

WISE | annual report

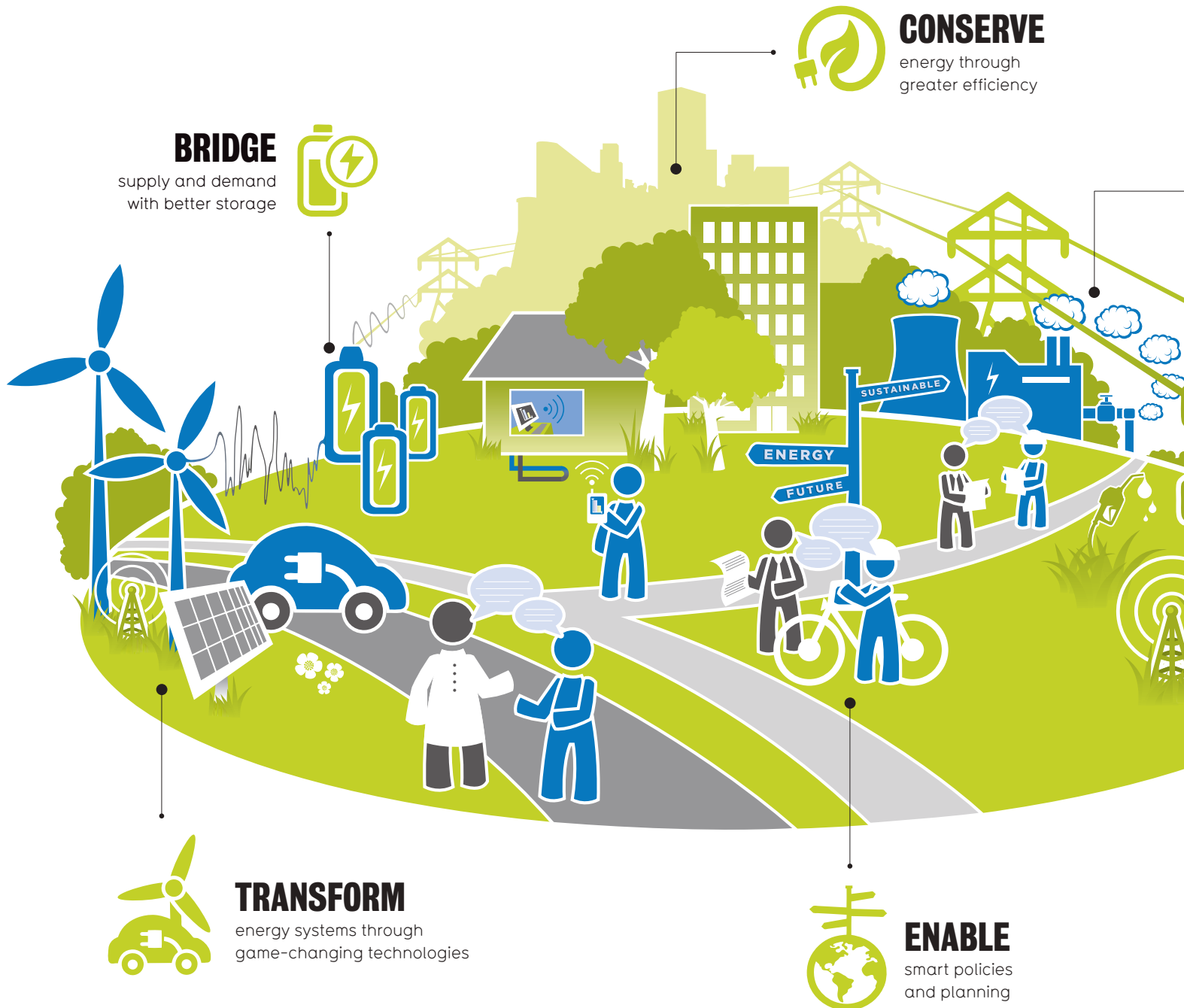
Waterloo Institute for Sustainable Energy
2020-2021



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 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

TABLE OF CONTENTS

Mission and Strategic Objectives	2
A Note from the Executive Director	3
A Note from the Vice President, Research	5
Explore WISE	11

COLLABORATE	12
Education and Training	16
Co-op Student Programming	17

REACH OUT	24
Energy Research Themes	25
1. Electric Vehicles	26
2. Energy Storage	28
3. Geothermal Energy	30
4. Wind Energy	32
5. A Global Change Initiative – Affordable Energy for Humanity (AE4H)	34
WISE Events	36
WISE Participation	37

INFLUENCE	40
Informing Public Dialogue	42
Public Lecture Series	43
Research Spotlights	44
Publications	48
Awards and Recognition	52

WISE BY THE NUMBERS	54
----------------------------	----

OUR PEOPLE	
Advisory Council	56
Internal Board of Management	56
WISE Members	57
Senior Executive Fellows	57
Staff	57
AE4H Participants	59



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 multi-disciplinary 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 wise audience, informing energy policy both here and around the globe.



FROM THE EXECUTIVE DIRECTOR

I submit this Annual Report of WISE with a great sense of pride in our collective accomplishments advancing energy research at Waterloo with my term as Executive Director of WISE ending effective Dec 31, 2020.

As the inaugural founding executive director of WISE, it has been a fulfilling personal journey for me, but the true measure of our success is the recognition of the contributions of each individual - faculty members and students - who continue to work diligently towards the goal of leading Canada towards a just and clean energy transition.

This year, more than ever, the need for a just and clean energy transition was highlighted due to the COVID-19 pandemic. As the pandemic continues to shift global energy landscapes, leadership and research from WISE members will be crucial for shaping emerging energy policy and technology. I am proud of WISE's ability to innovate and adapt to the energy needs of today and am confident that WISE will continue to be a guiding force in Canada and abroad.

I wish you a bright future and hope your commitment to the strategic goals of WISE will remain aligned with emerging research priorities.

A handwritten signature in black ink, appearing to read 'J. Nathwani', with a horizontal line underneath.

JATIN NATHWANI, Executive Director

FAREWELL NOTE FROM THE FORMER PRESIDENT

I had the pleasure of meeting Professor Jatin Nathwani long before we were colleagues at the University of Waterloo. The first meeting I had with him was at my first board meeting of the Ontario Centre of Excellence for Energy and I really liked what Jatin brought to the table. As a fellow board member, Jatin presented in a factual and engaging way that was backed up with a strong scientific and engineering base for the discussion, and above all, he did it in a highly articulate manner.

I was delighted when Jatin was appointed as the inaugural Ontario Research Chair in Public Policy for Sustainable Energy. Even though my former institution was also competing for the same chair, I knew his exceptional approach to scholarship in the field made him the right person to lead this important research. Our paths would cross again when I moved to Waterloo in 2009 and it has been wonderful getting to know him better over the past 12 years.

As a scholar, expert, leader and humanitarian, Jatin has exemplified what it means to be each of these things. As the Executive Director of the Waterloo Institute for Sustainable Energy, he brought every expert on energy across our institution together, making it one of the most impactful multi-Faculty, cross-disciplinary research units at Waterloo. He knew well that our excellence in various aspects of energy research – regardless of how great it was – had to be connected with other disciplines and combined with those external partners to the University whether they were industry, government or academia.

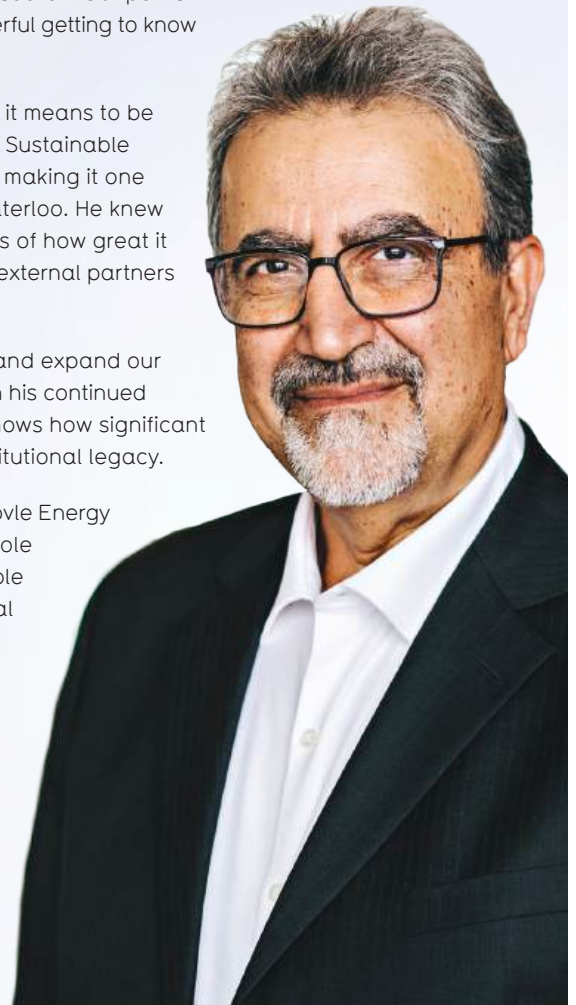
Jatin has worked tirelessly to deepen the knowledge base within his field and expand our network around the world. This is no small feat on its own but combined with his continued attention to his professorial and supervisory roles at our University, only shows how significant his contributions have been to our students, colleagues, partners and institutional legacy.

He has helped put Waterloo on the map. The Waterloo Institute for Sustainable Energy is now recognized around the world and Jatin, himself, has cemented his role as a thought leader in the field. His efforts to make energy green, accessible and affordable by all in the world has resonated with so many in our global community, particularly by many foundations around the world.

We owe Jatin a great deal of gratitude for his remarkable commitment, passion, dedication, service, not only to the University of Waterloo, but to our society. I wish him all the best and hope that I will personally get a chance to work with him again.



FERIDUN HAMDULLAHPUR,
Former President and Vice-Chancellor



FAREWELL NOTE FROM THE VICE PRESIDENT, RESEARCH

Twelve years ago, leaders at the University of Waterloo had a vision of an interdisciplinary research institute to ensure accessible and affordable clean energy worldwide.

Professor Jatin Nathwani had the same vision when he founded the Waterloo Institute for Sustainable Energy (WISE) and was named the first executive director in 2008. With December 2020 marking the end of his term, I would like to extend a warm and sincere thank you to Professor Nathwani for his commitment and dedication to innovation and collaboration at Waterloo and on a global level.

Known as an open-minded leader with a talent for connecting people and research, Professor Nathwani recognized that transforming the future of sustainable energy requires a global approach to collaboration. Over the years, the team at WISE developed partnerships worldwide to support research across a multitude of areas including energy storage, electric vehicles, and wind energy. Generating \$40 million in funding, the WISE team secured several high-profile research chairs, a research agreement with Hydro One, and funded scholarships for graduate students involved in research and development activities.

All of us at WISE offer our sincere appreciation to Professor Nathwani for his leadership in turning a tremendous concept into a thriving institute with worldwide recognition.

Thank you Jatin!



CHARMAINE DEAN,
Vice-President, Research and International



FAREWELL NOTE FROM THE DEAN OF ENGINEERING

On behalf of the Faculty of Engineering, I'd like to thank Jatin Nathwani for serving as the founding executive director of WISE from 2008 until the end of 2020.

He consistently brought his tremendous energy, insight and commitment to the vision and goals of WISE and worked tirelessly to ensure that the important work of the centre's researchers is recognized around the world.

Through his campaign to develop innovative solutions and policies to help transform the energy system for long-term sustainability, he forged a community of experts who reached far beyond the borders of our campus.

The Faculty also thanks Jatin for establishing the Engineering for Humanitarian Change – Nathwani Prize as part of our Engineer of the Future Fund. His prize supports our students' work on breakthrough technologies that offer the promise of being effective, simple and affordable for the poorest people on our planet.

