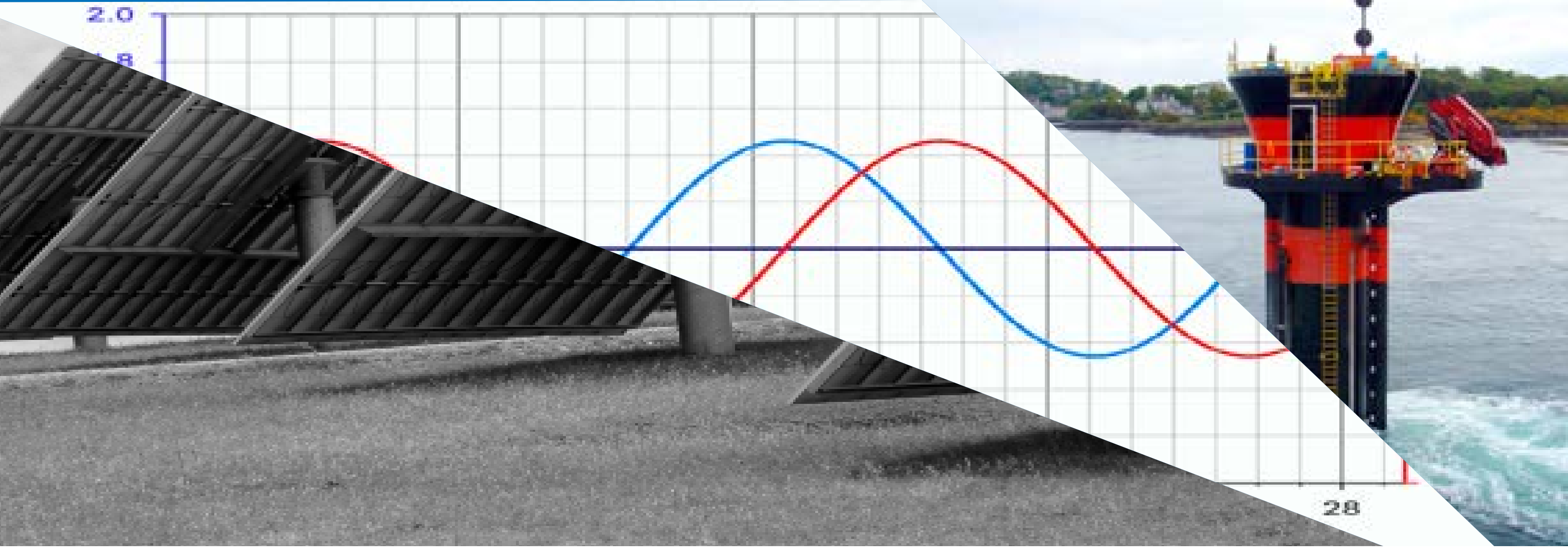

PIMS Workshop on Mathematical Sciences and Clean Energy Applications

University of British Columbia

21 -24 May, 2019

Program

Image credit: General Electric

Getting Started

Get connected: Select the "ubcvisitor" wireless network on your wireless device. Open up a web browser, and you will be directed to the login page.

Locations

- **UBC Forest Sciences Building: Room 1005**
- **Earth Sciences Building: Room 1012**
- **Chemistry Physics Building Block A: Room 112 (Thursday 5:45pm Lab Automation for Solar Cells. RSVP required)**

Full UBC Maps are available online [here]

Schedule at a Glance

	Tuesday, May 21	Wednesday, May 22	Thursday, May 23	Friday, May 24
All Morning Sessions in Forest Sciences Centre, Room 1005				
8:15am	Registration and refreshments			
8:40am	Welcome : Santa Ono- UBC President			
9:00am	Biomass	Water (I)	Electrochemical (I)	Wind (I)
9:45am	PIMS Welcome, Program Overview, Group Discussion of Workshop Goals			
10:30am	Coffee Break (Forestry Atrium)			
11:00am	Energy Policy	Water (II)	Electrochemical (II)	Wind (II)
All Afternoon sessions in the Earth Sciences Building, Room 1012 and ESB Atrium				
12:30pm ESB Atrium	Lunch (Hosted)- ESB Atrium & Pacific Institute for Climate Solutions, Info Session ESB 1012	Lunch (hosted) - ESB Atrium & Narratives in Math & Clean Energy ESB 1012	Lunch (hosted) - ESB Atrium & Video: Lab Automation for Solar Cells ESB 1012	Lunch (Hosted) ESB Atrium
2:00pm	Energy Market Modeling (I)	Optimization of energy supply and demand (I)	Solar, Storage, Distribution, and Microgrid (I)	Funding Opportunities
3:30pm	Coffee break	Poster Session & Coffee break	Poster Session & Coffee break	**3:00pm:** Coffee break
4:00pm	Energy Market Modeling (II)	Optimization of energy supply and demand (II)	Solar, Storage, Distribution, and Microgrid (II)	**3:30pm:** Closing Session: Andrew Weaver, Leader- BC Green Party & Panel on Clean Energy Policy
5:30pm Evening Events	Networking Reception		**Demo:** Chemistry Block A Lab Automation for Solar Cells (sign-up Required)	Closing Reception

Subject to changes and edits

Tuesday May 21, 2019

Forest Sciences Centre: Room 1005

8:30am Registration & Check-in, FSC Atrium

8:50am **UBC Welcome**:

- Santa Ono, President , University of British Columbia

Biomass:

9:00am Taraneh Sowlati Forestry, UBC

Use of forest-based biomass in clean energy applications: complexities and supply chain modeling approaches

9:45am **PIMS Welcome:**

- Jim Colliander, Director, Pacific Institute for the Mathematical Sciences

Program Overview and Discussion:

- Bill Aiello, Richard Karsten, Brian Marcus, Vakhtang Putkaradze: Workshop Organizers

10:30am **Coffee break**

Energy policy:

11:00am Rose Murphy, Energy and Materials Research, SFU

The math of energy-economy models CIMS and CIMS-Urban

11:45am Blake Shaffer, Spogli Institute for International Studies, Stanford

The effect of climate change on the level and timing of future electricity demand

Earth Sciences Building: Atrium and Room 1012:

12:30-2:00pm **Lunch: ESB Atrium**

1:00 -1:15pm **ESB 1012**: Info Session: Sara Muir-Owen, Pacific Instittute for Climate Solutons

Energy Market Modelling:

2:05pm Mike Thiessen, Genus Capital Management

Opportunities and Challenges within Clean Energy Investing

2:50pm Matt Davison, Statistics and Actuarial Sciences, University of Western Ontario

Thinking about Year 21: the Economics of Ontario Wind Power after PPA expiry

3:30pm **Coffee Break**

4:00pm Tony Ware, Mathematics and Statistics, University of Calgary

Reliability-constrained hydropower optimization

4:30pm Anatoliy Swishchuk , Mathematics and Statistics, University of Calgary

Overview of Some Results in Energy Market Modelling and a Vision on Clean Renewable Energy

5:00pm Panel Discussion

5:30pm Networking Reception: ESB Atrium

Wednesday May 22, 2019

Forest Sciences Centre: Room 1005

8:30am Check-in & Coffee

Water:

9:00am Richard Karsten, Mathematics and Statistics, Acadia University

An introduction to the challenges of Marine Renewable Energy

9:25am Justine McMillan, Rockland Scientific International

Turbulence Measurements at Proposed Tidal Energy Sites

9:50am Guy Dumas, Laboratoire de Mécanique des Fluides Numérique, Universite Laval

Hydrokinetic Energy Conversion --- Some CFD Contributions to the Development of Turbine Technologies and their Deployment in Arrays

10:15am Discussion

10:30am **Coffee break**

11:00am Anthony Truelove, Clayton Hiles, Pacific Regional Institute for Marine Energy (PRIMED), University of Victoria

