NSERC Energy Storage Technology Network

Year 1

Annual Report 2015-16

Ryerson University

Centre for Urban Energy

NSERC CRSNG

Students visit PowerStream as part of summer school activities. Cover photo: Hon. Kirsty Duncan, Minister of Science, announces the NSERC Energy Storage Technology Network March 1, 2016.

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Section 1: Introduction

Ryerson University is proud to lead a five-year, $5 million pan-Canadian network of 15 universities and 26 industry and government partners focused on the future of energy storage — an essential technology in the Canadian transition to clean energy.

Modern grid-scale energy storage is poised to transform the electricity system, bringing immense benefits to industries, utilities, governments and consumers. A confluence of factors is driving this surge of interest in Canada, including: advances in technology; environmental concerns leading to a renewed focus on renewable energy; aging electricity grid infrastructure that needs replacing; and the immense potential of smart grid systems that enable intelligent energy management.

Energy storage has been identified by the Natural Sciences and Engineering Research Council of Canada (NSERC) as a priority within its strategic target areas because Canada's capacity to store energy is currently seen as an underdeveloped component in its energy-management capabilities. Early stage Canadian companies and products are now entering a market that is on the verge of tremendous predicted growth with an international market opportunity estimated at $600 billion over 10 years according to Piper Jaffray (2009).

However, this global marketplace has multinational competition, and small and medium Canadian companies must be enabled to compete. A significant opportunity lies in positioning Canada to capitalize on the current momentum — similar to Denmark's capture of the first wave of the wind energy market — by developing a suite of technologies and systems to be commercialized by Canadian companies with trained, highly qualified personnel leading to employment and a robust economy.

The NSERC Energy Storage Technology Network (NESTNet) collaboratively explores many different types of energy storage, including flywheels, lithium-ion batteries and compressed air, while determining how best to integrate these technologies into electricity grids. In addition, researchers consider the implications arising from the increasing adoption of energy storage and how consumers will perceive, adopt and interact with these technologies. By partnering with the private sector, NESTNet enables directed progress — without duplication of efforts — towards a strong domestic Canadian energy storage industry that is also competitive in the global marketplace.

Section 2: Mission and vision

The NESTNet's mission is to bring together leading academic, industry, utility and government stakeholders to develop, test, demonstrate and, ultimately, commercialize innovative energy storage technologies, products, processes and services through multidisciplinary and collaborative research and development.

To achieve its long-term *vision* of creating more reliable, environmentally friendly and efficient electric power systems, the network will work to increase the market penetration of Canadian-made energy storage technologies worldwide.

This mission and vision is directed at transformational change, and will be achieved by meeting goals critical to academic, public and private sector stakeholders over five years:

1) Generate fundamental energy storage knowledge.
2) Facilitate energy storage technology commercialization.
3) Train Canadian highly qualified personnel.
4) Strengthen and deepen existing research partnerships between Canadian organizations and academic researchers.

Section 3: Message from the Board Chair

It gives me immense pleasure to introduce to you the first annual report for the NSERC Energy Storage Technology Network (NESTNet).

Our energy world is undergoing a generational transformation, driven by factors such as escalating energy prices, an imminent need for climate change mitigation, and evolving customer needs for reliability, resiliency and sustainability. Leading this disruptive transformation are innovative technology solutions — with energy storage being at the forefront.

While energy storage technologies will power next generation energy systems, NESTNet will empower people with the energy storage related knowledge, skills and abilities required to make the transformation possible! The network brings together 27 Canadian researchers and 41 partner organizations to work on 24 energy storage related projects, which will result in 240 student years of relevant training and research.

On behalf of the board of directors, I would like to thank NSERC for its strong support for the network. I would also like to applaud Network Director, Dr. Bala Venkatesh, for his relentless passion and dedication.

I eagerly look forward to the results and learnings from the NESTNet projects as they unfold themselves over the coming years.

Neetika Sathe

Neetika Sathe
Vice President, Corporate Development and Smart Grid Technologies, PowerStream

Section 4: Message from the Network Director

The NSERC Energy Storage Technology Network (NESTNet) has enjoyed a fruitful first year.

We were pleased to host the Hon. Kirsty Duncan, Minister of Science, and Mario Pinto, President of the Natural Sciences and Engineering Research Council, to officially announce the formation of the network in March 2016.

In the first year, the Board of Directors and the Research Steering Committee were formed. I remain grateful to members for their invaluable time and contribution. Twenty-four research projects are underway on time and the second-year budget has been approved for release by the Board of Directors.

Left to right: Mario Pinto (NSERC president), Hari Subramanian (commercialization outreach committee member), Neetika Sathe (board chair), Hon. Kirsty Duncan (Minister of Science), Imogen Coe (Ryerson University dean of science), Wendy Cukier (board member), Mohamed Lachemi (Ryerson University president), Bala Venkatesh (network director).

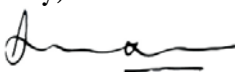
We welcomed close to 200 researchers, academics, professionals and students to Ryerson University in June 2016 for a week of events including the NESTNet annual technical conference and summer school. The program culminated with *Leading the Charge*, an industry

conference that provided a unique stage for manufacturers, utilities and customers to share their experiences.

Looking forward, in addition to working on the 24 projects, we will focus on efforts to patent and commercialize. One example is our pole-top energy storage system. It was developed by eCAMION and researchers at Ryerson with support from the Ministry of Energy's Smart Grid Fund and is already connected to the Toronto Hydro network. Stories like this — a collaboration between the business, academic and government sectors already making a tangible difference in the real world — will be key to NESTNet's overall success. Year two promises more progress in energy storage products, processes and policy.

A network of this scope and size is no easy undertaking. I would like to thank everyone who has played their part, especially the theme leaders Handan Tezel, Liuchen Chang, Claudio Cañizares and Miguel Anjos; the 24 research teams from universities across the country; our 26 industry and government partners; NSERC without whose funding this network would not have been possible; and my colleagues at Ryerson — especially the network administrator Karen Ho-Cespedes.

