its future directions. The Council members help guide our future initiatives, provide input to our strategic research directions and help to further the Institute's goals and mission.

COLIN ANDERSEN | Principal, CACS and Chair, Energy Council of Canada

CÉLINE BAK | President, Analytica Advisors

BRUCE CAMPBELL | Former President & CEO, Independent Electricity System Operator Chair, Energy Council of Canada

STEVE DOREY | Former Chair, Energy Council of Canada Studies Committee

GEORGE GREEN | Chair, Stratos Inc.

SERGE IMBROGNO | Former VP Strategy, Hydro One Inc.

CARMINE MARCELLO | Executive Director, Hetherington Kearney Group

VELMA MCCOLL | Principal, Earncliffe Strategy Group

DAVID MCFADDEN | Chair, International Practice Partner, Gowling LaFleur Henderson LLP

PAUL MURPHY | Chair, Advisory Board, Advanced Energy Centre, MaRS Discovery District

WILLIAM SMITH | Senior Vice President, Operations & Engineering, Terrestrial Energy

ANDY TEICHMAN | Former Executive Director of Investments, OPG Ventures Inc.

JOHN WILKINSON | Senior Vice President Sustainability, Greenfield Global

INTERNAL BOARD OF MANAGEMENT

The Internal Board of Management provides operational oversight and approval. The directors include:

- › **WISE Executive Director**
- › **Deans of Engineering, Environment and Science**
- › **Eight regular WISE faculty members from five faculties**

DR. GEORGE DIXON | Vice-President, University Research, University of Waterloo (Chair)

DR. JEAN ANDREY | Dean of Environment

DR. KANKAR BHATTACHARYA | Professor, Faculty of Engineering, Department of Electrical and Computer Engineering

DR. GIOVANNI CASCANTE | Professor, Faculty of Engineering, Department of Civil and Environmental Engineering

DR. NEIL CRAIK | Professor, Faculty of Environment, School of Environment Enterprise & Development

DR. HEATHER DOUGLAS | Professor, Faculty of Arts, Department of Philosophy

DR. MAURICE DUSSEAU | Professor, Faculty of Science, Department of Earth and Environmental Sciences

DR. KEITH HIPEL | Professor, Faculty of Engineering, Department of Systems Design Engineering

DR. BOB LEMIEUX | Dean of Science

DR. KESHAV SRINIVASAN | Professor, Faculty of Mathematics, Cheriton School of Computer Science

DR. PEARL SULLIVAN | Dean of Engineering

DR. OLAF WEBER | Professor, Faculty of Environment, School of Environment Enterprise & Development

- Industrial Research Chair
- Canada Research Chair
- Ontario Research Chair
- University Research Chair
- Distinguished Awards and Honours

WISE MEMBERS

William Anderson	Michael Fowler	Fue-Sang Lien	Catherine Rosenberg ●
Miguel Anjos	Roydon Fraser	Qing-Bin Lu	Leo Rothenburg
Dipanjan Basu	David Fuller	Jennifer Lynes	Ian Rowlands
Philip Beesley ●	Vincent Gaudet	SeyedBijan Mahbaz	Rebecca Saari ●
Kankar Bhattacharya	Bissan Ghaddar	David Mather	Magdy Salama ●
Philip Bigelow	Lukasz Golab ●	John McPhee ●	Armaghan Salehian
Terri Meyer Boake ●	Wojciech Golab	Christine Moresoli	Andrei Sazonov
Paul Calamai	Irene Goldthorpe	Sriram Narasimhan ●	Gerry Schneider
Claudio Cañizares ●	Robert Gracie ●	Jatin Nathwani ●	Anindya Sen ●
Giovanni Cascante	Komal Habib	Linda Nazar ●	Xuemin (Sherman) Shen ●
Trevor Charles	Feridun Hamdullahpur	Flora Ng	David Simakov
Zhongwei Chen ●●	Keith Hipel ●	Artie Ng	John Simpson-Porco
Pu Chen ●●	Anming Hu	Alain-Desire Nimubona	Siva Sivoththaman ●
Chih Hsuing (Perry) Chou	Robert Hudgins	Amer Obeidi	Madjid Soltani
Michael Collins	Ihab Ilyas	Chijioke Oji	John Straube
James Craig ●●	Shesha Jayaram	Qinmin Pan	Zhongchao Tan
Neil Craik	Beth Jewkes	Mahesh Pandey ●	Susan Tighe ●
Eric Croiset	Ranjini Jha	Paul Parker	Robert Varin
Cecile Devaud	David Johnson	Wayne Parker	Xiaoling Wang
Paul Doherty	Mehrdad Kazerani	Mehrdad Pirnia	Olaf Weber
Heather E. Douglas	Srinivasan Keshav	Kumaraswamy	Lan Wei
Peter Douglas ●	Behrad Khamesee	Ponnambalam	John Wen ●
Tom Duever	Holger Kleinke	Mark Pritzker	John Wright
Maurice Dusseault	Mark Knight	Eric Prouzet	Serhiy Yarsevych
Ali Elkamel	Nasser Lashgarian Azad ●	Pavle Radovanovic	Steven Young
Ehab El-Saadany ●	Hyung-Sool Lee ●	Omar Ramahi	Aiping Yu
Ramadan El-Shatshat	Yuri Leonenko	Sankaran Ramalingam	Jian Zhang
Robert Feick	Yuning Li	Garry Remple ●	Weihua Zhuang ●
Xianshe Feng	Xianguo Li	Luis Ricardez-Sandoval ●	