Modelling Wave Energy Success

11:25am Rajeev Jaiman, Mechanical Engineering, UBC

Harvesting of Ocean Current Energy via Self-Induced Flapping Dynamics

11:50am Joel Culina, Fundy Ocean Research Center for Energy (FORCE)

Wake characterization with X-band radar at the FORCE tidal energy site

12:15pm Summary/Discussion

Earth Sciences Building: Atrium and Room 1012

12:30-2:00pm **Lunch: ESB Atrium**

1:15- 1:40pm **ESB 1012:** Narrative in Mathematics and Clean Enerrgy

- **Richard Karsten,** Professor, Department of Mathematics and Statistics, Acadia University, NL, Canada
- **Vakhtang Putkaradze,** Professor, Department of Mathematics/Chemical Engineering, University of Alberta, AB, Canada
- **Deniz Sezer,** Associate Professor, Department of Mathematics and Statistics, University of Calgary, AB, Canada
- **Brian Wetton,** Professor, Department of Mathematics, University of British Columbia, BC, Canada

Optimization of Energy Supply/Demand

2:00pm Alexsander Aravkin, University of Washington

Introduction + Robust Time Series Forecasting Using Exponential Smoothing Cells

2:30pm Eric Anderson, Anderson Optimization

Line Failure Risk from Transmission Congestion : Incorporating Uncertainty from Renewable Generation

3:00pm	Cameron Wade, IESVic, University of Victoria
	Power system planning models in the age of variable renewables: overcoming challenges to the temporal dimension
3:30pm	**Poster Session & Coffee Break: ESB Atrium**
4:00pm	Younghun Kim, Utopus Insights
	Hot topics in the renewable industry
4:30pm	Summary/Discussion

Thursday May 23, 2019

Forest Sciences Centre: Room 1005

8:30am	Check-in & Coffee

Electrochemical:

9:00am	Brian Wetton, Mathematics, UBC
	Mathematical Modelling of Electrochemical Systems
9:30am	Lorne Gettel , Electra Motor Co
	Overview of Mathematical Modeling Techniques to Improve the Performance and Lifetime of Lithium Ion Batteries
10:00am	Iain Moyles, Mathematics and Statistics, York University
	Asymptotic Model Reduction: Why Mathematicians Have An Important Role in Electrochemistry
10:30am	**Coffee Break**
11:00am	Bhushan Gopaluni, Chemical and Biological Engineering, UBC
	State-of-charge estimation in lithium-ion batteries: A particle filter approach
11:25am	Pang-Chieh Sui, Automotive Engineering, Wuhan University of Technology
	Mesoscopic Modeling of PEMFC Catalyst Layers: Review & Outlook
11:50am	Tony Bi, Chemical and Biological Engineering, UBC
	Flow distribution and flow hysteresis in two-phase flow parallel channels
12:15am	Summary/Discussion

Earth Sciences Building: Atrium and Room 1012

12:30-2:00pm	**Lunch: ESB Atrium**
1:15-1:40pm	Amanda Brown, Curtis Belinguette Research Group, Chemistry Department, UBC
	Lab automation device for producing solar cells: **ESB 1012**

Solar, Storage, Disribution and Micro-grid

2:00pm	Vakhtang Putkaradze, Mathematics, Statistics and Chemical Engineering, U of Alberta
	Dynamics and control of flexible solar towers
2:30pm	Nima Fathi , Mechanical Engineering, University of New Mexico

	Applied Mathematical Evaluation of Solar Tower System: Hybrid Renewable Energy Development
3:00pm	Amir Badkoubeh, Engineer, Cognitive Systems
	Challenges and Opportunities in Clean Energy Applications
3:30pm	**Poster Session & Coffee Break: ESB Atrium**
4:00pm	Takashi Hikihara, Advanced Electrical Syhstems, Kyoto University
	Power packetization and its distribution in network: concept and applications
4:30pm	Elena Popovici, Senior Computer Scientist, Neurio Technologies
	Home-energy forecasting for storage optimization
5:00pm	Discussion/Summary

Friday May 24, 2019

Forest Sciences Centre: Room 1005

8:30am Check-in & Coffee

Wind:

9:00am	David Wood, Mechanical and Manufacturing Engineering, Universiy of Calgary
	Introduction to wind energy
9:30am	Mathew Breaky, WSP Wind Energy
	Past, Present and Future of Wind Resource Engineering
10:00am	Artem Korobenko, Mechanical and Manufacturing Engineering, Universiy of Calgary
	High-fidelity computational fluid-structure interaction framework for design and analysis of wind turbines
10:30am	**Coffee break**
11:00am	Deniz Sezer, Mathematics and Statistics, Universiy of Calgary
	Spatio-temporal modeling of wind power generation of Alberta
11:30	David Wood, Mechanical and Manufacturing Engineering, Universiy of Calgary
	Vorticity, Impulse, and Wind Turbine Aerodynamics
12:00	Summary/Discussion

Earth Sciences Building: Atrium and Room 1012

12:30-2:00pm **Lunch: ESB Atrium**

2:00-3:00 Funding Opportunities in Clean Energy

- NRCAN (Richard Karsten)
- NSERC (Rick Warner),
- MITACS (Sherry Zhao)

3:00-3:30 **Coffee break**

3:30-4:00 Andrew Weaver, BC Green Party and MLA for Oak Bay-Gordon Head, BC, Canada

TBA

4:00-5:00 Panel on clean energy policy:

- **Martin Mullany, Acting Executive Director, Clean Energy BC, Canada**

  Martin is the founding director of Brooks Macdonald, a London Stock Exchange listed fund management company with a market cap of $500 million. He was the director of a multi-family office company and many private holding companies. Martin came to Canada in 2006 and became involved in renewable energy in 2008 as an investor and strategic adviser to a private renewable energy company. Martin is also the Director and CEO of Bridge Power. Bridge Power was formed in 2013 as a development company focused on bringing sustainable renewable energy projects to market. They have multiple sites around the province of BC for wind power and run of river power development.

- **Rose Murphy, Energy and Materials Research Group, SFU, BC, Canada**

  Rose Murphy received her master's and doctoral degrees from the School of Resource and Environmental Management at Simon Fraser University. After completing her master's degree, she worked for several years as a consultant and university researcher on a variety of projects, many of which used the CIMS energy-economy model to analyze policies for reducing greenhouse gas emissions. Her doctoral research involved a number of projects on themes such as the risks associated with geological carbon storage, energy efficiency opportunities in the US economy, and the cost of forest carbon sequestration. Her current work as a post-doc with the PICS Built Environment project aims to combine advancements in energy-economy modeling at the national/regional scale with the spatial elements necessary to understand energy use within the built environment of cities

- **M. V. Ramana, Director, Liu Institute for Global Issues, University of British Columbia, BC, Canada**

  M. V. Ramana is the Simons Chair in Disarmament, Global and Human Security and Director of the Liu Institute for Global Issues at the School of Public Policy and Global Affairs. His research interests are in the broad areas of international security and energy supply, with a particular focus on topics related to nuclear energy and fissile materials that can be used to make nuclear weapons. He combines technical skills and interdisciplinary methods to address policy relevant questions related to security and energy issues.

- **Andrew Weaver, BC Green Party and MLA for Oak Bay-Gordon Head, BC, Canada**

  Dr. Andrew Weaver was elected as the first MLA for BC Green Party, for the riding of Oak Bay-Gordon Head, in May 2013. Since November 2015, he has served as the Leader of the BC Green Party. Born and raised in Victoria, Andrew has received a BSc in Mathematics & Physics from the University of Victoria, a Certificate of Advanced Studies in Mathematics from Cambridge University, and a PhD in Applied Mathematics from the University of British Columbia. Prior to his election, Dr. Weaver served as Canada Research Chair in climate modelling and analysis in the School of Earth and Ocean Sciences at the University of Victoria. He was a Lead Author in the United Nations Intergovernmental Panel on Climate Change 2nd, 3rd, 4th and 5th scientific assessments. Dr. Weaver is a Fellow of the Royal Society of Canada, Canadian Meteorological and Oceanographic Society, American Association for the Advancement of Science and the American Meteorological Society. He has received a number of awards, including the Killam Research Fellowship, a Guggenheim fellowship, the Royal Society of

Canada Miroslaw Romanowski Medal, and the A.G. Huntsman Award for Excellence in Marine Science. Dr. Weaver was appointed to the Order of British Columbia in 2008 and awarded the Queen's Diamond Jubilee Medal in 2013. His book "Keeping our Cool": Canada in a Warming World was published by Viking Canada in September 2008. His second book Generation Us: The Challenge of Global Warming was published by Raven books in 2011.

- **Session Chair: James Colliander, Director, Pacific Institute for the Mathematical Sciences**

  Dr. Colliander is a Professor of Mathematics at UBC and serves as Director of the Pacific Institute for the Mathematical Sciences. He is also the Founder/CEO of Crowdmark, an education technology company based in Toronto. He received his PhD in 1997 from the University of Illinois. After an NSF Postdoc at the University of California Berkeley, Colliander joined the University of Toronto and became Professor in 2007. He moved to UBC in 2015. Colliander was Professeur Invité at the Université de Paris-Nord, Université de Paris-Sud, and at the Institut Henri Poincaré. He has been a member of the Institute for Advanced Study. Colliander received a Sloan Fellowship, the McLean Award, and is an award winning teacher.

5:00-6:30 Closing Reception

Demo: Lab Automation for Solar Cells

Project Ada is an initiative led by Prof. Curtis Berlinguette (UBC), Prof. Jason Hein (UBC), and Prof. Alán Aspuru-Guzik (University of Toronto) that aims to accelerate the pace of materials R&D for clean energy technologies. Ada is a self-driving laboratory for thin film materials discovery and optimization. Advanced robotics and machine learning equip Ada with the capacity to make, test, and learn from new materials on the fly. Leveraging automation enables higher research throughput, and autonomy driven by machine learning algorithms can facilitate more efficient exploration of complex materials spaces relative to conventional methodologies. Project Ada's versatile approach allows for rapid and ongoing design and implementation of modular hardware and software that can be tailored to study myriad materials systems. Our first two proof-of-concept applications involve the development and optimization of: i) materials for perovskite solar cells; and ii) materials for CO2 conversion.

*A video demonstration is available for viewing over lunch

Participants can sign up for a tour at 5:45pm- 6:15pm or 6:15pm- 6:45pm.

Speaker Titles and Abstracts

Eric Anderson, Head of Technology, Anderson Optimization, MN, USA

Line Failure Risk from Transmission Congestion : Incorporating Uncertainty from Renewable Generation

The use of optimization models for operation of bulk power systems has been critical in creating an efficient and reliable system. However, reliability issues still have a large impact on the economy and are estimated to cost upwards of $79 billion per year. Additionally, there is an increased importance on models that can handle uncertainty due to the increasing penetration of wind and solar generation. This talk will start with an overview on economic dispatch models and extend them to handle uncertainty in net injection, modeled as a multivariate Gaussian distribution, by using chance constraints. We then tackle system level risk from transmission loading by introducing a joint chance constraint that allows for a trade-off between economics and risk of line failures.

Keywords: uncertainty, economic dispatch models, chance constraints

Alexander Aravkin, Professor, Applied Mathematics, University of Washington, WA, USA

Robust Time Series Forecasting Using Exponential Smoothing Cells

Exponential smoothing decomposes time series into interpretable components (such as level, trend, and seasonality), and is used to understand and to forecast time series is weather prediction, financial markets, and energy demand. Outliers, missing data, and nonstationary series make it difficult to reliably forecast trends and associated uncertainty. We develop a new time series model, by linking together exponential smoothing cells in a dynamic framework. The resulting approach uses robust losses and regularization to handle outliers and high levels of noise, detect evolving trends, interpolate missing data, and improve forecasting. The new model is fit by solving a single convex optimization problem.

Keywords: forecasting, time series model, convex optimization, modeling

Amir Badkoubeh, Engineer, Cognitive Systems Inc., AB, Canada

Challenges and Opportunities in Clean Energy Applications

This talk describes the system and structure for enabling radical deployment of clean energies (e.g. wind power plants, solar panels and plug-in electric vehicles) into current power systems. We explain what the technological, social, regulatory and environmental drives are. We explain how the power system is evolving in synchrony with the existing utility control centers and their supervisory control and data acquisition (SCADA) systems. Much greater intelligence gets embedded into the new hardware technologies themselves for managing temporal complexities and uncertainties in a distributed way. The real-time and near real-time measurement devices are integrated to SCADA and communication structures. We study the opportunities and challenges for new decision making algorithms and system modeling based on these measurement, control and communication infrastructures. We conclude the talk with case studies on the importance of sub-harmonics, torsional vibrations and predictive algorithms for radical deployment of clean energies into current power systems.

Keywords: algorithms

X. Tony Bi, Professor, Chemical and Biological Engineering, University of British Columbia, BC, Canada

Flow distribution and flow hysteresis in two-phase flow parallel channels

Parallel flow channels have been widely used in industrial applications to enhance heat/mass transfer and improve reactor performance. Substantial experimental evidences in the literature suggest that two-phase flow through parallel paths can distribute non-uniformly and cause pressure drop hysteresis, even when the flow paths are identical, leading to decreased system performance. In most cases, the mal-distribution and hysteresis are related to flow instability. Possible mechanisms, such as minimum energy dissipation and minimum pressure drop, Ledinneg instability, pressure drop oscillations and density wave oscillations, all may trigger mal-distribution and hysteresis in two-phase flow parallel channels, as supported by experiments and simulations. Strategies proposed in the literature to mitigate the flow mal-distribution and hysteresis are reviewed based on their effectiveness. In view of the importance of two-phase flow distribution in parallel channels to fundamental understanding of two-phase flow instability and enhancing the system performance and reliability, future research should focus on improving the instability analysis of multiphase flow systems and developing mitigation strategies for design and operation of parallel flow systems. This is a joint work with Guilin Hu, UBC

Keywords: Two-phase flow distribution, Parallel channels, flow hysteresis, flow instability, energy dissipation, fluid dynamics, simulation

Matthew Breakey, WSP Wind Energy, BC, Canada

Past, Present and Future of Wind Resource Engineering

The field of wind resource engineering in relatively new and has experienced significant growing pains as wind energy has boomed over the last decade. At the start of the boom in 2008, there was little operational experience and the technology was rapidly changing. With little data to calibrate models and errors in theoretical calculation methods having yet to be discovered, the industry earned a reputation of over-estimating energy by ~10%. This assessment bias was unacceptable to the financing community and wind resource engineers were forced to improve their calculation methods. With a decade of operational experience to calibrate models, methods have improved significantly and confidence in predicted numbers has grown, but still has not reduced calculation uncertainty to an acceptable level. This presentation will outline how a classic wind resource assessment was completed, the improvements that have been made over the last decade and areas that still need to be improved. The goal of the talk will be to increase the audience's understanding of designing and developing a wind farm and how an individual with a mathematical background can improve these processes to make wind energy more competitive in the energy mix.

Keywords: modeling

Curran Crawford, Professor, Mechanical Engineering, University of Victoria, BC, Canada

Intrusive Polynomial Chaos Approaches for Unsteady Wind Turbine Analysis and Optimization

Wind turbines operate in an inherently unsteady environment owing to atmospheric instabilities and earth boundary layer turbulence. That turbulence is ingested by the rotor and creates an aeroelastic response with the flexible blades, in turn driving ultimate and fatigue loads as well as unsteady power output. Design standards mandate an extensive set of 600s simulations across a range of mean wind speeds, creating a challenge to wind turbine optimization. The need for unsteady, aeroelastic simulations also drives the wind energy to corporately low-order analysis codes typically based on blade element momentum (BEM) theory. This talk will overview progress in an intrusive polynomial-chaos expansion (PCE) approach to wind turbine aerodynamic analysis. The idea is to project the governing equations of either low-fidelity BEM equations, or medium fidelity vorticity equations to enhance aerodynamic fidelity for non-straight blade concepts, onto a stochastic expansion space. The intrusive PCE method can then yield a stochastic model of the aerodynamic response in a single solve of the coupled equations. The intention, with a proper description of the inflow, is to both increase the accuracy of the aerodynamic stochastic response, and to reduce the computational burden of medium-fidelity aerodynamics codes to expand the rotor design space.

Keywords: fluid dynamics, numerical simulation, stochastic modeling

Joel Culina, Fundy Ocean Research Center for Energy (FORCE),Halifax, NS, Canada

Wake characterization with X-band radar at the FORCE tidal energy site

Wake characterization at in-stream tidal turbine sites is a critical endeavour towards optimizing power extraction and minimizing the environmental impact of turbine arrays. Most wake studies focus on turbine wakes and are conducted in numerical or laboratory settings. In reality, tidal turbine wakes are embedded within an energetic field of naturally-occurring eddies and wakes. At the Fundy Ocean Research Center for Energy (FORCE) in-stream tidal turbine demonstration site, the wake behind Black Rock island significantly impinges on, and thereby effectively limits, the turbine deployment region.

In this talk, we discuss the use of land-based X-band radar to accurately delineate the Black Rock wake. The derivation of the surface, horizontal/2-D velocity field from X-band radar is well-established, but the resolution of the derived field is too coarse for wake delineation. We develop and validate a new methodology, using proper orthogonal decomposition of the high-resolution (order metres) raw radar backscatter. With improvements to coverage (a radar network at the FORCE site is under development), land-based radar at the FORCE site will be used to generate detailed maps of the naturally-occurring eddy field and the surface signature of turbine wakes.

Keywords: fluid dynamics, statistical analysis

Matt Davison, Dean and Professor of Statistical and Acturial Sciences, University of Western Ontario, ON, Canada:

Thinking about Year 21: the Economics of Ontario Wind Power after PPA expiry

Wind Power has become a major component of the Ontario electrical generation mix due in large part to the generous feed in tariffs offered, for 20 year terms, to wind power producers. The end of these 20 year terms is in sight for many of the earlier wind farms constructed in the province. At around 20 years not only do feed in tariffs expire, many expensive components of a wind farm begin to fail. At the same time, the exchange -set Hourly Ontario Electricity Price is very low. What is the optimal course of action for Ontario Wind Farm operators? How might the decisions of the first producers to reach year 21 influence the power market for producers who reach year 21 later? What kind of contracts might be constructed to incent decisions, by wind farm operators, which seem desirable by provincial authorities? This talk will be an eclectic mix of engineering economic analysis, financial real options, and economic optimal contracting. This is a joint work with Rupp Carriveau and Lindsay Miller, from the Department of Civil Engineering, University of Windsor, and Arezoo Tahmabesi from the School of Mathematical & Statistical Sciences, Western University Canada.

Keywords: wind power; Ontario electrical generation; real options; economic optimal contracting, optimization, math finance

Guy Dumas, Director - Laboratoire de Mécanique des Fluides Numérique (LMFN/ Computational Fluid Dynamics), Université Laval, QC, Canada

Hydrokinetic Energy Conversion --- Some CFD Contributions to the Development of Turbine Technologies and their Deployment in Arrays.

In this talk, I will survey some of the contributions my research group has been involved with over the past decade in the CFD analysis of turbine technologies and of their operation in farms or arrays. I will focus more specifically on two types of cross-flow turbine concepts that we have been investigating in depth, namely the oscillating-foil turbine and the H-Darrieus turbine. Characterized by rectangular extraction planes, as opposed to the circular extraction plane of the axial-flow turbines, those two technologies are particularly well suited to shallow water deployments. Much insight into their optimal design and operating conditions has been gained through full-rotor URANS simulations under clean inflow conditions (uniform velocity and low turbulence intensity) and unconfined environment. Some key results will be discussed. However, when considering turbine array analysis and optimization, one has come to realize that turbine performances (power and drag coefficients) obtained under clean flow conditions and in isolation are not sufficient. One also needs to characterize the turbulent wake each technology generates as well as their respective recovery rates. In that regard, cross-flow turbines exhibit attractive features that will be surveyed.

On the way to develop real technologies and deploy large turbine arrays, one needs to consider simultaneously the local and the global scales. Each turbine in the array operates in a local flow environment and a local blockage, and the whole array operates in a global water resource environment. Turbine array analysis thus implies that very challenging issues have to be taken into account such as turbine-wake interactions, operation in perturbed and turbulent flow conditions, blockage effects and impact of the turbine array on the water resource itself. Some progress recently made toward addressing these issues will be discussed.

Some selected references:

1. Boudreau M., Gunther K., Dumas G. (2019): "Investigation of the energy-extraction regime of a novel semi-passive flapping-foil turbine concept with a prescribed heave motion and a passive pitch motion", J. Fluids and Structures, Volume 84, January 2019, Pages 368-390. https://doi.org/10.1016/j.jfluidstructs.2018.11.014
2. Bourget S., Gauvin-Tremblay O., Dumas G. (2018): "Hydrokinetic turbine array modelling for performance analysis and deployment optimization", Transactions of the Canadian Society for Mechanical Engineering, 2018, Vol. 42, N° 4: pages 370-381. http://dx.doi.org/10.1139/tcsme-2017-0088
3. Boudreau M. & Dumas G. (2018): "Vortex Dynamics in the Wake of Three Generic Types of Free-Stream Turbines", ASME J. Fluids Eng. 140(2):021106-021106-9. http://dx.doi.org/10.1115/1.4037974
4. Gosselin R., Dumas G., Boudreau M. (2016): "Parametric study of H-Darrieus vertical-axis turbines using CFD simulations", Journal of Renewable and Sustainable Energy 8, 053301 (2016). http://dx.doi.org/10.1063/1.4963240

5. Kinsey T. & Dumas G. (2014) : "Optimal Operating Parameters for an Oscillating Foil Turbine at Reynolds Number 500,000," AIAA Journal, vol. 52, No. 9 (2014), pp. 1885-1895. http://dx.doi.org/10.2514/1.J052700
6. Kinsey T. & Dumas G. (2008): "Parametric Study of Oscillating Airfoils in Power Extraction Regime", AIAA Journal, 46, no. 6, pp. 1318-1330. https://doi.org/10.2514/1.26253

Keywords: computational fluid dynamics, numerical simulation

Nima Fathi, Assistant Professor, University of New Mexico, Albuquerque, USA

Applied Mathematical Evaluation of Solar Tower System: Hybrid Renewable Energy Development

Here we present our recent advances on the mathematical modeling of renewable hybrid solar systems. The conceptual model of the solar tower system is key for the further steps of research development as well as more advanced simulation and experimental investigations. In solar tower systems, which are also called solar chimney power plant (SCPP), the air flow is driven by buoyancy in the open air-Brayton cycle. At ground level, SCPP includes a collector with a transparent roof to collect the solar radiation. The solar energy heats up the air inside the collector and the ground underneath. The energy of the buoyant hot air is ultimately converted to electrical energy. In this work, the renewable energy power plant is investigated in different aspects including a mathematical/analytical study and thermal cycle. The mathematical analysis was performed to derive a correlation to predict and calculate the output power of this system. The derived correlation has an accurate agreement against experimental data and our simulation results. In this analytical correlation, the simplified thermo-fluids behavior of the power plant is reflected. Our ongoing research is focused on increasing the thermal efficiency by topological optimization and combining SCPP with other thermal clean energy cycles. These efforts have the main objective of increasing the share of clean solar energy to the total energy consumption. The estimated US energy consumption in 2015 revealed that 82% of the energy was generated from fossil fuels which is one of the underlying reasons of global warming. On the other hand, the share of solar energy was only 0.43%. Our results confirm that SCPP has the potential to be used in dry cooling and thermal storage cycle. The key advantages of this system are the low-cost fabrication and cooling process when it serves as a dry cooling tower. In fact, open air-Brayton systems are one of the solutions in the clean cooling process since the ultimate heat sink for the supplied power is the atmosphere. In addition, the system can provide a great deal of flexibility in adjusting power plant electrical output without significantly ramping reactor power output. This is a joint work with Peter Vorobieff (University of New Mexico, Albuquerque, United States), Vakhtang Putkaradze (University of Alberta) and Seyed Sobhan Aleyasin(University of Manitoba).

Keywords: modeling, simulation, optimization

Lorne Gettel, President, Electra Motor Corporation, BC, Canada

Overview of Mathematical Modeling Techniques to Improve the Performance and Lifetime of Lithium Ion Batteries

Advanced electric vehicles exclusively use lithium ion batteries to power their propulsion system. A lithum ion battery pack used in electric vehicles consists of hundreds to thousands of lithium ion cells that are connected together. While lithium ion batteries provide superior performance and lifetime to other energy storage technologies, however, there is a much greater degree of technical complexity required to achieve these performance levels. A lithium ion battery pack used in electric vehicles requires a complex battery management system that controls every cell in the battery pack. To provide a long battery lifetime, it is essential that the battery pack is not over charged, over discharged, operated at excessive currents and operating temperatures, and has every cell precisely balanced at the same state of charge. If these conditions are not met, then the lifetime of the battery can be severely degraded, and in some circumstances the battery could overheat and potentially create a fire hazard. While it is relatively easy to measure in real time the individual cell voltages, current and temperature throughout the battery, the state of charge (SOC) and state of health (SOH) are not directly measureable parameters. Much effort has gone into techniques to accurately calculate SOC and SOH, including Coulomb counting techniques and Kalman filtering. In this presentation an overview will be given of current research efforts to develop mathematical models to be able to more accurately predict SOC and SOH. Equivalent circuit models will be discussed as well as AC impedance models that could possibly be used to determine SOH.

Keywords: modeling

Bhushan Gopaluni, Professor & Associate Dean of Applied Science, University of British Columbia, BC, Canada

State-of-charge estimation in lithium-ion batteries: A particle filter approach

The dynamics of lithium-ion batteries are complex and are often approximated by models consisting of partial differential equations (PDEs) relating the internal ionic concentrations and potentials. The *Pseudo two-dimensional model* (P2D) is one model that performs sufficiently accurately under various operating conditions and battery chemistries. Despite its widespread use for prediction, this model is too complex for standard estimation and control applications. This article presents an original algorithm for state-of-charge estimation using the P2D model. Partial differential equations are discretized using implicit stable algorithms and reformulated into a nonlinear state-space model. This discrete, high-dimensional model (consisting of tens to hundreds of states) contains implicit, nonlinear algebraic equations. The uncertainty in the model is characterized by additive Gaussian noise. By exploiting the special structure of the pseudo two-dimensional model, a novel particle filter algorithm that sweeps in time and spatial coordinates independently is developed. This algorithm circumvents the degeneracy problems associated with high-dimensional state estimation and avoids the repetitive solution of implicit equations by defining a 'tether' particle. The approach is illustrated through extensive simulations.

Keywords: modeling, partial differential equations, numerical simulation, control theory

Clayton Hiles, PRIMED, BC Canada

(Presented by Anthony Truelove, University of Victoria)

Modelling Wave Energy Success

PRIMED works with communities and marine renewable energy technology developers to fill knowledge gaps so the parties can engage together in innovative projects with decreased risk. We work with community leaders to identify synergies between community energy needs and local marine energy resources. We work with developers to evaluate and optimize their technologies for BC waters. We use our unique resource data, performance assessment experience and energy system know-how, to help guide site selection and provide *second party* assessment of the economic and environmental impacts a community might derive from a marine energy project.

The success of PRIMED rests primarily on our ability to use computational models to simulate and iteratively improve a marine renewable energy project before detailed design is even considered. This requires understanding the physics of the problem, ensuring that those physics are adequately represented by the simulator and where possible validating the results. While PRIMED is engaged in offshore wind, tidal and wave research, this presentation will focus primarily on wave energy and introduce the various types of associated modelling: ocean wave propagation, extremes weather events, floating body dynamics, hydraulic/pneumatic power transfer and electrical systems. Through global optimization techniques we incorporate each of these modelling streams to assess and improve the cost performance of the complete energy system. The physics and math behind each model will be briefly reviewed as well as the global optimization approach. While this may be an *ocean of knowledge an inch deep*, it will provide students and researchers outside the field a good starting point for understanding how applied math is driving marine renewable energy projects forward.

Keywords: fluid dynamics, modeling, optimization

Takashi Hikihara, Professor, Advanced Electrical Systems Theory Lab, Kyoto University, Kyoto, Japan

Power packetization and its distribution in network: concept and applications

Recent introduction of renewable energies and distributed power sources makes it clear that the conventional power distribution network, which has been developed to accept huge bulk of energy from source sides with one directional protocols, has been no more effective in bidirectional supply. The concept of power packet was introduced in 1990s. The appearance of the concept was reasonable along the history of technology even in power engineering. In this talk, research on power packetization and its dynamics of distribution, related to applications, are discussed based on the result of national project, the Cross-ministerial Strategic Innovation Promotion Program (SIP) in Japan. It will open the next generation of power engineering from the conventional power circuits to power processing.

Keywords: network flow, network optimization

Rajeev K. Jaiman, Associate Professor and Seaspan Chair, University of British Columbia, BC, Canada

Harvesting of Ocean Current Energy via Self-Induced Flapping Dynamics

In this talk, I will review some of our recent numerical methods and software development on flexible multibody and multiphase fluid-structure interaction (FSI) simulations, with applications to the clean energy from ocean currents. It is well known that ocean currents can offer an alternative source of clean energy owing to their higher reliability of kinetic energy extraction with a low level of temporal variation. The sustained water flow in ocean currents can be converted to usable power for marine/offshore systems and coastal population areas. According to the Bureau of Ocean Energy Management, it is estimated that the Florida Current portion of the Gulf Stream system can correspond to approximately 45 TWh/year with stable and sustainable extraction of kinetic energy. In addition to conventional turbine-based technologies, this kinetic energy can be harvested by exploiting the unsteady flow-induced flapping instability of a thin piezoelectric structure. A particular emphasis of this talk will be on the design and modeling of flexible flapping structures along the Pacific Northwest coastlines where strong and persistent ocean currents are present. We report a new and robust approach to harvest the ocean current energy from a self-induced flapping process using a piezoelectric flexible structure fixed at the trailing edge and the leading edge free to flap (termed as inverted foil). To simulate a highly nonlinear flapping dynamics of a flexible inverted sheet, a high-order variational fluid-structure solver based on the combined field with explicit interface has been developed for scalable computations on supercomputers. A simplified piezoelectric model has been implemented to transform a part of mechanical energy generated from the flapping deformation to the electric energy. A systematic study on the flapping response of an inverted flexible foil has been performed for a wide range of non-dimensional bending rigidity, Reynolds number, mass ratio and geometric configurations. The inverted limit-cycle oscillations are characterized by low-frequency large amplitude oscillations which generate $O(10^3)$ times greater strain energy than a flexible foil fixed at the leading edge, which has a profound impact on the development of ocean current based energy harvesting devices.

References:

1. Gurugubelli P.S, and Jaiman R.K. Self-induced flapping dynamics of a flexible inverted foil in a uniform flow. J Fluid Mech 2015;781:657–94.
2. Gurugubelli P.S, and Jaiman R.K Energy harvesting using flapping dynamics of piezoelectric inverted flexible foil. In: ASME 2015 34th Int. Conf. Ocean. Paper No. OMAE2015-41713
3. Hass et al. “Assessment of Energy Production Potential from Ocean Currents along the United States Coastline”, Georgia Tech Research Corporation, Final Report, 2013

Keywords: fluid dynamics, numerical simulation

Richard Karsten, Professor, Acadia University, NL, Canada

An introduction to the challenges of Marine Renewable Energy

Marine renewable energy (MRE) has been slow to develop, in large part due to the particular challenges of working in the marine environment. While the theoretical resource is substantial, the journey from theory to practice has been very challenging. In this talk, as an introduction to the session, I'll review the challenges common to most forms of MRE. As much as possible, I will describe the challenges from the viewpoint of a mathematician.

Keywords: modeling, fluid dynamics, simulation

Younghun Kim, Director of Data Science, Utopus Insights, NY, USA

Hot topics in the renewable industry

The energy sector has been experiencing a profound shift from traditional energy sources to renewable energy sources. The shift has been accelerated by the increased reduction in the levelized cost of renewable energy generation. Advancing research and development for new technologies are crucial and are the key enabler for the effective transformation of the energy industry. Equally importantly, the development of methodologies to manage existing infrastructure and enable the infrastructure to take renewables with minimal changes will be needed. In this talk, I'll cover hot topics and challenges in managing renewable assets in an effective manner. Topics include the power forecasting of wind and solar, optimization of asset maintenance through predictive analytics, and nexus among solar, wind and battery storage. The goal of the talk is to identify some possible research topics through interactive dialogue.

Keywords: optimization, predictive analytics

Artem Korobenko, Department of Mechanical and Manufacturing Engineering, University of Calgary, AB, Canada

High-fidelity computational fluid-structure interaction framework for design and analysis of wind turbines.

This talk presents the high-fidelity fluid-structure interaction (FSI) framework for analysis and design of multiple horizontal-axis wind turbines (HAWT) and vertical-axis wind turbines (VAWT) at full geometric and material complexities operating in atmospheric boundary layer (ABL) flows. The talk focuses on mathematical details of the framework, including stabilized and multi-scale methods, non-conforming discretization, coupling strategies, advanced geometry modeling techniques based on isogeometric analysis, solution of large sparse systems. The presented FSI framework provides accurate solutions for various challenging problems, providing the data-of-interest that is not readily available or hard to acquire during the experiments.

Keywords: fluid dynamics, numerical simulation, numerical analysis

Justine McMillan, Scientist, Rockland Scientific International, Victoria, BC, Canada

Turbulence Measurements at Proposed Tidal Energy Sites

Turbulence measurements at tidal energy sites are required to validate and improve numerical simulations used to estimate turbine performance and hydrodynamic loading. To date, tidal turbine models typically implement inflow conditions where turbulent fluctuations are represented simply as a percentage of the mean flow. In these simulations, the distribution of turbulent kinetic energy (TKE) across a range of spatial scales may be misrepresented in the simulations. More sophisticated models capable of reproducing measured spectral densities are frequently used in the wind industry; however, the applicability of the same input conditions in finite depth tidal flows is not well understood. As part of a larger resource assessment, turbulence measurements were acquired in Grand Passage, Nova Scotia, which is a tidal channel where the flow speed reaches 2.5 m/s and the Reynolds number is O(108). The data were collected during three separate field campaigns that included the deployment of acoustic Doppler current profilers (ADCPs) and an underwater, streamlined buoy ``flown'' at middepth. The data were used to: (1) assess the capabilities and limitations of both instrumentation techniques, (2) investigate the validity of existing theoretical and empirical relationships, and (3) characterize the spatial and temporal variability in turbulence and boundary layer parameters. The measurements have also been used to initialize a turbine simulation and the results – when compared to a steady flow simulation – show that both the power production and the wake dynamics are influenced by the more realistic turbulent flow.

Keywords: fluid dynamics, statistical analysis

Iain Moyles, Professor, Department of Mathematics and Statistics, York University

Asymptotic Model Reduction: Why Mathematicians Have An Important Role in Electrochemistry

There is a richness of mathematical models in electrochemical systems which continuously grow in complexity. One particular area of rampant growth is in the modelling and analysis of Lithium-ion batteries (LIBs) because of their ubiquity in society. As LIB models grow in complexity, the analytic and computational techniques used to solve them become more costly as well which is problematic for implementation in battery management systems. In this talk we will challenge the need for model complexity by asymptotically reducing a prototypical model for LIBs. We will compare our results to other models and battery data, demonstrating excellent agreement.

Keywords: modeling

Rose Murphy, Researcher, Energy and Materials Research Group, Simon Fraser University, BC, Canada

The math of energy-economy models CIMS and CIMS-Urban

Energy-economy models are applied at the global, national, and sub-national (state, province, region) levels to estimate the GHG emissions reduction from one or a portfolio of policies. While these models usually represent all GHG emission sources, they tend to focus on energy given its importance for GHG emissions – hence the term energy-economy models. Energy-economy models simulate the GHG-related decisions of firms and households. They are especially focused on the turnover of the capital stock, namely: infrastructure, buildings, industrial plants and equipment, electricity generation and other energy supply technologies, vehicles and other transport equipment, appliances and other household durable goods. Energy-economy models can have considerable regional detail; however, they generally lack city-level detail on land-use. And as a growing number of cities have set ambitious mid-century targets for GHG emissions reduction and increased use of renewable energy, new modeling tools are required in order to independently assess these targets. Urban planners and policy-makers focus on land-use zoning and the coordination of urban development (density, mixed uses) with mobility infrastructure (roads, transit, cycle paths) and perhaps energy infrastructure (district heating). Analysis of policies operating at this level requires an energy-economy model combined with urban land-use detail.

To address this need, researchers at the Energy and Materials Research Group at SFU have developed a spatially explicit version of CIMS, an existing energy-economy model, by linking it to a GIS model. The resulting model is called CIMS-Urban. In my talk I will discuss the following.

- The mathematical functions used in CIMS to estimate market shares of energy consuming and producing technologies.
- The techniques used to estimate the values of parameters within these functions, including discrete choice analysis.
- How urban travel demand is allocated between private vehicles, transit, cycling, and walking based on equations that represent the quality of transportation networks within the GIS component of CIMS-Urban.
- Mathematical challenges we are currently facing in our modeling with CIMS and CIMS-Urban.

Keywords: modeling, math finance

Elena Popovici, Senior Computer Scientist, Neurio Technologies Inc. BC, Canada

Home-energy forecasting for storage optimization

Climate change is arguably the biggest social challenge of our time. To overcome it, developing and adopting renewable energy sources is a must. However, relying entirely on sources like wind and solar comes with a challenge: they are intermittent and often out of synch with when energy is most needed. Total reliance on these sources without proper management is not feasible. But with the right hardware and software in place, households and businesses have the ability to monitor, control and optimize their energy consumption and generation. For example, the use of sensors and energy management software can help homeowners intelligently manage their home battery operation. Algorithms can be devised that take as inputs data such as real-time electricity usage, power generated from solar, the weather, the billing tariff of the utility company, and the battery capacity, then make decisions about when and how much to charge or discharge the battery. Not only does this save the user money, it's good for the grid: reducing the demand for electricity during peak periods in turn reduces the need for expensive infrastructure required to manage those peak consumption times. The gains from this can be further improved by incorporating the forecasting of upcoming energy consumption and generation. In this talk I will show how data analysis, visualization, optimization and machine learning techniques make all of this possible.

Keywords: data analysis, optimization, algorithms, machine learning

Vakhtang Putkaradze, Professor, Department of Mathematics/Chemical Engineering, University of Alberta, AB, Canada

Dynamics and control of flexible solar towers

The use of solar chimneys for energy production has been suggested more than 100 years ago. Unfortunately, this technology has not been realized on a commercial scale, in large part due to the high cost of erecting tall towers using traditional methods of construction. Recent works have suggested a radical decrease in tower cost by using an inflatable self-supported tower consisting of stacked toroidal bladders. While the statics deflections of such towers under constant wind have been investigated before, the key for further development of this technology lies in the analysis of dynamics, which is the main point of this talk. Using Lagrangian reduction by symmetry, we develop a fully three dimensional theory of motion for such towers and study the tower's stability and dynamics. Next, we derive a geometric theory of optimal control for the tower dynamics using variable pressure inside the bladders, and perform detailed analytical and numerical studies. Finally, we report on the results of experiments demonstrating the remarkable stability of the tower in real-life conditions, showing good agreement with theoretical results. This work has been supported by NSERC and the University of Alberta.

Keywords: modeling, optimal control, geometric mechanics

Deniz Sezer, Associate Professor, Department of Mathematics and Statistics, University of Calgary, AB, Canada

Spatio-temporal modeling of wind power generation of Alberta

In this talk, I will describe a study on the future wind power generation in Alberta, motivated by the growth in Alberta's wind power capacity. An important feature of wind power data is its spatial and temporal correlation. To capture this, we model the wind power generation in Alberta as a spatiotemporal process. We apply the method of Gaussian random fields to analyze the wind power time series of the 19 existing wind farms of Alberta.

Following the work of Gneiting et al. , "Space-Time Models, Stationary, Separability and Full Symmetry", we build several spatiotemporal covariance function estimates with increasing complexity: separable, non-separable symmetric, and non-separable, non symmetric. We compare the performance of the models using kriging predictions and prediction intervals for both the existing wind farms and a new farm in Alberta. We use the selected model to forecast the mean and the standard deviation of the future aggregate wind power generation of Alberta. (Joint work with, Y. Luo, M. Wu, D. Wood, H. Zareipour).

Keywords: statistical analysis

Blake Shaffer, Spogli Institute for International Studie, Stanford University, USA

The effect of climate change on the level and timing of future electricity demand

This paper examines how rising temperature due to climate change will affect the demand for electricity through mid- and end-century. We extend recent literature by directly incorporating adaptation in the form of increased air conditioner penetration into temperature responsiveness and focussing on changes to both the level and timing of future electricity demand. The latter is found to be of greater importance in colder countries, where the level effect is dampened by offsetting reductions in heating demand from warmer winters. Seasonal peaks are projected to shift from winter to summer and the diurnal range of hourly demand expands, exacerbating an increasing need for flexibility coming from the supply side due to a growing share of variable renewable energy.

Keywords: modeling, math finance

Taraneh Sowlati, Professor, Department of Wood Science, Faculty of Forestry, University of British Columbia, BC, Canada

Use of forest-based biomass in clean energy applications: complexities and supply chain modeling approaches

The importance of biomass as a renewable source of energy has been increasing. Forest-based biomass is an attractive type of biomass for producing bioenergy, biofuels and bioproducts, especially in regions with abundance of supply, and active forestry and wood manufacturing operations, such as Canada. Utilizing forest-based biomass in clean energy applications has the potential to reduce dependency on fossil fuels, decrease emissions and create jobs in forestry-dependent communities. However, forest-based biomass availability, quality, and cost affects its competitiveness as an energy source. Many previous studies used simulation and optimization modeling approaches to manage, improve and optimize the supply chain of forest-based biomass. Recent studies used hybrid approaches to incorporate variations in supply amount and quality as well as sustainability aspects of the supply chain into the models. This presentation provides a background on forest-based biomass, and the opportunities and challenges in utilizing this renewable source. Furthermore, a classification of supply chain modeling approaches is presented. Additionally, our recent projects that integrated sustainability aspects and addressed variations in forest-based biomass supply chains are discussed.

Keywords: forest-based biomass, supply chain modeling, optimization, simulation, modeling

Jay Sui, Professor of Automative Engineering, Wuhan University of Technology, Hubei, China

Mesoscopic Modeling of PEMFC Catalyst Layers: Review & Outlook

The catalyst layers (CLs) of a polymer electrolyte membrane fuel cell (PEMFC) have multiple functions during cell operation. They serve as a conductor for charged species (protons and electrons) and provide pathways for ordinary species (gases and liquid water). The transport processes in a CL take place in different phases, yet all species meet at the catalyst sites for electrochemical reactions. Our understanding on these transport processes has advanced from macroscopic models to microscopic/mesoscopic models lately, thanks to high resolution microscopes that reveal the CL's microstructure, and high-performance computing for rapid first-principles/pore-scale simulations. In this talk, classical/state-of-the-art CL models for PEMFC are revisited and examined using the volume-averaging method. Observations and insights gained from a series of numerical experiments performed on a pore-scale model are presented. Future directions of research and development for next generation PEMFC CL are also discussed.

Keywords: modeling, numerical simulation

Anatoliy Swishchuk, Professor, Mathematics and Statistics Department, University of Calgary AB, Canada

Overview of Some Results in Energy Market Modelling and a Vision on Clean Renewable Energy

The talk overviews my recent results in energy market modelling, including applications of weather derivatives, option pricing, variance and volatility swaps in the energy markets, pricing crude oil options using Levy processes and energy contracts modelling with delayed and jumped volatilities. I will also talk about my vision on clean renewable energy.

Keywords: energy market modelling; weather derivatives; option pricing; var. and vol. swaps; Levy processes; clean renewable energy, math finance, modeling, stochastic processes

Michael Thiessen, VP Sustainable Research, Genus Capital Management, BC, Canada

Opportunities and Challenges within Clean Energy Investing

The clean energy industry is going through drastic changes and continues to see growth despite political headwinds. Among the parties interested in the industry advancement are investors. We have seen investments in fossil fuel extractors and processors decline as IT and Financials replace them as the most valuable companies. Traditional investors are now looking for clean technology and utility companies for their portfolios and a new breed of investors called "impact investors" are striving to make a difference with their investment capital. This has led to the Divest/Invest movement which is backed by research showing that divestment from fossil fuels has historically not hurt returns. When looking for cleaner investments, investors have a growing number of options and financial firms are consistently coming out with new products. However, there are challenges that investors face, such as political risk, regulatory risk, and a lack of pure play equity investment options. The energy and financial industries need to solve these issues in order to mobilize more capital towards the growth of clean energy.

Keywords: clean energy; political risk; regulatory risk, math finance

Cameron Wade, PhD Student, Mechanical Engineering, University of Victoria, BC, Canada

Power system planning models in the age of variable renewables: overcoming challenges to the temporal dimension.

Power system planning (capacity expansion) models use optimization techniques to chart least-cost pathways of infrastructure investments subject to exogenous electricity demands and techno-economic and policy constraints. Multi-decadal model horizons require certain model dimensions be stylized in the interest of computational tractability. Conventional techniques to aggregate the temporal dimension result in under-approximating the variability inherent to solar and wind resources and therefore misrepresent their system value. This is particularly troublesome in the age of low-cost renewables. This talk outlines current developments in temporal aggregation techniques and introduces a probabilistic method to select representative operating periods that preserves wind and solar resource variability. The method involves the clustering of multidimensional time series to find `representative days' and the formulation of an optimization problem to further aggregate the resource profiles of the representative days. A capacity expansion model of the power system in Alberta, Canada is used as a case study to evaluate the proposed temporal aggregation technique.

Keywords: optimization, statistical analysis, probability

Antony Ware, Professor and Head of Mathematics and Statistics, University of Calgary AB, Canada

Reliability-constrained hydropower optimization

Maximizing the long-term value of hydropower generation requires management of uncertain reservoir inflows, potentially variable constraints on outflows, and exposure to possibly wildly varying power prices. We describe a stochastic dynamic programming approach to the quantification of reservoir reliability (for example, measures of the risk of over-topping the reservoir or failing to satisfy downstream flow requirements) and a related approach to determining the reservoir flow strategy that maximizes expected revenue, subject to defined target reliability levels.

Keywords: hydropower optimization; reservoir reliability; expected revenue; math finance, stochastic dynamic programming

Brian Wetton, Professor, Department of Mathermatics, University of British Columbia, BC, Canada

Mathematical Modelling of Electrochemical Systems

This will be a gentle introduction to some of the key processes in electrochemical systems for an audience with little or no previous background. A multi-scale model of a fuel cell will be shown, with a description of its mathematical character and computational implementation. The role that mathematical analysis can play in developing such a model and its computational approximation are highlighted.

Keywords: Fuel Cells, batteries, diffusion, reaction, multi-scale modelling, differential equations

David Wood, Schulich Professor of Renewable Energy, Department of Mechanical and Manufacturing Engineering, University of Calgary, AB, Canada

Vorticity, Impulse, and Wind Turbine Aerodynamics

The aerodynamics of wind turbines is determined to a large extent by the helical vortices that trail from the blades, much like wing tip vortices from aircraft wings. It is difficult, however, to include their effects in models of wind turbine power and thrust for two reasons. The first is the complicated mathematics of helical vortices even for simple cases. The second is that vorticity does not appear naturally in the "conservation" equations for momentum, angular momentum, and thrust. One way to make vorticity appear is to use an impulse formulation of the conservation equations. This technique was pioneered by Kelvin, Thomson and others in the late 19th century, partly for the study of vortex rings, but has not been used in wind turbine aerodynamics. The work of the author and colleagues on the use of impulse and helical vortex theory will be described in the context of its ultimate goal: to develop a simple, fast, an accurate aerodynamics model for use in real-time control of wind turbines.

Keywords: fluid dynamics, numerical simulation

Poster Presentations

Margaret Campbell, Research Assistant, University of British Columbia, BC , Canada

Numerical Weather Prediction as means to increase electrical transmission efficiency

Joule heating from electrical currents causes the conductor temperature of a transmission line to increase. Weather, namely wind speed and air temperature, can further heat or cool the line. Utility companies need to know the maximum current they can transmit without exceeding critical temperature thresholds for transmission line safety (e.g., excess sag or metallurgical damage). The maximum transmittable electrical current for safe transmission must be estimated from wind speed, direction, temperature, insolation, and maximum conductor temperature. Power utilities apply this thermal rating to all powerlines. Traditionally, power utilities do not monitor the weather surrounding powerlines, but assume relatively constant weather, leading to either overly conservative or unsafe thermal ratings. Dynamic thermal ratings (DTRs) take into account varying weather conditions in an effort to more realistically represent ampacity variations. To demonstrate the potential of numerical weather prediction (NWP) based DTR forecasts to improve powerline safety, increase transmission capacity, and provide power utilities a means of advanced planning, this study evaluates and compares seven bias-corrected, calibrated DTR forecast configurations to two traditional thermal rating methods to determine the most skillful DTR forecast method as well as to show the usefulness of probabilistic forecasts."

Charlotte Lafleur, Graduate Student, University of Victoria, BC, Canada

Wave energy integration in remote communities

Off-grid communities that rely solely on diesel have to face numerous electricity-related challenges that can be mitigated by integrating renewable energy to create a hybrid energy system. Diversification of the generation increases the stability, lowers the cost of energy, and reduces emissions. The Hesquiaht First Nation established in Hot Springs Cove is transitioning to a hybrid energy system. They currently import six barges containing 50,000 L of fuel annually to power two diesel generators of 100 kW and 250 kW. By 2019, the construction of a 350 kW hydro power generator will be completed, and their diesel consumption reduced to two barges. Once the hydro power generator is added, how can the community further reduce the cost of electricity and fuel consumption?

The following complements have been analysed: wave or solar energy, battery storage, load shifting, and demand-response. The main hypothesis is that wave energy converters are more cost-effective than solar for BS's coastal communities; although a more mature technology, past studies have shown that local insolation does not align with the demand. On the other hand, salted water is a predominant and constant resource.

Narges Golmirzaee, Graduate Student, University of Calgary, AB, Canada

Impulse Analysis of the Cascade Model of Wind Turbine

Calculation of lift and drag forces is a key factor for improving the efficiency of wind turbines. However, the conventional methods of calculating these forces are rudimentary. To derive more exact equations of lift and drag forces, we resort to cascades for simulation of wind turbine blades. A cascade consists of a column of infinite lifting bodies which are equally distant from each other. It is 2-dimensional equivalent to axisymmetric wind turbine blades. The novelty of this work is to use impulse equation for deriving lift and drag forces. The advantage of using the impulse equation is twofold. First, this equation excludes pressure by using linear-algebra techniques. Second, there is a relationship between force and vorticity in the impulse equation, and we can calculate the vorticity over the whole domain. For a two-dimensional steady state incompressible flow in far wake, the calculation gives us the lift force as the well-known Kutta-Joukowski equation plus another term that includes vorticity, and the drag force as an equation that has vorticity. The aim is to explore the role of the vorticity in the performance of wind turbines.

Kyle MacDonald, Graduate Student, University of British Columbia, BC, Canada

Current-voltage estimates in batteries and brains

One basic property of any electronic device is its current-voltage curve. For an ideal resistor (i.e. one to which Ohm's law applies) this curve is linear, but many resistors of interest are not ideal. For these, it is desirable to predict current-voltage characteristics from underlying material properties. Generally this has to be done numerically from measured data, but valuable insight into the numerics can be gained from an analytical study of a toy model. To illustrate this point, we present some results obtained in an undergraduate project by applying basic methods of real analysis and thermodynamics to the Planck-Nernst equations, which are a serviceable model of a two-species electrolyte solution, such as in a conventional battery. This work was supervised at McMaster University by Bartosz Protas. We also present more recent results that use asymptotic methods adapted from the neurophysiological literature, where the properties of electrolyte solutions in nerve cells have been explored at length. Future work will consider similar transport efficiency estimates in more specific models of promising energy technologies.

Rutvija Manohar, Graduate Student, Kyoto University, Japan

Modelling and control of DC generation network with DC/DC converters connected in a ring formulation

This poster presents an autonomous dispersed generation system of multiple DC/DC converters with DC power sources connected in a ring formulation. Passivity Based Control (PBC), with its energy-modifying and damping-injection technique, is applied to a ring coupled converter system to stabilize itself at a desired DC voltage in the presence of external disturbances. Energy shaping implies the design of a new energy function with its minimum at the desired equilibrium and damping injection indicates the introduction of appropriate damping to ensure asymptotic stability. The modified energy function is shown to be a candidate of Lyapunov function.

To apply PBC, it is desirable to shape the total energy of the system while considering the physical structure. The electrical system is modelled as a Port-controlled Hamiltonian (PCH) system, which facilitates network representation of the systems in interaction with their environment. Numerical simulations were carried out with the ode45 solver on Simulink. The results exhibit successful stabilization of the output voltage of the entire ring coupled DC network to the desired state. Comparison to the dynamic behaviour of the original system suggests the successful application of PBC during transient operation."

Paul Westermann, Graduate Student, University of Victoria, BC Canada

Segmentation of smart meter data for retrofit analysis

The significant share in final energy use of buildings is well known. Predominantly, this is caused by thermal energy demand for heating and cooling. Building codes on energy efficiency often pertain to new buildings. On the other hand, lack of analytical methods on the existing building stock inhibits large-scale retrofitting policies based on already available smart meter data. Although smart meter data can be disaggregated to identify active building components and appliances, it has limited use in retrofitting recommendations. In this study, we propose a novel data driven approach to identify existing buildings with high-energy demand reduction potential. This is done by applying piecewise linear regression on outside-air temperature vs. energy consumption data, also called the change-points plot. The resulting slopes of segments and location of change-points are analyzed in detail for each building. Such classification enables buildings to be sorted by high and low energy reduction potential. In addition, it gives information on improvement potential at both, envelop as well as heating system efficiency level. We showcase the approach using smart meter data from 480 buildings on Vancouver Island."

Thank you to our Partners