The **ReDeveLoP** Challenge **2019**

Link to website for cell phone users.

ucalgary.ca/science/redevelop

NSERC CRSNG

ReDeveLoP (Responsible Development of Low-Permeability Hydrocarbon Resources) is a CREATE initiative (Collaborative Research And Training Experience) funded by NSERC.

ENHANCED JOB-SKILLS DEVELOPMENT THROUGH COLLABORATION

UNIVERSITY OF CALGARY

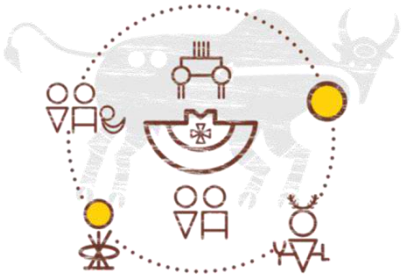
UNIVERSITY OF ALBERTA

Western

UNIVERSITY OF TORONTO

UNIVERSITY OF WATERLOO

"Coming together is a beginning, staying together is progress, and working together is success."
Henry Ford



We acknowledge the traditional territories of the people of the Treaty 7 region in Southern Alberta, which includes the Siksika, the Piikuni, the Kainai, the Tsuut'ina and the Stoney Nakoda First Nations, including Chiniki, Bearspaw and Wesley First Nation. The City of Calgary is also home to the Metis Nation of Alberta Region III.

Welcome from the Chair

The Faculty of Science at the University of Calgary welcomes you to **The ReDeveLoP Challenge 2019,** our 2nd Annual Conference on the *responsible development of low-permeability hydrocarbon resources.* This conference is a progress update and general meeting of academics, government, industry, and Indigenous stakeholders supporting an innovative training program for young researchers who will be the next generation of science and engineering leaders and policy makers in Canada.

Technological developments in the past several decades have unlocked vast energy resources in the form of hydrocarbons contained in low-permeability rock formations. Deriving full economic benefit from these unconventional resources, while also fulfilling Canada's international commitments for reducing greenhouse gas emissions, will require radical new approaches and innovative technologies. Future innovators and leaders within industry, government, and Indigenous communities will rely on technical knowledge that crosscuts western disciplines in the natural sciences, traditional knowledge, and a deep understanding of pertinent socio-economic and environmental factors.

ReDeveLoP is a six-year program delivering professional training of highly qualified personnel (HQP) at five Canadian universities within the inter-disciplinary area of unconventional energy resources in preparation for the Canadian workforce. In addition to existing programs offered at each institution, students participate in activities designed to enhance communication and project management skills, introduce them to Indigenous ways of knowing, and provide exceptional industry networking opportunities. Responsible development of low-permeability hydrocarbons and other resources must be efficient, restorative by design, and balance economic factors, environmental issues and public acceptability. The CREATE ReDeveLoP Annual Conference promises to be an exciting and thought-provoking experience for all participants, including 16 HQPs, 7 graduates, and 11 faculty members from 5 universities, and a diverse representation from stakeholder groups, including Dragon's Den judges, invited speakers and energy champion panelists who have volunteered their time and expertise to make this program a success.

Dr. David Eaton
Chair of ReDeveLoP

About Our Graduates

Some of our ReDeveLoP 2017-18 grads have completed their academic degree programs and moved on to energy-sector careers. Jake Fuss, MPP (LNG Team) is a Junior Policy Analyst with The Fraser Institute in Vancouver. Michael Lim, MPP (Orphan Wells Team) is a Regulatory Analyst with Canadian Pacific in Calgary. Jade McLean, MPP (Pipeline vs. Rail Team) is a Policy Analyst with Canada West Foundation in Calgary. Leah Wilson, MSc (Hydraulic Fracturing Team) is a Water Stewardship Advisor with Encana in Calgary, and Linh Tran has gone on to a PhD in Economics at the University of Alberta.

Testimonials from Our Grads

"The ReDeveLoP program took me completely out of my comfort zone; however, it was an experience and a very rewarding one. The program opened new topics for me, such as the perception of Indigenous communities with current oil & gas projects, and how media representation impacts such perceptions. It has also made me realize the importance of transparency and inclusivity of First Nations elders on energy projects that can benefit all people." - **Aly Abdelaziz.**

"The ReDeveLoP program allowed me to learn a variety of teamwork, networking, and project/team management skills. I feel that as a direct result of the program, my confidence as a young professional is significantly improved. The program improved my understanding of human behaviour when working under pressure or outside one's comfort zone - including my own behaviour in these conditions. Teamwork under any conditions can be challenging but working remotely from different universities with individuals from a variety of disciplines adds multiple levels to those challenges. The program provided an opportunity to experience these challenges in a way that encouraged positive growth and skill improvement." - **Jordan Phillips.**

"I learned many different perspectives about social science and economics that I never had exposure to before. The program definitely also tested my existing abilities to handle group and technical conflicts and was a good exercise in team conflict management. I thought the integration of Indigenous history and the experience of Indigenous culture in the program was the best part of ReDeveLoP and I definitely learned quite a bit. I will carry these lessons forward in all future stakeholder relationships and in my engineering work." - **Scott McKean.**