His passion for championing ways to create clean energy that is accessible for all has created a Waterloo Engineering legacy.

Thank you 

MARY WELLS,
Dean of Engineering



FAREWELL NOTE FROM THE DEAN OF ENVIRONMENT

Jatin, I want to thank you for your many contributions as Executive Director of WISE over the past 14 years. You have been a beacon of inspiration to the entire campus in your leadership on global challenges related to energy accessibility. I deeply appreciate your inclusive and respectful leadership style. The Faculty of Environment has benefited enormously from your involvement with our faculty and students. Wishing you all the best in future initiatives.



JEAN ANDREY,
Dean of Environment



BIOGRAPHY

Professor Nathwani was the founding Executive Director of the Waterloo Institute for Sustainable Energy (WISE) (2008–2020) and the inaugural Ontario Research Chair in Public Policy for Sustainable Energy (2007–2020). He is a faculty member in Engineering and was also cross-appointed in the Faculty of Environment (2007–2020). Within the Faculty of Engineering, his appointment has been with the Department of Management Sciences and the Department of Civil and Environmental Engineering. Professor Nathwani holds a Ph.D in Engineering from the University of Toronto and is a Registered Professional Engineer in the Province of Ontario.

Professor Nathwani, with Co-Director, Prof Joachim Knebel (Karlsruhe Institute of Technology, Germany), has established a platform for a Global Change Initiative – Affordable Energy for Humanity (AE4H). The consortium comprises 150+ leading STEM and social science researchers, energy access thought leaders and practitioners from 50 institutions in 30 countries committed to eradicating energy poverty by 2030.

At WISE, he has led research initiatives on accelerating energy transitions for a zero-carbon economy through systems assessments of technology, financing strategies, risk management and public policy.

Prior to his appointment at the University in 2007, Professor Nathwani worked in a leadership capacity in the Canadian energy sector for 30 years. He brings a unique combination of academic perspectives with extensive experience in the business sector that includes corporate planning and strategy, energy sector restructuring, integrated power system planning, environmental and regulatory policy developments, and research program management.

Professor Nathwani serves on several Boards at the provincial and national levels, has appeared frequently in the media (print, TV, radio), and has over 150 publications related to energy policy, environment and risk management, including seven books.



PROFESSIONAL AFFILIATIONS AND ACTIVITIES

- › Chair, Board of Directors, UNENE, University Network of Excellence in Nuclear Engineering (UNENE), 2008-2014, Reappointed Chair, 2018-Present
- › Research Cluster Lead, 'STEM for Global Resilience,' Balsillie School of International Affairs, 2020-Present
- › Member, The Ontario Smart Grid Forum, Renamed 'Energy Transformation Network Ontario (ETNO), Chaired by Ontario Independent Electricity System Operator (IESO), 2008-Present
- › Member, Public Policy Forum, Canada's Energy Future Forum, 2019-Present
- › Member, Board of Management, Ontario Centre of Excellence (OCE) Energy, Centre for Energy 2007-2015
- › Honourary Member, Council for Clean and Reliable Energy (CCRE), 2008-2018
- › Member, Clean Tech Advisory Board, Government of Canada, Department of Foreign Affairs and International Trade (DFAIT), 2010-2013
- › Expert Panel Member, Canadian Council of Academies, 'Potential for New and Innovative Uses of Information and Communication Technologies (ICTs) for Greening Canada' 2012-2014
- › Chief Science Advisor, Waterloo Global Science Initiative Summit, (WGSi), Open Access Energy, 2016-2017
- › Chief Scientific Advisor and Lead Author, Waterloo Global Energy Summit (WGSi), Equinox Energy 2030 Summit Blueprint, 2011-2013
- › Expert Testimony, Appearances before the Standing Committee of the House of Commons on Natural Resources, The Medical Isotopes Crisis, Ottawa, ON June 18, 2009 and February 2008.
- › Research Advisory Panel for the Science Media Centre of Canada, 2010-2015
- › Member, Advisory Board, Sustainable Waterloo, 2008-2013
- › Member, IEEE, 2008-Present
- › Member, American Association for advancement of Science (AAAS)



CONTRIBUTIONS TO WISE BY JATIN NATHWANI



RESEARCH LABS

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



BRIDGE:

SUPPLY AND DEMAND WITH BETTER STORAGE

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



CONSERVE:

ENERGY THROUGH GREATER EFFICIENCY

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



DELIVER:

ENERGY MORE INTELLIGENTLY

Electricity Market Simulation and Optimization Lab
High Voltage Energy Lab
Information Systems and Science for Energy Lab (ISS4E)
Non-destructive Testing Lab



ENABLE:

SMART POLICIES AND PLANNING

Sustainable Energy Policy Group



IMPROVE:

CONVENTIONAL GENERATION METHODS

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



TRANSFORM:

ENERGY SYSTEMS THROUGH GAME-CHANGING TECHNOLOGIES

Center for Advanced Photovoltaic Devices and Systems
Center for Advanced Materials Joining
Fluid Mechanics Research Lab
UWaterloo Live Fire Research Facility
Wind Energy Lab

Energy Harvesting Lab
Kleinke Research Centre
Fuel Cell and Green Energy Lab
Giga-to-Nano Centre
Mechatronics Vehicle Lab
Solar Thermal Research Center
Advanced Glazing System Lab
Laboratory for Research in Thermochemical Process and Green Energy



COLLABORATE

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

19

departments

6

faculties



gettyimages[®]
SelectStock



MESSAGE FROM AND UNIVERSITY IN SUSTAINABLE ENVIRONMENT, DEVELOPMENT

Professor Olaf Weber (WISE Faculty Member and University Research Chair in Sustainable Finance, School of Environment, Enterprise and Development) is an expert in the discipline of developing viable financial solutions for renewable energy technologies, and efficient energy projects in the power and energy sector. He is also a senior fellow at the Centre for International Governance Innovation (CIGI). His research addresses sustainable finance and fossil fuel divestment strategies. Prof. Weber's background is in the areas of environmental and sustainable finance, with emphasis on sustainable credit risk management, socially responsible investment, social banking and the link between sustainability and financial performance of enterprises. His research interests include financial risk and opportunities caused by climate change and environmental regulations.

In the past, Prof. Weber was a managing partner at GOE in Zurich, Switzerland, developing credit risk management and sustainability rating systems, and was head of the sustainable finance group at the Swiss Federal Institute of Technology, Zurich. He earned his Ph.D. from the Technical Faculty, University of Bielefeld, Germany and his M.A. from the Department of Psychology, University of Mannheim.

Prof. Weber was also the director of the master's program in Sustainability Management and supervises graduate students in core areas of Sustainability: (1) Environmental Finance, (2) Sustainability Accounting and Reporting, and (3) Theories and Tools for Sustainability Management.

At the School of Environment, Enterprise and Development (SEED), Prof. Weber has initiated multiple R&D projects with industry and other organizations to advance his research agenda in clean energy, climate change, and green and sustainable finance. He was also one of the main investigators to study the integration of the United Nation's Sustainable Development Goals (SDGs) into the Global Reporting Initiative (GRI)- based reporting thus exploring the factors that influence the adoption of the SDGs by organizations. He also led a project on the analysis of the influence of divestment strategies on the carbon

FROM THE PROFESSOR TO RESEARCH CHAIR IN FINANCE, SCHOOL OF ENTERPRISE AND (SEED)

intensity of portfolios and to understand the financial effect of divestment. In addition, he has also done extensive research work on the impact of divestment announcements on the share price of fossil fuel stocks.

SEED has tremendously benefited from Prof. Weber's research program. SEED is home to more than 1,000 students, faculty and staff, and has thousands of alumni worldwide. SEED's core expertise lies across several inter-related areas: sustainability management; international development, economic development and innovation and social innovation. SEED has a number of key program partners including St Paul's University College (Indev), World University Services Canada (Indev and MDP), the Global MDP Network (MDP), the Economic Developers Association of Canada (MEDI), as well as numerous industry and government partners that support our students through project partnerships, internships, and co-op positions. SEED's core sustainable developmental strategies lie within three interdependent areas: (1) Sustainability Management, (2) International and Local Development Practice, and (3) Environment and Business.

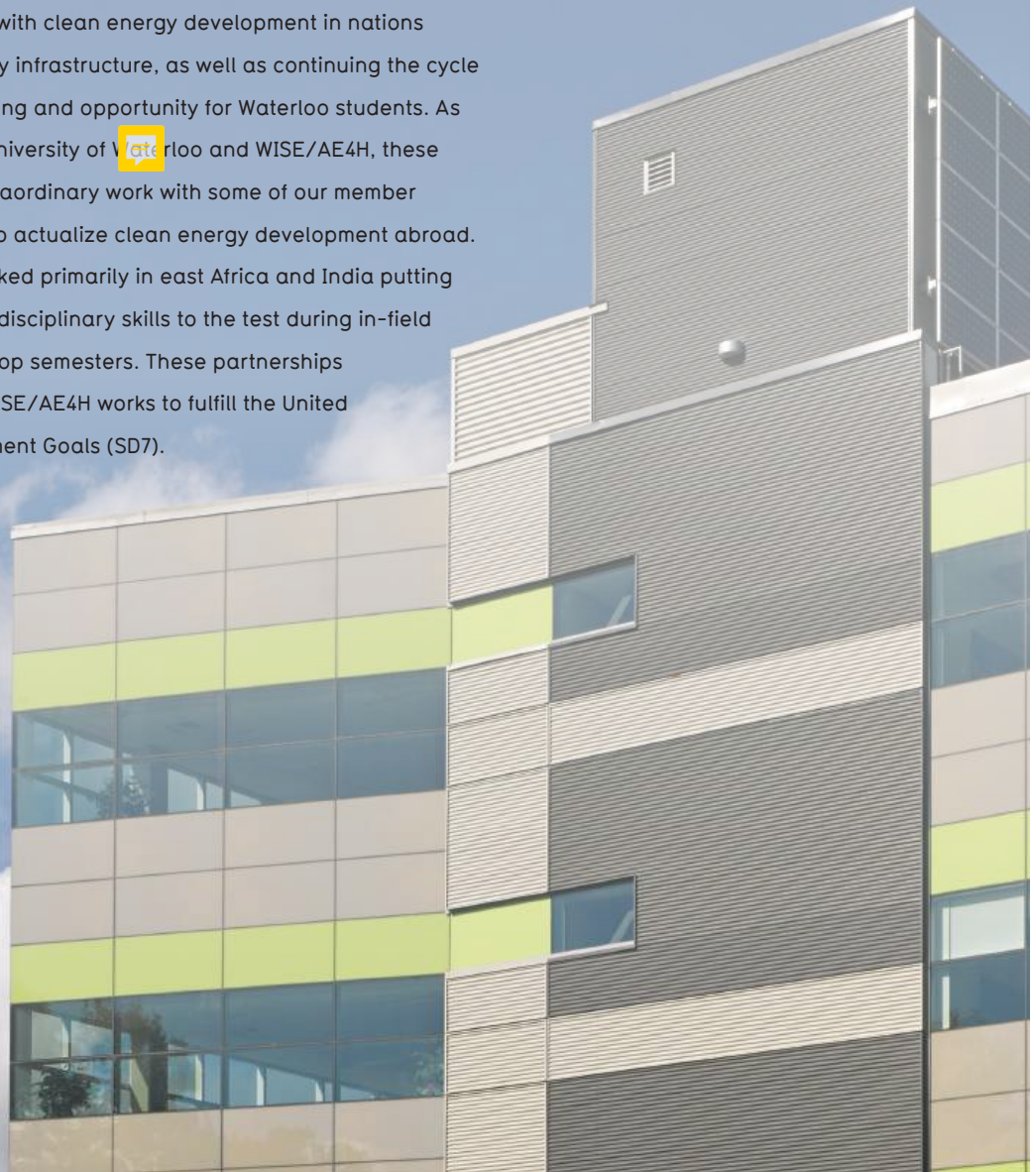
SEED's faculty is multidisciplinary, with a variety of backgrounds, including management, finance and business, engineers, political scientists, geographers, urban planners, economists, political ecologists, marketing experts and environmental lawyers. This disciplinary diversity enables our researchers and students to address collaboratively seemingly intractable issues in new ways and from varying innovative perspectives. SEED is leader in education and research for sustainable development in Canada and around the world. We are nationally and globally recognized as an education and research hub for sustainable development and play an integral role in the Sustainable Development Solutions Network (SDSN) Canada.