If we are all to make Canada a world-leader in energy storage and impact society in a positive way, much work is still to be done. I'm excited for the years ahead.



Bala Venkatesh

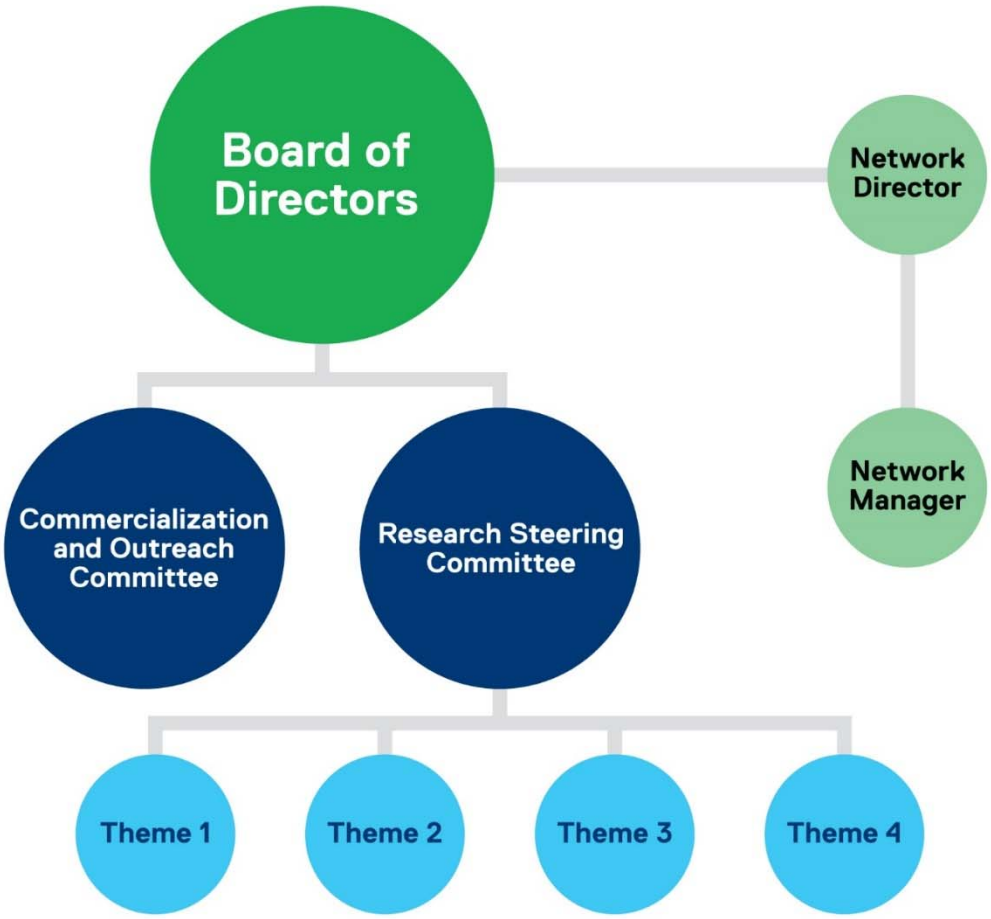
Section 5: Governance

As the Network Director, Dr. Bala Venkatesh coordinates Network affairs and leads the overall implementation of project activities through his participation in research, dissemination and training of HQP.

As the Network Manager, Karen Ho-Cespedes ensures the day-to- day operations of the Network and supports the Network Director and the RSC in all responsibilities related to the Network, including strategic planning and managing relationships.

The research activities of the Network are organized into four Themes and led by Handan Tezel, Liuchen Chang, Claudio Cañizares and Miguel Anjos. The Theme Leaders are responsible for overseeing each Theme's research projects and evaluating HQPs' research activities.

Figure 1: Governance structure



The Board of Directors (BoD) has overall responsibility for the governance of the Network. It is comprised of the Network Director, representatives of Network partners and independent representatives from academia, industry and government. Chaired by Neetika Sathe, the BoD provides strategic guidance, counsel and foresight, and administrative and financial guidance. The BoD oversees the NESTNet activities and approves the annual budget.

The Research Steering Committee (RSC) is comprised of the Network Director, Theme Leaders, partner representatives, and external academic experts to provide leadership and vision on the review and assessment of ongoing NESTNet research projects.

The purpose of the Commercialization and Outreach Committee (COC) is to identify potential technologies and intellectual property (IP) developed by Network researchers for commercialization opportunities. The COC will be managing the technologies, focusing on technology transfer and commercialization, enabling and expediting demonstration opportunities, and promoting ES to the public.

Section 6: Board of Directors

Neetika Sathe
Vice President, Corporate Development and Smart Grid Technologies, PowerStream *(Chair)*

Bala Venkatesh
Academic Director, Centre for Urban Energy; Professor, Electrical and Computer Engineering, Ryerson University
(Network Director)

Jessica Bian
Technical Staff, Federal Energy Regulatory Commission

Liuchen Chang
Professor, Department of Electrical and Computer Engineering, University of New Brunswick *(Theme 2 Leader)*

Wendy Cukier
Vice-President Research and Innovation, Ryerson University

Eric Deschenes
Vice President, Energy Division, Schneider Electric Canada

Brian Hewson
Senior Manager, Strategic Policy, Ontario Energy Board

Julia McNally
Director, Strategic Engagement and Innovation, Independent Electricity System Operator

Ken Nakahara
Director, Energy Networks and Partnerships, Ontario Ministry of Energy

Sundar Venkataraman
Director, GE Energy Consulting

Claire McAneney
Manager, NSERC *(Non-Voting)*

Karen Ho-Cespedes
Network Manager *(Non-Voting)*

Section 7: Research Steering Committee

Bala Venkatesh
Academic Director, Centre for Urban Energy; Professor, Electrical and Computer Engineering, Ryerson University *(Network Director)*