“The ReDeveLoP program certainly sheds light on how important it is to share information in a way that is clear, concise, and captivating to a general audience. In doing so, I gained a more thorough understanding of the subject matter, plus I was able to tap into my newfound creative side which I really enjoyed. Working with a team was very enlightening for me. I learned to predict situations where conflicts may arise by getting to know my teammates and having open discussions about our various work styles, including any strengths or weaknesses. My understanding of Indigenous history in Canada has changed drastically over my ReDeveLoP journey. I didn't realize how little I really knew until now, and I'm grateful for this awareness and new perspective.” – **Anonymous.**

“I gained an understanding of life cycle assessments and factors to consider when determining the feasibility of a project, as well as the importance of being able to effectively communicate topics of your understanding to others in different professional fields, and how to work together to come up with a solution. The project took me completely out of my comfort zone, and I didn't realize how much I had learned about a whole new topic/industry until the end. This was also my first time directly contacting Indigenous groups/leaders myself. It gave me a really good understanding of the troubles faced by those Indigenous communities in more remote areas of the country – things that I had not considered before or was unaware of until I reached out to speak with the people living here. The most important lesson that I took out of this was the community's desire for independence and how important it is to ensure highly trained personnel exist within the community in order to ensure that projects are successful.” – **Anonymous.**

The Academic Team

UNIVERSITY OF CALGARY

David Eaton
Chair

Nancy Chen

Chris Clarkson

Jeniffer Winter

UNIVERSITY OF CALGARY

Jeff Priest

Bernhard Mayer

Celia Kennedy
Project Manager

UNIVERSITY OF ALBERTA

Mirko Van Der Baan

Karlis-Muehlenbachs

UNIVERSITY OF TORONTO

Giovanni Grasselli

UNIVERSITY OF WATERLOO

Maurice Dusseault

Western

Burns Cheadle

ucalgary.ca/science/redevelop/team-1

David Eaton, Geoscience, University of Calgary, Professor, NSERC/Chevron IRC in Microseismic System Dynamics and NSERC CREATE ReDeveLoP Chair. Dave received his BSc from Queen's University in 1984 and his MSc and PhD from the University of Calgary in 1988 and 1992 respectively. Dr. Eaton completed post-doctoral research with Arco's Research and Technical Services (Plano, Texas) and the Geological Survey of Canada (Ottawa). He rejoined the University of Calgary in 2007, following an 11-year academic career at the University of Western Ontario. Dave is presently Co-director of the Microseismic Industry Consortium, a novel, applied-research geophysical initiative, dedicated to the advancement of research, education and technological innovations in microseismic methods and their practical applications for resource development. In addition to microseismic monitoring and induced seismicity, his current research is also focused on intraplate earthquake swarms, and the lithosphere-asthenosphere boundary beneath continents.

Mirko Van der Baan, Physics, University of Alberta, Professor and 2017 Honorary Lecturer (North America) for the Society of Exploration Geophysicists. Mirko received his MSc from the University of Utrecht (Netherlands) in 1996 and his PhD from the Joseph Fourier University (Grenoble, France) in 1999. He later became the Reader of Exploration Seismology at the University of Leeds (UK) and holds an HDR (Habilitation) from University Denis Diderot, Paris, France. Today, Dr. Van der Baan specializes in exploration seismology and is the Director of the Microseismic Industry Consortium, a collaborative venture with the University of Calgary, dedicated to research in microseismicity. He is also one of the founding members of the Integrated Petroleum Geosciences (IPG) professional MSc program at the University of Alberta.

Maurice Dusseault, Earth & Environmental Sciences, University of Waterloo, Professor. Maurice is a Professional Engineer in both Alberta and Ontario, and teacher of Geological Engineering at UW. He received his BSc in 1971 and his PhD in 1977 from the University of Alberta. Maurice is a well-known educator and consultant, holding >90 international patents and ~ 550 full-text papers published in journals and conferences. Dr. Dusseault's research is in deep underground engineering issues, including oil production, hydraulic fracturing, energy storage, geothermal energy, carbon sequestration, and deep injection disposal of granular solids and liquid wastes (including biosolids, oilfield wastes, and civil wastes). He is also interested in energy technologies that can be downscaled to community levels to provide robust and reliable heat and power, including natural gas approaches and heat geostorage. Maurice served as advisor to the Canadian Provinces of Alberta, Quebec, New Brunswick, Nova Scotia and Newfoundland and Labrador, on matters relating to energy development, hydraulic fracturing, energy geo-storage, wellbore integrity, technology and innovation. He also served as an advisor to the Alberta Government for many years, and to the US Bureau of Reclamation on the Paradox Valley brine disposal well.

Shengnan (Nancy) Chen, Chemical and Petroleum Engineering, University of Calgary, Associate Professor. Nancy received her BSc in 2003 from China University of Petroleum and her PhD in Petroleum Systems Engineering from the University of Regina in 2012. