2015–2016

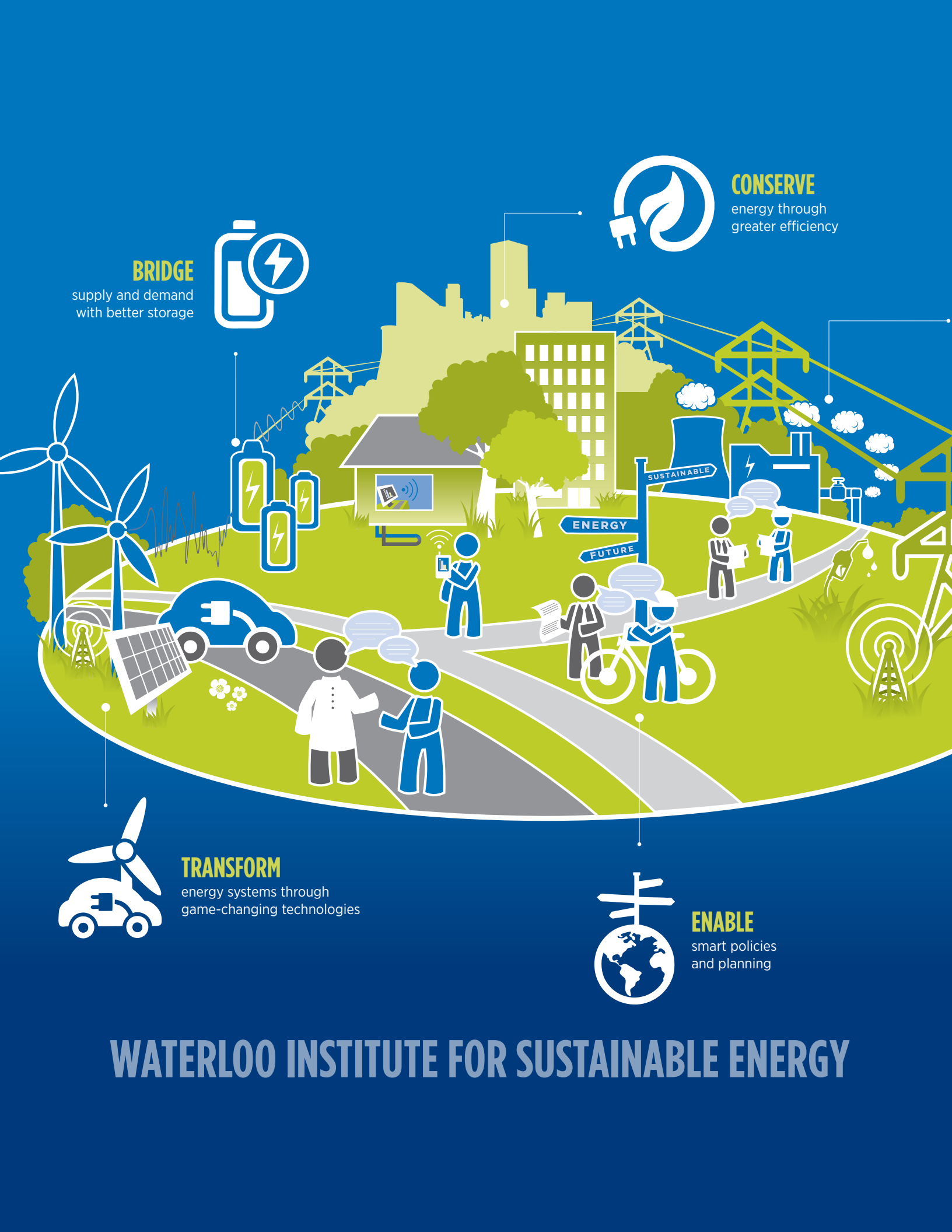
WISE

Waterloo Institute for Sustainable Energy

annual report

UNIVERSITY OF WATERLOO

WISE
WATERLOO INSTITUTE FOR SUSTAINABLE ENERGY



WATERLOO INSTITUTE FOR SUSTAINABLE ENERGY

SUSTAINABLE ENERGY

IMPROVE
conventional
generation methods

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.

DELIVER
energy more
intelligently

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

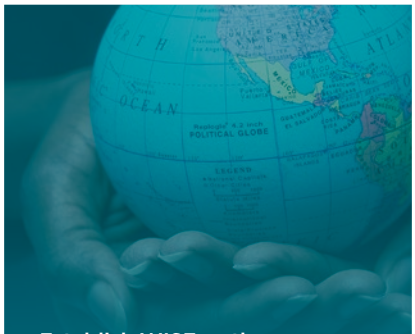
COLLABORATE

Expand opportunities for multidisciplinary energy research at Waterloo, improve research productivity — share facilities and resources and develop 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.

WISE EXECUTIVE DIRECTOR

A NOTE FROM THE EXECUTIVE DIRECTOR

We continue to enhance our collective efforts to advance the research agenda of our members and to strengthen our presence at the global level through effective collaborations at the institutional and individual levels.

Our focus remains on development of clean energy solutions to help achieve a low-carbon energy system over the long term.

WISE membership is diverse and represented by several departments through all the faculties at the University of Waterloo. Our faculty members and graduate students are involved in the full spectrum of energy research activities and have the opportunity to interact widely with business, government agencies and NGO's.

Since the launch of our Global Change Initiative — 'Affordable Energy for Humanity' (AE4H) in 2015, we have made important strides in cementing our relationships with our global partners. We have identified and committed to a wide range of specific initiatives that will shape the contours of the global innovation agenda in support of energy access and will build the capacity and talent required for implementing change.

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

JATIN NATHWANI
Executive Director

EXPLORE WISE

research labs

Photo: High Voltage Energy Lab

BRIDGE

Applied Nanomaterials and Clean Energy Lab

Carbon Nanomaterials Lab

Fuel Cell & Green Energy Lab

Giga to Nano Center

Nazar Research Group

CONSERVE

Advanced Glazing Systems Lab

DELIVER

Electricity Market Simulation and Optimization Lab

High Voltage Energy Lab

Information Systems and Science for Energy Lab

Real Time Simulation Lab

Smart Distribution Research Lab (SDRL)

ENABLE

Sustainable Energy Policy Group

IMPROVE

Center for Pavement and Transportation Technology Lab

Center for the Advancement of Trenchless Technology

Mechatronics Vehicle Lab

Non-destructive Testing Lab

Qing-Bin Lu's Lab

Solar Thermal Research Center

TRANSFORM

Air Pollution Research and Innovation Lab

Center for Advanced Photovoltaic Devices and Systems

Center for Advanced Materials Joining

Fluid Mechanics Research Lab

Lab for Biomanufacturing

Emerging Energy Research Lab

Printable Electronic Materials Lab

UW Live Fire Research Facility

Wind Energy Lab

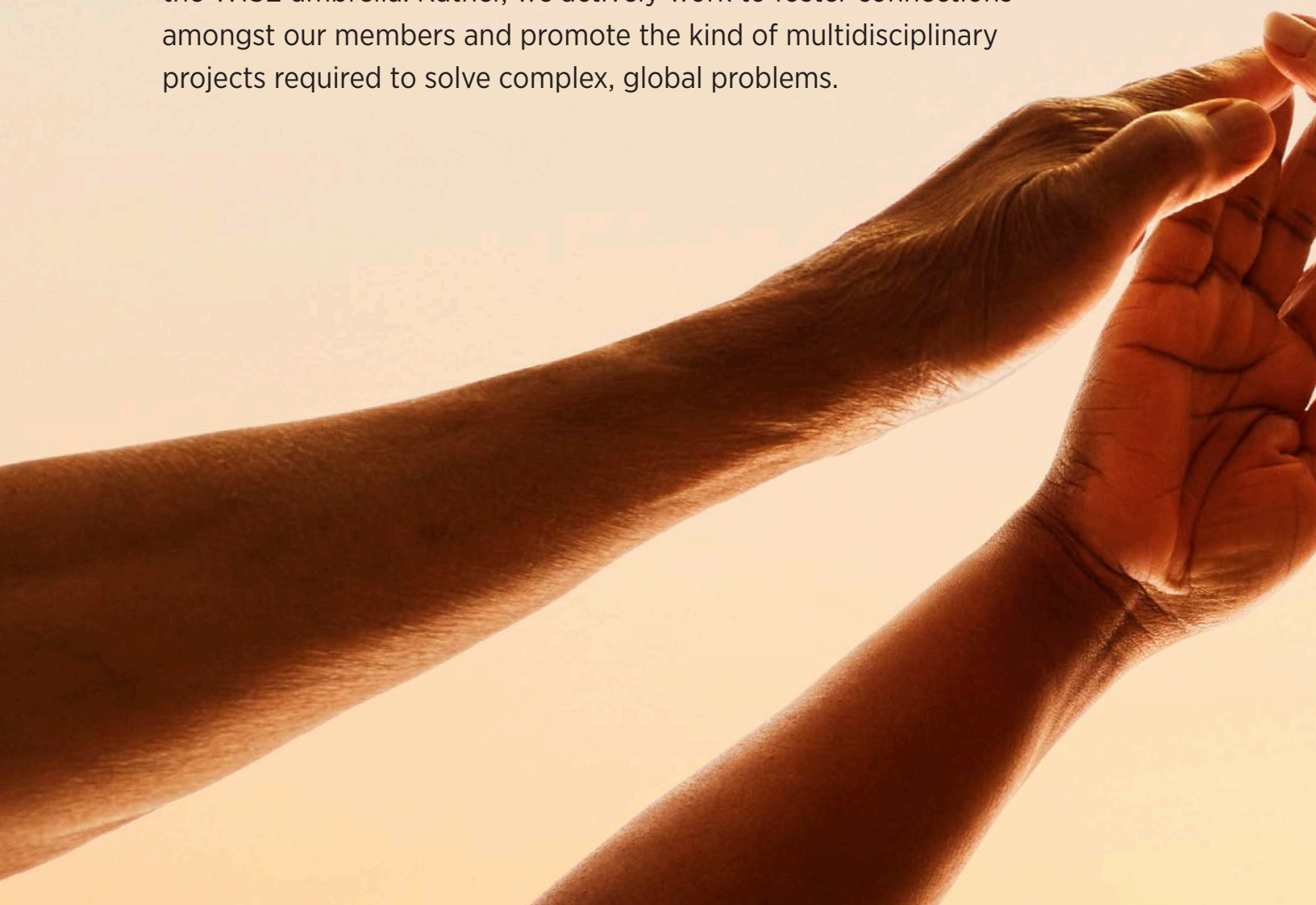
Energy Harvesting Lab

Kleinke Research Center

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.

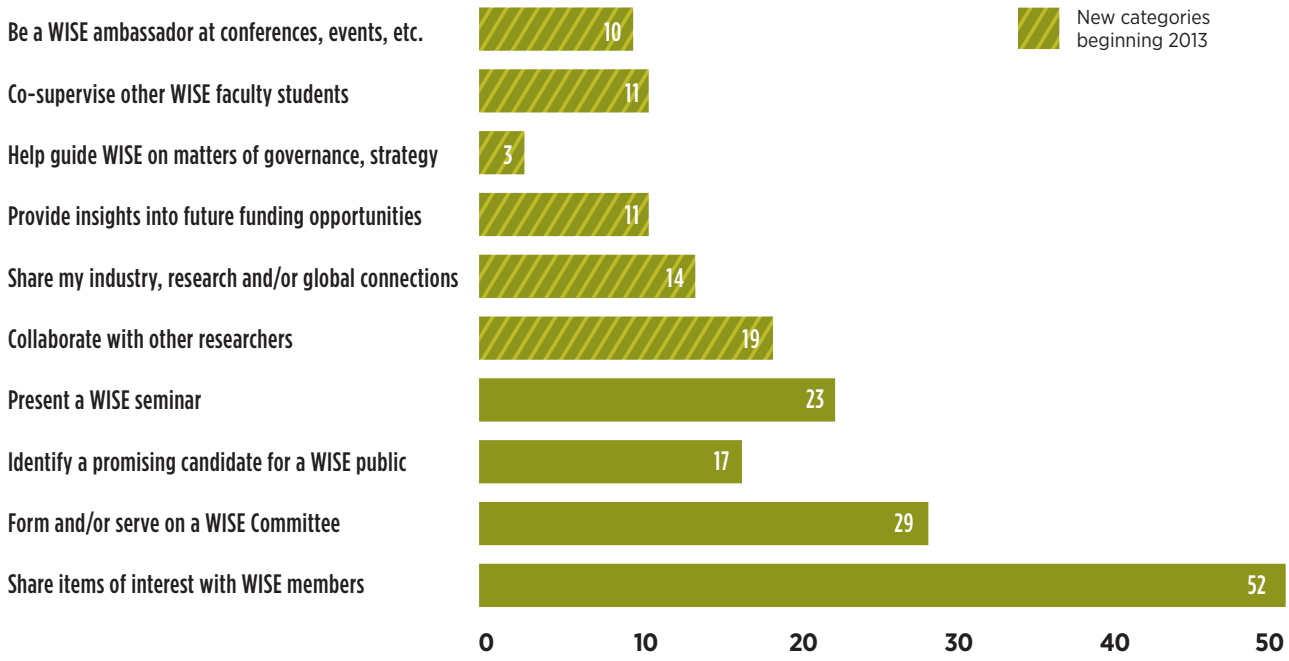
However, we're not content to simply gather great minds under the WISE umbrella. Rather, we actively work to foster connections amongst our members and promote the kind of multidisciplinary projects required to solve complex, global problems.



understanding our members

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

HOW MEMBERS ENGAGE WITH WISE



developing opportunities for multidisciplinary work

WISE searches out opportunities to unite our members on discipline-spanning projects — projects like World Wildlife Fund Canada's Arctic Program. When WWF needed a scientific partner, WISE was the destination of choice to study whether renewable energy is possible for the Arctic.

Promising studies indicate that renewable energy sources in the Arctic are feasible and viable technically and economically. **cbc.ca/news/canada/north/wwf-renewable-energy-1.3920028**

COLLABORATE

securing promising new sources of research funding

WISE keeps its members well informed about important sources of funding. But our services don't stop here.

We also help them secure access to additional funds and/or physical assets and mobilize the necessary commitments. We do this by leveraging our extensive network of partners and our formal collaboration arrangements. Some funding partnerships include:

- Research Chair agreement with CISCO Systems Canada
- MOU and Research Chair with Hydro One
- NSERC grants for basic and applied research, prototype development, and research commercialization
- OCE grants to connect entrepreneurs, policy makers, industry partners, and academic researchers to do fundamental research and technology development & deployment that help boost the Canadian economy,
- Mitacs programs to create a stream of bi-directional flow of knowledge between industry and academia
- Canadian Foundation for Innovation (CFI) grants for infrastructure development and fostering innovation in the area of renewable energy

Almost **$9M** **in funding** *secured since 2010*

"We have definitely benefited immensely from both **funding and networking opportunities** offered by this institute."

ARMAGHAN SALEHIAN
Professor, Department of Mechanical and Mechatronics Engineering

"I appreciate the **remarkable efforts of your team!**"

REBECCA SAARI
Professor, Department of Civil and Environmental Engineering

creating the space for collaboration

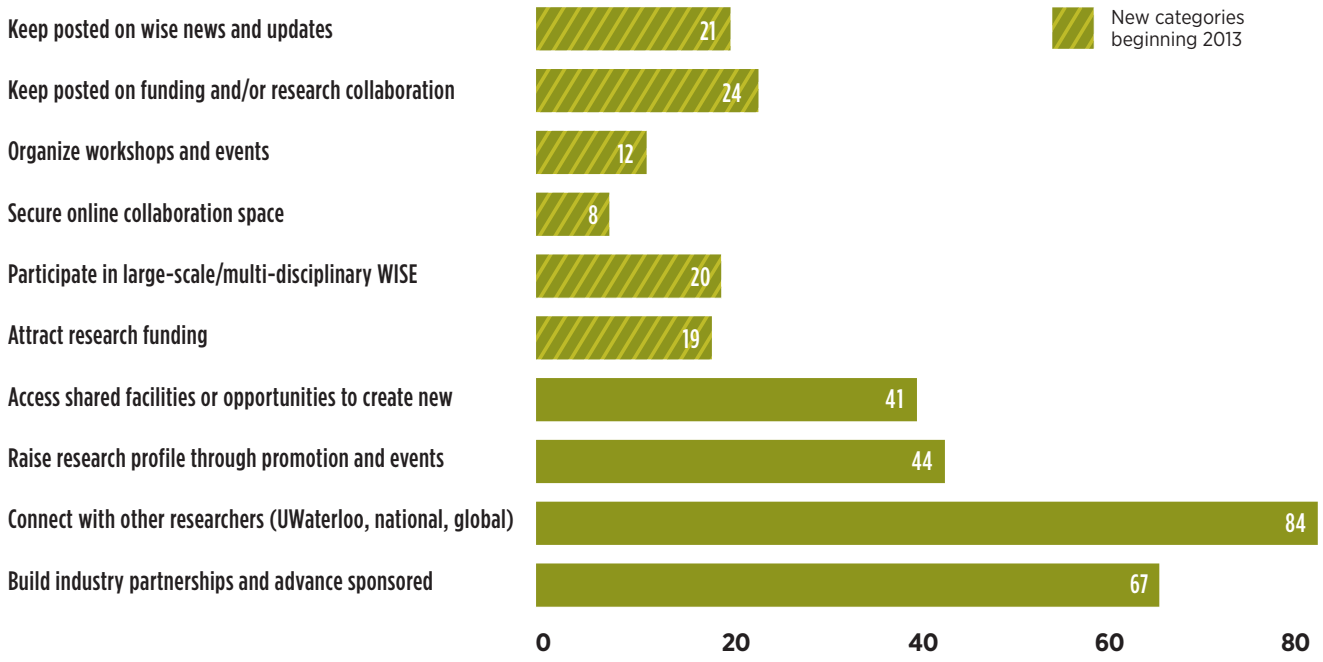
At WISE, multidisciplinary collaboration doesn't just happen on paper. We help our faculty and principal investigators to host workshops designed to shape the research agenda or seed early-stage collaborations. We take care of formulating agendas, selecting venues, managing logistics and securing funds for promotion and follow-up. That leaves our members free to focus on what they do best: advancing research.

We also host twice-yearly pizza lunches for graduate students, connecting them with WISE faculty and staff. These events offer a collegial environment for students to broaden their network and their perspective on sustainable energy issues.

"I am really grateful for your **leadership and honest commitment** of your team at WISE."

MEHRDAD KAZERANI
Professor, Department of Electrical and Computer Engineering

WHAT FACULTY VALUE ABOUT THEIR WISE MEMBERSHIP



COLLABORATE

driving research advancement

WISE constantly looks for ways to further the work of our members. For example, more than two dozen WISE members conduct research involving electric vehicles (EVs). The problem they face is limited real-world data, forcing them to rely on small-scale pilots or proxy information. That's why WISE launched the Drive4Data initiative in 2012.

This unique initiative brings together industry and local non-profit organizations to capture large-scale real-world data from plug-in vehicles. As a result, WISE researchers have access to information on everything from vehicle use and charging patterns to battery range and powertrain performance.

Already, the initiative is having an impact in Waterloo Region. In 2012, a WISE member research partnership with Grand River CarShare was launched to investigate local opportunities for EVs and barriers to their use.

The Waterloo Institute for Sustainable Energy gratefully acknowledges the financial support of the Community Environmental Fund administered by the Regional Municipality of Waterloo that helped us launch this initiative.

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. The Energy Council's mission is to forge a better understanding of energy issues in order to optimally shape the energy sector for the benefit of all Canadians. Energy corporations, energy industry associations, Canadian federal and provincial government departments and agencies, academic organizations, professional services firms, as well as Crown corporations are members of the Council. Their energy interests cover all forms of energy. The Energy Council holds public policy forums, accommodates various member activities and hosts the annual Canadian Energy Person of the Year Award. The Energy Council is a founding member of the World Energy Council (1923). The Energy Council represents Canada and coordinates participation in WEC activities, contributing to development of information and policy perspectives, global expert knowledge, energy information and policy perspective.

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.

"On Tuesday, November 24, I had the pleasure of attending the GridSmartCity 2015 Round Table, as a student member of WISE. GridSmartCity is a **co-operative of utilities, Smart Grid innovators, industry regulators, government, academia and other electricity industry stakeholders**."

STEPHANIE WHITNEY,
MEB, P.Eng. is an Energy Council of Canada Fellow with WISE and a Senior Project Manager at AET

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 energy research themes:

1. Smart energy networks
2. Affordable Energy for Humanity (AE4H) — A Global Change Initiative
3. Information systems and science for energy
4. Achieving deep decarbonization

1 smart energy networks

A smart energy network (SEN) is an enabler of diversity in the energy system. Clean energy technologies coupled with information and communication technologies (ICT) can improve the reliability and cost performance of the overall systems. Building on the concept of a smart electricity grid, a smart energy network allows integration of all available energy sources, including electricity, natural gas, heat, bioenergy, solar PV, wind, geothermal, and storage.

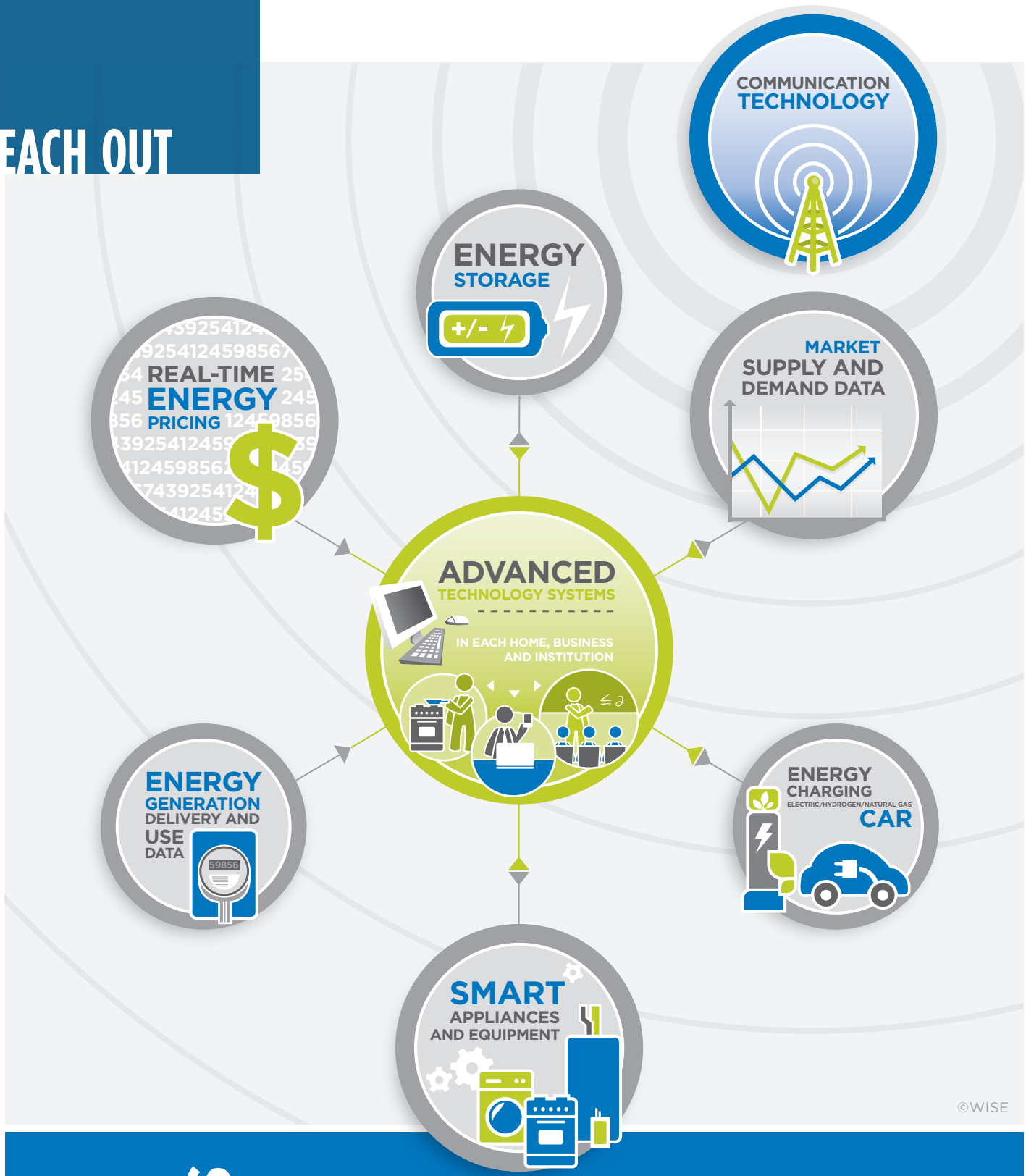
The value proposition of smart energy networks relies on the integration of disparate and diverse components through ICT. The potential and promise of ICTs utilizing big data to enable optimal performance of a networks is a focus of extensive research activity at WISE. Convergence of ICT with multiple networks including transport offers the potential for large benefits to consumers if demand and supply can be matched through real-time feedback. Eliminating or reducing the demand for services at peak times allows flexibility in the planning and operation of the infrastructure and helps achieve a lower societal cost.

Professors Croiset, Elkamel, and Douglas (Chemical Engineering) continue to advance the initiative of smart energy networks across Canada. This collaboration includes Union Gas, Horizon Utilities, Natural Resources Canada (NRCan), Canadian Gas Association (CGA), Canadian Electricity Association (CEA), Continental Automated Buildings Association (CABA), National Research Council (NRC) of Canada, and Quality Urban Energy Systems of Tomorrow (QUEST). The team has developed an extensive set of smart energy network models available for application on demonstration projects.

Professors Rowlands and Parker (Faculty of Environment) with Professors Cañizares and Bhattacharya (Electrical and Computer Engineering) have completed a major project on the 'Energy Hub Management System' (EHMS). The EHMS portal allows real-time management of energy demand, production, storage and import and export from different locations and types of facilities such as manufacturing, farm, retail stores and residential homes.

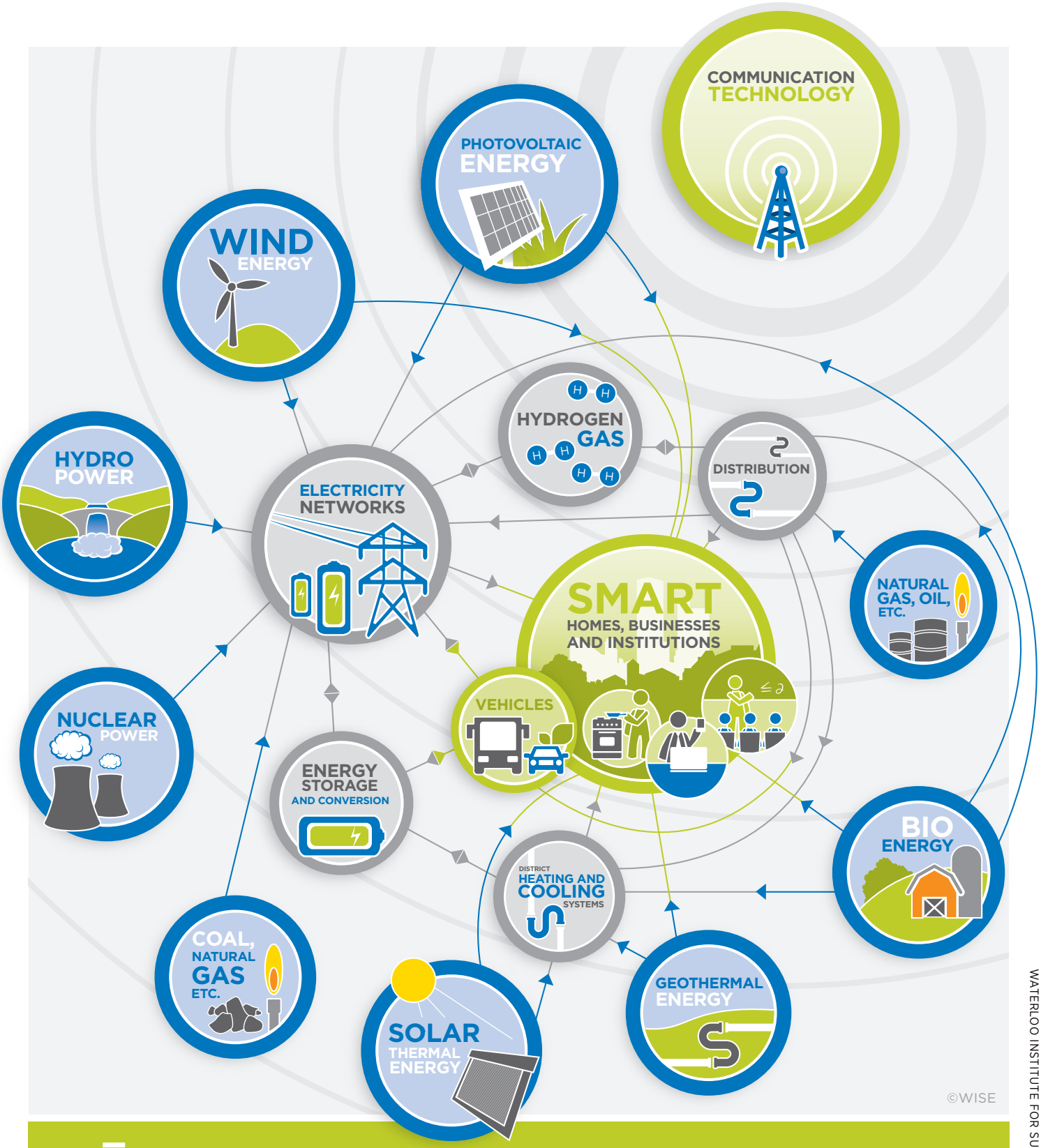
Professor Simpson-Porco (Electrical and Computer Engineering) has developed a 'plug and play' form of decentralized control by adding a distributed averaging proportional-integral (DAPI) controller that makes micro-grid more stable — and in the process enhances the integration of renewable energy resources.

REACH OUT



SMART

INFORMATION FLOW: In Smart Energy Networks, advanced technology systems use information from different sources to make better decisions: how much energy to use, when to use it, and what sources to tap at any given moment. The result? Consumers and businesses get the energy they need as efficiently as possible.



INTEGRATED

ENERGY FLOW: Smart Energy Networks link different sources of energy, delivery systems and storage systems. As a result, smart homes, businesses and institutions can choose the most efficient way to meet their needs for electricity, heating and cooling and transportation, choosing the best form of energy at any given moment. As new forms of energy and energy technology are developed, they can be integrated into the network.

2 Affordable Energy for Humanity A Global Change Initiative

(AE4H) –

Achieving universal access is one of the most urgent equity issues of our time and this is as true in the global context as it is for our remote and indigenous communities in the North. We believe the challenge is within our capacity to solve.

Our mission is to develop the next generation of clean distributed energy technologies for "off-grid" access that are robust, affordable, clean and scalable. The goal is to accelerate deployment by activating a global community of partners and a new generation of 'energy access leaders' empowered by information and communication technologies (ICT) to eliminate energy poverty with respect and ingenuity.

Our approach is simple: invest in people and in our shared capacity for innovation. The AE4H consortium comprises leading researchers, innovators, entrepreneurs and practitioners from 30 institutions in 12 countries and we bring together a high level of expertise and experience in the development and deployment of energy access projects around the world.

WE HIGHLIGHT BELOW SOME OF OUR RECENT ACCOMPLISHMENTS:

'The Open Access Energy Summit' was held April 2016 in partnership with the Waterloo Global Science Initiative (WGSI) at the Perimeter Institute for Theoretical Physics in Waterloo. The summit brought together an interdisciplinary and multigenerational group of leading thinkers and practitioners on energy access. Summit contributors included 22 different countries and four of Canada's First Nations. Extensive media coverage of the event included TVO's 'The Agenda', The Globe and Mail, and award-winning investigative journalism start-up Discourse Media.

The outputs of the summit include:

- 'OpenAccess Energy Brief', a comprehensive primer on energy access,
- 'OpenAccess Communique',
- 'OpenAccess Energy COP22 Brief' presented in Marrakech, Morocco and
- 'OpenAccess Energy Blueprint' — an in-depth, solutions-focussed summary of key recommendations from the summit.

(see **WGSI.org/openaccess-energy**).

Affordable Energy for Humanity (AE4H) – A Global Change Initiative (continued)

Energy Access for Economic Development: Professor Keshav's SPEED Project

Emerging from the WGSI OpenAccess Energy Summit, Professor Srinivasan Keshav and his undergraduate research assistant Kayla Hardie designed a simple and robust technology for charging cell phones with solar energy called SPEED (Self-serve Pre-paid Emissions-free Energy Delivery). The system uses RFID technology to track credits used to purchase energy for cell phone charging from a small solar device that can be operated by a shopkeeper and used to generate local revenue. It is currently being tested in India.

Energy Access for Canada's Remote and Indigenous Communities

Professor Cañizares' assessment of Off-Grid Renewables in Canada's Arctic for the World Wildlife Foundation examined the economic and environmental feasibility of potential renewable energy supply additions in off-grid communities in Canada's Arctic. The study has identified potentially large cost savings and reduction of environmental impacts are possible if projects are conducted at appropriate scale and scope. The assessment will inform policy discussions and investment decisions on Arctic energy planning over the coming years and its findings are being actively promoted by WWF and WISE.

KIT
Karlsruhe Institute of Technology

KIT/AE4H collaboration: Testing a hybrid renewable energy system

This project aims to develop a simple, economically viable and robust Hybrid Renewable Energy System (HRES) for off-grid electrical energy supply. The HRES is based on renewable and non-renewable energy sources, in combination with battery storage system. The energy sources for the project are PV generators and an optional gasoline generator (integration of further energy sources such as small wind may be investigated at a later stage). The battery storage system utilizes Lithium-Ion (Li-Ion) batteries. The system development and analysis for this project is being carried out by the Competence E (energy) lab at the Karlsruhe Institute of Technology (KIT) in Karlsruhe, Germany, led by PhD student Mohamed Mamdouh Elkadragy. The system itself will be tested in an off-grid house in Canada owned by an expert in off-grid renewable energy systems, George Colgate, who collaborated with WISE as a participant in the OpenAccess Energy Summit.

Power Shift: Design for Development

In February 2016 AE4H hosted an event on campus for students with a focus on humanitarian engineering, international development and social innovation to shape solutions for energy access in remote and energy impoverished communities. Guest speakers were: Steve Katsaros, Founder and CEO of Nokero which designs, manufactures and distributes super-efficient solar lights for developing world markets, and Iana Aranda, Director of Programs at Engineering for Change.

3 information systems and science for energy

INTERNET OF THINGS (IOT)

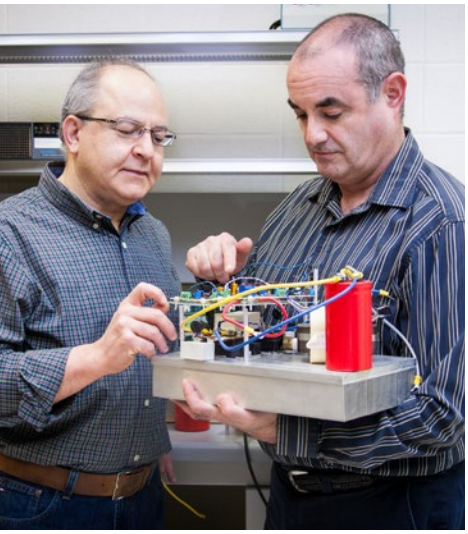
The Internet of Things (IOT) and the evolving 'Internet of Energy' (IOE) is a network of interoperable embedded sensors, computers and communication devices that enrich and transform the way energy is generated, transmitted, distributed, and delivered to the end user. The internet of things (IOT) represent a new reality in the energy sector with significant potential for disruption of the existing business models of the distribution. The interactions of ubiquitous sensors, devices, and diversity of systems allowing real-time decisions by many participants has the benefit of enhancing efficiency, effectiveness and productivity of the entire energy supply chain and this shifts control from producers to users.

CATHERINE ROSENBERG
Professor,
Electrical and Computer Engineering

Professors Rosenberg (Electrical and Computer Engineering) and Keshav (Cheriton School of Computer Science) continue to advance their research in low power connected devices (sensors, actuators); use of an energy storage system (ESS) to integrate solar energy generators into the electrical grid; designing and operation of hybrid energy storage systems; developing practical strategies for storage operation in energy systems; interaction between personal comfort systems and centralized HVAC systems in office buildings; multiple time-scale model predictive control for thermal comfort in buildings; integration of renewable generation and elastic loads into distribution grids; and optimal design of solar PV farms with storage.

Professor Rosenberg, in collaboration with Professor Abinav Kumar (IIT, Hyderabad, India), have developed a project on 'Energy and Throughput Trade-Offs in Cellular Networks Using Base Station Switching'. The information and communication technology (ICT) sector is responsible for approximately two per cent of the global CO_2 emissions. Within ICT, cellular networks are one of the biggest contributors. Base stations (BSs) operations consume up to 80 per cent of the energy required for the operation of a cellular network. The research highlighting a complex interplay between coverage, power management, scheduling, and interference and recommendations are developed to take into account a strategy for saving energy to enable base station switching.

information systems and science for energy (continued)



Professors Kazerani and Cañizares (Electrical and Computer Engineering)

VEHICLE TO GRID TECHNOLOGIES

WISE researchers are actively involved in addressing the emerging challenges and possible opportunities related to the Vehicle to Grid (V2G) technologies.

Professors Shen and Zhuang (Electrical and Computer Engineering) work on electric vehicle integration and Vehicle-to-Grid (V2G) system optimization which has the potential to revolutionize the role of energy storage and information and communication technology (ICT) in the energy sector. With high EV penetration, the battery storage of EVs can be leveraged to improve the efficiency and reliability of electricity delivery via V2G systems. The V2G system enables bidirectional energy delivery, which allows the EV to either draw energy from or feed energy back to the grid. In other words, EVs can facilitate two types of services to the grid, namely, load shaving services and ancillary services to the grid.

Professor El-Saadany (Electrical and Computer Engineering) has developed a new energy management system (EMS) for incorporating aggregated Plug-in Electric Vehicles (PEV) in parking lots. Demand response (DR) capability allows end-use customers to modifying electricity usage based on incentive payments to encourage lower electricity use at times of high prices.

Professor Salama (Electrical and Computer Engineering) has designed a model of charging plug-in hybrid electric vehicles using photovoltaic electricity in residential distribution systems and developed a comprehensive planning model for the electric vehicle charging infrastructure in Ontario.

Professors Cañizares and Kazerani (Electrical and Computer Engineering) have developed the concept of a bidirectional smart charger that give 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 when they don't need it.

4 achieving deep decarbonization

CARBON DIOXIDE CAPTURE AND STORAGE

Carbon dioxide capture and storage (CCS) technologies can be an attractive option to limit CO_2 emissions from fossil fuel power plants. If the technology can be developed cost-effectively, CCS can be a vital tool in meeting the goals of greenhouse gas (GHG) emission reductions. The large scale deployment of CCS projects would help to meet the increasing energy demand at the national level and also minimize environmental damage.

Professors Croiset, Douglas, and Ricardez-Sandoval's (Chemical Engineering) research in the area of CO_2 capture technologies includes a project on 'Dynamic modelling of a CO_2 capture and purification unit for an oxy-coal-fired power plant'. They have concluded that Oxy-combustion is a promising pathway to capture CO_2 from coal fired power plants and compete favourably with other CO_2 capture technology pathways, such as post-combustion and pre-combustion. The future research will focus on validating a dynamic model of the CO_2CPU for control design purposes.

Professors Croiset, Douglas, and Elkamel (Chemical Engineering) have also collaborated on a project using short-term resource scheduling for assessing effectiveness of CCS within the electricity generation subsector.

ELECTRIC VEHICLES AND THE FUTURE OF NETWORKED ENERGY

Electric Vehicles (EVs) will play a significant role in the decarbonization of the transport sector and will remain a key element of the transition to a low carbon economy. Current Government incentives and policies in support of EVs and deployment of EV charging infrastructure across provinces gives rise to a number of technical challenges and imposes several constraints on the operation of the distribution system.

Professor Bhattacharya's (Electrical and Computer Engineering) studies include: smart plug-in hybrid (PEV) charging station operation and design, evaluation of distribution system impacts, effect of PEV penetration on distribution system planning and time-of-use electricity prices, smart charging PEVs in an isolated microgrid, and adequacy assessment of power systems with PEV charging loads.

Professors Fraser and Fowler (Faculty of Engineering) have initiated a pilot project on UWaterloo campus along with various faculty members from Management Sciences, Environment, and Accounting and Finance, to study the impact of high-voltage, direct current (HVDC) charging stations on the distribution grid and battery life of electric vehicles.

Professor Fraser, Professor Fowler, and Professor Young (Faculty of Environment) have worked together on the reuse of electric vehicle lithium ion battery packs in energy storage system applications. Their work concluded that Li-ion battery packs present opportunities for powering both mobility and stationary applications.

Professors Cañizares and Rosenberg's (Electrical and Computer Engineering) award winning paper on 'Day-ahead dispatch of distribution feeders' addresses the issues related to high PEV charging penetration levels.

events

POWER SHIFT STUDENT WORKSHOP | February 25, 2016

An AE4H event hosted on campus for students with a focus on humanitarian engineering, international development and social innovation to shape solutions for energy access in remote and energy impoverished communities.

SUSTAINABLE DEVELOPMENT TECHNOLOGY CANADA (SDTC): FUNDING WORKSHOP

March 9, 2015

The Waterloo Institute for Sustainable Energy (WISE) and the Waterloo Institute for Nanotechnology (WIN) co-hosted the interactive workshop to provide key information and practical guidance to cleantech entrepreneurs who want to apply for SDTC funding. Workshop participation can help to better understand the potential fit of your cleantech solution with SDTC funds, the application process and key evaluation criteria. The workshop was of particular interest to small to medium sized entrepreneurial businesses and start-ups.

OPENACCESS ENERGY SUMMIT (WITH WGSI) | June 24-27, 2016

An AE4H event held April 2016 in partnership with the Waterloo Global Science Initiative (WGSI) at the Perimeter Institute for Theoretical Physics in Waterloo.

RESOURCE RECOVERY PARTNERSHIP WORKSHOP | June 24, 2015

The Canadian Plastics Industry Association teamed up with UW to host the second annual, invitation-only Partnerships Workshop. The full-day event engaged experts from universities, government and industry, facilitating new network connections to create important insights and ideas on the future of waste management. Wide-ranging discussions included waste-related matters from evidence-based decision making and policy planning to reduction through resource recovery and final disposal.

AFFORDABLE ENERGY FOR HUMANITY: A GLOBAL CHANGE INITIATIVE

September 29, 2015

Professor Jatin Nathwani, Ontario Research Chair in Public Policy for Sustainable Energy, University of Waterloo, discussed the pathways to a low carbon energy future. The goal is to unlock scientific and technological innovations to deliver clean, low cost energy services to every global citizen.

ENERGY DAY 2016 | March 30, 2016

The annual event brought academics, industry, and government experts together to share their insights and optimism for the future. The topics for this year's panel sessions considered the questions: a) Geothermal Energy in Canada: How can research shape the market outcomes? b) Electric Mobility Infrastructure: is it a technology or a business model challenge? and c) Social and Policy Issues of De-carbonizing the Canadian Energy Economy: is there a clear path?

WISE hosted several academic and scientific visitors in 2015 as well as delegations that included:

- Aruban Prime Minister and a government delegation — July 13
- Hong Kong Polytechnic University senior administrators — July 20
- Fraunhofer UMSICHT, UWaterloo Campus Visit — August 14
- Professor Giancarlo Spinelli, Politecnico di Milano — June 2
- Hanze University of Applied Sciences, Groningen The Netherlands — October 8
- Dr. Armando Román, Director, Monterrey Institute of Technology and Higher Education, Chihuahua — October 15

33 WISE visitors hosted

WISE participation

THE GRIDSMARTCITY 2015 ROUND TABLE | October 5-7, 2015

Energy Council of Canada Fellow Stephanie Whitney attended the GridSmartCity 2015 Round Table as a student member of WISE. GridSmartCity is a cooperative of utilities, Smart Grid innovators, industry regulators, government, academia and other electricity industry stakeholders. The partner organizations are committed to work collectively towards productivity and efficiency improvements, advancements in self-healing grids, conservation program implementation, the emergence of renewable energy and community energy planning.

ONTARIO ENERGY BOARD'S (OEB) ENERGY LEADERS SECTOR FORUM 2015

October 15, 2015

"Harnessing Innovation to Meet Customer Needs". During this one-day session Senior Leaders, along with Board Members and Executives, explored through presentations and peer discussions how changes in consumers' engagement with energy will create opportunities for innovation in Ontario's energy sector.

ELECTRICITY PRIVATIZATION AND RESTRUCTURING IN ONTARIO AND ABROAD

November 30, 2015

Organized by The Council for Clean & Reliable Electricity (**bythinkingpower.ca)** and The Ivey Energy Policy and Management Centre (**ivey.ca/energycentre)**. The Ontario government's decision to partially privatize Hydro One's transmission and distribution has restarted debate about the appropriate role of the private sector in the electricity industry, and ways in which privatization can effect short- and long-run performance. What will be the impact on costs, infrastructure investment, and rates of a part privately-owned and managed entity? What can be learned from other jurisdictions that have also restructured their electricity sectors over the last 20 years?

ECSEC 2015 | November 6-7, 2015

Eastern Canada Student Energy Conference held at the University of Waterloo and hosted by the UWaterloo Society of Petroleum Engineers Student Chapter. The student conference was an excellent opportunity to learn about and discuss oil and gas industry trends while networking with industry professionals.

NUCLEAR ENERGY: THE FUTURE OR THE PAST? | January 28-30, 2016

Hosted by The Ditchley Foundation: Plenary Sessions discussing: Is nuclear power an important part of the path to a lower carbon future, or an expensive and risky dead end? Where is technology likely to take us in the next 20 years? How much has the debate on safety been influenced by what happened at Fukushima? Are we likely to see long term waste solutions coming on stream in the next 20 years? The sessions were followed by Working Group discussions to address the economics and politics of nuclear power; nuclear technology and saftety; security risks and solutions.

ELECTRIC VEHICLE WORKSHOP | January 28, 2016

EV Infrastructure Requirements in the National Building Code of Canada and the Canadian Electrical Code. Professor Mehrdad Kazerani attended.

ENERGY SYMPOSIUM — LAMBTON COLLEGE, SARNIA | February 11, 2016

Professor Maurice Dusseault, Dept. of Earth and Environmental Science, was the Keynote Speaker at the inaugural Sarnia-Lambton symposium. A one day event that focused on renewable energies, energy storage, micro-grid technologies, material development for energy applications, policies, strategies, trends and initiatives. Talk title "Compressed Air Energy Storage in Salt Galleries in SW Ontario."

ENERGY COUNCIL OF CANADA, TORONTO REGIONAL MEETING | March 8, 2016

A closing keynote lecture was given by Jatin Nathwani on 'Energy Infrastructure: Issues, Opportunities and Implications' which concluded rich discussions throughout the day with several speakers who helped bring into a sharp focus the challenges of investment in the energy infrastructure.

TORONTO REGIONAL EVENT — ENERGY INFRASTRUCTURE: ISSUES, OPPORTUNITIES AND IMPLICATIONS | March 7-8, 2016

A multi-faceted examination of the challenges, issues, and potential future directions affecting energy infrastructure in Canada. Through the generous support of the Energy Council of Canada, ten Waterloo students including Energy Council of Canada (ECC) Fellows were able to attend the two-day event.

CCRE 2016 ANNUAL ENERGY LEADERS ROUND TABLE | April 11-13, 2016

The Executive Director of WISE participated in this invitation-only gathering that brought together leaders in the energy industry for discussions on issues that are important for today and tomorrow. A few thought leaders introduced each session followed by open discussions among participants. A candid exchange of views was facilitated by limiting the number of invitees and having a single "round" table.

UNACTO EARTH DAY 2016 — REFLECTIONS ON COP21 | April 23, 2016

A Call to Think Globally and Act Locally. Held at Hart House in Toronto with leaders from the government, community, academic and private sectors. The day included an exhibit of local art and environmental initiatives, a keynote, and two panel discussions. The public was invited to learn ideas on how to act locally on climate change. WISE participated with a booth at the event.

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.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INFLUENCE

informing public dialogue

By sitting on energy boards and engaging in industry forums, WISE brings evidence-based analysis to the governance and regulation of the energy sector. In the past year, for example, as a member of the Ontario Smart Grid Forum (Chaired by the IESO), WISE provided advice to government, regulators, agencies, and industry in order to advance the effective implementation of a smart grid in Ontario, to maintain a collective understanding of relevant developments in other jurisdictions and influence global developments in the interests of Ontario.

The WISE Executive Director serves as the lead Scientific Advisor to the Waterloo Global Science Initiative (WGSI) established by the Perimeter Institute and the University of Waterloo.

Upon request, members may provide expert testimony and give presentations to policy makers and legislators. As an example this year, WISE was invited to the UK House of Commons Committee Meeting of the All Party Parliamentary Group for Nuclear Energy to discuss 'Coping with a Large Nuclear Accident' with the Parliamentary Office of Science and Technology, London, UK.

The Council for Clean and Reliable Electricity provides a platform for open public dialogue and a solution-oriented approach to the challenges of the energy sector. It is a forum where representatives from universities, public and private sector business leaders, labour unions and strategic planning professionals collaborate to broaden public debate. As a member of the CCRE WISE has helped to develop a following among professionals within the energy sector through its highly regarded conference program and publications.

The 'Global Change Initiative — Affordable Energy for Humanity' will advance the scientific and technological capacity for innovations required to meet the challenge of global energy access and energy poverty. The initiative will establish a platform for large-scale adoption of low cost energy technologies and solutions intended to reach every global citizen.

disseminating

SNAPSHOTS OF CURRENT RESEARCH

Nasser Lashgarian Azad

Professor Azad's research program covers model-based control of hybrid and electric vehicles, modelling and identification of complex vehicle systems, and multi-objective design optimization of hybrid electric vehicles.
The multidisciplinary nature of his research program has allowed him to establish strong collaborative networks with researchers from universities in Europe, Asia and the USA, as well as world-leading vehicle manufacturers.

Rebecca Saari

Professor Saari's research is focused on understanding the sources and human impacts of harmful atmospheric emissions. She specializes in developing models to inform decisions in support of engineering sustainability and to quantify the linkages between air quality, energy, climate, and equity.

Philip Bigelow

Professor Bigelow works in environmental epidemiology and his contributions to risk assessment have been central in the development of health-based exposure guidelines. His research on wind energy focusses on changes in quality of life and perceptions of health impacts of wind energy.

Trevor Charles

Professor Charles is an expert on analyzing genetic material recovered directly from environmental samples, also known as functional metagenomics. In 2015, Prof. Charles was honoured with an Ontario Genomics Institute SPARK Award for an innovative project that uses methane to create renewable bioplastics with potential application for methane emission from the energy system.

research

James Craig

Professor Craig's research focuses on the development of improved numerical and analytical methods for modeling groundwater, surface water, subsurface contaminant transport and the surface water/groundwater interface, and analyzing the injection and sequestration of carbon dioxide (CO_2) in deep saline aquifers. Professor Craig's hydrologic simulation software 'Raven' is being used operationally by BC Hydro and TransAlta for their hydroelectric reservoir inflow forecasting. He is currently working with Ontario Power Generation (OPG) to provide them with similar forecasting capabilities.

Ali Elkamel

Professor Elkamel's research interests are in computer-aided modelling, optimization and simulation with applications to energy production planning, sustainable operations and product design. His work with Professor Michael Fowler is based on a power-to gas strategy for integrating renewable energy in oil sands.

Mark Knight

Professor Knight, Director of Centre for Advancement of Trenchless Technologies (CATT), has established techniques and analytics for strategic asset management for power utilities.

Armaghan Salehian

Professor Salehian's research is on the application of smart materials for energy harvesting, sensing, and actuation of mechanical systems. She has recently collaborated with University of Bordeaux in France on a project based on modelling and fabrication of a compliant centrally supported meandering piezoelectric energy harvester using screenprinting technology.

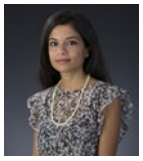
David Simakov

Profoessor Simakov's research focuses on conversion of greenhouse gases into renewable synthetic fuels. CO_2 conversion into useful products is his major initiative, for example, 'Nano-structured catalysts for thermo-catalytic conversion of CO_2'.

John Simpson-Porco

John Simpson-Porco works in control and optimization of smart power grids and distributed control. His research interests focus on the control and optimization of multi-agent systems and complex dynamic networks, with a focus on modernized electric power grids.

Bissan Ghaddar



Professor Ghaddar's research focuses on the theory and algorithms of mathematical optimization and utilizing them to solve real world problems in the areas of smarter cities and network planning. Her recent publication highlights the strength of optimization techniques for significant reduction in energy losses on the transmission grid with potential for large monetary savings.

INFLUENCE

disseminating research

WISE PUBLIC LECTURE SERIES

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

JUNE 2015		
Professor Zhong Li	Deputy Director, Institute of Coal Chemical Engineering, Taiyuan University of Technology	Synthesis of Coal-based Clean Fuels and Chemicals
SEPTEMBER 2015		
Dr. Jatin Nathwani	Ontario Research Chair in Public Policy for Sustainable Energy, University of Waterloo	Affordable Energy for Humanity: If Not Now, When?
Dr. Bala Venkatesh	Lecturer, Dept. of Electrical and Computer Engineering, Ryerson University	Microgrid Analysis, Optimization and Implementation
OCTOBER 2015		
Dr. Anand Puppala	Associate Dean, Research, College of Engineering, University of Texas at Arlington	Sustainability and Geothermal Energy Studies in Geotechnical Engineering
Dr. Alexandra Pehlken	Lecturer in Bioenergy for the International PPRE Program, Oldenburg University	The Impact of 'Energiewende' on Renewable Energies in Germany
NOVEMBER 2015		
Dr. Doris Sáez Hueichapan	Associate Professor, Department of Electrical Engiineering, Universidad de Chile	Design of a Participatory-Model/ Microgrid/Smart-Farm System for the Mapuche Indigenous Communities
FEBRUARY 2016		
Klaus Dohring	President, Green Sun Rising Inc.	Electric Vehicle (EV) Charging
APRIL 2016		
Teresa Jiang	Business Development Manager — Central Canada, Uponor Ltd.	Insights and Considerations for PEX Energy and Plumbing Applications

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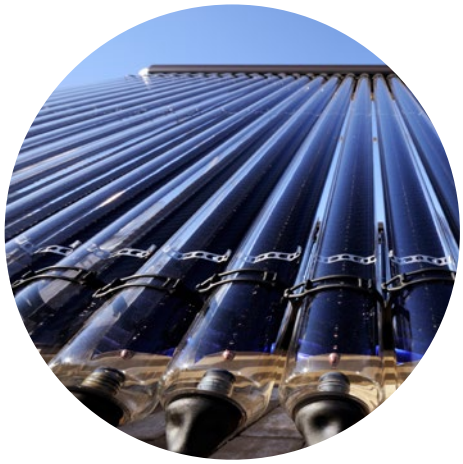
RESEARCH SPOTLIGHTS



HEAT PUMPS GIVE SOLAR HOT WATER A BOOST

Michael R. Collins

More and more rooftops across Canada are sporting solar thermal collectors that use heat from the sun to warm the water destined for household use. Because they use significantly less energy these domestic solar water-heating systems are great for the environment. Adding a heat pump will slash energy use even further. By incorporating a heat pump and a second tank to a standard solar water-heating set-up, Professor Collins has created a highly flexible system that adapts to changing household demands and weather conditions. A custom-built controller decides which of 12 configurations is the most energy-efficient option at any given moment. The dual-tank system can deliver businesses and homeowners significant electricity and cost savings.

CUTTING HEALTHCARE COSTS BY CUTTING CARBON

Rebecca Saari

Environmental engineer Rebecca Saari and her collaborators at the Massachusetts Institute of Technology have set out to determine just how much of an effect carbon policies can have on respiratory and cardiovascular diseases — and hence healthcare costs. They have created highly sophisticated models that look at the impact of three potential approaches to reducing U.S. carbon emissions: an economy-wide cap-and-trade program, policies that focus on the electricity sector and policies that focus on the transportation sector. The numbers that are emerging are compelling. Cutting carbon emissions produces healthcare savings. These insights can help decision-makers enable carbon policies that are good for the environment, good for health, and good for the economy.

A GREENER WAY TO STORE MORE ENERGY

David Simakov

Professor Simakov and his team are developing a highly efficient thermocatalytic converter for microgrids in order to provide a better and cheaper solution for the delivery of a reliable supply of wind and solar energy. Microgrids are well suited for renewables but the energy sources fluctuate daily. The scaled-down catalytic units combine hydrogen with carbon dioxide from raw sources to produce synthetic methane, a renewable natural gas that can be injected in the existing infrastructure. This green, highly-efficient energy storage technology will help conserve energy by making microgrids more viable thereby paving the way for greater use of renewable energy and reducing our reliance on fossil fuels.

Energy Research Centre,
University of Waterloo

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.

disseminating research

PUBLICATIONS AND INVITED PRESENTATIONS

(A SELECTION)

» Goortani, B.M., Gaurav, A., Deshpande, A., **Ng, F.T.T.**, & **Rempel, G.L.** (2015). Production of isooctane from isobutene: Energy integration and carbon dioxide abatement via catalytic distillation. Industrial and Engineering Chemistry Research, 54(14), 3570-3581.

» Cherney, E., Gorur, R., Krivda, A., **Jayaram, S**., Rowland, S., Li, S., Marzinotto, M., Ghunem, R., & Ramirez, I. (2015). DC inclined-plane tracking and erosion test of insulating materials. IEEE Transactions on Dielectrics and Electrical Insulation, 22(1), 211-217.

» Mehboob, N., **Cañizares, C.,** & **Rosenberg, C.** (2015). Day-ahead dispatch of distribution feeders considering temporal uncertainties of PEVs. Power Tech 2015 conference, Eindhoven, July 2015.

» Ou, C.-H., Liang, H., & **Zhuang, W.** (2015). Investigating Wireless Charging and Mobility of Electric Vehicles on Electricity Market. IEEE Transactions on Industrial Electronics, 62(5), 3123-3133.

» Gómez-Expósito, A., Conejo, A. J., & **Cañizares, C.** (Eds.). (2016). *Electric energy systems: analysis and operation*. CRC Press.

» Fergus, J., Hui, R., **Li, X.**, Wilkinson, D. P., & **Zhang, J.** (Eds.). (2016). *Solid oxide fuel cells: materials properties and performance*. CRC press.

» Dörfler, F., **Simpson-Porco, J. W.**, & Bullo, F. (2016). Breaking the hierarchy: Distributed control and economic optimality in microgrids. *IEEE Transactions on Control of Network Systems*, 3(3), 241-253.

» Sun, X., **Radovanovic, P. V.**, Cui, B. (2016). Advances in spinel Li Ti 5 O 12 anode materials for lithium-ion batteries. *Royal Society of Chemistry*, 39(1), 38-39.

» Gorbet, R., Memarian, M., Chan, M., Kulic, D., & **Beesley, P.** (2015). Evolving Systems within Immersive Architectural Environments: New Research by the Living Architecture Systems Group. *Next Generation Building*, 2(1), 31-56.

» Pang, Q., & **Nazar, L. F.** (2016). Long-life and high-areal-capacity Li–S batteries enabled by a light-weight polar host with intrinsic polysulfide adsorption. *ACS nano*, 10(4), 4111-4118.

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

» **Ghaddar, B.**, Marecek, J., Mevissen, M. (2016). Optimal power flow as a polynomial optimization problem. *IEEE Transactions on Power Systems*. 31(1), 539-546.

» Ismail, M., **Zhuang, W.**, Serpedin, E., Qaraqe, K. (2015). A survey on green mobile networking: From the perspectives of network operators and mobile users. *IEEE Communications Surveys & Tutorials*, 17(3), 1535-1556.

» Dhar, B. R., Elbeshbishy, E., Hafez, H., & **Lee, H. S.** (2015). Hydrogen production from sugar beet juice using an integrated biohydrogen process of dark fermentation and microbial electrolysis cell. *Bioresource technology*, 198, 223-230.

» Sharma, I., **Bhattacharya, K.**, & **Cañizares, C.** (2015). Smart distribution system operations with price-responsive and controllable loads. *IEEE Transactions on Smart Grid*, 6(2), 795-807.

» Xiufeng, L., **Golab, L.**, **Golab, W.**, Lhab, F. I. (2015). Benchmarking Smart Meter Data Analytics. *International Conference on Extending Database Technology (EDBT)*, doi: 10.5441/002edbt.2015.34

» Walker, S. B., Mukherjee, U.,**Fowler, M.**, & **Elkamel, A.** (2015), Benchmarking and selection of power-to-gas utilizing electrolytic hydrogen as an energy storage alternative. *International Journal of Hydrogen Energy*, 41(19), 7717-7731.

» Shareefdeen, Z., **Elkamel, A**., & Tse, S. (2015). Review of current technologies used in municipal solid waste-to-energy facilities in Canada. *Clean Technologies and Environmental Policy*, 17(7), 1837-1846.

» Ruo-Zhou Li, Rui Peng, Kenneth D. Kihm, Shi Bai, Denzel Bridges, Uma Tumuluri, Zili Wu, Tong Zhang*, Giuseppe Compagnini, Zhili Feng and **Anming Hu***, High-rate in-plane micro-supercapacitors scribed onto photo paper using in-situ femtolaser-reduced graphene oxide/Au nanoparticle microelectrodes. Energy Environ. Sci., 2016, 9, 1458

» T. M. Thompson, S. Rausch, **R.K. Saari**, N.E. Selin, "Air quality co-benefits of sub-national carbon policies." *Journal of the Air & Waste Management Association*, doi: 10.1080/10962247.2016.1192071

» "Affordable Energy for Humanity", **Jatin Nathwani**, Policy Engagement, Ontario Centre for Engineering and Public Policy, pp 44-48, July/August 2015

» Affordable Energy for Humanity, **Jatin Nathwani**, Ontario Smart Grid Forum, IESO, 120 Adelaide St, Toronto, October, 26, 2015

» 'Affordable Energy for Humanity: If Not Now, When,' **Jatin Nathwani**, The Oxford Round Table on Environment, Climate Change and Global Warming, Harris Manchester College, Oxford, England, July 22-25, 2015

our people

Siva Sivoththaman,
Professor, Ontario Research Chair

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Canada Research Chair ●
Ontario Research Chair ●
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Distinguished Awards & Honours ●

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» Deans of Engineering, Environment and Science

» Eight regular WISE faculty members from five faculties

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Jessica Strickler | Communications Specialist

AE4H participants

27 organizations from around the world are participating in the Affordable Energy for Humanity global change initiative.

- Ashesi University
- Carnegie Mellon University
- Earthspark International
- Engineering for Change
- ENVenture
- Harvard University
- IESO Ontario
- Institute for Advanced Sustainability Studies, Potsdam
- Karlsruhe Institute of Technology
- Le Centre National de la Recherche Scientifique
- Nokero Solar
- Paul Scherrer Institut
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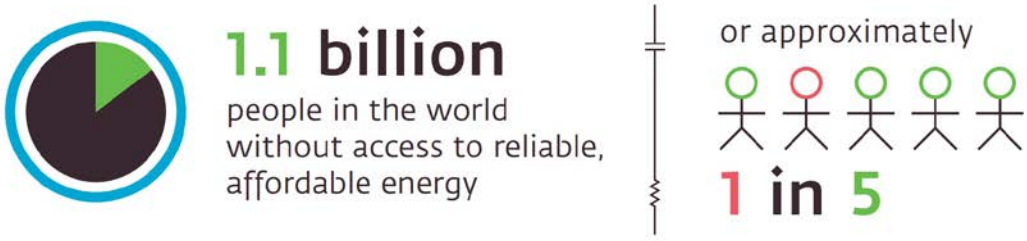
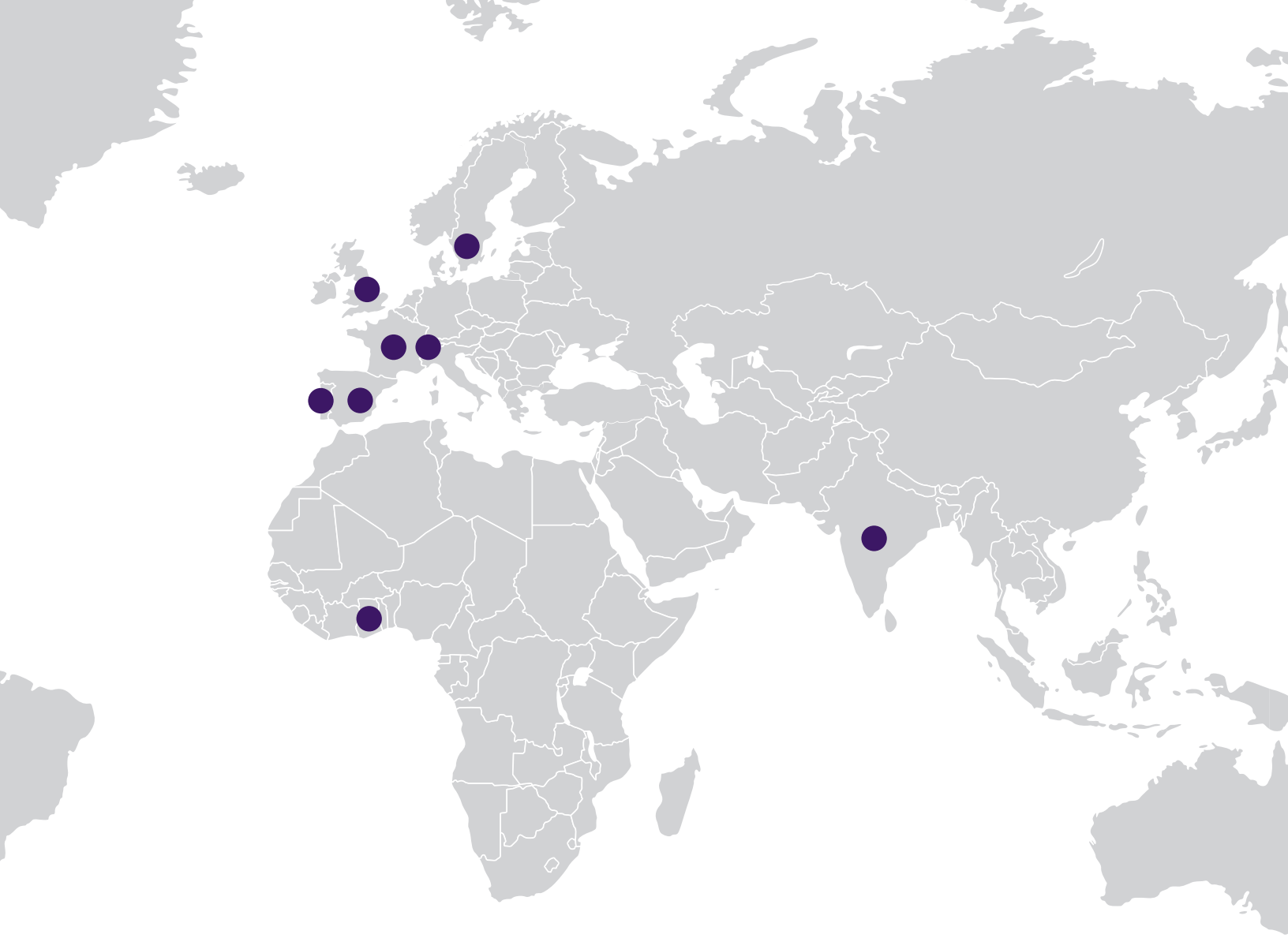
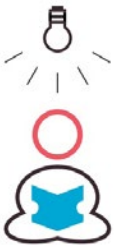


Image Credit: INTENT Source: WGSI's OpenAcesss Energy Blueprint





Today, only about

50% of students

from families in the planet's lowest income quintile attend primary schools that are connected to the grid

Image Credit: INTENT Source: WGSI's OpenAcesss Energy Blueprint

Traditional sources of fuel cause:

An estimated

4.3 million

premature deaths per year from indoor air pollution

1/2 of all premature deaths of

children under the age of 5

Approximately

300,000

deaths from fires every year

Image Credit: INTENT Source: WGSI's OpenAcesss Energy Blueprint

WISE by the numbers

OUR PEOPLE

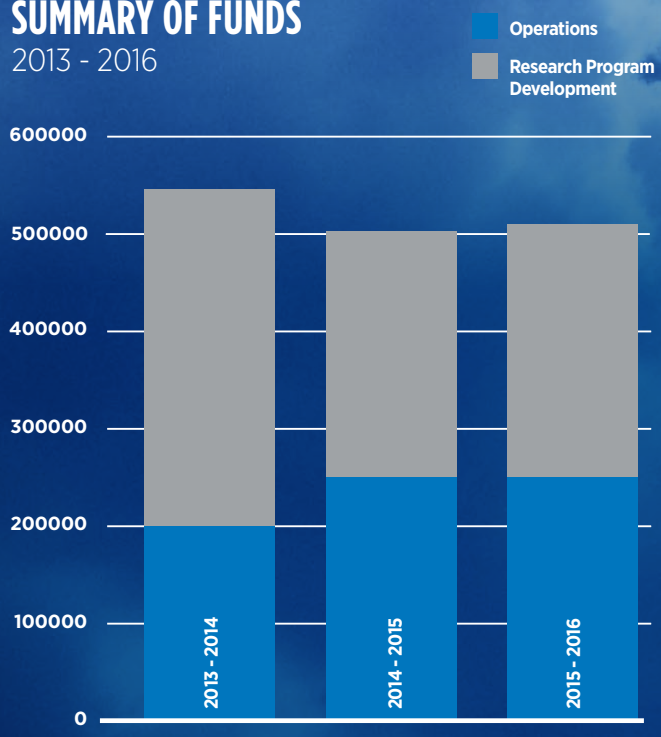
115 Members

29 Labs

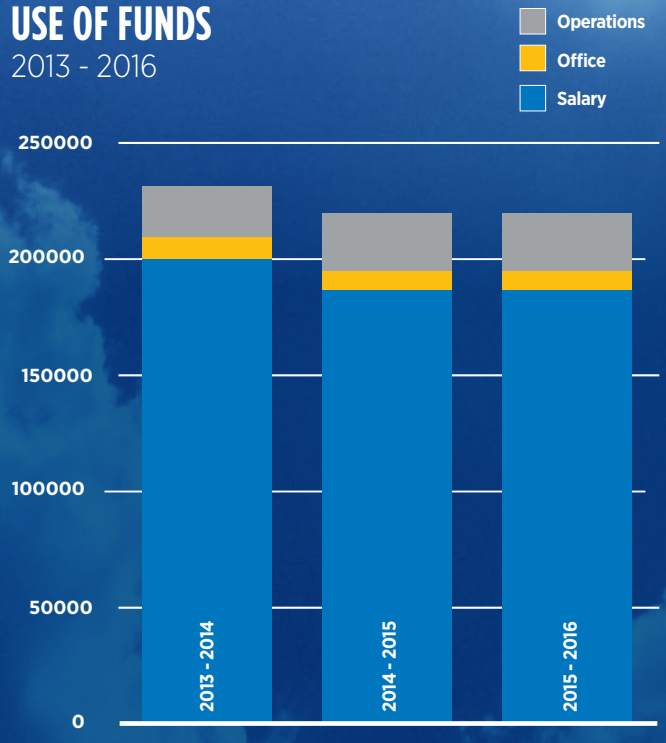
18 Research Chairholders

21 Areas of Expertise

SUMMARY OF FUNDS
2013 - 2016



USE OF FUNDS
2013 - 2016



33 industry & scientific visitors

SCHOLARLY OUTPUT

607 member publications *(2015-2016)*

AWARDS

9 CISCO System Smart Grid Research Awards | $160,000

11 Energy Council of Canada Fellowships totaling $184,500

31 Hydro One Undergraduate Scholarships totaling $102,000

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