

# Five-Year Review Report Senate Graduate & Research Council

## Waterloo Institute for Sustainable Energy

**UNIVERSITY OF  
WATERLOO**



## Note from the Executive Director

Dear Senate Graduate & Research Council,

I am pleased to present this review report summarizing our achievements over the past five years of research excellence, energy policy leadership and development of the scientific and technical capacity to support expansion of energy research activities underway at the Waterloo Institute for Sustainable Energy (WISE).

The success we have experienced is a testament to the collective strengths of our faculty and our efforts to engage with funding agencies and external partners to grow the scope and scale of energy research at the University of Waterloo.

We have been successful in providing support to our faculty members across all faculties and continue to foster a strong culture of collaboration across departments and faculties to engage in multi-disciplinary research projects. The alignment of specific interests of faculty members with the needs of the broader energy sector has created a vast network of positive relationships and engagement both within the university and beyond our walls.

The enhancement of our research facilities and laboratories has been an integral part of our success in obtaining funding for several projects that are in the multi-million dollar range. The establishment of the Energy Research Centre is but one example of several high quality laboratories that continues to attract attention of external partners and government agencies.

In the following pages, you will read a summary of the accomplishments of our researchers and students through their publications and presentations. We highlight the strong complement of research chairs and also describe breakthroughs over the past five years. We are proud of the efforts of our faculty and their unflinching commitment to work collaboratively.

The Institute has established a solid reputation within the energy community nationally and internationally. With WISE staff possessing the necessary leadership qualities, we look forward to playing a central role in building on this success. We expect to enhance Waterloo's reputation as the 'go-to' place for innovation in energy research.

Ours is a narrative of success that truly exemplifies the Waterloo spirit of 'Why not'? Our aspirations are to be recognized globally but beyond recognition, we are driven by a compelling desire to develop energy solutions that will help achieve the transition of the global energy economy to one with a lower carbon foot-print.

I invite you to read more about the next chapter in our journey: The Way Ahead.

Sincerely,

Jatin Nathwani

Professor and Ontario Research Chair in Sustainable Energy  
Executive Director, WISE

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# 1. Executive Summary

## Global Context

Energy challenges command our world's attention. A healthy energy equation requires balance amongst energy resources we know and those we have yet to discover. History has been a tough task master and has shown no single energy solution provides the ultimate answer. Over the past century and a half, it has become abundantly clear that provision of affordable and reliable energy services is a critical determinant of human welfare. Where energy is available, it has fostered education, improved personal and public health, become a cornerstone of modern economies, and enabled a flourishing of the arts.

However, our journey towards harnessing the full potential of energy for the benefit of all humanity is far from complete. Today some 1.4 billion people – a fifth of the world's population – live without electricity access and 2.5 billion live without access to clean energy sources. The challenge of meeting future demand is made even more difficult by the scientific reality that the dominant way we produce and use fossil fuels for energy is altering our planet's climate. Greenhouse gas emissions (GHGs) and its mitigation has become a critical determinant of energy policies and the pathways for energy developments.

The imperative to build a globally sustainable energy future requires us to rethink, and then refashion, the way we produce and use energy. In this crucial endeavour, we wish to engage emerging science and new technologies to unlock the previously unimagined pathways for the evolution of the energy system. To realise the full potential of science and technology also requires an integration of social, environmental and economic innovations that can enable rapid diffusion of transformative technologies.

## University of Waterloo's Strategy

As part of the University of Waterloo's vision for the sixth decade, WISE was founded in 2008 to address the complexities and challenges of energy transitions. The importance of energy as a strategic priority of the University was recognized with the goal of the Institute to foster alignment of research capacity and to advance multi-disciplinary research at Waterloo.

The original Senate report identified the goals as:

- a. Improving opportunities to develop multi-disciplinary approaches to complex, energy-based research problems
- b. Increasing research productivity through the sharing of infrastructure, facilities and support personnel
- c. Providing greater access to research funding in part through its institutional members and their affiliations
- d. Enhancing the visibility of research accomplishments through the Institute's workshops, publications and media releases and
- e. Creating a collegial and interactive environment in which to develop new research initiatives

At the University of Waterloo, we are engaged in this complex task of bringing the promise and potential of our technological prowess into alignment with societal needs that are truly sustainable over the long term. We recognize that sourcing of primary energy, its transmission, storage and distribution and delivery to end users comprises society's critical infrastructure. We also believe, strongly, that our economic well-being and Earth's well-being depend on sustainable management of our energy endowment.

Our research goals are to explore alternative energy sources, improve the management and efficient use of current resources and to bring to fruition energy options that are in the early stages of discovery and scientific development. At Waterloo, the hallmark of our contribution is towards a balanced energy equation that meets the tests of scientific rigour, economic feasibility and environmental sustainability.

## 2. The Waterloo Institute for Sustainable Energy (WISE)

WISE was founded in April 2008, building on the University's longstanding strengths in engineering, science and environment. Energy is a stated priority of the University – and Environment and Energy is a major thrust area in the University's strategic research plan.

WISE provides a focal point for energy research at Waterloo and we work to create the best possible research platforms for faculty to test their ideas, engage with their peers, and partner with external organizations to accelerate the pace of research, development and deployment of practical solutions.

### 2.1 Vision, Mission and Strategic Objectives

Our **vision** is simple: clean energy, accessible and affordable for all.

The **mission** is to conduct original research and develop innovative solutions and policies to help transform the energy system for long-term sustainability.

To fulfill our mission, consistent with the mandate and the goals described in the report of the Senate (2008), WISE activities are guided by three **strategic objectives** as follows:

1. **Collaborate:** To expand opportunities for multi-disciplinary energy research at Waterloo, improve research productivity – share facilities and resources, and develop HQP through research and education.
2. **Reach Out:** To promote engagement of external partners and advance energy research through partnerships and greater access to research funding.
3. **Influence:** Establish WISE as the authoritative source of energy insights and analysis, and translate important scientific discoveries for a wide audience, informing energy policy both here and around the globe.

## 2.2 Overview

Research initiatives developed at WISE are of an interdisciplinary nature – spanning theory and experiment – encompassing a broad range of expertise across several faculties and departments. In a short period of five years, WISE has grown to become Canada's largest concentration of researchers in academia devoted to sustainable energy. The Institute has created positive relationships with senior energy leaders from all sectors and has generated significant opportunities for its members to advance energy research.

The scope and scale of energy research activities underway at WISE is large and unique in its research coverage across a diverse range of areas such as:

- Renewable Energy (wind, solar, bioenergy, geothermal)
- Information Science and Systems for Energy (smart grid and smart energy networks)
- Sustainable Mobility (electric vehicles, hybrids, fuel cell vehicles)
- Power Systems and Delivery (transmission, distribution and DG integration)
- Emissions Management (carbon capture, sequestration and storage, GHG mitigation)
- Energy Management (buildings, energy, efficiency, conservation)
- Energy Storage (hydrogen, fuel cells, advanced batteries)
- Policy analysis at the interface of Environment and Energy

WISE continues to intensify communication and outreach programs to share the knowledge created and to cultivate energy literacy. WISE – and the University of Waterloo – are becoming internationally recognized as leaders in addressing the global energy challenge.

## 2.3 Governance

### 2.3.1 Advisory Council

The Executive Director, Director and Associate Directors seek guidance and advice of senior executives in government and industry to help shape the future agenda and activities of WISE.

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.

#### **2012 WISE Board Advisory Council**

David McFadden, Chair, International Practice, Partner, Gowling Lafleur Henderson LLP

Carmine Marcello, President & CEO, Hydro One Inc.

Andrew Teichman, Executive Director of Investments, OPG Ventures Inc.

Don MacKinnon, President, Power Workers' Union

John Wilkinson, Minister of Environment (former), Ontario Government  
Gordon Lambert, Vice President Sustainable Development, Suncor Energy Inc.  
Mel Ydreos, VP Marketing & Customer Care, Union Gas Limited  
George Greene, Chair, Stratos Inc.  
Andrew Pride, Vice-President Conservation, Ontario Power Authority  
Leo Piciacchia, VP of Sustainable Development & HSE, TOTAL E&P Canada  
Steve Dorey, Chair, Energy Council of Canada, Studies Committee  
Ken Kozlik, Chief Operating Officer, (former), IESO  
Richard Wunderlich, Director, Smart Grid Initiatives, SIEMENS Canada Limited

The advisory council meets once a year in person and once a year via conference call. Besides offering guidance and advice to WISE, the Advisory Council members in turn learn about the latest cutting edge research in the energy sector, and get to interact with other industry leaders who have an interest in advanced energy technology developments.

Meetings offer an opportunity for Council members, WISE researchers and administrators to connect, discuss member research and gain insights into challenges facing the energy sector.

Number of meetings: 2 annually

### **2.3.2 Board of Management**

The WISE members of the internal Board of Management were appointed in 2008 upon consultation with Department Chairs and the Dean and they provide advice and guidance to the Executive Director on the operational aspects of the Institute. The meetings of the internal Board were consolidated with quarterly meetings of WISE membership post 2009.

The Associate Directors of the Institute from Engineering, Science and Environment were appointed to help strengthen the interests and input from departments and to assist with the future development and direction of WISE initiatives.

#### **2012 Board of Management**

Jatin Nathwani, Chair  
Professor, Management Sciences/ Civil & Environmental Engineering  
Ontario Research Chair in Public Policy for Sustainable Energy Management  
Executive Director, Waterloo Institute for Sustainable Energy

Ian Rowlands  
Professor, Department of Environment & Resource Studies  
Associate Director, Global Initiatives, WISE  
Distinguished Teaching Award

Claudio Cañizares

Professor, Electrical & Computer Engineering

Associate Director, External Partnerships, WISE

Hydro One Chair in Power Engineering

Fellow of the Royal Society of Canada

Faculty of Engineering Outstanding Performance and Distinguished Performance

Outstanding Performance Award, Faculty of Engineering

David Johnson

Professor, Mechanical & Mechatronics Engineering

Director, Wind Lab

David Fuller

Professor, Management Sciences

Associate Chair Graduate Studies and Research

Linda Nazar

Professor, Department of Chemistry

Cross appointed to Department of Physics and Astronomy

Canada Research Chair in Inorganic Chemistry

Senior Canada Research Chair in Solid State Energy Materials

Associate Director, Research, WISE

Mahesh Pandey

Professor, Civil & Environmental Engineering

NSERC-UNENE Industrial Research Chair in Risk-Based Life Cycle Management of Engineering Systems

Outstanding Performance Award

Premier's Research Excellence Award, Province of Ontario

Distinguished Performance Award

Michael Fowler

Associate Professor, Chemical Engineering

Associate Chair Undergraduate Studies

Director, Hydrogen Lab

Teaching Excellence Award

Magdy Salama

Professor, Electrical & Computer Engineering

University Research Chair

Faculty of Engineering Outstanding Performance Award



Peter Douglas  
Professor, Chemical Engineering  
Director of University of Waterloo United Arab Emirates Campus  
Former Associate Dean of Engineering (Computing)

Siva Sivoththaman  
Professor, Electrical & Computer Engineering  
Ontario Research Chair in Renewable Energy Technologies and Health  
Director, Centre for Photovoltaic Devices and Systems (CAPDS)

Xianguo Li  
Professor, Mechanical & Mechatronics Engineering  
Engineering Research Excellence Award  
Faculty Research Award – Professor Category  
Fellow of the Engineering Institute of Canada

#### **2012 Associate Directors**

Ian Rowlands, Associate Director, Global Initiatives  
Claudio Cañizares, Associate Director, External Partnerships  
Kankar Bhattacharya, Associate Director, Advanced Training  
Linda Nazar, Associate Director, Research

## **2.4 Staff**

Strategic and Operational Leadership  
Tracey Forrest, Director, Waterloo Institute for Sustainable Energy

Finance and Administration  
Iris Strickler, Administrative Assistant

Communications and Outreach  
Co-op student

## 3. Achievements & Results

During our first five years, we have built the operational foundation of excellence needed to pioneer the field of energy research and to transform the scientific and industrial landscape. Our success is predicated on attracting talent and researchers willing to participate and engage with others in challenging projects.

The Institute's membership has grown from 60 to 95 researchers since April 2008, now representing all faculties. WISE continues to attract a diverse group of researchers who wish to apply their traditional expertise towards meeting the challenges of the energy sector. The ultimate goal of the Institute is to make technological breakthroughs that will enhance quality of life through better use of our energy resources.

WISE has been successful in bringing to Waterloo major (multi-million dollar) research projects to enhance our research capacity and intensity and to provide a solid basis for the training of graduate students and highly qualified personnel. We continue to influence policy outcomes through publications, and a strong media presence complemented by community outreach (see Section 3). We also draw your attention to the letters of support (see Section 5, Appendix A).

In the following section, we outline the measures and metrics that provide an indication of the University of Waterloo's strengths and capacity for energy research currently underway, level of funding, and the experimental facilities and laboratories available to our members for specific WISE initiatives.

### 3.1 Expanding opportunities for multi-disciplinary research

#### 3.1.1 Research Output

Number of Members: 96

Number of Research Chairs: 18

Number of Laboratories: 33

The overall strength of energy research activity at UW, based on the average annual research dollars per faculty member, is approximately \$22 Million.

For a complete list of WISE members see Appendix B.

The distribution of WISE expertise is shown in Figure 1<sup>1</sup>. WISE Member research output includes over 740 publications over the period 2008-2013. For a list of publications, awards and achievements by WISE members please refer to Appendix C and Appendix D.

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<sup>1</sup> WISE member expertise may overlap categories, so the sum of the pie is greater than the total membership.

### 3.1.2 Collaborative Research

We believe that the biggest breakthroughs come from uniting leading researchers from different disciplines. WISE membership spans 24 departments and encompasses every faculty at the University of Waterloo. WISE actively works to foster connections amongst its members and promote the kind of multidisciplinary projects required to solve complex, global problems.

#### 3.1.2.1 Major energy research projects

Below, we highlight several major (multi-million dollar) energy research initiatives underway at Waterloo that illustrate the depth, range, complexity and scale of the projects and WISE accomplishments over the past five years. The projects are innovative, they are highly supported by WISE funding partners and government agencies and they reveal the desire of WISE faculty to participate collaboratively.

WISE provides a leadership role in attracting external partners. Subsequently, WISE staff helps shape the development of the projects to approvals and execution. A brief description of the scope and funding levels of a few select projects is provided. For additional information on research conducted by WISE members, please refer to research spotlights in Appendix E.

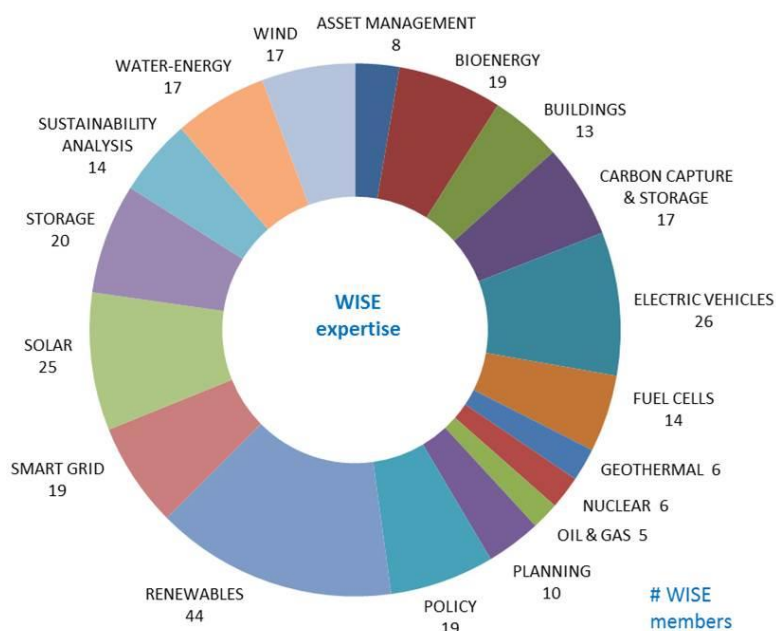


FIGURE 1. WISE MEMBER EXPERTISE BY AREA OF RESEARCH

**Energy Hub Management System I & II:** This \$5.13M collaborative project combines expertise across WISE in the development of an energy management system that allows utilities and customers in various sectors to effectively manage their energy use. The first phase of this project, led by Ian Rowlands, investigated how to empower energy hubs so that they can contribute to the development of

a sustainable society through real-time management of their energy demand, production, storage and import or export of energy. A smart web-based tool empowers consumers to control and change the way they use energy, allowing them to switch from the central energy grid at peak times to on-site alternatives such as solar and wind energy. The second phase led by Claudio Cañizares enhances the utility's capability to manage voltage regulation and improve the interactions with the microhubs and other load controllers. Project partners include the Ontario Centres of Excellence, Hydro One Networks Inc., Energent Energy Solutions, Milton Hydro Distribution Inc., Ontario Power Authority.



**Off-Grid Access and Microgrids:** Around the world, and in remote communities across Canada, there is a compelling need to supplant existing sources of energy with clean, reliable and cost-effective supplies.



WISE members are developing a unique controller for use in microgrid applications incorporating renewable energy production and storage as part of a \$4.4M research and development initiative (ecoEnergy and OCE project). Researchers are conducting system studies, developing new control algorithms, and developing data acquisition tools. Engaging with the Kasabonika Lake First Nations Community is an integral feature of this project that recognizes the importance of community leadership. Kasabonika Lake F.N. is part of the Nishnawbe Aski's 26 communities that relies on diesel – currently they use about 20 million litres annually. The multi-disciplinary research team is led by Claudio Cañizares and includes Ehab El-Saadany,



Paul Parker, Mehrdad Kazerani and Kankar Bhattacharya together with Natural Resources Canada, Hatch, University of Toronto, Hydro One and Wenvor as project partners. In a parallel effort to reduce diesel dependency in remote Northern Ontario communities, David Johnson focuses on developing new kinds of rugged wind turbines, specifically designed, for extreme Northern climates (Project funded through OCE at a level of \$1M). This off-grid hybrid power system provides a lower-cost, environmentally friendly solution to alleviate the significant financial burden of diesel power systems on remote communities.

**Smart Transmission and Distribution Systems with Increasing Renewable Energy Penetration:**

Numerous research activities in power systems and delivery are advanced by the \$2.5M investment by



Hydro One supporting both an endowed Chair in Power Systems Engineering (Claudio Cañizares) and a Hydro One research program. The Hydro One research program (\$1.2M) was used to leverage an additional \$4M through federal, provincial and other sources thereby increasing the scale of activity and raising the total envelope of external funds to \$6.7M. As one example, Magdy Salama has significantly advanced research in the field of active distribution systems, distributed generation controls and energy management made possible through Hydro One funds. His research addresses critical questions such as how do we control short circuit levels in distribution systems with the proposed increase in renewable energy generation in order to avoid damage to system components and obviate any major system reconfiguration. By developing a unified framework for studying possible dynamic interactions in active distribution system and mitigating undesirable interactions via controller design, Salama has provided new tools for electricity system operators to effectively integrate renewables into their transmission and

distribution systems. These include: (i) Design and development of novel distributed generator controls, and techniques to enhance the stable power transfer limits of the existing transmission lines in Ontario minimizing the need to construct new transmission lines, and (ii) Analysis of the impacts of grid interconnection of large-scale renewable energy systems (wind and photovoltaic solar) through to field-validated models, and specification of the technical requirements and performance standards for implementing interconnections.

**Operation, Communications and Information Management for Smart Electricity Grids:** This \$1.6M research initiative brings together, for the first time, a collaborative effort to develop solutions for Smart



Grids not only from the viewpoint of power systems or communications engineering or only as an information management problem, but the three aspects merged to meet the requirements of the day. A smart home energy management device needs communication channels with the individual controllable appliances but it cannot stand alone- it needs "information" from the external "power system" in terms of real-time market prices. Within the architecture of Smart Grids, all the three important pillars –

the power system, the communication system, and the information system are linked. This three-year project combines expertise in computer science, power systems engineering and smart grid policy to develop new and innovative solutions in five areas: Smart Grid Modeling, Analysis & Operation; Smart Loads in Smart Grids; DER, Storage & Integration; Communication & Security in Smart Grids; and Smart Grid Information and Data Management. Researchers include Kankar Bhattacharya, Catherine Rosenberg, Claudio Cañizares, Srinivasan Keshav and Jatin Nathwani. Project partners include NSERC, IBM, ABB and Hydro One.

**Information Systems and Science for Energy:** The next generation development of a Smart Grid is characterized by an emerging paradigm shift from a static predictable system to a highly dynamic



system with elastic loads, two way power flows and millions of points of control. This research is supported by a \$1M investment by Cisco Systems Canada Co. towards the Cisco Systems Research Chair in Smart Grid held by Srinivasan Keshav. On the basis of this investment, an additional \$1M in research funds through NSERC CRD's will enhance the scope of activities. Keshav and Rosenberg are the co-directors of the Information Systems and Science for Energy laboratory. The mission of the ISS4E laboratory is to use information

systems and science to increase the efficiency and reduce the carbon footprint of energy systems. Specific research projects include: integration of distributive energy systems; stochastic analysis and large scale simulation; data mining and machine learning; exploration of how the design, deployment and operational management of a smart-grid can be enhanced through utilization of information science and technology concepts; incentive compatible distributed generation control and protection; modeling and control of grid energy storage; efficient and secure communication network for the grid; consumer behaviour aspects in networks, economics and game theory and new enabling technologies for smart grids.

**Large-Scale Solar Photovoltaic (PV) Integration into Electricity Networks:** The University of Waterloo partnering with Western University has developed a set of comprehensive solutions to help grid operators incorporate large-scale solar farms on to their networks. This \$4.5M research project is a co-operative effort with multiple project partners including Hydro One Networks Inc. (Toronto), OptiSolar Farms Canada (Sarnia), Bluewater Power Distribution Corporation (Sarnia) and London Hydro (London). Six professors from UW's electrical engineering department - Kankar Bhattacharya, Claudio Cañizares, Ehab El-Saadany, Mehrdad Kazerani, Magdy Salama and Siva Sivothythaman were involved in the project.



Among the issues they tackled is the fact that decentralized sources of electricity such as solar farms can create frequency and voltage problems when they're connected to the grid. Kazerani and Salama developed new technology to increase the solar farm efficiency by reducing the impact of the shading on the solar panel. Kazerani also developed cost-effective technologies to convert the DC power produced by PV systems into the three-phase AC power required by the grid, while Salama enhanced solar farm performance by developing a new technology to reduce the impact of harmonics generated from the power electronics devices connected to solar panels. Cañizares and El-Saadany combined real-time weather models and meteorological data with PV models to predict how much solar power will be transmitted to the grid. Professor Siva Sivothythaman developed novel technology to maximize the power output of PV cells using textured conductive oxide coatings and optically active coatings. Together, these researchers are not only working to make large-scale PV generation a reality in Ontario but are creating a pathway for global adoption, successfully integrating solar farms with existing transmission and distributions systems.

The research and commercialization outcomes from this project have considerably advanced our knowledge base for integration of PV solar power into electricity distribution and transmission systems.

**Wind Power Health Impacts:** Development of large-scale wind farms in Ontario has resulted in a new concern identified by communities. Residents close to wind farms claim that exposure to the noise generated from wind turbines is extremely irritating because of its rhythmic nature. This rhythmic sound noise, caused by the aerodynamic or mechanical noise of wind turbines, characterized as infrasound and low frequency noise, is most controversial in terms of health. Research focuses on the prediction of aerodynamic noise produced by wind turbines by combining Computational Fluid Dynamic (CFD) software and Computational



AeroAcoustic (CAA) code in flow over wind turbines numerical simulation. The CFD software generates unique information about the flowfield and uses Ffowcs Williams and Hawkings equation, based on Lighthill acoustic analogy to calculate the far field noise. In parallel, researchers in Applied Health Studies are developing the clinical and epidemiological basis for estimating the health effects of turbine noise. They are investigating the relationships of exposure to sound from wind turbines (low frequency as well as audible) with various health outcomes such as sleep disturbances and stress. The studies are highly multidisciplinary in nature (e.g., include inputs from the wind model) and involve both field studies, with collection of data on noise exposures, as well as health information from study subjects. This research is supported by the Ontario Research Chair in Renewable Energy Technologies and Health to Siva Sivothythaman, made possible by a \$1.5M investment by the Province.



**Novel Batteries:** Canada Research Chair Linda Nazar focuses on lithium-sulfur (Li-S) and lithium-oxygen (Li-O<sub>2</sub>) batteries to achieve a far higher energy density than their lithium-ion counterparts. In Li-S batteries, the electrons and lithium are stored at the positive electrode by reacting them with sulfur to form lithium sulfide (Li<sub>2</sub>S). The process is reversible, so directing the flow of electrons the other way regenerates the sulfur, creating a rechargeable cell. Li-O<sub>2</sub> batteries rely on similar chemistry, except that storage is in the form of Li<sub>2</sub>O<sub>2</sub>. Although Li-S cells are further along in development, the main hurdles to commercialization to keep the sulfur – or the discharge product, Li<sub>2</sub>S – in intimate contact with a conductive material in the cathode. The other challenge is preventing the soluble polysulfide intermediates from getting "lost" into the electrolyte, thus reducing the capacity of the batteries with each cycle.



According to Nazar, the solution could lie in nanoporous carbon, a form of carbon riddled with tiny pores or channels 2-20 nm in diameter. Incorporating of sulfur into these pores forms a network of sulfur nanofibres surrounded by conductive carbon walls, creating that all-important contact to "wire up" the sulfur. The carbon framework also acts as a mini-reaction chamber, encouraging a more complete reaction. Adding a polymer coating to the surface reduces the diffusion of the polysulfide ions to minimize the capacity fade, thus extending the life of the battery. As a result, the composite boasts three times the energy density of a lithium-ion cathode. In theory, a five-fold increase is possible, while the Li-O<sub>2</sub> cell has even greater potential. Nazar's work, supported by BASF and NSERC, paves the way for a new generation of batteries that can power a car for several hundred kilometers on a single charge - and cost far less than today's lithium-batteries.

**Life Cycle Management of Li-Ion Battery Systems in Electric Vehicles:** The objective of this project (\$0.5M) is to develop an environmental life cycle management study of Lithium ion (Lilon) battery packs in electric vehicles. Design and control systems in vehicles will account for the battery state of health (SOH) to optimize use and performance of the battery pack in service while allowing for second use repurposing applications for the batteries. Research pathways include: (i) Life Cycle Assessment (LCA) of lithium and other strategic metals, including mining, manufacture, use, and recycling, (ii) Battery degradation models that provide predictive information on battery state of charge (SOC) for battery first-use in vehicles and readiness for second-use in repurposing applications, and eventual recycling, (iii) Vehicle to drive-cycle matching models that allow retail dealers to match driver behavior and drive cycles to appropriate battery and vehicle selections, (iv) Battery multi-use systems, life-cycle management studies of Lilon batteries from 'cradle to grave' with specific incorporation of second use applications to extend battery service life, and (v) Lilon promising recycling processes and metallurgy with 'design for environment' recommendations, including incorporation of recycling processes within the LCA. This multi-disciplinary project is led by Steven Young, Michael Fowler and Roydon Fraser along with industry partner Mitsui.



**Novel Processes for Upgrading Bitumen Emulsions:** Flora Ng in chemical engineering, a pioneer in the field of catalytic distillation, has developed new green energy processes with her team, including one that creates biodiesels from waste oils and novel catalysts for bitumen upgrading. Through a \$618K research program, Ng has developed nano-catalysts that react with the water to produce hydrogen,



removing the water and upgrading the bitumen in a single step. This novel process has numerous benefits as follows: higher pitch conversion and naphtha yield; higher percentage removal of S, metals and asphaltenes; lower viscosity, higher API gravity; and meets Canadian pipeline standards. It produces higher quality oil, is cost-effective and reduces the requirement to clean oily water from oil sand tailings.

**Electric Vehicle Demonstration:** This electric vehicle demonstration project with collaborative research conducted by Chemical and Mechanical Engineering at the University of Waterloo and approximately



\$330K in funding from Transport Canada, is designed to increase understanding of the operating characteristics of Burlington Hydro's all-electric fleet vehicle in practical, working applications. This includes its recharging patterns and requirements, how to optimize the usage and recharging cycle in a "real life" setting; overall performance, drive-cycle, battery state-of-health and electricity grid impacts. Rapid Electric Vehicle

Technologies Inc. developed the motor and drive system technology specifically for the fleet vehicle. The University of Waterloo develops the data analytics and modeling of the electric vehicles, and also provides assessment and management tools to assist with the integration of Plug-in Hybrid Electric Vehicles (PHEV's) into the electricity grid. The findings will provide the insights and tools to designers and prospective operators of electrified fleet vehicles. Roydon Fraser is the lead researcher on this project, with research partners involving Community Carshare, utilities and the WISE Drive4Data program.