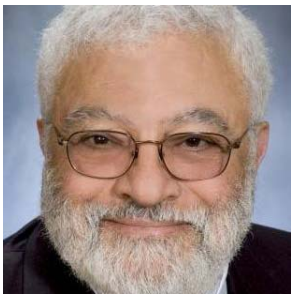
Handan Tezel
Professor, Department of Chemical and Biological Engineering, University of Ottawa *(Theme 1 Leader)*

Liuchen Chang
Professor, Department of Electrical and Computer Engineering, University of New Brunswick *(Theme 2 Leader)*

Claudio Cañizares
Associate Director of Waterloo Institute for Sustainable Energy *(Theme 3 Leader)*

Miguel Anjos
Professor and Canada Research Chair, École Polytechnique de Montreal; INRIA International Chair *(Theme 4 Leader)*

Tom Chapman
Market Design and Development, Independent Electricity System Operator



Mohamed El-Hawary
Professor, Dalhousie University

Peter Hall
Professor of Energy Storage Engineering, University of Sheffield

Nelson Martins
Assistant to Director General and Research Consultant on Power System Analysis, Electrical Energy Research Center

Pratap Revuru
Smart Grid Solution Architect, Schneider Electric Canada

Usman Syed
Director, Conservation and Energy Efficiency, Ontario Ministry of Energy

Adam Tuck
Program Leader, Energy Storage for Grid Security and Modernization, National Research Council Canada

Section 8: Commercialization Outreach Committee

Bala Venkatesh
Academic Director, Centre for Urban Energy; Professor, Department of Electrical and Computer Engineering, Ryerson University
(Network Director)

Geoff Osborne
Associate, NRStor

Hari Subramaniam
Chief Executive Officer, eCAMION

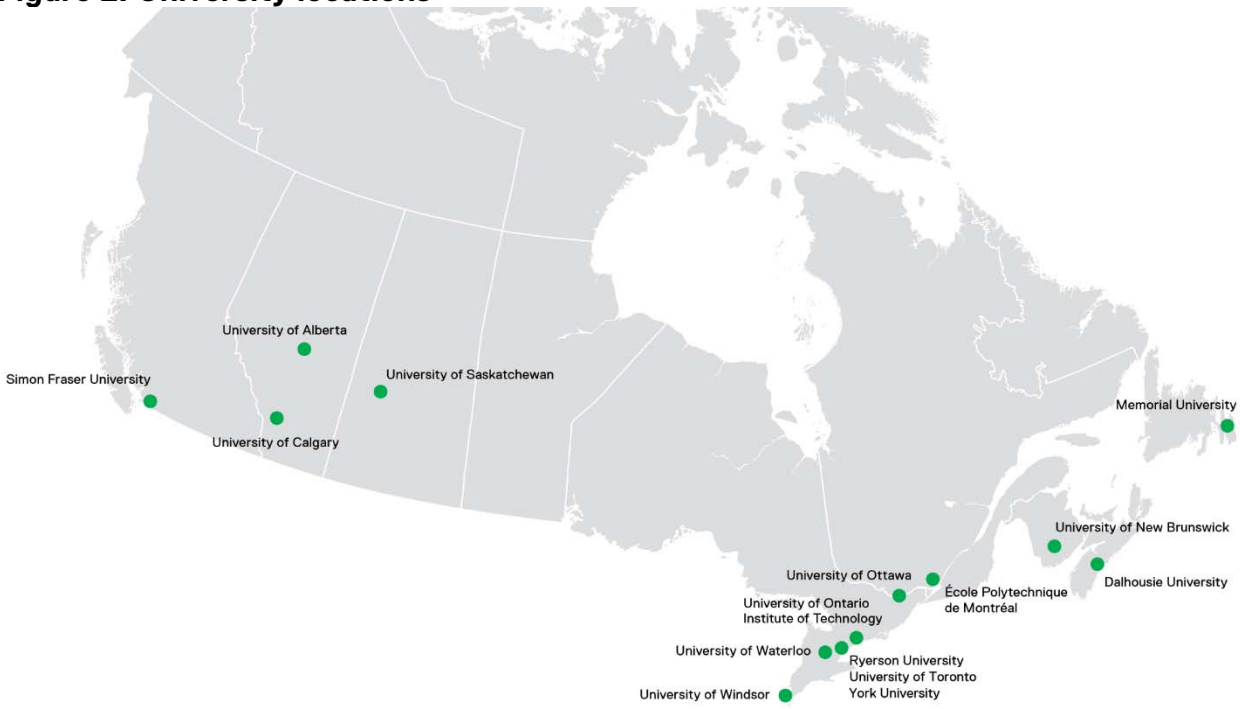
Jennifer MacInnis
Senior Legal Counsel and Senior Director, Applied Research and Commercialization, Ryerson University

Pratap Revuru
Smart Grid Solution Architect, Schneider Electric Canada

Section 9: Academic partners

There are a total of 27 researchers from 15 universities across Canada participating in the NESTNet.

Figure 2: University locations



Section 10: Industry and government partners

There are a total of 26 industrial, utility and government partners participating in the NESTNet.

Not listed above: Cowessess First Nation.

Section 11: By the numbers

The NSERC Energy Storage Technology Network (NESTNet) is committed to training the next generation to power the future of Canadian energy storage. Through the first year of research, 72 highly qualified personnel (HQP) worked with NESTNet project leaders.

Table 1: Total HQP

9	22	24	17
Postdoctoral fellows	PhD students	MSc students	Undergraduate students

Table 2: HQP by theme

19	16	22	15
Theme 1	Theme 2	Theme 3	Theme 4

In addition, NESTNet produced 14 journal articles, six conference papers and one patent in year one.

Table 3: Year one outputs	Theme 1	Theme 2	Theme 3	Theme 4	**Total**
Journal articles	3	4	5	2	14
Conference papers	1	5	0	0	6
Patents	0	1	0	0	1

Section 12: Finances

For year one, NSERC provided a cash contribution of $999,200 to the NESTNet. Partners (university and industry/government) provided a cash contribution of $852,409 over a nine-month period. These funds covered expenses related to network research projects across themes 1-4 as well costs associated with management of the network, hosting of NESTNet events, and internal and external communication and dissemination (central activities).

Table 4: Year one NSERC funding	Budget	Expenses
Theme 1	$265,500	$110,261
Theme 2	$181,500	$118,700
Theme 3	$192,500	$93,126
Theme 4	$273,500	$123,780
Total: four research themes	**$913,000**	**$445,867**
Central activities	**$86,200**	**$62,295**
Total	**$999,200**	**$508,162**

Table 5: Year one university and partner contributions	Prorated budget (9 mo.)	Expenses (9 mo.)
Theme 1	$351,094	$252,438
Theme 2	$42,000	$39,050
Theme 3	$278,250	$240,936
Theme 4	$81,315	$11,112
Total: four research themes	**$752,659**	**$543,536**
Central activities	**$99,750**	**$98,629**
Total	**$852,409**	**$642,165**

Section 13: Project themes and highlights

The 24 projects comprising NESTNet are detailed in this section, along with a description of each and list of team members. In the following years, this section will also report on their progress.

Theme 1: Energy storage technologies

Theme Leader: Handan Tezel, University of Ottawa

In this theme, research is focused on batteries (thermal management systems and innovative housing designs), flywheels (designs and modeling), compressed air energy storage (CAES; enhanced underwater designs and operation), thermal storage (materials and system designs), and hybrid energy storage models.

Project 1.1: Hybrid multi-level grid-scale battery thermal management system

The project will aim to develop a novel and custom-designed BTMS solution for thermal management of large-scale battery systems for grid applications that can maintain the temperature of the batteries within the recommended range under various loads and climate conditions. The BTMS should be compact, cost-effective, and reliable with minimal maintenance and packaging requirements. It must also promise low parasitic power requirements and be able to operate under variable climatic conditions.

Project Leader:
Majid Bahrami, Simon Fraser University

Project Collaborators:
Handan Tezel, University of Ottawa
Liuchen Chang, University of New Brunswick

HQP:
Martin Cermak (PhD student)
Maryam Yazdanpour (PhD student)
Adrian Wikarna (undergraduate)
Jason Wallace (undergraduate)

Project 1.2: Fabrication, mathematical modelling, design and testing of flywheels for grid-scale energy storage

Develop mathematical models of flywheel systems considering energy losses, discrete design variables, rotor dynamic effects and novel material systems. A flywheel system with an energy capacity of 0.25 kWh will be fabricated, characterized, and tested to validate and optimize the model.

Project Leader:
Marc Secanell Gallart, University of Alberta

Project Collaborators:
Pierre Mertiny, University of Alberta
Liuchen Chang, University of New Brunswick
Magdy Salama, University of Waterloo

HQP:
Miles Skinner (MASc)
Vaishnavi Kale (MASc)

Project 1.3: Design and testing of an innovative energy accumulator for underwater CAES

Research will focus on the development and testing of an innovatively simple and robust energy accumulator architecture based ultimately on pre-fabricated pipe elements. The experimental program will explore the fabrication, installation, operation, and recovery of this accumulator design.

Project Leader:
Rupp Carriveau, University of Windsor

Project Collaborators:
David Ting, University of Windsor
Handan Tezel, University of Ottawa
Mark Winfield, York University
Ian Rowlands, University of Waterloo

HQP:
Zhiwen Wang (PhD exchange student with Dalian Maritime University)
Haoyang Cen (PhD)
Sara Alhasan (MASc)
Curtis Simpson (Undergraduate)

Project 1.4: Thermal energy storage in adsorbent beds for space heating and cooling applications

In the project, promising new adsorbent materials will be examined, modelled and optimized to increase energy density (by 4 to 5 times over current materials) in order to improve the economic viability of adsorption based systems for space heating and cooling applications.

Project Leader:
Handan Tezel, University of Ottawa

Project Collaborators:
Tariq Iqbal, Memorial University
Miguel Anjos, École Polytechnique de Montreal
Majid Bahrami, Simon Fraser University

HQP:
Patrice Amyot (Undergraduate; MASc candidate)
Amanda Godin (Undergraduate)
Mohamed Khanafer (Undergraduate)

Project 1.5: Hybrid energy storage system designs

This research aims to develop hybrid ES systems, where several types and sizes of ES systems are combined to provide a composite storage solution. The first objective is to develop an optimization solution that provides the optimal hybrid design of an ES system that combines two or more storage elements to provide certain performance metrics and features at the lowest cost, and with the longest life and highest reliability. The second objective of this research is to develop scheduling methods for the developed hybrid systems to deliver the required services, while maximizing asset life.

Project Leader:
Bala Venkatesh, Ryerson University

Project Collaborators:
Bin Wu, Ryerson University
Reza Iravani, University of Toronto

HQP:
Kamran Masteri Farahani (PhD)
Ayman Elkasrawy (PhD)
Amr Adel (MASc)
Gouri Barai (MASc)

Project 1.6: Design of pole-top energy storage

Development and testing (both in the laboratory and in the partnering utility) of an ES solution that can be mounted on the utility pole, adjacent to pole-top transformers. The pole-top ES solution will be housed in two containers, one with power converter and the other with lithium-ion batteries.

Project Leader:
Bala Venkatesh, Ryerson University

Project Collaborators:
Bin Wu, Ryerson University
David Xu, Ryerson University
Majid Bahrami, Simon Fraser University

HQP:
Mohamed Awadallah (Postdoctoral fellow)
Manuel Baun (Undergraduate exchange student from Germany)

Researchers gather for technical conference.

Theme 2: Power electronics converters

Theme Leader: Liuchen Chang, University of New Brunswick

Research in this theme focuses on power electronic converters, including modular converters, digital controllers, supervisory controllers, supervisory control and data acquisition (SCADA) systems, and power electronics for repurposed electric vehicle batteries.

Project 2.1: Modular architecture and functionality of energy storage power converters

The objectives of this project are to develop advanced power converter architectures for battery and flywheel systems with modular design, bi-directional power flow and embedded fault diagnosis algorithms, and to develop enhanced grid support functions (anti-islanding and black start).

Project Leader:
Liuchen Chang, University of New Brunswick

Project Collaborators:
David Xu, Ryerson University
Vijay Sood, UOIT
Saleh Saleh, University of New Brunswick
Bala Venkatesh, Ryerson University

HQP:
Bo Cao (Postdoctoral fellow)
Shuang Xu (PhD)
Guanghong Song (PhD)
Majed Shakir (Undergraduate)

Project 2.2: Digital control systems of power converters for energy storage

The objectives of this project are to develop advanced digital control systems for power converters in ES applications, including fully digital control hardware and software; an upper level energy management controller; and a communication system.

Project Leader:
Vijay Sood, UOIT

Project Collaborators:
David Xu, Ryerson University
Tariq Iqbal, Memorial University
Liuchen Chang, University of New Brunswick

HQP:
Jignesh Patel (PhD)
Negar Honormand (MASc)
Mohammed Yasin Ali (Undergraduate)

Project 2.3: Coordinated operation of multiple storage units and technologies

This project develops supervisory-control and protection strategies and algorithms for (1) homogeneous storage systems (i.e., multiple nominally identical sub-units, e.g., multiple flywheel units that need to operate in unison) and (2) heterogeneous storage systems (composed of different technologies, e.g., battery and flywheel sub-units). The envisioned development serves as the interface between the up-stream utility command signals (objectives of Theme 3) and the required sub-units' controls/operation (objectives of Projects 2.1 and 2.2), and is designed considering requirements of end users (objective of Project 1.5) to ensure optimal utilization and operation of the storage system in response to the utility requirements and the storage unit (and its interface converter) constraints.

Project Leader:
Reza Iravani, University of Toronto

Project Collaborators:
Liuchen Chang, University of New Brunswick
Vijay Sood, UOIT
Amir Yazdani, Ryerson University

HQP:
Mojtaba Ashourloo (MASc)
Arman Ghasaei (PhD candidate)
Hoda Yussef (MASc candidate)
Sitan Wang (Undergraduate)

Project 2.4: SCADA interface for energy storage systems

Research aims to develop an innovative SCADA interface for smart grids that enables remote control of grid-tied converters for ES, and facilitates control and communication methods.

Project Leader:
Tariq Iqbal, Memorial University

Project Collaborators:
Liuchen Chang, University of New Brunswick
Vijay Sood, UOIT
Reza Iravani, University of Toronto

HQP:
Sarinda Jayasinghe (MASc)
Terashimla Kubalathara (MASc)

Project 2.5: Control systems for second-life batteries for grid-scale energy storage

A new concept is to repurpose various EV batteries by separately connecting them to a multi-channel power converter, which is able to handle various used batteries of differing capabilities. Therefore, the principal research objective of this project is to develop a new control strategy to utilize the best EV battery packs depending upon the specific electricity grid service requirements.

Project Leader:
Lukas Swan, Dalhousie University

Project Collaborators:
Vijay Sood, UOIT
Tariq Iqbal, Memorial University
Saleh Saleh, University of New Brunswick

HQP:
Ben Thompson (MASc)
Bryan Ellis (Undergraduate)
Grant Poulain (Undergraduate)

Theme 3: Power systems integration

Theme Leader: Claudio Cañizares, University of Waterloo

Research in this theme will enable the seamless integration of energy storage into power systems by developing planning tools, operational tools, protection systems, power quality mitigation solutions, and reliability benchmarks.

Project 3.1: Optimal planning for energy storage facilities in transmission systems

Deterministic co-optimization models will be built for sizing and siting of ES facilities, considering many services and technologies. The models will be built for both utility-owned ES facilities as well as investor-owned merchant facilities. The deterministic models will then be extended to include sources of uncertainty in power systems operation and planning. Stochastic versions of the deterministic models will be developed using techniques such as robust optimization or approximate chance-constrained optimization that make use of convexity and hence can be solved efficiently.

Project Leader:
Hamid Zareipour, University of Calgary

Project Collaborators:
Miguel Anjos, École Polytechnique de Montreal
Amit Kumar, University of Alberta

HQP:
Ehsan Nassrolahpour (PhD)
Juan A. Gomez Herrera (PhD)
Mostafa Kezemi (PhD; visiting student)
David Adair (MASc)
Benjamin Thomas (Undergraduate)

Project 3.2: Optimal planning of energy storage in distribution systems considering feeder investment model

Research will focus on the development of a new algorithm for the Feeder Investment Model for distribution systems considering ES, such that ES units and feeders are simultaneously optimally located and sized. The algorithm will ensure that all customer loads and renewables are fully connected and reliably serviced over the plan period. The algorithm will minimize the annual amortized cost of investment for the utility, considering both purchases of feeders and ES units.

Project Leader:
Bala Venkatesh, Ryerson University

Project Collaborators:
Claudio Cañizares, University of Waterloo
Amit Kumar, University of Alberta

HQP:
Peng Yu (Postdoctoral fellow)
Bhanu Opathella (Postdoctoral fellow)
Santhi Karthikeyan (Postdoctoral fellow)

Project 3.3: Energy storage device protection

This research will develop and test new protection architectures for ES systems, digitally implemented to be embedded within the main ES system controller. This architecture is required for developing fault detection and classification methods that will be based on signature extraction, rather than magnitudes of voltages or currents. The fault detection and classification methods will be based on processing current signals from the main ES system controller to facilitate full embedding.

Project Leader:
Saleh Saleh, University of New Brunswick

Project Collaborators:
Eduardo Castillo Guerra, University of New Brunswick
Liuchen Chang, University of New Brunswick
Reza Iravani, University of Toronto

HQP:
Ryan McSheffery (MASc candidate)
Ryan Meng (MASc candidate)
Sarah Buck (Undergraduate)
Mathieu Malone (Undergraduate)

Project 3.4: Integration of energy storage for improving power quality of smart distribution systems

Research will develop novel solutions using ES systems to overcome PQ issues due to switching, load cycling, or intermittency of renewables. Further, the negative impact of integrating different ES technologies on grid-related PQ under low or high loading conditions will be investigated.

Project Leader:
Magdy Salama, University of Waterloo

Project Collaborators:
Tarek El-Fouly, CanmetENERGY and University of Waterloo
Saleh Saleh, University of New Brunswick
Liuchen Chang, University of New Brunswick

HQP:
Haytham Rafaat Ibrahim (MASc)

Project 3.5: Operation and control of power systems with energy storage systems

In this research, mathematical models of ES systems will be developed that account for operational features, operating constraints, and other details for use with power systems optimization algorithms meant for daily operations. Such ES system models will be integrated into existing optimization models and simulation tools for power systems operation and control. These models will be used to evaluate the contribution and impact of ES systems on the overall power system operation. At the distribution system level, optimal operation will examine and derive benefits from ES systems to manage increased renewable integration, feeder loading management, arbitrage, etc. At the transmission level, optimal operation will examine the use of ES for frequency regulation, energy arbitrage, etc.

Project Leader:
Claudio Cañizares, University of Waterloo

Project Collaborators:
Kankar Bhattacharya, University of Waterloo
Bala Venkatesh, Ryerson University
Miguel Anjos, École Polytechnique de Montreal

HQP:
Ivan Calero (PhD)
Fabian Calero (PhD)
Dario Peralta (MASc)

Project 3.6: Reliability modeling and assessment of power systems with energy storage systems

New reliability models will be developed for battery, CAES, flywheel, and thermal ES systems. Probabilistic techniques will be developed to incorporate market scenarios and operating strategies in quantifying adequacy benefits of ES systems with large-scale renewables penetration. Value-based reliability of different ES technologies and capacity credit increments of renewables due to ES systems will be analyzed, providing invaluable investment decision information. New methodologies will be proposed to incorporate the aforementioned factors, assess the implications of operating reserve requirements and response capabilities, and quantify the impact and worth of ES systems.

Project Leader:
Rajesh Karki, University of Saskatchewan

Project Collaborators:
Bala Venkatesh, Ryerson University
Handan Tezel, University of Ottawa
Rupp Carriveau, University of Windsor

HQP:
Junpeng Zhan (Postdoctoral fellow)
Saket Adhikari (MASc)

Project 3.7: Capacity markets for energy storage – design and implementation

Research will examine the potential of ES to provide services such as demand response, ramping, frequency regulation, etc., considering that ES holds the potential for being an element in power systems that can act as both load and generator, and thus can provide these services in new ways that benefit power systems. With knowledge of potential of ES solutions, this research will examine and develop capacity markets for ES considering various services.

Project Leader:
Bala Venkatesh, Ryerson University

Project Collaborators:
Kankar Bhattacharya, University of Waterloo
Handan Tezel, University of Ottawa
Rupp Carriveau, University of Windsor
Amit Kumar, University of Alberta

HQP:
Reza Ghaffari (Postdoctoral fellow)
Mohamed Sadek (Postdoctoral fellow)
Amr Adel (PhD)
Ayman Elkasrawy (PhD)

Theme 4: Economics and policy

Theme Leader: Miguel Anjos, École Polytechnique de Montréal

This theme investigates and provides solutions for techno-economic challenges in the successful integration of energy storage into power systems. In addition, it examines policy, regulatory and social challenges faced by storage solutions to enable successful uptake by utilities and societies.

Project 4.1: Development of life cycle net energy ratio of energy storage technologies

This project aims to assess ES pathways in terms of the ratio of energy input to output to calculate much energy is required over a life cycle to store a unit of energy from a particular energy source. The ratio of energy input to energy output through a particular pathway is referred to as Net Energy Ratio (NER). First, a LCA framework of ES technologies specific to Canada will be developed and used to create LCA models for the various storage solutions. Then a comparative assessment of NER and greenhouse gas (GHG) emissions for ES technologies will be undertaken.

Project Leader:
Amit Kumar, University of Alberta

Project Collaborators:
Bala Venkatesh, Ryerson University
Rajesh Karki, University of Saskatchewan

HQP:
Sahil Kapila (MASc
Spandan Thaker (MASc)

Project 4.2: Modelling electricity market prices considering large-scale energy storage penetration

To build techno-economic models for estimating the price impacts of the large-scale integration of ES in competitive electricity markets.

Project Leader:
Miguel Anjos, École Polytechnique de Montréal

Project Collaborators:
Hamid Zareipour, University of Calgary
Kankar Bhattacharya, University of Waterloo

HQP:
Juan Artega (PhD)
Adrien Barbry (MASc)
Payam Zamani (PhD candidate)
Soroush Shafiee (PhD candidate)

Project 4.3: Provision of ancillary services by energy storage systems

This project will examine the role of ES solutions as ancillary service providers and their integration with the grid system. Research will be undertaken to determine cost structures and appropriate pricing mechanisms for these services.

Project Leader:
Kankar Bhattacharya, University of Waterloo

Project Collaborators:
Steven Wong, CanmetENERGY
Miguel Anjos, École Polytechnique
Hamid Zareipour, University of Calgary
Mark Winfield, York University

HQP:
Nitin Padmanabhan (PhD)
Hisham Alharbi (PhD)

Project 4.4: Optimal brokerage models for the grid integration of energy storage

To investigate different brokerage models for integrating ES into power systems, and to test the applicability and potential impact of such models using real-world data from Canadian settings.

Project Leader:
Miguel Anjos, École Polytechnique de Montréal

Project Collaborators:
Michel Gendreau, École Polytechnique de Montréal
Gilles Savard, École Polytechnique de Montréal
Bala Venkatesh, Ryerson University

HQP:
Franklin Djeumou-Fomeni (Postdoctoral fellow)
Adham Ismail (PhD)
Mathieu Tanneau (MASc)

Project 4.5: Towards federal and provincial energy storage policy frameworks for Canada

1) Assess existing legislative and policy frameworks at the federal and provincial levels as they relate to the development and use of ES technologies, particularly in support of the large-scale integration of low impact but intermittent renewables, such as wind and solar energy; and
2) Make policy framework recommendations at the federal and provincial levels to advance the further development and deployment of ES technologies in an environmentally and economically sustainable manner for the purpose of facilitating the large-scale integration of intermittent renewable energy technologies. The project will include engagement with non-academic partners with experience and expertise in ES technologies, and their regulation, to address the need.

Project Leader:
Mark Winfield, York University

Project Collaborators:
Ian Rowlands, University of Waterloo
Amit Kumar, University of Alberta
Rajesh Karki, University of Saskatchewan

HQP:
Shahab Shokrzadeh (Postdoctoral fellow, University of Manitoba)
Adam Jones (MASc)
Amanda Gelfant (MASc)
Stephan Sanguiliano (MASc)

Project 4.6: Social acceptance of energy storage systems

The main objective of this project is to explain why some ES technologies have been, and will continue to be, in turn, 'supported', 'accepted' or 'rejected' by communities.

Project Leader:
Ian Rowlands, University of Waterloo

Project Collaborators:
Mark Winfield, York University
Amit Kumar, University of Alberta
Rajesh Karki, University of Saskatchewan

HQP:
James Gaede (Postdoctoral fellow)

Section 14: Summer School and Technical Conference

Summary by Jonathan Nikodem, fourth-year Environment and Urban Sustainability student at Ryerson University.

From June 20–24, 2016, the NSERC Energy Storage Technology Network (NESTNet) came together for its first annual gathering. The five days provided a wealth of information and thoughtful discussion regarding the progress made so far and what's next for the network.

The week was broken up into three main events. It began with a two-day summer school for students of the network, followed by a two-day technical conference which provided project leaders the stage to talk about their projects in more depth with other members of the network.

Students visit PowerStream as part of summer school activities. Karen Ho-Cespedes (network manager) pictured far-right.

The week culminated with the *Leading the Charge* conference which brought together over 100 guests from academia, utilities, industry and government to discuss the future of energy storage by way of four expert panel discussions and a keynote address from Bruce Campbell, President and CEO of the Independent Electricity System Operator.

Twenty-six students from across Canada joined us for our two-day summer school which was kicked-off on Monday, June 20 with a welcome message from Bala Venkatesh. Our first presenter Gary Thompson of Toronto Hydro began a discussion on how storage can be practically integrated into our energy system. In the challenge of engaging with customers, Thompson believes that if customers cannot interact with the technology, then it will be of no use to them. Shuvo Chowdhury of PowerStream then stressed the importance of engaging with customers as electricity is one of the most important commodities and not one people are willing to go without.

Students visit eCAMION as part of summer school activities.

This was a recurring theme during a tour of the PowerStream control room which allowed students a behind-the-scenes view of the challenges related to delivering sustainable uninterrupted power to customers.

Day two followed a similar format, beginning with Bob Singh, IESO distinguished research fellow at the Centre for Urban Energy (CUE), who presented Hydro One's major energy storage projects. Their flywheel design seeks to increase reliability of service by supporting the grid during wind farm outages.

Lack of space is often a critical factor to consider with energy storage. In order to solve this, Mohamed Awadallah, a research fellow at CUE, and eCAMION developed a pole-mounted energy storage system which solves the issue of space and keeps the technology safely out of people's reach. A tour of eCAMION allowed the students to see the project first hand. The intimate setting allowed the students to have engaging and thoughtful conversations with some of the leading figures in Canadian energy storage.

Day three marked the first day of our technical conference at which the researchers involved with NESTNet were able to update everyone on the progress made in their first year of research. The NESTNet is made up of four research themes: energy storage technologies; power electronic converters; power systems integration; and economics and policy. Each is led by a theme leader, and Handan Tezel of the University of Ottawa kicked off the conference as the leader of theme one. The first three themes were presented on the first day of the technical conference. The second day of the technical conference saw the last theme take to the stage. This was followed by the Research Steering Committee meeting and the Board of Directors meeting.

Members of our Board of Directors and Research Steering Committee. Top from left to right: Bala Venkatesh, Pratap Revuru, Eric Deschenes, Neetika Sathe, Brian Hewson, Hamid Zareipour (standing in for Miguel Anjos), Adam Tuck. Bottom from left to right: Karen Ho-Cespedes, Sundar Venkataraman, Handan Tezel, Ken Nakahara, Jessica Bian, Claire McAneney.

Following the end of the summer school and technical conference, I was able to talk to a couple of the visiting students. Patrice Amyot and Amanda Godin of the University of Ottawa were impressed by the broad range of research topics and the different fields represented. Godin was pleased that she, "got to see a lot of people in different fields, and it's good to see they are involved because we do need their help." Similarly, Amyot noted that it "opened my eyes to the interdisciplinary possibilities." Their comments reinforce the fact that the future of energy storage will require cooperation from a broad range of fields and expertise – a founding principle of NESTNet.

Section 15: *Leading the Charge* Conference

The inaugural *Leading the Charge* Conference took place on Friday, June 24, 2016 at Mattamy Athletic Centre in Toronto. The intention of the conference was to provide a unique stage for manufacturers, utilities and customers to share their perspectives on the challenges and opportunities of energy storage. Welcoming remarks were provided by Chris Evans, Interim Provost and Vice President Academic at Ryerson University, and Bala Venkatesh, Academic Director of Ryerson's Centre for Urban Energy.

Leading the Charge conference kicks off at the Mattamy Athletic Centre.

Bruce Campbell, President and Chief Executive Officer of the IESO, provided the keynote address in which he found three main roles for energy storage: Congestion relief, voltage control and emergency preparedness. Campbell is "confident that all the continued changes that lie ahead, from the expansion of renewable resources such as wind and solar, to the growing customer engagement in managing their electricity consumption and the realization of smart grid, will expand the opportunities for energy storage."