PROFESSOR OLAF WEBER,
Department Chair, Chemical Engineering

EDUCATION AND TRAINING

QUEEN ELIZABETH SCHOLARSHIPS

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



CO-OP STUDENT PROGRAMMING

The COVID-19 pandemic has brought a temporary halt to the Queen Elizabeth Scholars program, which for the last three years has facilitated international co-op positions for UWaterloo students in many countries around the world. However, this has not hindered WISE's creation of opportunities for UWaterloo co-op students, and instead led to new partnerships and innovation in the realm of remote international positions.

The new Energy Access Internship Program is a remote international internship program that facilitates 3-5 online co-op placements with AE4H partners per term. Students work remotely from their homes for AE4H employers abroad, in positions such as Hardware Engineering Intern, Strategic Communications Intern, Business Development Intern, and more.

WISE is grateful for the support of the following AE4H employers who have hosted students through the Energy Access Internship Program in 2020-2021.

STUDENTS

The 14 amazing students who participated in the Energy Access Internship Program used their skills and hard work to create meaningful impact at AE4H institutions to promote access to energy. The students are truly interdisciplinary – they represent five of the six faculties at the University of Waterloo. It is our goal to continue to broaden the scope of these internship opportunities and create opportunities for students in all disciplines.

- › Sean Diehl, Mechanical Engineering
- › Sam Bisutti, Mechatronics Engineering
- › Aysha Cotterill, Systems Design Engineering
- › Anthony Wang, Software Engineering
- › Shehryar Suleman, Computer Science and Business
- › Kyprianos Antzoulidis, Mechanical Engineering
- › Ryan Schmied, Computer Engineering
- › Xin Lu (Lulu) Guo, Management Engineering
- › Steven Shen, Mathematics/Financial Analysis and Risk Management
- › Steven Xu, Electrical Engineering
- › Chawthri Kanagarasa, Physics
- › Yelda Safi, English Rhetoric and Communication
- › Ayesha Asim, Environment and Business
- › Sean Tang, Math and Business Double Degree



ENVENTURE, UGANDA

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

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



JAZA ENERGY, TANZANIA

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

– Laurel Pilon, co-op student Winter and Spring 2019



MANDULIS ENERGY, UGANDA

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



AVANI BIO ENERGY, INDIA

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

– Andrew MacMillan, co-op student Spring 2019



PAMIR ENERGY AND BADAKHSHON ENERGY, TAJIKISTAN AND AFGHANISTAN

Pamir Energy (Tajikistan) and Badakhshon Energy (Afghanistan) are social enterprises within the Aga Khan Development Network that work to provide access to energy in remote and mountainous areas of Tajikistan and Afghanistan. Many of these communities have never had access to electricity, and through Pamir and Badakhshon's work they are able to experience an improved quality of life and in turn, regional trade and cooperation have increased.

SPECIAL THANKS

WISE would like to thank Co-operative and Experiential Education for their support in facilitating these positions and would also like to thank Waterloo International and the Student Wage Placement Program for their financial support of this program.

STUDENT TESTIMONIALS

SHEHRYAR SULEMAN

MANDULIS ENERGY

"I am quite fortunate of getting a chance to work with Mandulis Energy as a Software Developer Intern. As a person who loves working for non-profits and projects that benefits the community, I enjoyed every minute of working on such an impactful project which has the potential to change the lives of many people living in Uganda. I learned numerous technical and non-technical skills during my internship. On top of that, learning about Ugandan culture and lifestyle was a great learning experience and something that I would remember for the rest of my life."

SAM BISUTTI

MUNDULIS ENERGY

"My co-op through WISE during the 2020 summer semester was a special and unique experience. It provided me with an opportunity to do a wide variety of meaningful and impactful work within a company that uses exciting technologies to improve the lives of the less fortunate. It allowed for me to connect and work with people from a wide variety of cultural and professional backgrounds around Europe and Africa, all while being in a remote work from home environment. Working such passionate people about energy access and cleantech has inspired me to pursue future co-ops in similar fields."

YELDA SAFI

PAMIR ENERGY

"As an intern for WISE's international partners in the renewable energy sector, my co-op term has been a very beneficial and inspiring experience. In the virtual work-from-home setting, I have the opportunity to collaborate with individuals across Central Asia on meaningful and impactful tasks for companies who are working to provide electricity and improve lives in the remote villages of Tajikistan and Afghanistan, most of whom are gaining access to electricity for the first time in history. This memorable experience introduced me to the field of sustainable energy, widening my career perspective and motivating me to pursue similar positions in the future."

AYESHA ASIM

WISE

"This was my first international co-op term facilitated through WISE and it was an incredible learning experience. Not only did I get to learn more about sustainable energy and apply the skills I have developed through my undergrad, but I also got to learn more about energy initiatives in developing regions. Working with team members from different countries was really interesting as I got to learn about practices and policies that I was previously unfamiliar with."

SEAN DIEHL**WISE**

"My experience working at WISE helped me realize my interest in academic research work, something that has influenced my career decisions moving forward. Being able to work remotely with like-minded individuals from other parts of the world helped me feel connected during a period of isolation, and I was able to take pride in and feel passion for my work, knowing the research I was doing would help us better understand some of the energy challenges facing the world today."

AYSHA COTTERILL**PAMIR ENERGY**

"My research semester at WISE was eye-opening and rewarding. While at WISE, I had the opportunity to work on multiple research projects related to remote clean energy in Canada. The mentorship I received during this co-op was extremely valuable, and I was able to learn a lot about energy access challenges in Canada and globally. I was impressed by WISE's commitment to sustainable development, and how many projects they were working on around the world related to clean, affordable, and sustainable energy access. The passion and expertise of WISE's members was inspiring, and my time there motivated me to pursue a career in sustainable energy engineering."

WISE-AE4H CAPSTONE

TEAM SOLIT

In 2020-21 WISE recruited two fourth-year engineering design teams to develop projects to support AE4H. Team Solit, comprised of five Electrical and Computer Engineering students, developed a modular lighting system to provide emergency and backup lighting for health clinics in rural Uganda. They were able to design a low-cost, high-power system that has the potential to provide basic energy access to many health clinics that currently rely on kerosene lamps or cellphone lighting to perform medical care.



ANDRE CAYEN



FELIX ZHEN



GAURI GOYE



HUIXIN JIN



ANNE ZHAO

MENTORSHIP PROGRAM

TEAM INFRA-SOLIS

Team Infra-Solis, comprised of four Environmental Engineering students, conducted research into several types of solar energy systems with the potential to improve rural access to electricity. They designed an agrivoltaics system to meet the needs of a case study location in Uganda with a large focus on community engagement. Team Infra-Solis' project was selected as one of Canada's top 30 youth projects in the 2020 Youth Impact Challenge.



JESSICA DULKU



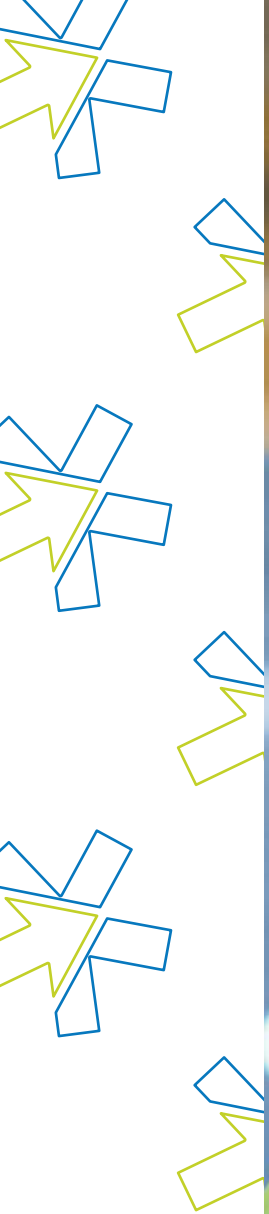
JENAN BUALAT



MANASI GOYAL



NITI LAD



REACH OUT



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

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

- › Electrical Vehicle
- › Energy Storage
- › Geothermal Energy
- › Wind Energy
- › A Global Change Initiative – Affordable Energy for Humanity (AE4H)

1 ELECTRIC VEHICLES

The transition to low carbon energy economy, reducing dependence on fossil fuels and increasing understanding of the challenges of climatic conditions has steered to the adoption of alternative energy technologies. Among a variety of low and zero emissions technologies, one such alternative technology is electric vehicles (EVs) that is swiftly becoming a feature of the current transportation system. EVs will play a key role on road transportation, reduction of carbon emissions, and supplying power to electric grid during peak energy demands of the day.

Thanks to the advantages of zero carbon dioxide emissions and low operation cost, the number of on-road electric vehicles (EVs) is expected to keep increasing. They usually get charged through charging stations powered by either the grid or renewable plants. Due to the potential difference in electricity price between the grid and the renewable plants, an EV may purchase electricity at charging stations powered by renewable plants, and then discharge the surplus energy in the battery to the grid, to gain profits and enhance the overall renewable energy utilization.

Professor Shen (Electrical and Computer Engineering) did a study to optimize the route selection and charging/discharging scheduling to improve the overall economic profits of EVs, taking into account the constraints, including the time-varying energy supply caused by the intermittent generation of

renewable energy, the limited number of charging piles in a charging station, and the traveling delay tolerance of EVs. Firstly, a time-expanded vehicle-to-grid graph was designed to model the objective and related constraints. Then, an AI-based A* algorithm was applied to find K-shortest paths for each EV. Finally, a joint routing selection and charging/discharging algorithm, namely, K-Shortest-Paths-Joint-Routing-Scheduling (KSP-JRS), was proposed to minimize the total cost of EVs by maximizing their revenue from energy discharging under time constraints. The proposed approach was evaluated using the real traffic map around Santa Clara, California. The simulation, with different numbers of testing EVs, showed the feasibility and superiority of the proposed algorithm.

To pursue a higher energy density ($>300 \text{ Wh kg}^{-1}$ at the cell level) and a lower cost ($<\$125 \text{ kWh}^{-1}$ expected

at 2022) of Li-ion batteries for making electric vehicles (EVs) long range and cost-competitive with internal combustion engine vehicles, developing Ni-rich/Co-poor layered cathode " $\text{LiNi}_{1-x-y}\text{Co}_x\text{Mn}_y\text{O}_2$, $x+y \leq 0.2$) is currently one of the most promising strategies because high Ni content is beneficial to high capacity ($>200 \text{ mAh g}^{-1}$) while low Co content is favorable to minimize

battery cost. Unfortunately, Ni-rich cathodes suffer from limited structure stability and electrode/electrolyte interface stability in the charged state, leading to electrode degradation and poor cycling performance.





To address these problems, **Professor Chen** (Chemical Engineering) did a research project in which various strategies have been employed such as doping, structural optimization design (e.g., core-shell structure, concentration-gradient structure, etc.) and surface coating. In this study, five key aspects of Ni-rich/Co-poor layered cathode materials were explored: energy density, fast charge capability, service life including cycling life and calendar life, cost and element resources, and safety. This enabled a comprehensive analysis of current research advances and challenges from the perspective of both academy and industry to help facilitate practical applications for EVs in the future.

Power management strategies play a key role in the design process of hybrid electric vehicles. Electric Assist Control Strategy (EACS) is one of the popular power management strategies for hybrid electric vehicles (HEVs).

Professor Azad (Systems Design Engineering)



proposed a new framework to advance the EACS. Dynamic Programming method is applied to an HEV model in several drive cycles, and as a result, some optimal operating regions are found. The obtained regions are almost distinct, and consequently, some threshold lines can be defined to separate them. The obtained threshold lines were used to eliminate some parameters of the EACS to reduce its sensitivity to the driving behavior. It was shown that by applying the mentioned modification, the sensitivity of the EACS decreased without a significant increase in the HEV's FC. All in all, the research findings indicated the effectiveness of the proposed methodology to improve the EACS strategy for HEV supervisory control applications.

2 ENERGY STORAGE

Energy-storage systems will act as a key performer both technically and financially in shaping the future of our energy infrastructure because of the unpredictable and volatile demand for energy and the intermittency of renewable energy technologies. It is an excellent source of flexibility and an enabler of integrated operations. Energy storage is essential to stabilize supply and demand at residential and regional level. The storage type and size vary in regard to seasonal, weekly, daily, and hourly demand. Long-term energy storage is still facing technical challenges. The combination of operation of both heat and electricity storage is desirable. The energy storage has the potential to enable location-based netting, promising local energy balance and overall higher renewable energy system performance.

Professors Cañizares and Bhattacharya (Electrical and Computer Engineering) examined a dynamic modeling of battery energy storage and applications in transmission systems. In this study, a Battery Energy Storage System (BESS) dynamic model was presented, which considered average models of both Voltage Source Converter (VSC) and bidirectional buck-boost converter (dc-to-dc), for charging and discharging modes of operation. The dynamic BESS model comprised a simplified representation of the battery cells, which allowed to



CLAUDIO CAÑIZARES
Professor, Electrical and
Computer Engineering

simulate the effects of battery degradation, dc-to-dc converter, VSC, and the dynamics associated with the filter and transformer connecting the BESS to the grid. A decoupled dq-current control is used for the VSC, allowing the operation of the BESS in several modes, i.e., constant active and reactive power, constant power factor, voltage regulation, frequency regulation, oscillation damping, and a combination of the latter two. The proposed model is implemented in DSATools and tested for different contingencies on a benchmark system, and compared with a industry-grade BESS model used in power system dynamic studies. The importance of modeling the current control and dynamics of the dc-to-dc are demonstrated, especially when the battery cells are degraded due to, for instance, aging.

Professor Bhattacharya (Electrical and Computer Engineering) examined the non-strategic and strategic participation of a pumped hydro energy storage (PHES) facility in day-ahead energy and performance-based regulation (PBR), which included regulation capacity and mileage markets. The PHES is modeled with the capability of operating in hydraulic short-circuit (HSC) mode with detailed representation of its operational constraints, and integrated with an energy-cum-PBR market clearing model. For its strategic participation, a bi-level market framework was proposed to determine the optimal offers and bids of the PHES that maximize its profit. The operation of PHES was modeled at the upper level, while the market clearing was modeled in the lower level problem. The bi-level problem was formulated as a mathematical program with equilibrium constraints (MPEC) model, which was linearized and solved as a mixed integer linear programming problem. Several case studies were carried out



KANKAR BHATTACHARYA
Professor, Electrical and
Computer Engineering

to demonstrate the impact of PHES' non-strategic and strategic operations on market outcomes. Furthermore, stochastic case studies were conducted to determine the PHES strategies considering the uncertainty of the net demand and rivals' price and quantity offers. The study found out that the PHES operations in both the non-strategic and strategic participation increased the social welfare, and the strategic HSC PHES accrued more profit compared to conventional PHES because of its flexibility in the regulation-up capacity and mileage provisions. Considering the stochastic scenarios of the demand, renewable energy source (RES) generation, and rivals' offers, the offer/bid strategy of PHES was more conservative in the energy market than that in the regulation markets, to ensure the selection of the PHES offers and hence maintain its reservoir water volume, in all the considered scenarios.

The goal of limiting global warming to 1.5 °C requires a drastic reduction in CO₂ emissions across many sectors of the world economy. Batteries are vital to this endeavor especially storing renewable electricity. Present lithium-ion technologies are preparing the public for this inevitable change, but their maximum theoretical specific capacity presents a limitation. Their high cost is another concern for commercial viability. Metal-air batteries have the highest theoretical energy density of all possible secondary battery technologies and could yield step changes in energy storage, if their practical difficulties could be overcome. **Professor Nazar** (Chemistry) and her colleagues have conducted a study to provide an objective, comprehensive, and authoritative assessment of the intensive work invested in nonaqueous rechargeable metal-air batteries over the past few years, which identified the key problems and guides directions to solve them. The research team has focused primarily on the challenges and outlook for Li-O₂ cells but include Na-O₂, K-O₂, and Mg-O₂ cells for comparison. The study highlighted the interdisciplinary

nature of this field that involved a combination of materials chemistry, electrochemistry, computation, microscopy, spectroscopy, and surface science. The mechanisms of O₂ reduction and evolution are considered in the light of recent findings, along with developments in positive and negative electrodes, electrolytes, electrocatalysis on surfaces and in solution, and the degradative effect of singlet oxygen, which is typically formed in Li-O₂ cells.

As the next generation of compressed air energy storage systems (CAESs) are being developed and the technology is gaining momentum, designing the right system is essential for its successful adaptation in the

electricity market. **Professor Fraser** (Mechanical and

Mechatronics Engineering) investigated the impact of performance requirements on the design and operation of any potential adiabatic compressed air energy storage system, using one full year worth of real operating data of the Ontario grid for analysis. The objective was to introduce a new approach to designing CAESs based on specific grid requirements. The adiabatic

compressed air energy storage system thermo-mechanical requirements under real operating conditions are identified using a model-based approach. It was shown that using an adiabatic CAES with one-tenth of the size commonly assumed in the literature, will satisfy the Ontario grid requirements. Such a system will require charge and discharge durations of less than

two hours. In addition to understanding sizing and

performance requirements, this analytical approach provided a valuable insight into long-term trends required for optimum operational planning and scheduling. The results of this study showed that a properly sized adiabatic CAES can provide improved functionality while reducing the overall system cost.



LINDA NAZAR
Professor, Chemistry



ROYDON FRASER
Professor, Mechanical and
Mechatronics Engineering

3 GEOTHERMAL ENERGY

Geothermal energy is a type of renewable energy that is accessible 24/7 regardless of weather and climate. It comes from the useable heat from the Earth that can produce electricity at the utility scale and space heating and cooling and hot water integrated with HVAC systems of buildings. Geothermal energy has the potential of creating a positive transformative impact on northern communities by providing low-cost, green electricity and heat.

One significant obstacle to the adoption of geothermal heat pump (GHP) technology is the installation costs of geothermal heat exchangers (GHE). Cost reduction through optimization of system parameter offers the potential for increased applications.

Professor Nathwani (Management Sciences) has done a study in which five major parameters were considered: length, radius, well numbers, the flow discharge inside the pipe, and the pipe's external radius for optimization using a genetic algorithm (GA) for a residential building in hot climatic conditions. In addition, system optimization is critical in determining values of design parameters for assessing the impact different circulating fluids on the energy consumption of GHP. A ten-year simulation was undertaken to evaluate the capacity of various circulating fluids and their effects on energy



JATIN NATHWANI
Professor, Management Sciences



MAURICE DUSSEAULT
Professor, Earth and Environmental Sciences

consumption reduction. The simulation showed a significant decrease in energy consumption based on varying levels of Ethylene glycol, Methanol, Potassium acetate, Sodium chloride, Freezium™ compared to pure Water in the GHP. The COP of the GHP system was also calculated with different circulating fluids. In addition, the circulating fluid with the highest performance loss during ten years of operation was identified. Based on the results, Ethylene glycol was selected as the preferred solution for use in the GHP. In the present study, the team has also established the optimum configuration of GHEs according to a reliable evolutionary algorithm for investigating the effect of various circulating fluids on the system's energy consumption.

Professor Dusseault (Earth and Environmental Sciences) and **Professor Nathwani** (Management Sciences) did an evaluation of the needs and requirement for the provision of critical energy services to communities in Canada's northern region. Enhanced geothermal system concepts were introduced as part of a set of integrated solutions that are cost-competitive and sustainable over the long-term. The goal is to establish a low-carbon energy supply system that not only generates sufficient power and heat to satisfy basic needs but can be scaled to meet higher level requirements for economic empowerment. For remote and isolated communities, a reliable and cost-effective supply of energy is a critical factor to develop and sustain a



standard of living comparable to southern regions of Canada. The high cost of energy supply, specifically diesel transport over long distances, is a severe impediment to sustainable development in the northern regions of Canada. A first-order technical and economic feasibility study of the integration of different local energy sources (both renewable and non-renewable) with geothermal energy (deep and shallow) was developed to establish a pathway for a more efficient, low-carbon, sustainable energy sources. The results of this analysis provided a strong basis for investment in modular small-scale integrated geothermal systems for seasonal heat storage and electricity services.

Thermal load systems may be capable of participating in energy markets through load aggregators to optimize its load demand, but it could also provide other ancillary services, such

as load shifting, on-peak load demand reduction, and provision of Demand Response (DR) services. A thermal load aggregation approach to minimize the aggregator's energy procurement cost

was proposed in a study by **Professors**

Bhattacharya and Canizares (Electrical and Computer Engineering), together with a mathematical model based on the thermal load, particularly Ground Source Heat Pump (GSHP), characteristics to optimize the electricity usage by end-users, while considering household thermal comfort. Simulations of an aggregator's optimal heating load dispatch with a conventional Heating Ventilation and Air Conditioning (HVAC) and proposed GSHP alternative were presented, demonstrating the effectiveness of the proposed two stage strategy for optimal aggregator load dispatch of HVAC and GSHP systems, and the advantages of GSHP compared to HVAC.



KANKAR BHATTACHARYA
Professor, Electrical and
Computer Engineering



CLAUDIO CAÑIZARES
Professor, Electrical and
Computer Engineering

4 WIND ENERGY

Wind power is a mature, zero-emission energy source that provides a feasible option for reducing the carbon footprint of the electricity market across the globe. It proves to be financially viable in good wind resource regimes and its levelized cost of energy (LCOE) are quite comparable to the inexpensive fossil fuel based technologies where adequate wind resources are available. Also, there are no enormous challenging technical hurdles for the deployment of this technology. Wind power can grow at scale in the near future at acceptable costs with the help of an optimized design strategy.

Most modern large wind turbine blades are made of composite materials which are naturally anisotropic. Modern wind turbine blade design, such as BTC design tends to further enhance the anisotropy of a composite blade. As a result, the modelling of an anisotropic rotating wind turbine blade is an important topic in the wind energy industry.

Professor Lien (Mechanical and Mechatronics Engineering) led a study in which the governing equations of an anisotropic rotating beam is derived using Newtonian theory. These governing equations are discretized and solved using a finite-difference time-domain (FDTD) method. This methodology was shown to be highly computationally



FUE-SANG LIEN
Professor, Mechanical and Mechatronics Engineering

efficient owing to the fact that the governing equations are solved element by element alternately and explicitly, so only a few operations are required per grid point. The anisotropic beam model developed in this study was validated using four test cases: (1) modal analysis of an anisotropic box beam; (2) dynamic simulation of a spin-up maneuver; (3) simulation of the NREL 5 MW wind turbine blade; and, (4) simulation of the WindPACT wind turbine blade. The validation was conducted in terms of the predicted natural frequencies and tip displacements for both inertial and non-inertial frames. It was shown that the proposed model can be extended to deal with the case of large rotations.

The study of aeroacoustic noise generated by small wind turbines is important to increase acceptance and implementation of the wind energy technology. Small wind turbines have unique challenges due to the low Reynolds number (Re) flow the blades experience, which introduces a potential for tonal noise. Computational aeroacoustics can be applied during the design stage of the turbine blades to improve acoustic performance.

Professor Johnson (Mechanical and Mechatronics Engineering) validated a fully analytical aeroacoustic model by analyzing a SD 7037 blade segment at static angles of attack, with comparison to experimental flow and acoustic data. The Ffowcs-Williams and Hawkings (FW-H) acoustic model is used in combination with Large Eddy Simulation (LES). The following simulation parameters were examined: mesh quality, mesh density, inlet turbulence and spanwise boundary condition. These parameters change the boundary layer (BL) transition process and the formation of the laminar separation bubble on the suction side of the



DAVID JOHNSON
Professor, Mechanical and Mechatronics Engineering

blade segment, both of which impact the aeroacoustic noise prediction. It was found that improvement in mesh quality and density on the surface of the blade segment resulted in improved BL simulation and tonal noise prediction. Alteration of the inlet turbulence and spanwise boundary condition did not have as large of an effect.



MEHRDAD KAZERANI
Professor, Electrical and
Computer Engineering

Professor Kazerani (Electrical and Computer Engineering) conducted a study on an offshore wind farm with direct current (DC) collection system featuring differential power processing. The analysis of wind turbine output power measurements from the offshore wind farm Horns Rev 1 demonstrated a significant likelihood of wind turbine output powers to be very similar at a given time within offshore wind farms. This study exploited this observation by proposing a new offshore wind farm configuration with DC collection system and series-connected wind turbines based on partial power processing converters (PPPCs) and diode-bridge rectifiers. In the proposed wind farm configuration, PPPCs are only required to process output power differences among wind turbines in a wind farm to achieve maximum power point (MPP) operation, yielding a potential for efficiency and sizing improvements. This project addressed major design considerations at wind farm, wind turbine, and PPPC levels. System operation of the wind turbine design was derived, alongside with a matching control system and HVDC-link current scheduling algorithm. The proposed wind farm was successfully tested for low voltage ride through, power curtailment, inertia response, and communication system outage scenarios. Time-transient simulations of a 30-turbine series string using measured and artificial

wind speed profiles demonstrated that wind turbines can achieve MPP operation while only a fraction of power needed to be processed by the PPPCs.

Wind power uncertainties have made the large integration of wind power generating units in the power system highly challenging. One promising solution to overcome the challenges associated with the intermittency of the renewable energy resources (RESs) is to connect areas with diverse renewable energy portfolios via high voltage direct current (HVDC) transmission lines with controllable power transfer capability. The installation of HVDC transmission lines in the power system has resulted in the evolution of conventional alternating current (AC) networks to mixed AC-HVDC power systems. **Professor Azad** (Electrical and Computer Engineering) led a project that addressed wind power uncertainties in mixed AC-HVDC multi-area power systems, a modified robust optimisation (RO) model for the security-constrained economic dispatch (SCED) problem is proposed. The proposed RO model was used to minimize the generation cost and wind power curtailment under the worst-case scenario of actual wind power. Unlike the existing RO models, the proposed RO model considered a modified uncertainty set based on the wind power admissibility and addressed the budget of uncertainty more accurately to adjust the solution's level of conservatism. Extensive numerical studies demonstrated the economic and operational advantages of the proposed RO model for solving the SCED problem in mixed AC-HVDC power systems with high penetration of RESs.



NASSER LASHGARIAN AZAD
Professor, Electrical and
Computer Engineering

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



Created by Dr. Jatin Nathwani and Dr. Joachim Knebel in 2015, the Affordable Energy for Humanity global change initiative is a consortium of over 150 energy access researchers and practitioners from over 34 countries. AE4H members represent some of the leading energy access institutions and experts from around the world and have an incredible cumulative impact.

There remain over 2.5 billion people around the world without access to reliable electricity and clean cooking services, approximately 800 million of whom have no access to electricity. Access to energy is a catalyst of at least 13 of the 17 Sustainable Development Goals, and as such should be a priority in global sustainable development. For example, access to clean cooking services can reduce mortality and disease due to indoor air pollution, access to reliable lighting can help improve the quality of medical care and the quality of education, and access to electricity can provide the opportunity for the creation of microbusinesses and other income-generating opportunities.

150
members

34
countries



AE4H members work together to promote research, education, and projects regarding global access to energy. In 2020-21, this included remote international co-op placements for UWaterloo students, an energy project mentorship program, energy access publications, and several new or completed partnership initiatives with AE4H members.

AE4H PARTNERSHIP INITIATIVES

The greatest strength of the Affordable Energy for Humanity Initiative is its diverse and impactful partners. We are pleased to partner with AE4H members on initiatives that promote awareness, capacity, and research regarding access to energy. Here are three partnership initiatives that were either initiated or completed in 2020-21.

1. Hybrid Off-grid Techno-Economic Modeling (HOTEM) and Off-grid and decentralized System Data Analysis Platform (OSDAP)

Led by Karlsruhe Institute of Technology (KIT) scientist Dr. Mohamed Mamdouh Elkadragy, this research initiative looked to compare the techno-economic performance between identical hybrid off-grid systems installed in Jinja, Uganda, and Nemiah Valley, British Columbia. Dr. Elkadragy also led the creation of a data analysis platform to capture and analyze data from these systems, in an effort to standardize the performance assessment of hybrid systems in varying geographic contexts. These initiatives were completed in 2020–21.

2. Three Island Energy

Three Island Energy is a program led by Indigenous Clean Energy that seeks to support global Indigenous, islanded, and coastal communities in the development and scaling of clean energy microgrids. WISE, under the AE4H initiative, was invited as a core partner in the initiative and will be supporting research initiatives regarding microgrids and three island communities. WISE is joined by other incredible core partners: Gull Bay First Nation, the Assembly of First Nations, Métis Nation, Samso Denmark, the International Institute for Sustainable Development, Global Affairs Canada, Natural Resources Canada, and Environment and Climate Change Canada.

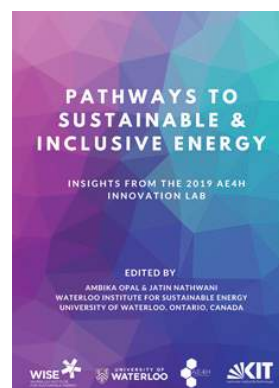
3. Energy Narratives under COVID-19

COVID-19 has drastically affected sustainable development, the energy sector, and globalization, and has highlighted global North–South inequalities. While many research and media outlets are focused on the impact of the pandemic on businesses and the economy, few are asking about the impacts on grassroots-level development. This research initiative, in partnership with researchers at Arizona State University, seeks to explore the impact of COVID-19 on grassroots level access to energy through surveys and interviews of AE4H members and other global energy access organizations.

AE4H PUBLICATIONS

Elkadragy, M., Alici, M., Alersy, M., Opal, A., Nathwani, J., Knebel, J., Hiller, M. Off-grid and decentralized hybrid renewable electricity data analysis platform (OSDAP). Forthcoming. Journal of Energy Storage.

Opal A., Nathwani J. Pathways to Sustainable and Inclusive Energy. Waterloo Institute for Sustainable Energy. September 2020. ISBN: 978-1-7774268-0-4



PARTNERS

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

WISE EVENTS

RIPPLE EFFECT — TEDX TALK (TEDXQUEENSU)

February 28, 2021

Ambika Opal (WISE Manager, Global Projects and Initiatives) gave a talk at TEDxQueensU this year. In her presentation, she explored the idea of access to energy as a catalyst for many forms of international development and presented tangible examples from her past experience at the United Nations Development Programme Cambodia and current projects at the Waterloo Institute for Sustainable Energy.



HACKATHON: SDG IMPACT CHALLENGE

March 20-21, 2021

UWaterloo's Impact Alliance and Global Spark hosted a virtual solutions hackathon called the "SDG Impact Challenge". This event has partnered with three local organizations who are tackling some of the UN's Sustainable Development Goals: Waterloo Institute for Sustainable Energy (WISE), the Interdisciplinary Centre on Climate Change (IC3) and Food4Kids.



SOLVE CLIMATE BY 2030: 4 KEY STEPS FOR CLIMATE CHANGE

April 7, 2021

The webinar was hosted by the Waterloo Institute for Sustainable Energy (WISE) and the Interdisciplinary Centre on Climate Change (IC3). The featured speakers explored a range of climate solutions and recommendations as they discussed critical topics like Green Recovery and a Just Transition. This webinar was part of the Solve Climate By 2030 series led by the Bard College in the US. The series is an international movement educating university and high school students about how an ambitious Green Recovery based on local action can put us on the way to solving climate change by 2030.



WISE PARTICIPATION



CAST-LASG WORKSHOP

Winnipeg, Canada | February 17-22, 2020

The CAST-LASG Workshop was a week-long collaboration between the Living Architecture Systems Group and the Centre for Architectural Structures and Technology (CAST) at the University of Manitoba in Winnipeg, held February 17-22, 2020. The workshop focused on the terminology and form-language of polyhedral and related geometry, culminating in the design and installation of a lightweight architectural scaffold which integrated CAST's ongoing experiments concerning fabric as formwork for liquid-to-solid casting and shell structures. A new form-making method was advanced during the development of the scaffold installation, by which basic hexagon-to-pentagon geometries were scaled up to produce dramatic changes in surface curvature. The workshop was preceded by preparatory talks and instructional folios as well as an introductory lecture by Prof. Beesley (School of Architecture).



WEBINAR, CANADIAN ASSOCIATION OF BUSINESS ECONOMISTS (CABE)

Toronto, Canada | May 19, 2020

Prof. Nathwani (Executive Director, WISE) was invited to give a webinar on the topic of Covid-19 crisis leading to a clean energy future. He discussed the three dimensions of energy, environment, and economy in his talk. He also emphasized on four key, interrelated global trends that not only pose a serious threat to the long-term viability of the oil and gas sector in Canada, but also point to clear pathways for alternatives that will sustain a low-carbon energy future: (1) Divestment of fossil fuel securities and disclosures of carbon liability, (2) Decarbonization, (3) Diversification of supply, and (3) Digitalization and electrification to replace existing energy sources.



THE POST-COVID-19 REBOOT WEBINAR SUPPLY CHAIN CONSIDERATIONS – GLOBAL ENTREPRENEURSHIP AND DISRUPTIVE INNOVATION (GED) WEBINAR SERIES

Waterloo, Canada | May 27, 2020

COVID-19 has shaken the world, challenging societies and altering life as we know it. But from this crisis, opportunities have emerged calling us to action as we prepare to reboot from the COVID-19 lockdown. In this series of six free, weekly, online panels, experts from the University of Waterloo and representatives from some of Canada's leading companies will share their research, real-world expertise, and experience to help identify the risks and plot the future of adapting to this new normal.

Prof. Nathwani (Executive Director, WISE) and Prof. Olaf Weber (School of Environment, Enterprise and Development) looked at restarting, rebuilding, and reimagining both local and global supply chains. Through a lens of environmental and social sustainability, they discussed changes in governance, the rise of populism, and cost vs. other drivers in building, or re-building, supply chains.



CREATING RESILIENT FUTURES: CLIMATE, COVID AND THE ECONOMY

Waterloo, Canada | September 23, 2020

The Balsillie School of International Affairs, in partnership with the Ditchley Foundation, created the first in a three-part series of 'Critical Conversations'. This 'Critical Conversations' series serves as a forum which brings global thought leaders together to bridge important perspectives on intersectional issues currently challenging the global policy world. This inaugural event was entitled "Building Resilient Futures: Covid, Climate and the Economy" - a discussion on possible measures to shape a future for global resilience that is economically sustainable and capable of meeting the twin threats of climate stress and the health burdens of COVID-19.

Prof. Nathwani (Executive Director, WISE) moderated a panel consisted of three speakers: (1) Diana Fox-Carney (Climate Policy Expert), (2) John Hancock (Senior Policy Adviser to the Director-General, World Trade Organization), and (3) William White (Former Chairman of the OECD Economic and Development Review Committee, Head of the Monetary and Economic Department at the Bank for International Settlements, and Deputy Governor of the Bank of Canada). The dialogue at the event was based on three key themes that guided the sessions of the day: Bankability and Finance, International Competitiveness, and Climate Legitimacy. Each session had a thematic speaker who gave an overview of the topic and the key issues, a panel that discussed the topic and offered diverse perspectives and a pathways to an outcomes piece where roundtable participants discussed the topic in a workshop format and provided recommendations.



FIRST VIRTUAL RESEARCH COLLOQUIUM

November 12, 2020

It was jointly held by University of Strathclyde and University of Waterloo. The principal of University of Strathclyde and president of University of Waterloo, Sir Jim McDonald and Dr. Feridun Hamdullahpur, invited paper/abstract submissions for the first virtual research colloquium. The colloquium was for graduate students at any stage in their journey. The colloquium provided an interactive space for graduate students from each University to present to international scholars in the field. Graduate students received constructive feedback from international scholars, and offered an opportunity to be part of international research clusters that enhance research collaborations between the two institutes. Both presidents have committed to the possibility of funding post-doctoral fellowship opportunities to keep collaborations going. The research areas included: Sustainable energy, quantum technologies, nuclear engineering, digital health, and entrepreneurship.

HYDROGEN, SUSTAINABILITY AND FINANCE CONFERENCE 2020

November 19, 2020

The theme of this conference was "Hydrogen, Sustainability and Finance: Local Roles for Global Goals". This event explored the entire suite of clean hydrogen applications as part of a broader effort to reduce carbon emissions and address climate change. The focus was on the emergent and self-sustaining Canadian community of end users, product suppliers, project developers, system integrators, and supporting infrastructure. The emphasis was to discuss strategies to achieve some serious reductions in CO₂ emissions and make economic use of off-peak 'surplus' power that is derived from low or zero emission sources to make 'green' hydrogen.

Prof. Fowler (Chemical Engineering) and Prof. Fraser (Mechanical and Mechatronics Engineering) was invited as guest speakers to give a talk on new hydrogen generation and commercialization technologies and the support of hydrogen deployment.



WIN INTERNATIONAL WORKSHOP ON NANOTECHNOLOGY FOR A SUSTAINABLE FUTURE

November 19-20, 2020

The Waterloo Institute for Nanotechnology (WIN) hosted the "International Workshop on Nanotechnology for a Sustainable Future". This virtual workshop brought together world leaders in nanotechnology to address current global issues, to meet United Nations Sustainable Development Goals (UN SDG) in nanotechnology and society, policy and science diplomacy, industry and innovation, energy and environment, devices for healthcare and communications, and resource management and the circular economy.

Prof. Nathwani (Executive Director, WISE) and Prof. Nazar (Chemistry) participated as guest speakers. Prof. Nathwani discussed unique challenges of a global energy transition to a clean energy future whereas Prof. Nazar talked about the complexities of electrochemical energy storage at the nanoscale.



WATERLOO INNOVATION SUMMIT – GREEN INNOVATION DRIVING OUR ECONOMIC RECOVERY

November 30, 2020


The summit showcased breakthroughs in green innovation and technology, and explored how cleantech can drive economic growth while ensuring our planet's future. Business leaders, entrepreneurs and academics came together virtually to discuss the possibilities for a greener economic recovery. The Waterloo Innovation Summit explored the business case for climate capitalism and illuminated the imperative to balance sustainable financial growth with sustainable environmental impact. As we all look for solutions to recover from a global pandemic and a climate in crisis, we asked speakers how we can seize this crisis as an opportunity to rethink our priorities and redesign the global economy, cities and job markets.

Prof. Weber and Prof. Craik (School of Environment, Enterprise and Development) were invited speakers who talked about the role of government policies and investment banking to address the challenges of clean economy.



INFLUENCE

HYDROGEN/FUEL CELL TECHNOLOGY
RESEARCH AT WATERLOO



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

INFORMING PUBLIC DIALOGUE



PUBLIC LECTURE SERIES



JUNE

Maurice Dusseault

Professor, Engineering Geology,
Earth and Environmental Sciences,
University of Waterloo

Helping People

AUGUST

Professor Olaf Weber

Truzaar Dordi, doctoral candidate
in Sustainability Management at the
University of Waterloo

Decarbonizing Financial Portfolios: Risks,
Opportunities, and Impact on the Energy
Industry and Climate

OCTOBER

Oskar Sigvaldason

Project Manager for the Trottier
Energy Futures Project (TEFP)

Climate Change and Transformation Of Energy
System In Canada

NOVEMBER

Steven Wong

Research Advisor in the Renewable
Energy Integration Group, PhD in
Electrical Engineering from the
University of Waterloo

Local Energy Flexibility in Future Power Systems



Dr. Majid Amidpour

Professor of Mechanical and Energy
engineering at K. N. Toosi university of
Technology

Empowering communities: Energy planning by,
with, and for the diesel-powered North

Nicholas Mercer

Research Advisor in the Renewable
Energy Integration Group, PhD in
Electrical Engineering from the
University of Waterloo

Local Energy Flexibility in Future Power Systems

DECEMBER

Professor Bissan
Ghaddar

Associate Professor of Management
Science at the Ivey Business School

Optimizing EV Operations under Time-Variant
Electricity Prices for Last-mile Delivery

FEBRUARY

Dr. Nitin Padmanabhan

Postdoctoral Fellow, Electrical and
Computer Engineering, University
of Waterloo and Chair, IEEE
Kitchener-Waterloo Section

Battery Energy Storage System Participation
in Wholesale Electricity Markets: Opportunities,
Practices, and Challenges

Adedoyin Adeleke

Founder-cum-Executive Director,
(ISNAD-Africa), and, Ph.D. Candidate,
UNESCO Chair, Energy for Sustainable
Development, Politecnico di Milano,
Italy

Do not say I cannot: ISNAD-AFRICA'S
Contributions to green growth in Africa

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.



CARBON EMISSIONS FROM COAL-FIRED POWER PLANTS

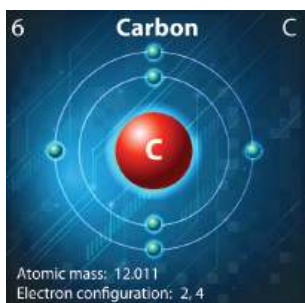
RESEARCHERS: Xiao-Yu Wu, Lili Cai, Xuefeng Zhu, Ahmed Ghoniem, and Weishen Yang

September 2020

More than a third of the world's electricity comes from coal-fired generating plants — and so does a hefty chunk of carbon emissions. WISE researcher Xiao-Yu Wu and his colleagues set out to make the process greener.

In the next-generation coal-fired plants, integrated gasification combined cycle (IGCC) is used to increase power output. High pressure and temperature is used to convert coal into syngas — a mix of carbon and hydrogen — that is burned to drive turbines. The more carbon you can remove from the syngas, the more cleanly it burns. But current pre-combustion carbon-capture technologies significantly reduce the plant's efficiency.

Wu and his colleagues took a different approach. Rather than scrub the syngas, they broke it down and created clean-burning hydrogen from steam instead.



CO₂ TRANSFORMATION TO MULTICARBON PRODUCTS BY PHOTOCATALYSIS AND ELECTROCATALYSIS

RESEARCHERS: Cheng Du, Xiaochu Wang, Wei Chen, Shouhua Feng, J. Wen, and Yimin A. Wu

October 2020

Carbon dioxide levels in the atmosphere keep rising, warming up our planet. And that has many researchers looking at two key catalytic reactions — photocatalysis and electrocatalysis — that can convert CO₂ into hydrocarbons. It's an exciting idea, using either sunlight or electricity to activate a catalyst that transforms CO₂ pollution into fuels and other valuable chemicals.

However, current techniques tend to create products with just a single carbon atom. That's a problem, because single-carbon products have lower energy densities comparing with more carbon atoms. And the smaller the volume of multi-carbons you create, the more expensive it is to separate them out.



WISE researcher Yimin Wu and his colleagues were invited to give an overview of the strategies to make these systems more economically viable. In a comprehensive review article, they highlight key strategies for favoring the production of multi-carbons.



PUTTING THE RIGHT PRICE ON ENERGY STORAGE

RESEARCHERS: Nitin Padmanabhan, Kankar Bhattacharya, Mohamed Ahmed

November 2020

In recent years, there has been a significant deployment of battery energy storage systems (BESSs) in the electricity grids around the world. The important characteristics of BESS such as ability to act both as generation and load, fast response time, high ramp rate etc. makes them promising and viable options for the system operators to reduce the peak demand, facilitate renewable energy integration.

RESEARCH SPOTLIGHTS

In jurisdictions where electricity is bought and sold through wholesale markets, BESS owners can sell electricity to the grid when they discharge their batteries and buy for charging. However, until now, cost models haven't captured the very important aspect of battery degradation phenomenon in short-term electricity market operation.

To create the fairest system for all buyers and sellers — and to operate the grid as efficiently as possible — the BESS bids and offers should correctly capture the physical and operational characteristics of the battery and, therefore, their true operating costs. That's where WISE researchers come in.

Waterloo electrical engineering professors Kankar Bhattacharya and Mohamed Ahmed and post-doctoral fellow Nitin Padmanabhan teamed up to factor battery degradation in the cost function, focussing on two key factors: the depth of discharge and the discharge rate. Using the proposed cost model, they formulated detailed charging bid and discharging offer structure.

TUNING WIND TURBINES FOR GREATER GRID STABILITY

RESEARCHERS: Mohammad Hasan Ravanji, Claudio A. Cañizares and Mostafa Parniani

December 2020

One of the crucial jobs of North American grid operators is keeping the frequency of the electricity as close to 60 hertz as possible. Mismatches between electricity generation and demand can shift that number higher or lower, damaging equipment, triggering blackouts and causing other problems.

To keep the system within safe margins, operators temporarily speed up or slow down the massive turbines at conventional generating plants, releasing or absorbing energy as required. But with renewables making up a growing share of the electricity grid, wind farms need to start help regulating frequency as well.

The question is how. Although the output of wind turbine generators can be controlled with virtual inertial controllers, releasing energy when wind speeds are low may stall the rotors and create even greater grid instability.

That's where the group of WISE researcher Dr. Claudio Cañizares comes in. They started by developing a nonlinear analytical model that describes how wind turbine generators respond to frequency disturbances in the grid, and then proposed two methods for tuning virtual inertial controllers.



THE SOCIAL ACCEPTANCE OF SUSTAINABLE ENERGIES IN INDIGENOUS DIESEL-POWERED COMMUNITIES

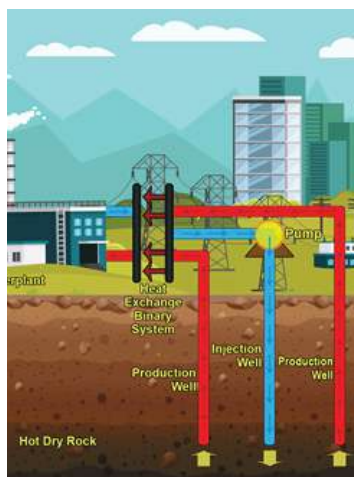
RESEARCHERS: Nicholas Mercer, Paul Parker, Amy Hudson and Debbie Martin

January 2021

Shifting electricity generation from diesel to greener options like wind or solar power would cut greenhouse gas emissions in off-grid communities. But not all technologies are compatible with local land use and community values, so how do the people who live there feel about renewables?



To find out, the NunatuKavut Community Council's Director of Research, Amy Hudson, invited WISE researchers Nicholas Mercer and Paul Parker and Inuk researcher Debbie Martin to southeast Labrador, where their team surveyed and interviewed more than 200 residents in nine Inuit communities about their perceptions of sustainable energy technologies. Next, they conducted a qualitative analysis to identify what factors influence local support.



SOLVING THE EQUATIONS THAT GOVERN GEOTHERMAL POWER

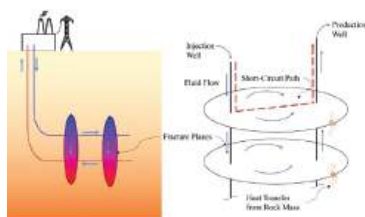
RESEARCHERS: Robert Gracie and Bruce Gee

March 2021

Exploiting geothermal power is easy in volcanic regions like Iceland, where geology brings heat from the Earth's core close to the surface. In other places, however, accessing this source of renewable energy requires enhanced geothermal systems (EGS).

These systems use a network of channels created by hydraulic fracturing. Water pumped down one borehole extracts heat from rocks a kilometre or more underground as it travels through those channels and then brings it to the surface via a second borehole. While the concept is simple, modelling it gets a little complicated.

WISE researchers Robert Gracie and Bruce Gee tackled that problem. The duo focussed on solving the differential equations that predict how four key geothermal processes interact with each other and change over time: heat transfer within the rock; heat transfer within the fluid; how fluid flows through the rock; and deformation of the rock.



UNPACKING PERFORMANCE PROBLEMS IN GEOTHERMAL SYSTEMS

RESEARCHERS: Robert Gracie and Maurice Dusseault

April 2021

Enhanced geothermal systems (EGSs) take advantage of heat deep beneath the Earth's surface, forcing water through an engineered set of fractures at high pressure. The resulting steam can then be used to generate electricity or to heat buildings. However, this complex process is vulnerable to short-circuiting a positive feedback loop in which the thermal contraction of cooled regions of the reservoir leads to increased fluid flow through these regions and diversion of fluid away from warmer regions – which can drastically reduce the efficiency of an EGS.

Bruce Gee, Robert Gracie and Maurice Dusseault set out to understand how this happens. The WISE researchers started by creating a custom Thermo-Hydro-Mechanical (THM) mathematical model and Finite Element Analysis software for both single-fracture and multi-fracture EGSs.

PUBLICATIONS

SELECTED MEMBER PUBLICATIONS

- Roushenas, R., Razmi, A. R., **Soltani, M.**, Torabi, M., **Dusseault, M. B.**, and **Nathwani, J.** (2020). Thermo-environmental analysis of a novel cogeneration system based on solid oxide fuel cell (SOFC) and compressed air energy storage (CAES) coupled with turbocharger. *Applied Thermal Engineering*, 181, 115978, 1-18.
- Soltani, M.**, Nabat, M. H., Razmi, A. R., **Dusseault, M. B.**, and **Nathwani, J.** (2020). A comparative study between ORC and kalina based waste heat recovery cycles applied to a green compressed air energy storage (CAES) system. *Energy Conversion and Management*, 222, 113203, 1-19.
- Gupta, B. K., and **Basu, D.** (2020). Offshore wind turbine monopile foundations: Design perspectives. *Ocean Engineering*, 213, 107514, 1-17.
- Roy, D., Chakraborty, T., **Basu, D.**, and Bhattacharjee, B. (2020). Feasibility and performance of ground source heat pump systems for commercial applications in tropical and subtropical climates. *Renewable Energy*, 152, 467-483.
- Prabhu, S. R., **Pandey, M. D.**, Christodoulou, N., and Leitch, B. W. (2020). A surrogate model for the 3D prediction of in-service deformation in CANDU® fuel channels. *Nuclear Engineering and Design*, 369, 110871, 1-17.
- Järvine, A. K., Murchison, A. G., Keech, P. G., and **Pandey, M. D.** (2020). A probabilistic model for estimating the life expectancy of used nuclear fuel containers in a Canadian geological repository: Effects of latent defects and repository temperature. *Nuclear Technology*, 206 (7), 1036-1058.
- Anierobi, C. C., **Bhattacharya, K.**, and **Cañizares, C. A.** (2020). Behind-the-meter compressed air energy storage feasibility and applications. *Electric Power Systems Research*, 189, 106630, 1-7.
- Alharbi, H., and **Bhattacharya, K.** (2020). Participation of pumped hydro storage in energy and performance-based regulation markets. *IEEE Transactions on Power Systems*, 35 (6), 4307-4323.
- Calero, I., **Cañizares, C. A.**, and **Bhattacharya, K.** (2020). Implementation of transient stability model of compressed air energy storage systems. *IEEE Transactions on Power Systems*, 35 (6), 4734-4744.
- Vera, E. G., **Cañizares, C.**, and **Pirnia, M.** (2020). Renewable energy integration in Canadian remote community microgrids: The feasibility of hydrogen and gas generation. *IEEE Electrification Magazine*, 8 (4), 36-45.
- Van Cutsem, T., Glavic, M., Rosehart, W., **Cañizares, C.**, Kanatas, M., Lima, L., Milano, F., Papangelis, L., Ramos, R.A., Santos, J.A.D., Tamimi, B., Taranto, G., and Vournas, C. (2020). Test systems for voltage stability studies. *IEEE Transactions on Power Systems*, 35 (5), 4078-4087.

Violante, W., **Cañizares, C. A.**, Trovato, M. A., and Forte, G. (2020). An energy management system for isolated microgrids with thermal energy resources. *IEEE Transactions on Smart Grid*, 11 (4), 2880–2891.

Yazdavar, A. H., Shaaban, M. F., **El-Saadany, E. F.**, **Salama, M. M. A.**, and Zeineldin, H. H. (2020). Optimal planning of distributed generators and shunt capacitors in isolated microgrids with nonlinear loads. *IEEE Transactions on Sustainable Energy*, 11 (4), 2732–2744.

Filabadi, M. D., and **Azad, S. P.** (2020). Robust optimization framework for SCED problem in mixed AC-HVDC power systems with wind uncertainty. *IET Renewable Power Generation*, 14 (14), 2563–2572.

Ahmed, H. M. A., Awad, A. S. A., Ahmed, M. H., and **Salama, M. M. A.** (2020). Mitigating voltage-sag and voltage-deviation problems in distribution networks using battery energy storage systems. *Electric Power Systems Research*, 184, 106294, 1–11.

Khayat, Y., Guerrero, J. M., Bevrani, H., Shafiee, Q., Heydari, R., Naderi, M., Dragicevic, T., **Simpson-Porco, J.W.**, Dorfner, F., Fathi, M., and Blaabjerg, F. (2020). On the secondary control architectures of AC microgrids: An overview. *IEEE Transactions on Power Electronics*, 35 (6), 6482–6500.

Bakhshizadeh, N., Tarighat, R. S., and **Sivorththaman, S.** (2020). Effective work function of screen printable graphene-decorated conductive nanocomposites. *Transactions on Electrical and Electronic Materials*, 21 (6), 594–598.

Lyu, L., Chen, C., Cheng, N., Zhu, S., Guan, X., and **Shen, X.** (2020). NOMA-assisted on-demand transmissions for monitoring applications in industrial IoT networks. *IEEE Transactions on Vehicular Technology*, 69 (10), 12264–12276.

Liu, P., Wang, C., Hu, J., Fu, T., Cheng, N., Zhang, N., and **Shen, X.** (2020). Joint route selection and charging discharging scheduling of EVs in V2G energy network. *IEEE Transactions on Vehicular Technology*, 69 (10), 10630–10641.

Chen, Y., Zhang, Y., Wu, Y., Qi, L., Chen, X., and **Shen, X.** (2020). Joint task scheduling and energy management for heterogeneous mobile edge computing with hybrid energy supply. *IEEE Internet of Things Journal*, 7 (9), 8419–8429.

Parvizimosaed, M., and **Zhuang, W.** (2020). Enhanced active and reactive power sharing in islanded microgrids. *IEEE Systems Journal*, 14 (4), 5037–5048.

Mevawalla, A., Panchal, S., Tran, M.-K., **Fowler, M.**, and **Fraser, R.** (2020). Mathematical heat transfer modeling and experimental validation of lithium-ion battery considering: Tab and surface temperature, separator, electrolyte resistance, anode-cathode irreversible and reversible heat. *Batteries*, 6 (4), 1–26.

Ozden, A., Shahgaldi, S., Li, X., and **Hamdullahpur, F.** (2020). Degradations in the surface wettability and gas permeability characteristics of proton exchange membrane fuel cell electrodes under freeze-thaw cycles: Effects of ionomer type. *International Journal of Hydrogen Energy*, 45 (54), 29892–29903.

Shahgaldi, S., Ozden, A., Li, X., and **Hamdullahpur, F.** (2020). A scaled-up proton exchange membrane fuel cell with enhanced performance and durability. *Applied Energy*, 268, 114956, 1–13.

- Meng, H., **Lien, F.-S.**, Yee, E., and Shen, J. (2020). Modelling of anisotropic beam for rotating composite wind turbine blade by using finite-difference time-domain (FDTD) method. *Renewable Energy*, 162, 2361-2379.
- Rua Taborda, M. I., Elissalde, C., Chung, U.-C., Maglione, M., Fernandes, E., **Salehian, A.**, Santawitee, O., and Debéda, H. (2020). Key features in the development of unimorph stainless steel cantilever with screen-printed PZT dedicated to energy harvesting applications. *International Journal of Applied Ceramic Technology*, 17 (6), 2533-2544.
- Herdem, M. S., Mazzeo, D., Matera, N., **Wen, J. Z.**, **Nathwani, J.**, and Hong, Z. (2020). Simulation and modeling of a combined biomass gasification-solar photovoltaic hydrogen production system for methanol synthesis via carbon dioxide hydrogenation. *Energy Conversion and Management*, 219, 113045, 1-18.
- Sangsong, S., Ratana, T., Tungkamani, S., Sornchamni, T., Phongaksorn, M., and **Croiset, E.** (2020). The demonstration of the superiority of the dual ni-based catalytic system for the adjustment of the h₂ /co ratio in syngas for green fuel technologies. *Catalysts*, 10 (9), 1-16.
- Preston, N., Maroufmashat, A., Riaz, H., Barbouti, S., Mukherjee, U., Tang, P., Wang, J., Haghi, E., **Elkamel, A.**, and **Fowler, M.** (2020). How can the integration of renewable energy and power-to-gas benefit industrial facilities? From techno-economic, policy, and environmental assessment. *International Journal of Hydrogen Energy*, 45 (51), 26559-26573.
- Ganowski, S., and **Rowlands, I. H.** (2020). Read all about it! Comparing media discourse on energy storage in Canada and the united kingdom in a transition era. *Energy Research and Social Science*, 70, 101709, 1-14.
- Mercer, N., Hudson, A., Martin, D., and **Parker, P.** (2020). "That's our traditional way as indigenous peoples": Towards a conceptual framework for understanding community support of sustainable energies in NunatuKavut, Labrador. *Sustainability (Switzerland)*, 12 (15), 6050, 1-32.
- Zanjani, A. M., **Gharali, K.**, **Al-Haq, A.**, and **Nathwani, J.** (2020). Dynamic and static investigation of ground heat exchangers equipped with internal and external fins. *Applied Sciences (Switzerland)*, 10 (23), 1-19.
- Zhou, L., Kwok, C. Y., Shyamsunder, A., Zhang, Q., Wu, X., and **Nazar, L. F.** (2020). A new halospinel superionic conductor for high-voltage all solid state lithium batteries. *Energy and Environmental Science*, 13 (7), 2056-2063.
- Gee, B., and **Gracie, R.** (2021). Comparison of fully-coupled and sequential solution methodologies for enhanced geothermal systems. *Computer Methods in Applied Mechanics and Engineering*, 373, 113554, 1-30.
- Calero, F., **Cañizares, C. A.**, and **Bhattacharya, K.** (2021). Dynamic modeling of battery energy storage and applications in transmission systems. *IEEE Transactions on Smart Grid*, 12 (1), 589-598.
- Mendieta, W., and **Cañizares, C. A.** (2021). Primary frequency control in isolated microgrids using thermostatically controllable loads. *IEEE Transactions on Smart Grid*, 12 (1), 93-105.
- Elghitani, F., and **El-Saadany, E. F.** (2021). Efficient assignment of electric vehicles to charging stations. *IEEE Transactions on Smart Grid*, 12 (1), 761-773.
- Ameli, A., Saleh, K. A., **El-Saadany, E. F.**, **Salama, M. M. A.**, and Zeineldin, H. H. (2021). Wide-band current

transformers for traveling-waves-based protection applications. *IEEE Transactions on Smart Grid*, 12 (1), 845–858.

Simpson-Porco, J. W. (2021). On stability of distributed-averaging proportional-integral frequency control in power systems. *IEEE Control Systems Letters*, 5 (2), 677–682.

Huda, N., Whitney, M. A., Razmpoosh, M. H., Gerlich, A. P., **Wen, J. Z.**, and Corbin, S. F. (2021). How phase (and) and porosity affect specific heat capacity and thermal conductivity of thermal storage alumina. *Journal of the American Ceramic Society*, 104 (3), 1436–1447.

Luo, D., Zheng, L., Zhang, Z., Li, M., **Chen, Z.**, Cui, R., Shen, Y., Li, G., Feng, R., Zhang, S., Jiang, G., Chen, L., **Yu, A.**, and Wang, X. (2021). Constructing multifunctional solid electrolyte interface via in-situ polymerization for dendrite-free and low N/P ratio lithium metal batteries. *Nature Communications*, 12 (1), 1–11.

Zhang, M., Pei, Y., Liu, W., Liang, R., Deng, Y.-P., **Chen, Z.**, and **Yu, A.** (2021). Rational design of interlayer binding towards highly reversible anion intercalation cathode for dual ion batteries. *Nano Energy*, 81, 105643, 1–8.

Wang, D., Luo, D., Zhang, Y., Zhao, Y., Zhou, G., Shui, L., **Chen, Z.**, and Wang, X. (2021). Deciphering interpenetrated interface of transition metal oxides/phosphates from atomic level for reliable Li/S electrocatalytic behavior. *Nano Energy*, 81, 105602, 1–11.

Xiao, K., Liu, Z., **Chen, Z.**, Cao, X., Huang, Y., Deng, H., Chen, X., Shen, Z.X., and Liu, J. (2021). Unraveling the effects of anions in NixAy@CC (A=O, S, P) on li-sulfur batteries. *Materials Today Nano*, 13, 100106, 1–8.

Shalaby, A., **Elkamel, A.**, **Douglas, P. L.**, Zhu, Q., and Zheng, Q. P. (2021). A machine learning approach for modeling and optimization of a CO₂ post-combustion capture unit. *Energy*, 215, 119113, 1–8.

Xu, S., Kwok, C. Y., Zhou, L., Zhang, Z., Kochetkov, I., and **Nazar, L. F.** (2021). A high capacity all solid-state li-sulfur battery enabled by conversion-intercalation hybrid cathode architecture. *Advanced Functional Materials*, 31 (2), 1–8.

Labonte, D., and **Rowlands, I. H.** (2021). Tweets and transitions: Exploring twitter-based political discourse regarding energy and electricity in Ontario, Canada. *Energy Research and Social Science*, 72, 101870, 1–13.

Soltani, M., Farzanehkhameh, P., Moradi Kashkooli, F., **Al-Haq, A.**, and **Nathwani, J.** (2021). Optimization and energy assessment of geothermal heat exchangers for different circulating fluids. *Energy Conversion and Management*, 228, 113733, 1–11.

Momeni, M., **Soltani, M.**, Hosseinpour, M., and **Nathwani, J.** (2021). A comprehensive analysis of a power-to-gas energy storage unit utilizing captured carbon dioxide as a raw material in a large-scale power plant. *Energy Conversion and Management*, 227, 113613, 1–16.

M. Elkadragy, M., Alici, M., Alsersy, A., **Opal, A.**, **Nathwani, J.**, Knebel, J., and Hiller, M. (2021). Off-grid and decentralized hybrid renewable electricity systems data analysis platform (OSDAP): A building block of a comprehensive techno-economic approach based on contrastive case studies in Sub-Saharan Africa and Canada. *Journal of Energy Storage*, 34, 101965, 1–29.



AWARDS AND RECOGNITION

MRS MEDAL

The Materials Research Society (MRS) presented Waterloo chemist Linda Nazar with the 2020 MRS Medal award for her “outstanding contributions to advanced materials design, synthesis and characterization for energy storage, particularly Li battery technologies.”

The MRS Medal is awarded for “an exceptional achievement in materials research in the past ten years”. Nazar presented her award-winning work as part of a Lightning Talk where she described energy storage materials that go “beyond lithium”, including promising new developments in solid state batteries and approaches to creating lithium-sulfur cells.

Linda Nazar is a world leader in inorganic materials research, best known for her advancements in battery systems and clean energy storage. One of her most recent publications on solid-state batteries in collaboration with the Joint Center for Energy Storage Research (JCESR) shows how solid electrolytes can potentially replace liquid organic electrolytes in today’s lithium-ion batteries.

Professor Nazar has published more than 200 papers, review articles, and patents in the field, which have been cited over 41,000 times. Her work has earned her a place on the Web of Science’s 2020 Highly Cited Researcher Lists.

2020 IEEE POWER AND ENERGY SOCIETY WORKING GROUP RECOGNITION AWARD

Professor Claudio Cañizares (Electrical and Computer Engineering), and his working group members, Jim Reilly and Rodrigo Palma Behnke, were selected to receive the 2020 IEEE Power and Energy Society Working Group Recognition Award–Technical Report for PES-TR66, Microgrid Stability Definitions, Analysis and Modeling. This award recognizes the most outstanding working groups from among those nominated by each Technical Committee. Only two working groups are chosen each year to win this award, one for Technical Report and one for Standard or Guide.

The IEEE Power and Energy Society (PES) provides the world's largest forum for sharing the latest in technological developments in the electric power industry, for developing standards that guide the development and construction of equipment and systems, and for educating members of the industry and the general public.

OUR PEOPLE

108 University
of Waterloo
members

19 distinguished
awards and
honours

31
labs

22 Non-University
of Waterloo
members

21
areas of
expertise

14 research
chairs

11 Senior Executive
Fellows

7 Research
Fellows

**WISE BY THE
NUMBERS**

SCHOLARLY OUTPUT

WISE hosted almost **15**
visiting researchers,
industry executives and
government delegations

650+ member
publications



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 and CEO, Independent Electricity System Operator
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 and Engineering, Terrestrial Energy
ANDREW TEICHMAN | Business Strategist and Investment Manager, ACT Investments
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. CHARMAINE  N | Vice-President, University Research, University of Waterloo (**Chair**)
DR. JEAN ANDREY | Dean of Environment
DR. RICHARD CULHAM | Acting Dean of Engineering
DR. BOB LEMIEUX | Dean of Science
DR. NEIL RANDALL | Executive Director, Games Institute
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. MAURICE DUSSEAUT | Professor, Faculty of Science, Department of Earth and Environmental Sciences
DR. KEITH HIPEL | Professor, Faculty of Engineering, Department of Systems Design Engineering
DR. RANJINI JHA | Professor, Faculty of Arts, School of Accounting and Finance
DR. OLAF WEBER | Professor, Faculty of Environment, School of Environment Enterprise and Development

SENIOR EXECUTIVE FELLOWS

COLIN ANDERSEN

Chair, Energy Council of Canada

STEVE DOREY

(Retired)

RICHARD FLORIZONE

Director, Quantum Valley Ideas Lab

NEIL FREEMAN

Principal/CEO, NBF Group Inc.

THOMAS GOTTSCHALK

CEO, Mobisol

CHRISTOPHER HENDERSON

President, Lumos Clean Energy Advisors

CATHERINE JACKSON

Founder, Jackson Principled Governance

YVES LOSTANLEN

President and CEO, SIRADEL North America Inc.

ZOHRAB MAWANI

Co-Founder/President, oneGRID Corporation

DON MCCUTCHAN

Partner and International Policy Advisor,
Gowling WLG LLP

SANKARAN RAMALINGAM

National President,
Energy and Fuel Users' Association of India

STAFF

Manager, Program Development,
Partnerships and Finance

ARMUGHAN AL-HAQ

Manager, Global Programs and Initiatives

AMBIKA OPAL

Administrative Assistant

SANA SADIQ

Administrative Assistant (Special Projects)

IRIS STRICKLER

Communications Specialist

JESSICA STRICKLER

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

WISE MEMBERS

William Anderson

Dipanjan Basu

Philip Beesley

Kankar Bhattacharya ●

Philip Bigelow

Terri Meyer Boake

Paul Calamai

Claudio Cañizares ●

Giovanni Cascante

Trevor Charles

Zhongwei Chen ● ●

Pu Chen

Chih Hsiung (Perry) Chou

Michael Collins

James Craig ●

Neil Craik

Eric Croiset

Cecile Devaud

Paul Doherty

Peter Douglas

Maurice Dusseault

Ali Elkamel ●

Ehab El-Saadany ●

Ramadan El-Shatshat

Robert Feick

Xianshe Feng

Michael Fowler ●

Roydon Fraser

Mel Gabriel

Vincent Gaudet

Bissan Ghaddar

Lukasz Golab ●

Wojciech Golab

Irene Goldthorpe

Jeff Gostick

Robert Gracie

Komal Habib

Feridun Hamdullahpur

Keith Hipel ●

Anming Hu

Robert Hudgins

Ihab Ilyas ●

Shesha Jayaram ● ●

Beth Jewkes

Ranjini Jha

David Johnson

Mehrdad Kazerani

Srinivasan Keshav ●

Behrad Khamesee

Holger Kleinke

Nasser Lashgarian Azad

Hyung-Sool Lee

Yuri Leonenko

Xianguo Li ●

Yuning Li

Fue-Sang Lien

Jennifer Lynes

Azadeh Maroufmashat

David Mather

Christine Moresoli

Sriram Narasimhan ●

Jatin Nathwani

Linda Nazar ● ●

Flora Ng

Alain-Desire Nimubona

Amer Obeidi

Qinmin Pan

Mahesh Pandey ●

Paul Parker ●

Wayne Parker

Mehrdad Pirnia

Sahar Pirooz Azad

Kumaraswamy Ponnambalam

Mark Pritzker

Eric Prouzet

Pavle Radovanovic ●

Omar Ramahi

Luis Ricardez-Sandoval ●

Catherine Rosenberg ●

Ian Rowlands

Rebecca Saari

Magdy Salama

Armaghan Salehian

Andrei Sazonov

Gerry Schneider

Anindya Sen

Xuemin (Sherman) Shen ●

David Simakov

John Simpson-Porco

Siva Sivioththaman

Madjid Soltani

John Straube

Zhongchao Tan

Susan Tighe ●

Robert Varin

Olaf Weber ●

Lan Wei ●

John Wen

Markus Wieland

Jeffrey Wilson

Chul Min Yeum

Steven Young

Aiping Yu ●

Boxin Zhao

Weihua Zhuang ●



AFFORDABLE ENERGY FOR HUMANITY

A Global Change Initiative



AE4H PARTICIPANTS

79 organizations from 33 countries are participating in the Affordable Energy for Humanity Global Change Initiative.

79
organizations

33
countries



Private / 31%
Government / 12%
Non-Profit / 15%
Academic / 40%



UNIVERSITY OF
WATERLOO



FOR MORE INFORMATION

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

info@wise.uwaterloo.ca