**Risk-Based Life Cycle Management of Engineering Systems:** Mahesh Pandey holds the NSERC-UNENE Industrial Research Chair in Risk-Based Life Cycle Management of Engineering Systems. It is valued at



\$6M over three five-year terms (currently in its second five-year term). His research program aims to improve the life cycle management of nuclear plant systems through the development and application of advanced risk and reliability models. The program focuses on: (i) Developing advanced probabilistic models for risk analysis and (ii) Development of highly qualified personnel (HQP). Research outcomes have included critical support to the Canadian Nuclear Safety Commission, the effective and safe operation of Ontario's nuclear reactors and training of regulatory and utility staff.

**The Risks of Capturing and Storing Carbon:** The goal is to trap greenhouse gases from big emitters (power plants) and storing it deep in the Earth's crust as part of a carbon mitigation strategy to address



the challenge of climate change. However, we currently know very little about the risks of storing carbon dioxide underground or how to manage it. Robert Gracie is part of a collaborative project with the University of Ottawa and the University of Calgary aims to change that. This multidisciplinary team, supported by a \$900K grant from Carbon Management Canada, which includes experts from engineering, social science,

economics, policy analysis, and communications, is investigating the risks involved in carbon capture and storage. In the second phase of the three-year project, the objective is to develop strategies to minimize those risks, drawing on current risk-management strategies used for other underground storage technologies. The result is a tailored-for-Canada framework to guide decisions on feasibility of carbon capture and storage facilities.



**Research into Solar-Assisted Heat Pumps, Thermal Storage and Natural Refrigerants:** Researchers in Mechanical and Civil Engineering, led by Michael Collins, have partnered with a local heat pump developer, Ecologix, to assist in research and development of their technology. Previous research focused on ways to reduce cost by modifying existing heat pump technologies to the Canadian climate. The findings from this work led to a partnership with Emerson Climate Technologies to utilize their variable capacity digital scroll compressor matched with a EC3 refrigerant management system, and the integration of this technology, with the assistance of the University, into a demonstration project (Solar Decathlon) sponsored by the US DOE. Current research continues to advance heat pump technologies for cold climates in three main areas: solar panels to assist space heating in cold weather; use of CO<sub>2</sub> or hydrocarbon refrigerant system alone or in combination with other refrigerants; thermal storage to allow at least partial load shifting to take advantage of time of use electric rates.



**Hydrogen & Storage Potential for Grid Application:** This \$200K project, led by Michael Fowler focuses hydrogen-based technologies for electrical and transportation systems in the context of a Hydrogen Economy, addressing the economic and technical aspects of hydrogen production, storage, distribution, and utilization. The improvement and application of electrolysis and fuel cell technologies for the generation and utilization of hydrogen are an integral part of this project. On the electrical side, feasibility studies have been carried out on the use of hydrogen for electricity storage to facilitate the integration of wind-power as well as the use of the grid to generate hydrogen for transportation applications. This project has been funded and supported by Bruce Power, the Canadian Hydrogen and Fuel Cell Association (CHFCA), NSERC, MITACS and OCE.



**Bioenergy:** Energy derived from biomass, especially in the form of waste recovery, has the potential to play an important role in greening our energy supply mix. Wayne Parker, a professor in the civil and environmental engineering department, and Ray Legge in chemical engineering, are conducting research to enhance the application of anaerobic digestion of farm, agricultural and municipal waste to produce biogas for heat and electricity generation. Anaerobic digestion and biogas products offer several advantages in terms of use of a renewable resource and providing a sustainable energy carrier. Anaerobic digestion promotes pathogen reduction, increased nutrient recovery and carbon return to the soil. Biogas combustion reduces methane emissions that would have otherwise occurred resulting in a net reduction in greenhouse gas emissions. This research provides a basis for the development of advanced biogas systems that are effective and economically viable in an Ontario context with significant energy generation, ecological and environmental benefits.



**High Performance Graphene Electrochemical Energy Systems:** Aiping Yu and Gordon Chiu are collaborating with Grafoid Inc. to investigate and develop a grapheme-based composite for electrochemical energy storage for the automotive and/or portable electronics sectors as part of an approximately \$600K research initiative. They will research and develop patentable applications using graphene derived from raw graphite ore to target specialty high value graphene derivatives such as



nanoporous graphene foam. New graphene materials will have far reaching impacts on the development of the next generation composites for fuel cells, electrochemical supercapacitor applications such as electrodes, nanocatalyst support, electrolyte membrane, and bipolar plates, transparent electrodes to create high-efficiency solutions in electrochemical energy systems and portable electronics.

**Energy Policy:** The University of Waterloo recently signed a 10-year \$500K agreement with the Energy Council of Canada (ECC) to establish The Energy Council of Canada Energy Policy Research Fellowship. This collaboration provides funding for annual fellowships valued at \$15,000 for Master's students and \$25,000 for Doctoral students. WISE in conjunction with ECC will develop further the Energy Policy Research agenda. Currently, the topics of interest identified by ECC include energy literacy, inter-provincial trade and carbon management.

The collaboration between ECC and WISE will pave the path for significant interaction with governments, the public and other stakeholders. The results of the research are expected to facilitate public policy objectives on energy matters in keeping with ECC's interests in energy security, energy supply, energy poverty and climate change. The research will provide policymakers with pragmatic, action-oriented recommendations for addressing an energy issue, question, or problem.

WISE, through its Executive Director, continues to play an important role in helping shape the dialogue on energy policy issues in Canada and globally (see details under Section 3, Media Coverage and Promoting Policy Advancement).

For more information on research conducted by WISE members please refer to the research spotlights (Appendix E).

### ***3.1.2.2 Understanding our Members***

We focus on understanding the needs and priorities of our members. Active engagement of WISE members is an important factor in establishing successful research projects. WISE does this through one-on-one meetings throughout the year, as well as online surveys. The charts included in the Strategy and Operations section of this report illustrate the results of member surveys and identification of issues and concerns. An understanding of what faculty members value helps WISE to shape opportunities for the future.

### ***3.1.2.3 Developing opportunities for multidisciplinary work***

WISE has been instrumental in identifying opportunities that unite our members on discipline-spanning projects – projects such as the large-scale Renewable Energy Map for Canada supported by the World Wildlife Foundation (WWF) Canada. When WWF needed a scientific partner, WISE was the destination of choice. WISE drew upon our breadth and depth of expertise to lead the scope development for this multi-million dollar study. The resulting proposal included 10 WISE members from seven departments to

lay the groundwork for the development of evidence-based research required to understand impacts of large scale renewable energy projects at the national level.

#### ***3.1.2.4 Securing promising new sources of research funding***

WISE not only keeps members well informed about important sources of funding but we go a step further. WISE assists in securing access to additional funds, physical assets where appropriate and mobilizes the necessary commitments. WISE does this by leveraging our extensive network of partners and our formal collaboration arrangements, such as our memorandum of understanding with Natural Resources Canada (NRCan). As an example, response to NRCan's Ecoenergy Innovation Initiative required a significant effort. WISE was involved in more than a dozen submissions, representing a total project value of approximately \$13M. Five letters of intent reached the proposal stage in this highly competitive selection process. Ultimately, two projects were successful representing approximately \$3M in research funding for WISE members. Meanwhile, several WISE members benefitted from 2011 Smart Grid funding from the Ontario Centres of Excellence (OCE). Out of a total OCE investment envelope of \$2.9M, WISE researchers were successful in securing \$2.2M of the approved projects, representing 77 per cent of the entire fund.

WISE also secures additional sources of research funding by fostering partnerships as described in Section 3.2.1 Partnerships.

#### ***3.1.2.5 Creating the space for collaboration***

WISE assists its members in hosting workshops designed to shape the research agenda and seed early-stage collaborations. WISE provides the administrative support, selection of venues, managing logistics and securing funds for promotion and follow-up. That leaves WISE members free to focus on advancing research.

WISE Membership Meetings strengthen information sharing and provide informal and formal ways for faculty to connect with colleagues on campus working in energy research through social events, pizza lunches for undergraduate and graduate students and poster presentations. These events offer a collegial environment for students to broaden their network and their perspective on sustainable energy issues.

See Appendix F for a full list of Workshops hosted by WISE and its members.

#### ***3.1.2.6 Enabling Initiatives***

WISE sees value in providing unique access to 'real world' energy data as a mechanism to engage researchers from various disciplines and promote collaboration. For example, more than two dozen WISE members conduct research involving electric vehicles (EVs). The problem they face is limited real world data, forcing them to rely on small-scale pilots or proxy information. That's why WISE launched the Drive4Data initiative in 2012 with the generous financial support of The Regional Municipality of Waterloo, Waterloo North Hydro, Cambridge North Dumfries Hydro and Kitchener Wilmot Hydro.

This unique initiative brings together industry and local non-profit organizations to capture large-scale real-world data from plug-in vehicles. As a result, WISE researchers have access to information on everything from vehicle use and charging patterns to battery range and powertrain performance. Already, the initiative is having an impact in Waterloo Region. In 2012, a WISE member research partnership with Community CarShare was launched to investigate local opportunities for EVs and barriers to their use.

### **3.1.3 Facilities for Research and Training**

Number of laboratories: 33

Selected labs are highlighted below.

See Appendix G for the full list of laboratories and energy research facilities at Waterloo.

#### **Centre for Advanced Photovoltaic Devices and Systems**



CAPDS promotes cutting-edge research and development that spans the spectrum of photovoltaic (PV) technology. The 14,000-square-foot facility includes infrastructure for synthesizing semiconductor base materials; developing nanotechnologies for PV; designing and fabricating advanced PV devices and modules; and testing and characterizing PV materials, devices and systems. Director: Siva Sivoththaman

#### **Laboratory for Emerging Energy Research**



LEER explores potential solutions to energy security and global warming. Focus is on not only revisiting the existing technologies for energy conversion and utilization but developing novel methods by means of nanotechnology and multi-disciplinary approaches. The lab is equipped with a 'big' drop tube reactor which is 3 meters tall, for developing and evaluating the catalytic combustion technology in the industrial scale.

Director: John Wen

#### **Information Systems and Science for Energy Lab**



ISS4E is applying the concepts and techniques pioneered by the Internet to energy problems, from monitoring individual buildings to developing an efficient, decentralized "smart" grid that draws energy from millions of small-scale sources and uses communications technology to match supply and demand. Directors: Srinivasan Keshav and Catherine Rosenberg

### High Voltage Energy Lab



HVEL is a leading research and teaching lab in the field of insulation, applied electrostatics, nanodielectrics, pulse power applications, and power electronics. Extensive experimental and test facilities - available to industry - allow the design, prototyping, and testing of high-voltage components and advanced dielectric materials. The research experts are recognized around the world. Director: Shesha Jayaram

### Wind Energy Laboratory



The lab investigates a broad range of wind energy topics, from turbine blade aerodynamics to wind resource assessment. The advanced experimental measurement tools include laser Doppler and particle image velocimetry, while the wind flow facility was designed to permit large-scale air-flow studies under controlled flow conditions. Director: David Johnson

### Fuel Cell and Green Energy R&D



The lab investigates green energy topics through modeling, system analysis, experimental research and scale-up design. Among current projects, researchers are developing reliable, cost-effective polymer electrolyte membrane fuel cells and clean biodiesel engines for automotive purposes. Lab capabilities include materials characterization, process development, circuit design and fabrication, and prototyping. Director: Xianguo Li

### Solar Thermal Research Laboratory



The rooftop test platform for the development of next generation solar thermal technologies, predominantly for residential applications is in the Energy Research Centre. Established expertise is in experimental, numerical and theoretical research comprising three separate laboratories: the Main Lab, an Optical Measurements Lab and a rooftop test platform. Directors: John Wright and Michael Collins

### Centre for Pavement and Transportation Technology



The research focuses on the advancement and optimization of conventional pavement technology, which also involves utilization of the latest technologies from other disciplines. As well, much of the research focuses on issues particularly relevant to Canada, such as the effects of low temperatures on pavement, concrete durability, and use of polymer and recycled rubber for upgrading pavement performance. Director: Susan Tighe



### **Advanced Glazing System Lab**



Researchers are creating a library of tools to model window glazing and shading for green building design. Cutting-edge equipment includes a rooftop test facility, an exceptionally high-resolution spectrophotometer and the unique Broad Area Illuminated Integrating Sphere, which allows researchers to measure directional and spectral transmittance and reflectance of spatially non-uniform samples. Directors: John Wright and Michael Collins

### **Centre for Advancement of Trenchless Technologies**



Research areas include horizontal directional drilling (HDD), trenchless construction of leachate drains in municipal solid waste, waste water and water pipeline condition assessment, buried infrastructure asset management, testing of pipeline renovation materials, deterioration and renewal of water and waste water networks, etc. During the last 10 years, CATT has achieved significant recognition as an international leader in trenchless technology education and research. Director: Mark Knight

### **UW Live Fire Research Centre**



The University of Waterloo Fire Research Group collaborates with a wide range of industrial and government partners on fire safety. Among other things, researchers examine the behaviour of full-scale fires, the flammability and performance of materials and products, fire initiation and spread, and methods of fire detection. The world-class, \$5.6 million fire research infrastructure includes a large cross-flow test area used for a variety of wind-driven experiments, including wind turbine performance. Director: David Johnson

### **Giga to Nano Centre**



G2N is a \$17 million lab that offers a wide range of capabilities for processing electronic materials and devices, from nano-materials to large-area electronics and electronics on unconventional substrates. Unique in Canada, it provides users with training and access to conduct their own cutting-edge research, as well as rapid system prototyping for commercial applications. Facilities include equipment for characterization, deposition, etching, lithography and packaging and bonding. Directors: William Wong and Hany Aziz

### **Wind Turbine Acoustics Lab**



A rooftop test platform for acoustic characterization of wind turbine noise using an anechoic chamber is shown here. The goal is to assess causes of excessive wind turbine noise and study its potential impact on human health.

Director: Fue-Sang Lien

### 3.1.4 Education and Training

The current courses available to undergraduate and graduate students are given by WISE members through their departments. The departments include: Chemical Engineering, Management Science, Mechanical and Mechatronics Engineering, Electrical and Computer Engineering, System Design, Civil and Environmental Engineering, Environment and Resource Studies and the School of Environment, Entrepreneurship and Development in the Faculty of Environment.

To further strengthen the focus on education and training in energy at UW, WISE has developed a proposal for a graduate program with specialization in Sustainable Energy. This proposal builds on the existing strengths of the academic courses on Energy given by the Faculties of Engineering and Environment. The proposal, when implemented, will help meet an emerging need identified by several industry partners as an area of study and training that needs to be enhanced within academic institutions.

The WISE proposal for graduate students will enhance the collaborative inter-disciplinary research already underway and it will provide graduate students to deepen their knowledge base along three research tracks: sustainable energy systems, sustainable energy technologies, and sustainable energy and environmental policy. The proposal for a collaborative inter-disciplinary graduate program in sustainable energy will be developed further and the necessary approvals sought during the second mandate of the Institute.

In addition to the above program, there is currently available an advanced training program (ATP) in Power Systems Engineering developed by WISE members (Profs Canizares, Bhattacharya and El-Saadany with participation by Salama, Kazerani, Jayaram) in the Department of Electrical and Computer Engineering.

The context and history of the development of the training program in power systems engineering illustrates not only the nature of strong collaboration among our faculty but also their enthusiasm for responding to external needs.

Recognizing the emerging demographic challenge (retirements) within the Ontario electricity sector, the University of Waterloo (Power & Energy Systems group) responded to a request from Hydro One, the leading Canadian power transmission and distribution company, to embark on the development of a specialized advanced training program (ATP) for professional staff. The concern at Hydro One, and the general electricity sector, was the lack of qualified individuals with adequate training and technical background to make decisions on various new aspects of power engineering, such as competitive electricity markets, distributed generation, and smart grid technologies. This was identified as a pressing need.

The objectives of the training program are to increase the power sector practitioners' skills to respond to emerging challenges in the sector and to provide learning opportunities for qualified candidates to develop a level of technical proficiency and capacity to meet new requirements. In addition, the training program provides a strong path for employment opportunities in the power and energy sector for new graduates, new immigrants and other engineering graduates.

A shortage of qualified power engineers was forecast due to a large number of expected retirements and the limited available electric power engineering undergraduate and graduate programs in Canada. To overcome this, several organizations and universities have taken steps to address the challenge by developing short courses. However, a majority of the initiatives were not successful in providing a comprehensive, well defined, career advancement program for those seeking training as well as gaining a higher engineering degree. Combining training and academic accreditation is vital in personal development for many practicing engineers and is considered a strong motivation for employees. The UW program fills this niche and has been highly successful.

The advanced training program (ATP) is a web-based Master of Engineering program. The program is geared towards power industry professionals. The attractive features of the program are that it provides multi-track options for the participants, and offers courses that are delivered on-line through the internet using multi-media communication technologies. The broad benefits for sector partners and for the broader community are as follows:

- For the local businesses, it provides a state of the art training of its employees in latest developments in power engineering, while retaining their current employment status.
- For the university faculty, the initiative opens the door for exchange of ideas with power industry personnel, updated information on current technology developments and familiarization with power industry issues and needs.
- For the government, the initiative provides a strong mechanism for cooperation between the university, industry and the participant.
- For the individual participant, the ATP leads to several personal career and job opportunity gains through a state-of-the-art education in power engineering and with the knowledge gained help increase productivity of the overall business.

The program was launched in 2003 and during the first year of its operation, the courses were offered in Toronto at Hydro One premises – taking the University to the place of work. The program went on-line in Fall 2004 and all courses are given through the web-based interface. The program has been highly successful in attracting a large number of participants and operates on full cost recovery.

The growth in student enrollment in the ATP courses over the past academic terms remains high. During the period 2003-2009, the ATP offered a package of 12 courses which were delivered in a two-year cycle that effectively resulted in six courses per year or two courses per term. Since Fall 2009, a total of 18 courses in the program were delivered in a two-year cycle (nine courses per year or three courses per term). The total course enrollment units have been very high since 2008. On an average, each course has attracted at least 20 students, since the past three years, and some courses have attracted students in excess of forty.

The Advanced Training Program in power engineering is an illustration of how WISE, working with its key partners, is advancing the agenda of education and training. In the emerging challenges of the energy sector, there is a strong need to develop new knowledge and understanding and to integrate it seamlessly into the work place. The program objectives continue to meet the increasing demand of



professional development and to prepare engineers for the technological challenges and of a constantly changing industry. The various power engineering courses and covered topics in the program have been defined with the help of the program's industrial partners, so that these meet today's power sector needs. It is expected that the program will continue to provide a well-trained pool of engineers with the appropriate needed technical background for the foreseeable future.

### **Developing Highly Qualified Professions (HQP)**

With respect to development of HQP for the energy sector, the total capacity of 95 WISE members and the graduate students and post-doctoral fellows under their supervision, the number of graduate students involved in energy research is in the range of 500+.

The unintended positive consequence of the master's level advanced program in power engineering (ATP) described above, has been the effect on the strengthening of the undergraduate program in power engineering. Although the ATP was initially directed at working professionals, it has also provided the impetus to our faculty to offer more courses at the undergraduate level.

The scholarships provided through Hydro One investments have resulted in a high level of attraction to undergraduate students to the Power Engineering Program. These scholarships are provided to top students in each of the Power & Energy Systems' 4th year courses, in recognition for their academic achievements and their commitment to Power Engineering. Recipients are selected among the students registered in the Power Engineering program with an 80% minimum GPA and the top marks in ECE 261 and ECE 362. Over the period 2008 - 2013, there have been 61 recipients of Hydro One Scholarships some of whom have obtained employment there or within the sector. The University of Waterloo's Power Engineering Program has grown, over the past five years, to become the largest such program in Canada.

See Appendix H for a list of scholarship recipients.

## **3.2 Developing Partnerships**

Transformative change is best enabled through partnerships. WISE has shown leadership by working closely with industry, government and the non-profit sector in Canada and abroad with the goal of creating sustainable energy solutions. WISE has been effective in fostering connections and establishing formal partnerships to pursue major initiatives with external organizations.

As a result, WISE members gain access to new partners, financial and in-kind support, shared research facilities, relevant data and the benefit of intellectual engagement with experts in the energy sector. WISE makes external collaborations as easy as possible for our members through a wide range of services that include drafting progress reports, providing financial statements and assisting with proposals.

### 3.2.1 Partnerships

In the last two years alone, WISE has developed the following key partnerships with external organizations:

- i Natural Resources Canada (NRCan): A Memorandum of Understanding with the Federal Department of Natural Resources to enhance collaboration in support of clean technology initiatives was established. This partnership has indirectly led to a number of positive outcomes including two EcoEnergy Innovation Initiative projects at Waterloo with a combined value of approximately \$3M.
- ii Cisco Systems Canada Co.: A five-year \$1M agreement provides funding for the Cisco Chair in Smart Grid (Srinivasan Keshav is the Chairholder) and the funding will allow, through leverage with NSERC, to increase the scope of research activities by an additional \$ 1M in the field of smart grid.
- iii Hydro One: In 2009, WISE signed a five-year memorandum of understanding and agreement with Hydro One investing \$2.5M. This established an endowed chair (currently held by Claudio Cañizares) including \$1M funding for research. Since then, Hydro One has committed an additional \$210,000 in funding and in-kind support bringing the total number of Hydro One research projects to fourteen. WISE members have made the most of that investment, using the \$1.2M Hydro One funds to leverage an additional \$4.0M in research funding from NSERC, OCE and others. Thus, the total scope of research activity from Hydro One's commitment and other agencies is \$6.7M.
- iv The Energy Council of Canada (ECC): This 10-year \$500K agreement sets out the establishment of The Energy Council of Canada Energy Policy Research Fellowships awarded to eligible students at the University of Waterloo. The Energy Council of Canada is a vehicle for strategic thinking, networking and action by senior executives in the private and public sectors who have a broad interest in national, continental and global energy issues. The energy policy research topics are selected annually in collaboration between WISE and ECC. WISE also administers the Call for Applications.
- v Mitsui & Co. Ltd.: WISE introduced Mitsui to a multi-disciplinary team of WISE members. The team's \$500K proposal relating to lifecycle battery management was ranked #1 in North America in competing for the global Mitsui Environment Fund.
- vi IBM Southern Ontario Smart Computing Innovation Platform (SOSCIP): IBM approached WISE to advance innovation in the areas of micro-weather forecasting for utility applications and smart meter data analytics. WISE quickly identified the right expertise, leading to two proposals, both of which were successfully funded.
- vii Union Gas Ltd. (Union): Union has provided \$118K in funding to support Smart Energy Network research and policy development. A multi-disciplinary team of WISE researchers have benefited from this funding. Aside from research, the funding has also led to the formation of a Smart Energy Network Advisory Panel comprising senior energy leaders across Canada and a major event to be hosted in Toronto (Sept. 2013), co-chaired by Ian Rowlands and Tracey Forrest.

- viii WWF Canada: WWF Canada has partnered with WISE to develop a renewable energy map for Canada. WWF has raised approximately \$75K to-date for WISE members to undertake the preliminary scope under this multi-million dollar initiative.
- ix Roxul Inc. is providing \$20K to WISE for the advancement of building-energy related research at Waterloo.
- x Greater Toronto Airport Authority: In June 2011, GTAA approached WISE to help them develop strategies and approaches for reducing the carbon footprint of their operations and to meet their ambitious emissions targets. In turn, WISE partnered with The Delphi Group to develop a strategic RoadMap, providing GTAA the information they needed to prioritize action and move forward with implementation. Work has since expanded, and several WISE members continue to contribute to this initiative.
- xi Toyota Tsusho Canada Inc., Waterloo North Hydro, Union Gas (amongst others): WISE pulled together a multi-disciplinary team of researchers and secured private and utility funding for an OCE-NSERC proposal entitled "Smart Energy City". The proposal is valued at approximately \$250K.
- xii City of Abbotsford: WISE spearheaded a partnership with this municipality and three researchers in WISE to analyze the City's 28,000 water meters and provide insights (including energy-water correlations). The metered data is obtained from a unique water advanced metering infrastructure that provides fine grain data on usage.
- xiii Mahindra Satyam: WISE has teamed up with this multinational systems integration company to advance a smart grid research and innovation centre at the University of Waterloo and launch global training programs (starting in India).

WISE has also established partnerships with a number of leading national and international organizations in order to foster research with global impact. A few select examples are included below.

- Canada-India Scientific and Technological Cooperation: This partnership development proposal submitted in September 2008 was approved. A two-day Workshop with the theme: 'Indo-Canada Workshop on Electricity Generation Using Renewable Energy' was hosted in India (Delhi) 12-13 October 2009 under the Partnership development activities of ISTP (Canada) and GITA (India).
- A Canada-India Collaboration Project: A proposal with a 'Mission to Develop Affordable Solar Energy' was prepared following a visit to UW by India's ex-president Abdul Kalam and subsequent visit to India by UW President David Johnston. Siva Sivoththaman (Director, CAPDS) continues to provide scientific leadership with Jatin Nathwani to develop the partnerships for this initiative. Process Research Ortech Inc. (PRO): A memorandum of Understanding to work on joint projects associated with affordable solar energy between Process Research Ortech Inc. (PRO) and UW was signed by the Executive Director in January 2009.
- University of Petroleum & Energy Studies (UPES): A Memorandum of Understanding for Educational and Scientific Cooperation between University of Petroleum & Energy Studies, India

(UPES) and the University of Waterloo to explore the potential for cooperation and active collaboration to foster exchanges in education, training and research. Both institutions have continued to encourage institutional contact and cooperation between their faculty members, departments and research institutes under provisions of this Memorandum.

- Dalian University of Technology, China: A Memorandum of Understanding with the Institute for Eco-planning and Development of DUT, the International Eco-Safety Research Institute of DUT and WISE to advance collaboration and continuing co-operation. The intention is to promote (i) Regular communication of academic research results and information (ii) Exchange of academic visits (iii) Participation and support in applying for research funding (national and international) or consulting projects (iv) Supportive communication among doctoral candidates (v) Encouraging and supporting applications for distinguished university professors and (vi) Exchange of information of international conferences and activities.

### **3.2.2 Connecting members with external partners**

WISE has been successful in forging links between academia and external partners in many ways. WISE helps members develop their research ideas by focusing on real-world problems by establishing dialogues with external organizations and participating in key energy boards and forums. Our extensive online library of resources keeps WISE members up to date on industry trends, issues and developments.

WISE organizes presentations by industry leaders and funding agencies to help shape early exploratory pathways, align research with strategic opportunities and maximize available funding.

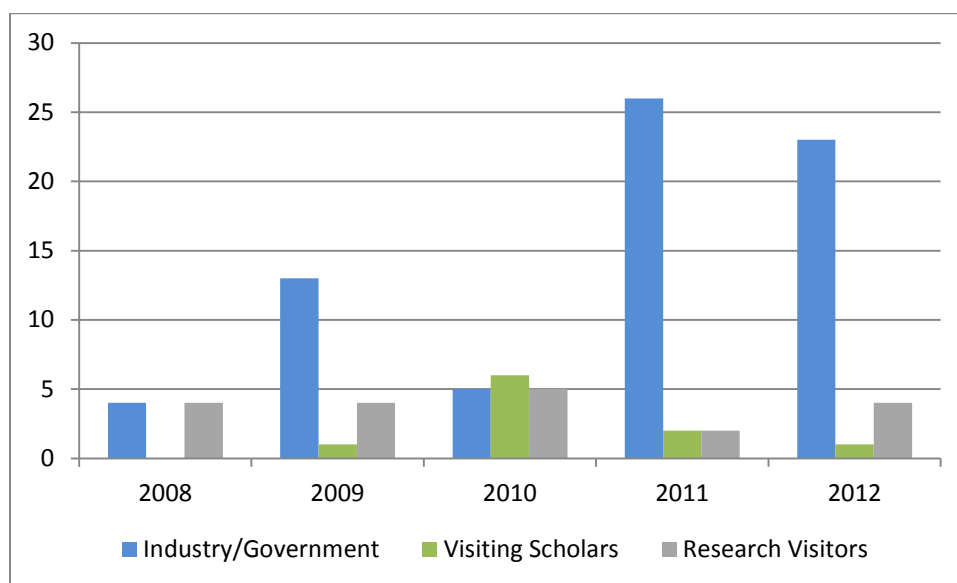
Select examples are described below:

- *Electric Vehicle Leadership Forum, January 23, 2013*  
The forum brought together representatives from local electric distribution companies, Waterloo researchers, and supporting partners to discuss the latest utility-related electric vehicle (EV) research and explore collaboration pathways based on the Drive4Data initiative.
- *Bio-Energy Mixer, November 8, 2012*  
The WISE-NSERC BioEnergy Mixer was another successful opportunity to bring together industry and researchers. Eleven researchers and six representatives from Ontario based companies in the bioenergy field used the opportunity to network, to gain new perspectives on the topic of bioenergy, and to learn about funding opportunities to start collaborative research. As a result, five WISE members engaged with four different companies on areas specific to their research.
- *Electric Vehicle Mixer, June 9, 2011*  
WISE partnered with the Engineering Research Office and NSERC to host a researcher/industry mixer event focused on electric vehicles and the grid. The informal evening event saw 11 University of Waterloo faculty and a wide range of industry representatives explore research interests and opportunities for collaboration.

### 3.2.3 Visitors

Over the past five years, WISE has partnered or collaborated with many organizations, nationally and internationally, to advance energy research. Appendix I provides details on the level of activity and number of visiting organizations hosted by WISE in the past five years. By fostering this interaction with visitors, faculty have broadened their networks and in several cases have accessed increasing funding and/or in-kind resources.

Number of visits hosted: 112



**FIGURE 2. EXTERNAL VISITORS TO WISE: 2008 – 2012**

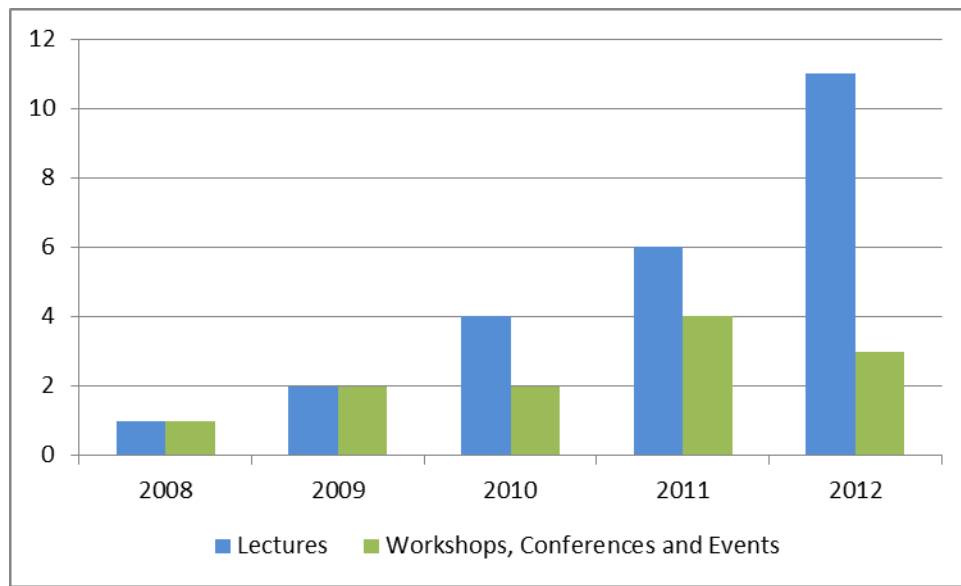
## 3.3 Advancing Policy and Public Dialogue

### 3.3.1 Communication and Outreach

Building on the scientific research accomplishments of our members, the Institute is being increasingly recognized as an authoritative source of insight, analysis and commentary on the public policy dimensions of energy debates. The Institute has been highly effective in promoting a balanced view of future energy options and to help shape the directions of national and global energy discourse.

Over the past five years, this has been achieved through advancing policy goals through active participation on Boards and energy forums, conferences, workshops, public lectures and meetings with legislators and thought leaders in government, business, industry, non-governmental organizations (NGO's) and community groups. Providing timely responses to media requests is an important function that we promote among our members to ensure public dialogue is informed by solid evidence.

Figure 3 below illustrates the continuous growth of the WISE events and public lecture series.



**FIGURE 3. WISE LECTURES AND EVENTS 2008 - 2012**

Noted below are some of the examples.

### ***3.3.1.1 Workshops, Conferences and Public Events***

A few select examples of events where WISE members have played important leadership roles are included below. They illustrate a wide range of activities undertaken to shape and influence future directions. Refer to Appendix F for a detailed listing.

- Inaugural Launch of the Council of the Great Lakes Region (CGLR), Canada-US Law Institute Conference, *'New Realities in Canada-US Relations Cross Border Collaboration' Panel on Shared Energy Resources and Strategies in the Great Lakes-St Lawrence Region,* Cleveland, Ohio, April 10- 12<sup>th</sup>, 2013 (Panelist, Jatin Nathwani)
- Council for Clean and Reliable Electricity (CCRE), *'Annual Energy Leaders Roundtable - Inter-Regional Electricity Trade'* Hockley Valley Resort, Orangeville, ON, April 3-5, 2013 (Panelist, Session Chair, Jatin Nathwani)
- Public Lecture, *'How Your Energy World Has Changed ... and will continue to change ...'* January 30, 2013 (Vancouver) and April 15, 2013, Waterloo. (Maurice Dusseault)
- Equinox Blueprint: Energy 2030, Vancouver, February 2012 and Equinox Summit : Energy 2030, Waterloo, 5-9 June, 2011 (Jatin Nathwani, Linda Nazar, Terri Boake, John Straube)
  - The Energy Summit (2011) was organized under the Waterloo Global Science Initiative (WGSI) by the University of Waterloo and the Perimeter Institute to bring together

leading scientists, policy experts, entrepreneurs, and young leaders from around the world to discuss realistic strategies for reducing the global carbon footprint.

- WISE Executive Director Jatin Nathwani served as a scientific advisor to the Summit. Linda Nazar was a featured speaker and Terri Boake served as a panelist on TVO's "The Agenda with Steve Paikin" taped live at the Summit. Jatin Nathwani was the lead author for the development of the Communiqué and the Equinox Summit Blueprint launched at the American Association for the Advancement of Science (AAAS) Annual Meeting in February, 2012 in Vancouver. The Blueprint has received extensive media coverage nationally and globally.
- "A Networking Approach to the Smart Grid," Invited Lecture, ETH Zurich, Jan. 2012. (S. Keshav)
- Commission for Environmental Cooperation (CEC) North America (NAFTA), Joint Public Advisory Committee (JPAC), North America Wide public forum, '*North America's Energy Future: Powering a Low-carbon Economy for 2030 and Beyond*', April 18, 2012 (Keynote Lecture, Jatin Nathwani)
- Council for Clean & Reliable Electricity, 'Smart Governance for Smart Electricity: Moving Forward from the Auditor General's Report' April 12, 2012, Toronto, (Co-Chair, Panelist, Jatin Nathwani)
  - This event brought together leading experts in the electricity sector from industry, labour, government and academia interested in improving the performance of Canada's agencies and crown corporations in the electricity sector and allowed them to assess and debate policy priorities.
- Smart Grid Development in China, June 2012, Shanghai, Beijing, Nanjing, Guangzhou and Hong Kong, (Ian Rowlands)
  - Rowlands travelled to China at the invitation of the Department of Foreign Affairs and International Trade and Smart Grid Canada as part of a Canadian 'Smart Grid' trade mission to explore key contemporary issues in China's significant advances in the smart grid issue-area and to initiate broader discussion regarding China's contributions to global energy sustainability.
- Smart City Mission to Japan, November 1-9, 2012, Yokohama, Tokyo and Nagoya. (Tracey Forrest)
  - A smart city mission to Japan was funded and organized by Toyota Tsusho Canada. The trip focused on 'smart city' related R&D including Smart Grid, Smart Houses/Buildings, Renewable energy, and Next-generation mobility and involved travel to three cities in Japan.
- NATO Science for Peace & Security Series: 'Environmental Security, Advanced Research Workshop Sustainable Cities and Military Installations: Climate Change Impact on Energy & Security' June 3-6, 2012, Hella, Iceland, (Jatin Nathwani, Co-Chair Energy Track)
  - Book In Publication (Springer Verlag)

- Smart Grids in the North American Context: A Policy Leadership Conference. A US-Canada Clean Energy Dialogue Event, Waterloo, 24-25 January, 2011 (Ian Rowlands and Jatin Nathwani)
  - o The US-Canada Clean Energy Dialogue was initiated in Ottawa in February 2009 by Prime Minister Harper and President Obama to work together on key clean energy science and technology issues. With one of its three working groups investigating the electricity grid, WISE led the development of the workshop with IESO and contributed to the goals of advancing smart grid and clean power technologies and of enhancing bilateral cooperation.
  - o Approximately 80 experts contributed to a discussion of smart grids that would lead to a better understanding of the full potential offered by smart grids to achieve sustainability, community development and consumer acceptance.
- Scientific Integrity: From Theory to Practice, AAAS Meeting, Vancouver BC, February 21, 2012. (Invited, Heather Douglas)
- Canadian Science Policy Conference, CSPC 2012, Building Bridges for the Future of Science Policy, *'Global Energy Transitions: A Canadian View'*, Calgary, Alberta, Nov. 5th, 2012. (Jatin Nathwani)
- WE Innovate, November 2010, 2011, 2012, University of Waterloo. (Giovanni Cascante, Shesha Jayaram)
  - o WE Innovate is the biggest showcase of Waterloo Engineering innovation. WISE was present with a booth and supported WISE researcher booths, poster presentations and demos. Industry representatives, students and the public had a first-hand look at world class emerging research in engineering and cutting edge technology that will shape the world of tomorrow. Over 110 attendees from industry, the public, students and researchers networked at the annual event.
- CIGI Conference, 'Environment and Energy' January 13, 2011, (Jatin Nathwani, Ian Rowlands, Tracey Forrest)
- Ontario Economic Summit (8th Annual), *Ontario's Energy Future: Today's Costs and Tomorrow's Needs*, Toronto, ON, Nov. 21-23, 2011 (Theme Leader, Jatin Nathwani, Invited presentation)
- Moneco-Econtro, CIBE, 'Economic Outlook Policy Forum', Kingston, ON, August 22-23, 2011 *Canada's Clean Energy Opportunity: An Outlook*. (Invited Speaker, Jatin Nathwani)
  - o An annual gathering of senior economists and policy leaders (Bank of Canada, Finance, Industry Canada, DFAIT and provincial counterparts) has been a 62 year tradition.
- Energy Materials & Climate Change, Lawrence Berkeley National Laboratory, August 11, 2011 (Invited Speaker, Linda Nazar)
- Public Lecture and Discussion, 'The Great 2011 Tohoku Earthquake and Tsunami,' Faculties of Art, Environment and Science, University of Waterloo, March 28, 2011. *Post Fukushima - The Nuclear Safety Issue* (Invited Speaker, Jatin Nathwani)



- OCE Discovery 2010, Theatre Session, Toronto, ON, May 18, 2010. *'Is the Ontario Grid Plug-In Ready for Electric Vehicles?'* (Panelist, Jatin Nathwani)
- Smart Grid Roundtable Investment & Trade Advisory Council, Ministry of Economic Development & Trade, 'Linking Energy Sector Innovation to Economic Development,' Toronto, January 20, 2010. (Invited Speaker, Jatin Nathwani)
- 'Lessons from Canada.' Invited Panelist in Roundtable: Economic and political challenges for low energy housing retrofits, Substantial energy savings in existing houses now. Final results from the IEA SHC Task 37 and the IEA ECBCS Annex 50, Lindner Hotel, Antwerp, Belgium, Oct. 14, 2009. (Invited Speaker, Paul Parker)
- Electricity Generation Using Renewable Energy, S&T Collaboration between the governments of India and Canada through ISTP (Canada) and GITA/CII, *Smart Grids and Distributed Renewable Energy Generation: Innovation for sustainability* at IIT Delhi, India October 9-10, 2009. (Invited Speaker, Jatin Nathwani)
- Canada-India Energy Forum, Ontario Government and the Canada India Foundation, *Abundant, Affordable Energy in a Carbon Constrained World: Feasible?* Toronto, ON. April 15-17, 2009. (Invited presentation Jatin Nathwani)
- "Renewables-based Micro Grid Development for Remote Communities", 14th Technology Summit: Clean Technologies, Hotel The Grand, Delhi, India, Dec. 4-6, 2008, Sponsor Cdn. Dept. Foreign Affairs (Invited Speaker, David Johnson)
- Council for Clean and Reliable Electricity (CCRE) *Distributed Generation and the Future of Ontario's Electricity Grid Conference, Waterloo, October 26-27, 2008, Distributed Generation Resources: Promise and Potential* (Invited Speaker, Jatin Nathwani)
- Ontario Public Service (OPS) Expert Policy Forum – Engaging Policy Research, *Partnering with Academic and Other Research Organizations* November 27, 2008, Toronto, ON, Live Broadcast Province Wide (Invited presentation, Jatin Nathwani)

### **3.3.1.2 Public Lectures**

WISE continues to attract numerous distinguished professionals to present on a wide range of sustainable energy related topics. The public lectures are free and open to the public. Many students attend these events and enjoy the collegial atmosphere and networking opportunities.

#### **2013 WISE Lecture Series**

##### *Electric Vehicle Development in China*

Dr. Lifang Wang, Professor, Chinese Academy of Sciences, PR China

##### *How Your Energy World Has Changed ... And Will Continue to Change...*

Dr. Maurice Dusseault, Professor, Earth and Environmental Sciences, University of Waterloo

*Brazil's Energy Plans and Strategies: Challenges Related to Climate Change*

Dr. André Lucena, Professor, Federal University of Rio de Janeiro (UFRJ)

*Alberta's Strategic Research Directions in Energy Development*

Mr. Chris Holly, Branch Head, Research & Technology Resource Development, Policy Division, Alberta Energy

**2012**

*Carbonaceous Adsorbents with Unique Bulk and Nanostructured Properties and Their Applications to Improve Air Quality*

Dr. Mark J. Rood, Racheff Professor of Environmental Engineering, Department of Civil and Environmental Engineering, University of Illinois, Urbana-Champaign

*Climate Geopolitics through 2020: Disruptive Issues on the Horizon*

Dr. Jason Blackstock, Institute for Science, Innovation and Society, University of Oxford, England

*Solving Energy Loss in Supercapacitive Energy Storage*

Dr. Heather Andreas, Department of Chemistry, Dalhousie University, Nova Scotia

*Hybrid Photovoltaic Power Systems and Rural Micro Grids: Lessons Learned and Case Studies in Developing Countries*

Xavier Vallvé, International Consultant and Partner, Trama TecnoAmbiental, Barcelona, Spain

*Do We Pay Too Much for Tap and Bottled Drinking Water?*

Dr. Mark Knight, Executive Director, Centre for Advancement Technology, Waterloo Professor, Department of Civil and Environmental Engineering, University of Waterloo

*Thermochemical and Catalytic Upgrading Biomass into Industrial Bioproducts*

Prof. Charles Xu, Institute for Chemicals and Fuels from Alternative Resources, Faculty of Engineering, Western University

*Computational Chemistry and the Design of Dye Sensitized Solar Cells*

Dr. Carlo Adamo, Chair of Theoretical Chemistry, Senior Member of Institut Universitaire de France (IUF)

*Modeling and Optimization of a Micro-Grid: Huatacondo, Isolated Village in Northern Chile*

Dr. Doris Sáez, Department of Electrical Engineering, University of Chile

*Demand Responsive Buildings: Reducing on-peak electricity use in offices and houses*

Dr. Guy Newsham, Principal Research Officer, National Research Council Canada

*Climate Change: The Corporate and Collective Response*

Michael Gerbis, CEO, The Delphi Group

*Smart Grid Development in China*

Dr. Ian Rowlands, Associate Director, Global Initiatives, Waterloo Institute for Sustainable Energy and  
Professor, Environment and Resource Studies, University of Waterloo

## **2011**

*A Field Experiment to Evaluate the Impact of Information on Electricity Consumption*

Dr. Anant Sudarshan, Kennedy School of Government, Harvard University

*Smarter Energy: The Promise of Cyber-Physical Systems*

Shivkumar Kalyanaraman, IBM

*Energy MOVES me*

Erin Woodrow, Senior Sustainability Advisor, Suncor Energy

*Estimating the Volatility of Wind Energy from High Frequency Data*

John Boland, Environmental Mathematics, Barbara Hardy Institute, University of South Australia

*Low Carbon Green Technologies for Off Grid Power Generation using Renewable Energy for Developing Economies to Energize Dispersed Communities*

Dr. S.S. Murthy, Indian Institute of Technology, Delhi, India

*The Making of Canada's Greenest Office Building*

Stephen Carpenter, President, Enermodal Engineering

## **2010**

*Smart Grid, Renewables, Electric Mobility: Challenges and Potential of an Integrative Approach*

Prof. Dr. Hartmut Schmeck, Karlsruhe Institute of Technology

*Energy Technologies, Energy Security & Climate Change*

Dr. R. Chidambaram, Principal Scientific Adviser to the Government of India, Chairman of the Scientific Advisory Committee to the Cabinet

*Sustainable Electric Power Systems in the 21st Century: Requirements, Challenges and the Role of New Technologies*

Dr. Prabha Kundur, President of Kundur Power Systems, Solutions Inc., Toronto

*Kicking Our CO<sub>2</sub> Addiction: Difficult but doable; dither or deploy*

Dr. Alistair Miller, Researcher Emeritus, AECL

## 2009

### *The Changing Realities in Ontario's Electricity System*

Paul Murphy, President and CEO, Independent Electricity System Operator

### *The Evolution of Electricity*

Jan Carr, former CEO, Ontario Power Authority

## 2008

### *Future Energy Scenarios & R&D: India/Canada Collaboration Potential*

Dr. S.S. Murthy, Professor and CEA Chair, Indian Institute of Technology (IIT), Rajasthan, India

### **3.3.1.3 Community Outreach**

WISE continues to support activities in support of our communities. Select examples are:

*Sustainable Waterloo* - This community based organization guides corporations in Waterloo Region towards a more environmentally sustainable future by facilitating collaboration between industry, local government, academia, and non-governmental organizations. The goal is to ensure that Waterloo Region is more environmentally sustainable as a result of its efforts in environmental leadership. Several WISE members serve in various governance and advisory positions including Steve Young, Ian Rowlands and Jatin Nathwani. Ian Rowlands served as emcee at the most recent SWR Annual Evening of Recognition event which attracted more than four hundred guests.

*Third Age Learning Series (TALS)* is a community based independent organization that arranges lectures by university professors and experts. TALS offers continuing education challenges for active, mature minds. Upon their request, several WISE members developed a lecture series with the theme "Sustainable Energy: What it Means for Planet Earth – and You." (October – December, 2008). This community outreach activity was extremely well received.

- i Sustainable Energy: What It Means for Planet Earth – and You, Carbon Capture and Storage: From the Boiler to the Fleet. How can Ontario reduce carbon dioxide emissions from its electric generating stations over the next 20 years? Peter Douglas.
- ii Biological Solutions to the Energy Problem: How do microbial fuel cells create biogas and biofuels? Raymond Legge.
- iii Getting "Energy Smart" through Solar Electricity: How solar energy is fast becoming a reality to the community and industry. Siva Sivonthaman.
- iv Feel the Breeze: Wind Energy takes Root in Canada. The history of wind energy, current issues and future prospects of this expanding renewable technology. David Johnson.

- v Energy, Environment, Economy: Cross-currents. How do we provide reliable, accessible and affordable energy services that will endure and improve our lives? Jatin Nathwani.
- vi The Hydrogen Economy: Alternative Fuel of the Future. How hydrogen and fuel cell technology will contribute to transportation energy and facilitate the integration of renewable power sources such as wind and solar. Mike Fowler.
- vii Electricity Conservation and Demand Management Strategies in Ontario: Powerful Choices that make Cents: The importance of reducing electricity demand and load, and the prospects of key programs. Ian Rowlands.

#### ***3.3.1.4 Promoting our members' expertise***

To facilitate collaboration and showcase the research capabilities of WISE members, WISE launched a new, transformed WISE website in 2011. The website has enhanced interactivity, audience-specific features, expanded scientific information, and greater use of social media platforms. The website serves as a news source, recruiting tool, learning resource and a gateway to WISE social media.

The highly functional content management platform includes:

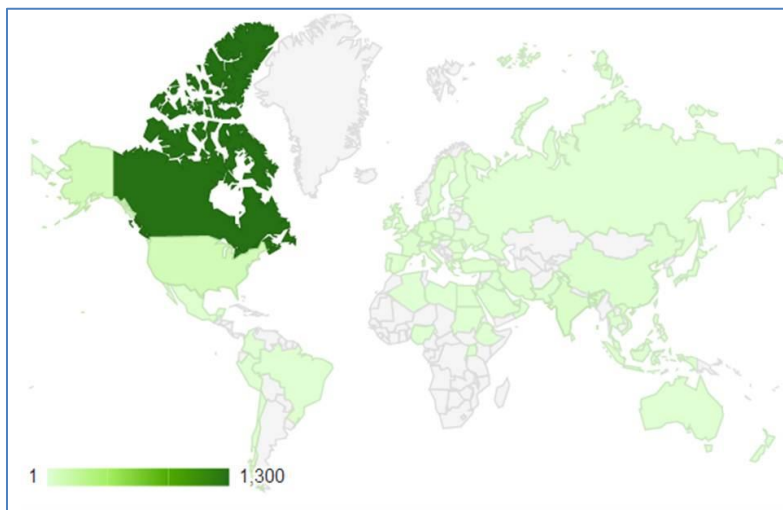
- Dynamic news feeds
- A powerful keyword index for our researchers – unique to the University of Waterloo – that allows outside parties to easily look up specific areas of expertise
- Research spotlights highlighting our members' latest work

The WISE website is in many ways the external face of the Institute on a global scale. It is home to all of the information and resources relevant to all of WISE's target audiences – from WISE members, industry and prospective students to government and the general public.

In the next year and beyond, we will continue to strengthen our web presence. The goal is to convey high quality information on energy research broadly and to attract energy talent and partners to Waterloo. Plans include further enhancement of interactivity features, usability and content. Creating an expanded WISE library of publications, videos, commentary, analysis and more is high on WISE's web priority list. The Institute will also continue to refine the presentation of its website as online styles and conventions evolve. Below is a map from Google Analytics showing where the highest concentrations of visitors to the WISE website are located. Forty-one countries/territories are shown to have at least one visitor coming to the site. Canada, the United States, India, and Germany have the highest number of visitors respectively.

Social media is powerful tool that extends the Institute's reach and interaction in our global world. WISE has adapted its communications strategies in pace with the global shift from traditional news outlets to online and new media. The Institute's social media channels such as Twitter, LinkedIn and YouTube have grown in usage and popularity in the past year. These are vital channels for communicating key messages to its target audiences. The Institute has produced 34 online videos which have been watched by almost 2,000 viewers and has over 190 followers on twitter. WISE uses social media not only to

convey its messages, but to generate interest and spark conversations about energy in society and the role of science and public policy on influencing change on a global scale.



**FIGURE 4. THE WISE WEBSITE ATTRACTS ATTENTION FROM AROUND THE GLOBE**

### ***3.3.1.5 Media Coverage***

Over the past five years WISE has attracted increasing coverage from national and international media outlets — print, online and broadcast. The coverage reflects a growing recognition of the Institute and its members as leaders in sustainable energy development. WISE members comprise an independent but authoritative source of commentary and analysis of energy issues.

Growing national public interest in the pressing issues of sustainable energy is clear from the frequent requests for the expert opinion of WISE members from radio, television and national newspapers. These include Op Ed publications in the Globe and Mail and Toronto Star, the Hill Times and other publications.

Notable coverage in the national and international coverage was around the Equinox Summit: Energy 2030 and subsequent release of the Blueprint. WISE members participating were Jatin Nathwani, Linda Nazar, Terri Boake and John Straube.

The Equinox Summit and the Blueprint generated:

- Over 155 stories via online, radio and television media
- Additional media coverage included:
  - o Scientific American
  - o MSNBC
  - o New York Times – Dot Earth Blog
  - o BBC (Africa)
  - o Nature & Nature Climate Change
  - o Australian Broadcasting Corporation (ABC)
  - o COSMOS Magazine
  - o CBC.ca
  - o CTV (Southwestern Ontario)

- TVO's *The Agenda*
- Number of online articles: 121

Additional examples of WISE researchers in the media are included in Appendix J.

### 3.3.2 Promoting Policy Advancement

Advancing public dialogue on energy issues through analysis and evidence-based assessments is an important function of the Institute. A current example is the leadership WISE has shown in developing the concept of a smart energy network.

#### *Smart Energy Networks (SEN)*

Several WISE researchers including Dr John Wen helped define the concept of a 'Smart Energy Network' through a comprehensive technical report and accompanying policy summary. Smart Energy Networks (SENs) are inherently multi-disciplinary in scope: SENs use advanced information and communication technology to monitor and manage the transport of energy from all fuel sources to meet the varying energy service demands of end users. To advance the Smart Energy Network agenda, Dr. Ian Rowlands, Associate Director, WISE and Tracey Forrest, Director, WISE are co-chairs of a national Advisory Panel on Smart Energy Networks comprised of distinguished energy leaders across Canada. They are also co-leading a major event on September 30, 2013 in Toronto entitled "The Future of Smart Energy Networks: Identifying, shaping and advancing Canadian interests".

The SEN Advisory Panel is engaged to inform associated White Papers that will be written and distributed widely, and to help shape the event agenda. The event brings together about 72 leaders in government, utilities, business, civil society and academia to start the discussion about the potential role of integrated, multiple-fuel, and communicative systems in Canada's energy future. Altogether over six WISE members have been involved this multi-disciplinary initiative.

The research findings have already been shared widely and have positioned WISE favourably for major funding calls by OCE and NSERC. To further advance the research agenda, WISE will convene a follow-up R&D workshop in November 2013 to set the stage for multi-million dollar grant development including, for example, NSERC Strategic Network. These activities foster multi-disciplinary collaboration, advance research by attracting external sources of funding, and help translate our scientific discoveries to a wide audience informing energy policy both here and around the globe.

To assist governments and stakeholders reach consensus on policy choices often characterized by divergent perspectives, active participation on several Boards and energy forums and working closely with thought leaders and legislators is one avenue. WISE Executive Director Jatin Nathwani serves on several Boards at the provincial and national levels. Select activities are highlighted here to illustrate the contributions and impacts.

Recently, Professor Jatin Nathwani was appointed Expert Panel Member by Canadian Council of Academies (CCA) for the study on the 'Potential for New for Innovative Uses of ICTs for Greening Canada'. He also served as the lead Scientific Advisor to the Waterloo Global Science Initiative (WGSi)

established by the Perimeter Institute and the University of Waterloo and was the lead author of the 'Equinox Summit-Energy 2030' Blueprint. Several other roles include:

- i Chairman of the Board, Canadian University Network of Excellence in Nuclear Engineering (UNENE)
- ii Member, Ontario Energy Board's Advisory Roundtable for Industry
- iii Member, Ontario Smart Grid Forum, Board Member, Ontario Centre of Excellence (OCE)
- iv Member, Department of Foreign Affairs and International Trade (DFAIT) Clean Tech Advisory Board, Member
- v Council for Clean and Reliable Electricity (CCRE)
- vi Member, Advisory Panel for the Science Media Centre of Canada (SMCC)

*The Ontario Smart Grid Forum (Forum)* - provides advice to government, regulators, agencies, and industry in to advance the effective implementation of a smart grid in Ontario, to maintain a collective understanding of relevant developments in other jurisdictions and influence global developments in the interests of Ontario. In early 2009, the Forum issued its report 'Enabling Tomorrow's Electricity System.' Within two weeks of the release of the Report, the Ontario government introduced Bill 150 incorporating all the key recommendations of the Forum in the Green Energy and Green Economy Act, 2009 (the GEGEA) to facilitate renewable generation, conservation and the development of Ontario's smart grid.

- The report provides recommendations to advance the development of Ontario's smart grid, including calling on the provincial government to provide a framework to promote the smart grid project.
- The second report of the Ontario Smart Grid Forum, "Modernizing Ontario's Electricity System: Next Steps", issued in May 2011 and ongoing work of the Forum continues to inform the regulatory framework for smart grid investments, emerging standards and industry practice.
- The work of the Forum continues to inform and shape Canada's Clean Tech Trade Strategy developed at the Federal level by the Clean Tech Advisory Board, Department of Foreign Affairs and International Trade (DFAIT).

*Council for Clean and Reliable Electricity (CCRE)* - provides a platform for open public dialogue and a solution-oriented approach to the challenges of the energy sector. It is a forum where representatives from universities, public and private sector business leaders, labour unions and strategic planning professionals collaborate to broaden public debate. WISE has been a partner with CCRE over the last five years and hosted a number of conferences on distributed generation, nuclear, public sector governance and regulation and energy leader's roundtable retreats.

*Canadian Council of Academies (CCA)* - is an independent, not-for-profit organization that supports evidence-based, expert assessments that inform public policy development in Canada. The Panel on innovative uses of ICT's for Greening Canada continues to draw from WISE expertise in the Information Systems and Science for Energy (ISS4E).

*Science Media Centre Canada (SMCC)* - focuses on making the results of evidence-based research available to everyone through the media by providing science journalists timely assistance. WISE continues to be involved with the Research Advisory Panel of SMCC.



Professor Jatin Nathwani has, upon request, provided expert testimony and made several presentations to policy makers and legislators. A few examples include:

#### **House of Commons**

- Expert Testimony at the House of Commons Standing Committee on Natural Resources, 'The need for a reliable supply of isotopes, governance aspects and public acceptance' June 18, 2009, Ottawa.
- Expert Testimony at the House of Commons Standing Committee on Natural Resources on 'The medical isotope crisis arising from a shutdown of the NRU reactor at Chalk River,' February 07, 2008, Ottawa.

#### **Ontario Legislature**

Policy Engagement Series with the Legislators 'Shaping Ontario's Energy Future: Charting a path to sustainable prosperity' Ontario Centre for Engineering and Public Policy (OCEPP), October 29, 2009.

#### **Cabinet Secretariat**

Policy Innovation and Leadership (PIL), Cabinet Office, to Ontario Assistant Deputy Ministers, 'Energy, Environment, Economy: Cross-Currents', January 15, 2008, Toronto.

Policy Innovation and Leadership (PIL), Cabinet Office, Expert Policy Forum, 'Partnering with Academic and Other Research Organizations,' Ontario Public Service (OPS) Expert Policy Forum – Engaging Policy Research, Partnering with Academic and Other Research Organizations, Live province wide webcast, November 27, 2008.

#### **Ministry of Energy**

Ministry of Energy, Expert Advice to the Ministry of Energy on the development of the Long Term Energy Plan for Ontario, "Shaping Ontario's Long Term Energy Future" Ministry of Energy and Infrastructure (MEI), October 07, 2010, Toronto.

Expert Advice, Order in Council, Minister of Energy's Directive to the Ontario Energy Board in relation to the establishment, implementation and promotion of a Smart Grid. Directive Issued, November 23, 2010, Toronto.

An earlier example of timely response to policy developments is the RoadMap for electric vehicles in Ontario.

#### *Sustainable Mobility and Plug-in Electric Vehicles (PEV's)*

The Ontario Government set the policy framework (July 2009) for developing the next steps of a plan to introduce plug-in hybrid and battery electric vehicles (PEVs) in Ontario. There was an urgent need to provide a solid basis for an action plan to implement the vision. At the request of the Ontario Centres of Excellence - Energy (OCE), WISE brought together a research team (Canizares, Nathwani, Rowlands, Fraser, Kazerani, Bhattacharya, and Fowler) to conduct a comprehensive multi-disciplinary study to pave the path for a large-scale implementation of Plug-In Electric Vehicles in Ontario.

The study was prepared on behalf of a large number of key stakeholders with interest in promoting sustainable mobility through electrification. The stakeholders included several not-for profit community

groups and all those who would either be influenced by the plan or drive the action plan for Ontario: utilities, the auto sector, government agencies, manufacturers, industry partners, consumers and financing entities. The report addressed the development needs of the auto sector, the electricity sector the consumers, communities and markets as they relate to infrastructure issues, institutional aspects and consumer issues.

## 4. The Future of WISE: Five-Year Plan

### 4.1 Scientific Direction

Current patterns of energy resource development and energy use are proving detrimental to the long term human welfare and well-being of all citizens worldwide. The integrity of the natural systems is at risk from climate change and yet basic energy services are not available to a third of humanity. Ensuring an adequate supply of affordable energy is an obligation of governments. The challenge is to meet growing needs consistent with the global goals of sustainable development.

In our view, science and engineering provide a solid basis for not only achieving a sustainable energy future, but also the basis for a rational public discourse about trade-offs and risks and for selecting research and development priorities for new opportunities. A policy focus ensures that the rate of advancement can be accelerated by exploring parallel paths and integrating the diverse outputs of research projects towards credible practical solutions.

Achieving a sustainable energy future will require intensive efforts to build the capacity for implementing solutions and to ensure wide-spread dissemination in society. Thus, a strong focus on policies, institutional frameworks and a deeper understanding of the role of individuals and their behaviour is also critical to advancing the agenda. At WISE, through multi-disciplinary research efforts, we draw on the strengths of our members in all the faculties (Arts, Applied Health Sciences, Mathematics, Environment, Science and Engineering).

WISE has identified three major directions for research to address the scientific complexity and the inter-related nature of the challenges as they relate to the transformation of the global energy system:

- i Achieving a Global Low-Carbon Energy System
- ii Smart Urbanization and Growth of Cities
- iii Off-Grid Energy Access

These directions provide a focus for our activities and allow WISE members to play an effective role in developing the necessary solutions for implementation at scale. The research activities include:

- i Achieving a global low-carbon energy system.
  - Solar
  - Wind
  - Bioenergy
  - Geothermal
  - Carbon-capture techniques

- Asset health & optimization
- Power delivery and markets
- Energy storage (batteries, fuel cells, CAES, super capacitors)
- ii Smart Urbanization and Future Cities
  - Building
  - Energy efficiency
  - Smart grids
  - Smart energy networks
  - Sustainable mobility (electric cars, fuel cells, hybrids)
- iii Off-grid Energy Access
  - Micro and mini grids
  - Remote access and solutions for remote communities
  - Low cost local renewables & resources: solar, wind, hydro, bioenergy

The nature of the global energy challenge lends itself to the need for strong collaboration with scientific disciplines that are related to energy research. Figure 5 depicts Waterloo's existing strengths in the area of water, transportation, nanotechnologies, environment and sustainable development. The Venn diagram illustrates several areas of complementarity. In the spirit of enhancing our capacity to respond to issues where energy is not the primary focus but has a complementary role, we would seek to identify opportunities with Institutes, Centres and Departments, as appropriate, to develop solutions through collaboration.

- **Global Low-carbon Energy System**
- **Smart Urbanization and Future Cities**
- **Off-grid Energy Access**



**FIGURE 5. WISE RESEARCH DIRECTIONS**

## 4.2 Strategy and Operations

We face increasing global competition for talent and diminishing national support for university research. To ensure the Institute's research directions are in alignment with university's strategic goals, it is essential that WISE remains focused on innovation where it can make a difference. WISE begins its strategic planning process with member consultations: through annual surveys and continuous engagement (membership meetings, events). Feedback from members helps shape future plans and priorities that underpin the relevance and value of our efforts.

WISE members have expressed strong support for the Institute as a hub for connecting researchers and fostering multi-disciplinary research collaboration including partnership building. WISE members have confirmed unanimous support for the renewal of the Institute. Yet there is much more work to do in order to increase effectiveness of a multi-disciplinary approach and fundraising that will form the basis of activity for the next five years. Survey results for the last two years are presented below.

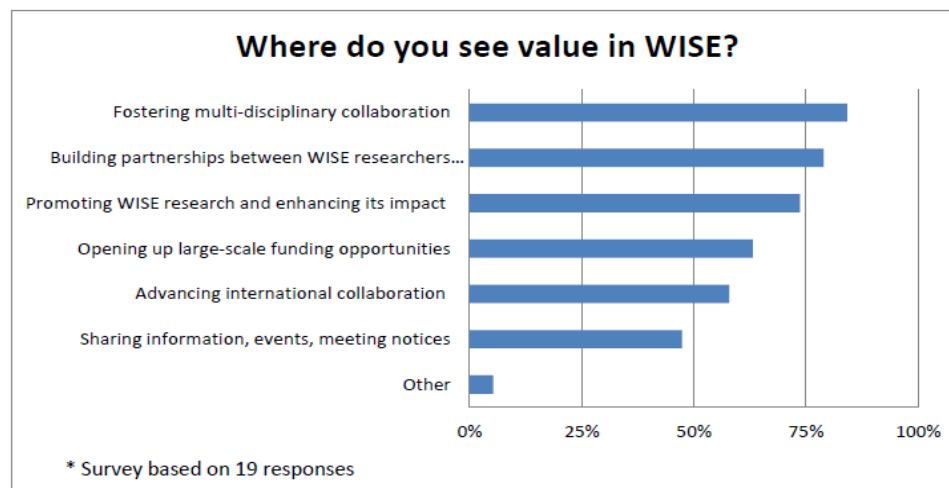


FIGURE 6. WISE SURVEY RESULTS (2013) PART I

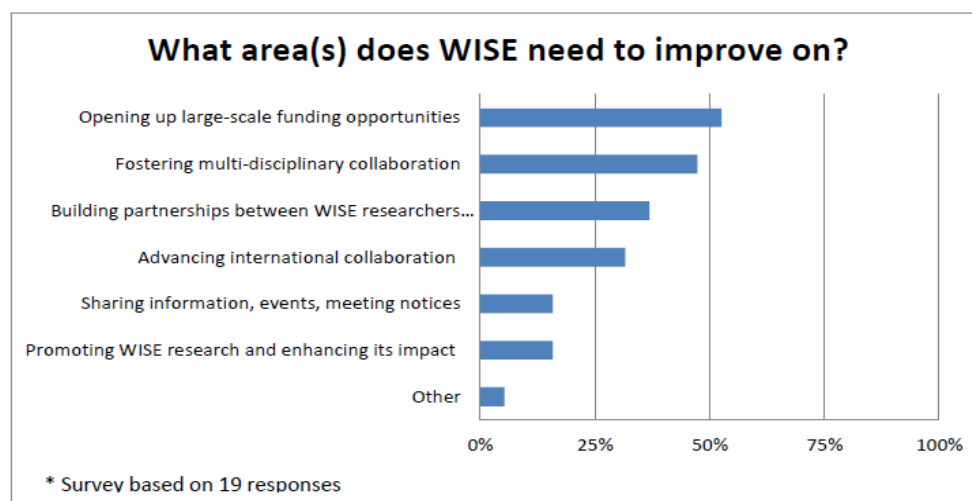
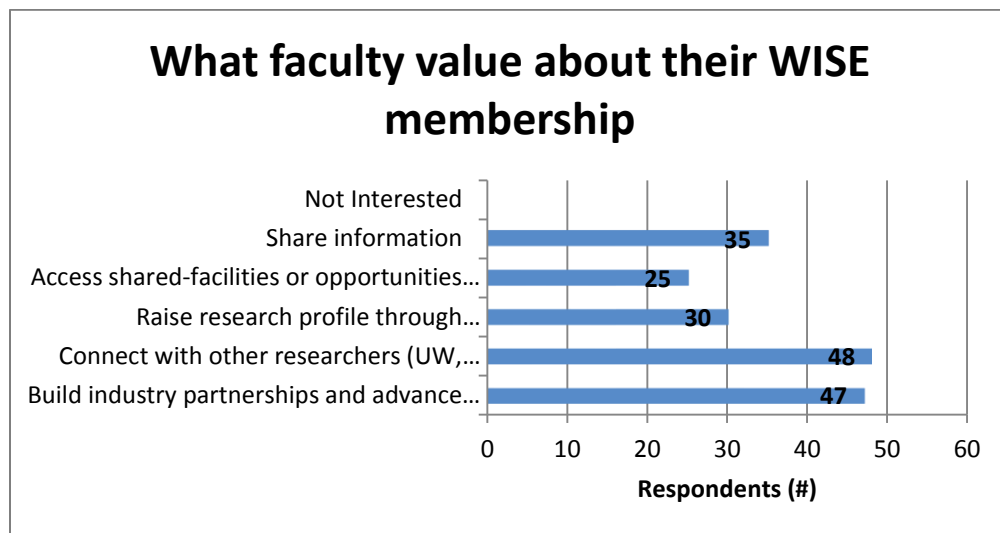
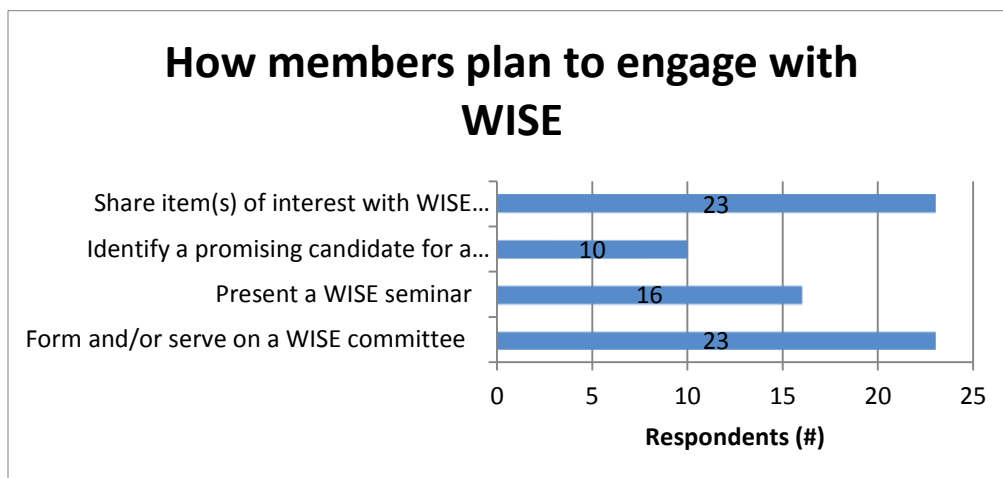


FIGURE 7. WISE SURVEY RESULTS (2013) PART II



**FIGURE 8. WISE SURVEY RESULTS (2012) PART I**



**FIGURES 9. WISE SURVEY RESULTS (2012) PART II**

The Institute's vision, mission and strategic objectives are also guided by consultations with the university's senior leadership and the Advisory Council to WISE. WISE objectives are consistent with the strategic priorities of the University and align well with the needs of the energy sector and our global energy challenges: to foster "inter and trans-disciplinarity"; increase promotion of Waterloo by better "communicating what we do" or "telling our story(ies)"; build partnerships locally and internationally with universities, organizations and business; increase Waterloo's environmentally sustainable practices; decrease "silo-ism" and increase external sources of funding and new sources of funding.

The table on the following page is an elaboration how our strategic objectives relate to the vision and goals of the University. We describe how the Institute will achieve its long-term goals through a series of shorter-term specific actions.

	Collaborate	Reach Out	Influence
	Expand opportunities for multi-disciplinary energy research at Waterloo, improve research productivity, and develop HQP through research and education.	Promote engagement of external partners and advance energy research through partnerships and greater access to research funding.	Establish WISE as the authoritative source of energy insights and analysis, and translate important scientific discoveries for a wide audience, informing energy policy in Canada and around the globe.
Outputs / Short-term Outcomes	<ul style="list-style-type: none"> <li>• New knowledge</li> <li>• Grants, new research opportunities</li> <li>• New significant partnerships with key global energy leaders</li> <li>• Publications, expanded number and size of collaborations and research networks, IP, new projects</li> <li>• Increased level of investment (\$) in multi-disciplinary energy research</li> <li>• Expanded courses and labs, opportunities for practical experience, graduate program</li> <li>• Increasingly skilled HQPs in the energy field (students advancing to graduate/postdoc levels). Increased opportunities for students to learn and apply new multi-disciplinary knowledge</li> </ul>		<ul style="list-style-type: none"> <li>• Increased awareness and knowledge of WISE in the energy community and among Canadians generally</li> <li>• Enhanced national and international opportunities for WISE members</li> <li>• Increasing levels of evidence-based energy research that supports effective public policy decision-making</li> <li>• Increased number of energy researchers attracted to Waterloo</li> </ul>
Ultimate Outcomes	<ul style="list-style-type: none"> <li>• WISE, Waterloo and Canada are a world centre of research in energy technology, policy and applications that advance solutions directed at clean energy accessible and affordable for all (top in Canada, one of the top 10 world-wide)</li> <li>• Energy system transformations for long-term sustainability</li> <li>• Increased research intensity and excellence</li> <li>• Waterloo as a magnet for HQPs in the energy field</li> </ul>		

**TABLE 1. WISE STRATEGIC FRAMEWORK**

#### 4.2.1 Collaborate

*To expand opportunities for multi-disciplinary energy research at Waterloo, improve research productivity, and develop HQP through research and education.*

Over the next five years, WISE will develop the Collaboration program in the following categories:

1. Enhance networking opportunities for faculty, researchers, staff and students engaged in energy research. WISE will facilitate greater interaction between energy researchers across all faculties. We will accomplish this through a variety of networking activities including a monthly brown-bag series for researchers, informal receptions, and R&D workshops. We will also create

opportunities for WISE members to share their views on pressing energy issues through campus energy debates and other forums accessible to the Waterloo research community. Collaboration cannot and will not be forced – however, under the right set of conditions it will flourish. We will provide the ‘glue’ for collaboration.