The NESTNet would like to thank all of our speakers who graciously donated their time, experience and insights. We would also like to gratefully acknowledge the support from our partners, NSERC and the CSA Group, without whom the event would not have been possible.

Last but not least, we extend our thanks to the over 100 conference attendees who enlivened the day with thought-provoking questions and discussion.

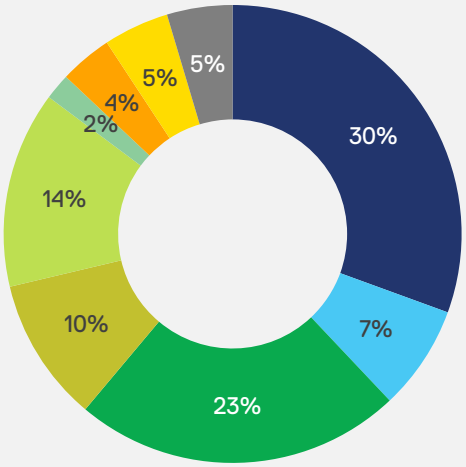


Figure 3: Conference attendees by professional association

- Academia and research
- Non-governmental organization or association
- Technology and manufacturing
- Local distribution companies
- Services and consulting
- Healthcare
- Government
- Law
- Regulatory and market operations

The manufacturers' perspective (panel 1)

Geoff Osborne
Associate, NRStor

Carmine Pizzurro
President, eCAMION

Pratap Revuru
Smart Grid Solutions Architect, Schneider Electric

Curtis VanWalleghem
Chief Executive Officer, Hydrostor

Moderator:

Jessie Ma
IESO Distinguished Research Fellow, Centre for Urban Energy at Ryerson University

Left to right: Curtis VanWalleghem, Geoff Osborne, Pratap Revuru, Carmine Pizzurro, Jessie Ma

The utilities' perspective (panel 2)

Gary Thompson
Lead, Generation Planning and System Studies, Toronto Hydro

Neetika Sathe
Vice President, Corporate Development, PowerStream

Samantha Evelyn
Project Manager, Capital Projects, Hydro Ottawa

Moderator:

Bob Singh
IESO Distinguished Research Fellow, Centre for Urban Energy at Ryerson University

Left to right: Neetika Sathe, Samantha Evelyn, Gary Thompson, Bob Singh

Energy storage in Ontario – experiences to date and opportunities for expansion (keynote address)

Bruce Campbell
President and Chief Executive Officer,
IESO

Bruce Campbell delivers the keynote address

The customers' perspective (panel 3)

Brad Cochrane
Director, Energy Management, York University

Brian Hewson
Senior Manager, Strategic Policy, Ontario Energy Board

Michael Lithgow
Manager of Energy and Sustainability, Sunnybrook Hospital

Brett Smith
Manager, Distribution and Grid Modernization, Ontario Ministry of Energy

Moderator:

Sean Conway
Public Policy Adviser, Gowling WLG

Safety and implementation (panel 4)

Paul Marot
President, Virelec

Mohammad Sedighy
Principal Consultant and Associate, Technologies Business Practice, Hatch

Erik Spek
Chief Engineer, TUV SUD Canada

Moderator:

Bhanu Opathella
IESO Distinguished Research Fellow, Centre for Urban Energy at Ryerson University

To download a full report on this conference, written by postdoctoral research fellow Omid Alizadeh, please visit ***ryerson.ca/nestnet****.*

Section 16: Future outlook

A note from the Network Manager

First, I'd like to express my gratitude to the many people involved with the highly successful first NESTNet Week.

To our speakers and site visit hosts of the two-day Summer School; presenters at the annual Technical Conference; and panel moderators and speakers at our Leading the Charge conference; thank you for contributing your time and sharing the much needed wealth of knowledge and experience for the advancement of the network.

To my colleagues, especially the NESTNet team (Matthew Kerry, Charlotte Mihailov, Carolinne Magalhaes, Hugo Almeida, Jonathan Nikodem, Sara Azimi, Eric Cho, and Lorena Arenas Garcia), I am greatly appreciative of your help in planning and executing the events.

Finally to members of NESTNet, I thank you for taking the time out of your busy schedules to attend these events and participate in fruitful discussions.
We have much to look forward to in the coming years. Building on the first year's momentum, below are the upcoming events for year two.

Karen Ho-Cespedes

Winter Schools

Theme-specific winter schools will be held in January-March of every year, rotating through locations of their project leaders each year. In these one-day events, students will gather to discuss a topic of interest to the theme and participate in a workshop, which may be led by an industry or government partner. The purpose of these winter schools is to drill deep into research conducted in a particular theme.

With year two well underway, the one-day winter schools are planned for the following dates and locations:

Theme 1 - February 24, 2017
University of Ottawa

Theme 2 - January 20, 2017
University of Toronto

Theme 3 - February 14, 2017
University of Waterloo

Theme 4 – February 27, 2017
University of Waterloo

First meeting for the Commercialization and Outreach Committee

The first meeting for the COC will be conducted in spring 2017 to review research outcomes from the projects and identify opportunities and targets. Project leaders interested in pursuing commercialization should raise this to the Theme Leaders and Network Manager prior to this meeting.

NESTNet Week

Each summer in June, a week of events are held at Ryerson University in Toronto for members of the Network. The second annual NESTNet Week will be held from June 19– 23, 2017 at Ryerson University. Please block these dates and stay tuned for travel details on the NESTNet website.

Monday, June 19–Tuesday, June 20, 2017
Summer School for students of the network (with one student from each project attending, rotating annually).

Wednesday, June 21–Thursday, June 22, 2017
Annual technical conference for all researchers (project leaders, collaborators and students), committee members and partners (industry/government).

Thursday, June 22, 2017
Annual General Meeting for the Board of Directors and Research Steering Committee members.

Friday, June 23, 2017
Industry conference for all project leaders and committee members of the network. Please note that this is a paid event with discounted rate for members.

Location

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