SENIOR EXECUTIVE FELLOWS

YVES LOSTANLEN

CEO, SIRADEL North America (ENGIE)

CHRIS HENDERSON

President, Lumos

CATHERINE JACKSON

Founder, Jackson Principled Governance

DON MCCUTCHAN

Partner & International Policy Advisor, Gowling WLG LLP

STEVE DOREY

Former Chair, Energy Council of Canada Studies Committee

COLIN ANDERSEN

Chair, Energy Council of Canada

STAFF

Manager, Program Development and Partnerships

ARMUGHAN AL-HAQ

Manager, Global Programs and Initiatives

NIGEL MOORE

Administrative Assistant

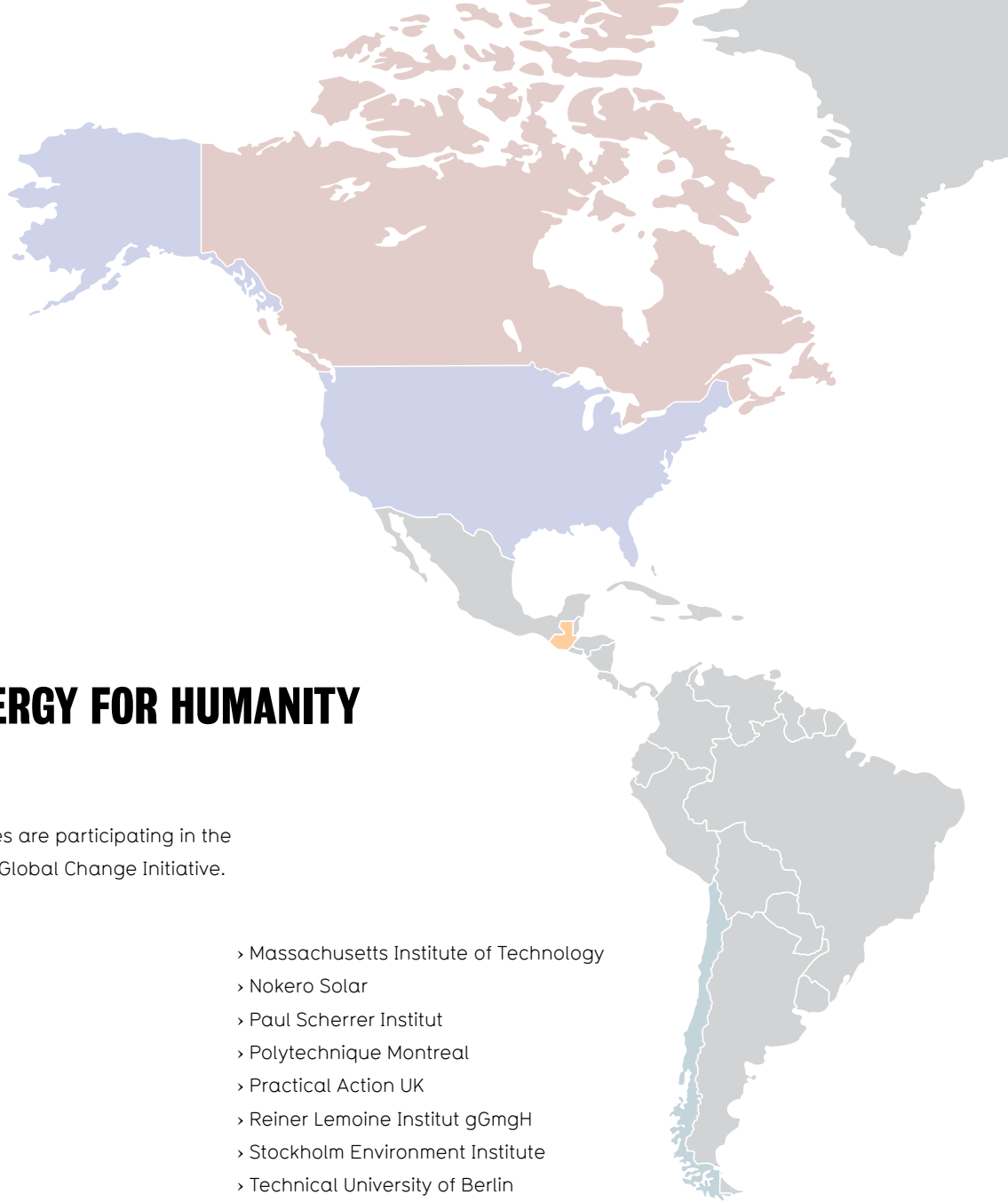
IRIS STRICKLER

Communications Specialist

JESSICA STRICKLER

Student Contributor

SAJEDA MOKBEL

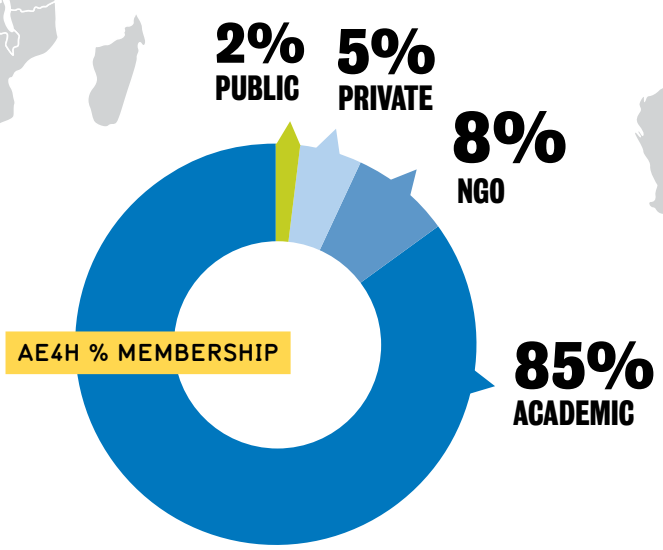
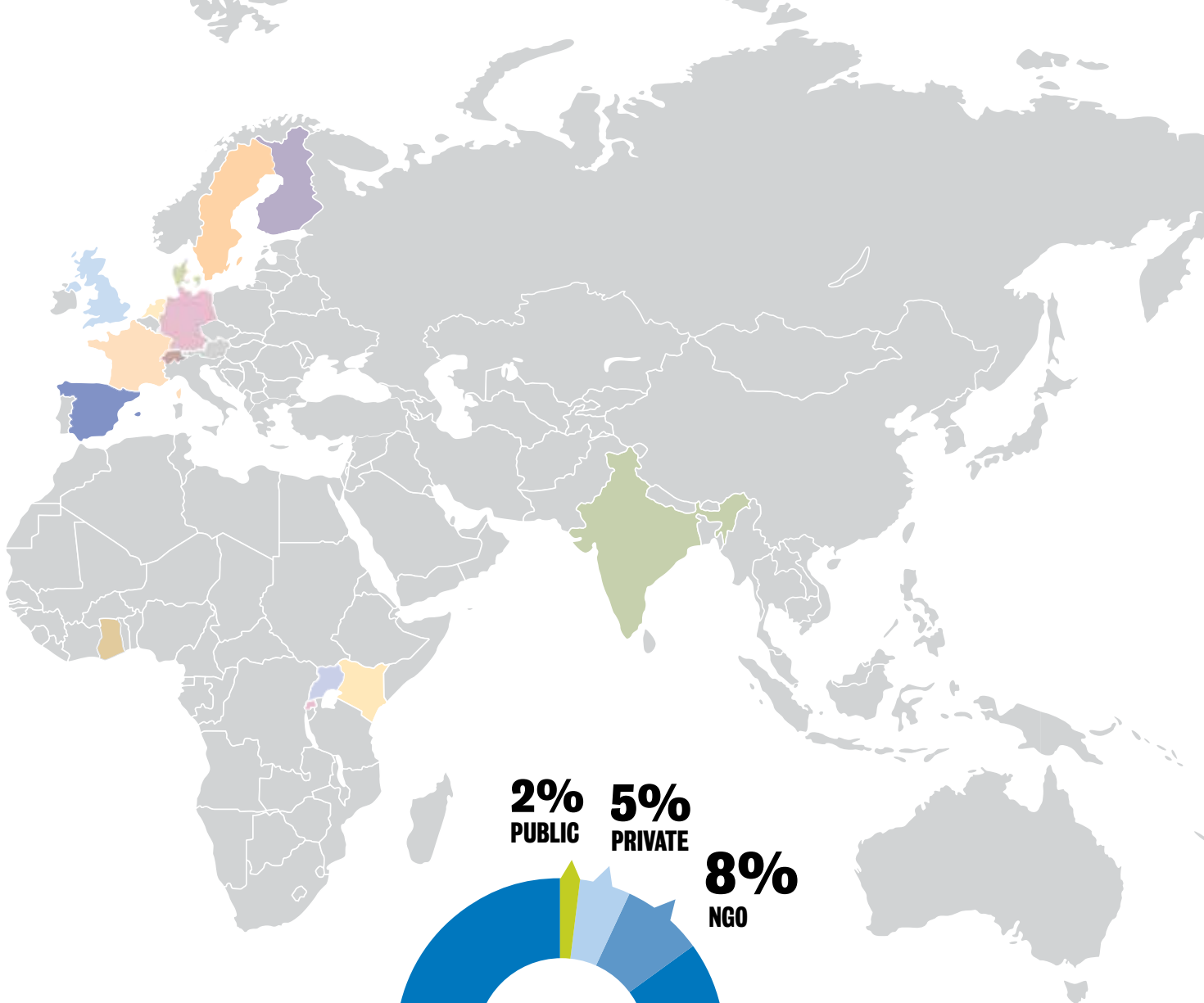


AFFORDABLE ENERGY FOR HUMANITY

AE4H PARTICIPANTS

42 organizations from 18 countries are participating in the Affordable Energy for Humanity Global Change Initiative.

- › Aalto University
- › Ashesi University
- › Carnegie Mellon University
- › Centre for Global Equality
- › Denmark Technical University
- › E3 Analytics
- › Earthspark International
- › Endeva
- › ENERGIA
- › ENFUSE
- › Engineering for Change
- › ENVenture
- › Harvard University
- › HITCH (by Flexfinity)
- › IASS Potsdam
- › IESO Ontario
- › 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
- › Nokero Solar
- › Paul Scherrer Institut
- › Polytechnique Montreal
- › Practical Action UK
- › Reiner Lemoine Institut gGmbH
- › Stockholm Environment Institute
- › Technical University of Berlin
- › Trama TecnoAmbienta
- › Universidad de Chile
- › Université de Bordeaux
- › University of British Columbia
- › University of California, Berkeley
- › University of Cambridge
- › University of Oxford
- › University of San Carlos of Guatemala
- › University of Southampton
- › University of Toronto
- › University of Waterloo
- › Waterloo Global Science Initiative
- › World Hope International



129
AE4H
members

42
institutions

18
countries

**ENERGY ACCESS = SUSTAINABLE
DEVELOPMENT GOALS MULTIPLIER**





UNIVERSITY OF
WATERLOO



FOR MORE INFORMATION

or to request additional copies of this report, please contact us at:

info@wise.uwaterloo.ca