2. Channel external agency funds to multi-disciplinary research themes. Fundraising activities for energy research will focus on the key themes described in Section 4.1 above. Therefore, WISE will attract partners who are interested in solving complex energy challenges that necessarily require a multi-disciplinary response, and simultaneously WISE will attract researchers from a range of disciplines to contribute towards the solution. This activity is linked with energy research fundraising as described in the Section 4.2.2 below.
3. Catalyze the formation of multi-disciplinary energy training programs. WISE will identify the need for, and support the development of, multi-disciplinary energy training programs. A graduate program with specialization in Sustainable Energy was discussed in Section 3.1.4. WISE will advance this program in the next five years.
4. Augment capacity under key multi-disciplinary themes by developing a WISE Research Network through a research (or visiting) fellow program. WISE will pro-actively engage senior energy leaders (from academia, industry and government) to participate as “WISE Fellows”, thereby augmenting our research capacity. The Fellows may provide senior counsel to our members, offering advice and feedback on their research proposals and application of research outputs. The Fellows would be encouraged to work with our members on specific research initiatives, possibly co-supervise students, and help identify additional partners and funding support. Contributions by WISE Fellows could also include leading international initiatives and assist in identifying ‘Distinguished’ lectures for the WISE public lecture series.
5. ‘Real-world’ energy data portal. Energy research is often limited by access to data. WISE will provide its members with unique access to ‘real-world’ data that supports innovative energy research. This may be accomplished through direct means – i.e. obtaining the data directly as in the case of Drive4Data (electric vehicle data) – or indirectly through partner arrangements. The data sets will be made accessible to WISE members through secured access on the WISE website.

#### **4.2.2 Reach Out**

*To promote engagement of external partners and advance energy research through partnerships and greater access to research funding.*

To achieve this objective, WISE will strengthen and further develop the following:

1. Pro-actively engage with local/global organizations on key multi-disciplinary themes including targeted fundraising activities. WISE will develop a fundraising strategy and framework that will cultivate business and private investment in WISE, deepen ties with our partners and facilitate future investment in WISE. Targeted industrial relations will be undertaken in concert with other

complementary operations at the University (e.g. Office of Research Industry Liaison Officers, Department Industry Liaison Officers and other Institutes).

2. Launch energy leadership forums that attract senior energy leaders to Waterloo for insightful and free-flowing discussion on important energy topics. WISE will secure external sources of funding for these forums and provide opportunities for WISE faculty to discuss their research with a distinguished audience of national and international guests. Feedback received by WISE members will help advance their research program, promote its impact and global recognition, while opening up new opportunities for partner engagement and funding.
3. Increase faculty introductions to relevant energy organizations leading to successful long-term collaborations. WISE aims to make one new introduction a week between a WISE researcher and an external organization. WISE will build on its earlier successes of organizing visits with researchers on campus (through focused meetings and industry-faculty mixer events) by developing new mechanisms for industry-faculty interaction. This may include increased use of new technology platforms and, where appropriate, arranging for WISE member visits to external organizations.
4. Create a unique advantage for WISE members in competing for large-scale funding opportunities. WISE will identify promising funding opportunities, obtain intelligence on success criteria, build multi-disciplinary teams of researchers, attract external partners, assist in the proposal development and support the team members until the project is funded and underway. WISE will add value by cultivating new opportunities (not public), notifying its members well in advance of important funding opportunities and providing strategic counsel to build a competitive advantage. WISE will also facilitate R&D workshops and other collaborative and consultative approaches to promote multi-disciplinary energy research – increasingly valued by philanthropic donors and research funders alike.
5. Attract funding for world-class facilities that serve to enhance Waterloo’s energy R&D capacity. This may include ‘living’ laboratories where research takes place in an actual live (or real-world) environment, demonstrations projects and innovation parks, that spur innovative research and entrepreneurial activity and promote greater interaction with external partners.

#### **4.2.3 Influence**

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

The goal of the Influence program is to enhance the global recognition of energy research at Waterloo while promoting sound public energy policy as follows:

1. Develop major multi-disciplinary research reports that are highly-cited and have global impact. WISE will strengthen and expand its existing energy network of researchers (see WISE Research Network above) and external partners (both national and international) to serve as key advisors and contributors. Research subject matter will align with WISE research expertise, interest and capacity. WISE will endeavour to secure funding for one ground-breaking study per year and



provide professional assistance throughout the research period. Research results will be translated for a wide audience and communicated effectively through multiple channels for maximum impact and recognition. Aside from web and print media, this may include video productions and speaking opportunities for WISE members at highly influential events. This activity is re-enforced by the leadership forms discussed above.

2. Communications and outreach efforts aim to enhance the University and WISE brands through outreach programs such as conferences, workshops, public lecture series and participation on Advisory Boards and Expert Panels. WISE will present at least twelve public lectures a year, and add an annual distinguished lecturer to its roster (high calibre, internationally recognized).
3. Continuous enhancement of the WISE web presence and e-communications to become the authoritative source of energy insights and analysis to a variety of audiences. WISE will expand its research spotlight series to include in-depth features on energy research activity, blogging and commentary opportunities for graduate students and other mechanisms to engage our audience and attract top talent to Waterloo.
4. WISE will organize and host one major annual energy event on Waterloo campus to showcase our energy research, facilities and innovative ecosystem. The event will help drive interest and investment in energy research at Waterloo.
5. WISE will access Waterloo's innovative student talent to incubate energy entrepreneurship initiatives on campus. WISE will support the development of student-led national and international energy competitions by offering connections and counsel. WISE will nurture strong ties with local innovation groups such as the Accelerator Centre and Communitech and forge deeper connections with local technology players such as Google, IBM and Cisco. By making it easier for investors to invest in energy innovation at Waterloo, we aim to increase the global impact and recognition of Waterloo's energy research.

### 4.3 Financial Summary

Currently, WISE is supported by the Provost's Office in the amount of \$200K per year. The Institute is administered through the Faculty of Engineering on behalf of the Provost. This is an operational budget that supports two staff (Director and the Administrative Assistant to the Executive Director), office and communication and outreach expenses.

In addition, WISE administers funding from partner organizations in the amount of approximately \$2M over a 5 to 10 year timeframe (depending on the source of funds). Administration includes calls for applications, selection and approval of research topics and proposals, financial and annual reporting, organizing and hosting visits and chairing conference calls, and relationship management with funding partners. Currently, the active partnerships that exist between Hydro One, The Energy Council of Canada and Cisco require significant administrative effort. WISE and its members have been very successful in leveraging industry funds through granting organizations, namely NSERC, NRCan, OCE, MITACS and others.

As of April 30, 2013, WISE is projected to have \$ 63,905 funds available in its operations budget at the end of the 2012/2013 fiscal year (April 30, 2012 - May 1, 2013). Please refer the current-year financial statement enclosed in Appendix K. WISE has secured funding, in the amount of \$102,916, for specific initiatives that help drive research investment and support communication and outreach objectives. Based on existing commitments and prospective investments we expect this funding level to grow in 2013/2014.

The level of administrative activity at WISE has increased over three-fold since its inception. The operating budget has remained constant at \$200K per year.

The five-year financial plan for WISE is currently under preparation to support a growth strategy consistent with the University's objectives, and is based on the following assumptions:

- Funding support in the amount of \$350K per annum (a level commensurate with similar institutes on campus). This level of financial support is necessary to achieve the goals and objectives set out in this Report.
- WISE will seek to attract additional external funds to enhance the scope and scale of activities to achieve our goals.

Over the next five years, with effective financial and leadership support, WISE will incubate self-sustainable programs and initiatives that will serve to attract external investments and increase Waterloo's energy research capacity leading to high-impact outcomes.

## 5. Letters of Support

Please refer to Appendix A to read the letters of support.

<b>External</b>		
1.	Bonnie Patterson	President and CEO Council of Ontario Universities
2.	Carmine Marcello	President and CEO Hydro One Inc.
3.	Elizabeth Dowdeswell	President and CEO Council of Canadian Academies
4.	Colin Andersen	Chief Executive Officer Ontario Power Authority
5.	Tom Corr	President and CEO Ontario Centres of Excellence
6.	Paul Murphy	President and CEO IESO – Independent Electricity System Operator
7.	Andrew Hrymak	Dean, Faculty of Engineering, Western University
8.	David Collie	President and CEO Electrical Safety Authority
9.	David McFadden	Chair, International Practice, Partner, Gowlings Lafleur Henderson LLP

10.	Dr. John Robinson	Member, WISE Advisory Council University of British Columbia Professor, Department of Geography Associate Provost, Sustainability Professor, Institute of Resources, Environment and Sustainability
11.	Glen Wright	Chair, Council of Clean and Reliable Electricity
12.	Rene W. Gatien	President & CEO, Waterloo North Hydro Inc.
13.	Paul Spekkens	Vice President – Science & Technology Development Nuclear Engineering Ontario Power Generation
14.	Bob Oliver	Chief Executive Officer Pollution Probe
15.	Don MacKinnon	President, Power Workers’ Union
	<b>Internal</b>	
1.	Dr. Adel Sedra	Former Dean, Faculty of Engineering Professor, Department of Electrical & Computer Engineering
2.	Dr. André Roy	Dean, Faculty of Environment Professor, Department of Geography and Environmental Management
3.	Dr. Keith Hipel	University Professor, Systems Design Engineering Department Coordinator, Conflict Analysis Group Senior Fellow, CIGI President Elect, Academy of Science, Royal Society of Canada Chair, Board of Governors, Renison University College
4.	Dr. Ian Goulden	Professor, Combinatorics and Optimization Department Dean, Faculty of Mathematics
5.	Dr. Terry McMahon	Dean, Faculty of Science Professor, Department of Chemistry
6.	Dr. Maurice Dusseault	Professor, Department of Earth and Environmental Sciences Deputy-Director, Porous Media Research Institute
7.	Dr. Claudio Cañizares	Professor, Electrical and Computer Engineering Department Hydro One Endowed Chair Associate Director, External Partnerships, WISE
8.	Dr. Pearl Sullivan	Dean, Faculty of Engineering Professor, Department of Mechanical & Mechatronics Engineering
9.	Dr. Srinivasan Keshav	Professor, Cheriton School of Computer Science Canada Research Chair Cisco Chair in Smart Grid
10.	Dr. Siva Sivoththaman	Professor, Department of Electrical & Computer Engineering Ontario Research Chair in Renewable Energy Technologies and Health Director, Centre for Advanced Photovoltaic Devices and Systems
11.	Dr. Heather Douglas	Associate Professor, Department of Philosophy Waterloo Chair in Science and Society
12.	Dr. Olaf Weber	Professor, School of Environment, Enterprise and Development
13.	Dr. Kankar Bhattacharya	Professor, Electrical and Computer Engineering Department

14.	Dr. Susan Tighe	Associate Director, Advanced Training, WISE Professor, Department of Civil and Environmental Engineering Canada Research Chair in Sustainable Pavement & Infrastructure Management Norma W. McLeod Professor in Sustainable Pavement Engineering' Director, Centre for Pavement and Transportation Technology
15.	Dr. Giovanni Cascante	Professor, Civil and Environmental Engineering Department
16.	Dr. Michael Fowler	Associate Professor, Department of Chemical Engineering Associate Chair Undergraduate Studies
17.	Dr. David Fuller	Professor, Department of Management Sciences Associate Chair Graduate Studies
18.	Dr. Lukasz Golab	Assistant Professor, Department of Management Sciences Cross appointed to Cheriton School of Computer Science
19.	Dr. Mehrdad Kazerani	Professor, Department of Electrical & Computer Engineering
20.	Dr. Fue-Sang Lien	Professor, Department of Mechanical & Mechatronics Engineering
21.	Dr. Stephen Murphy	Professor, Department of Environment and Resource Studies Department Chair Associate Editor, Restoration Ecology & Weed Science Director, Centre for Applied Science in Ontario Protected Areas Director, Centre for Ecosystem Resilience and Adaptation
22.	Dr. Linda Nazar	Professor, Department of Chemistry Cross appointed to Department of Physics and Astronomy Senior Canada Research Chair in Solid State Energy Materials Associate Director, Research, WISE
23.	Dr. Flora Ng	Professor, Department of Chemical Engineering University Professor University Research Chair
24.	Dr. Mahesh Pandey	Professor, Department Civil and Environmental Engineering NSERC/UNENE Industrial Research Chair in Risk and Life Cycle Management
25.	Dr. K. Ponnambalam	Professor, Department of Systems Design Engineering
26.	Dr. Eric Prouzet	Professor, Department of Chemistry CNRS Senior Scientist
27.	Dr. Catherine Rosenberg	Professor, Department of Electrical & Computer Engineering Canada Research Chair
28.	Dr. Ian Rowlands	Professor, Department of Environment and Resource Studies Associate Director, Global Initiatives, WISE
29.	Dr. John Wen	Assistant Professor, Department of Mechanical & Mechatronics Engineering
30.	Dr. Roydon Fraser	Professor and Teaching Chair, Department of Mechanical & Mechatronics Engineering
31.	Dr. Magdy Salama	Professor, Department of Electrical & Computer Engineering University Research Chair

## Appendices

Appendix A Letters of Support

Appendix B Membership List

Appendix C Publications List

Appendix D WISE Member Awards and Achievements

Appendix E Research Spotlights

Appendix F Workshops, Conferences and Public Events

Appendix G Research Labs

Appendix H HQP

Appendix I Visitors

Appendix J Media Coverage

Appendix K Finance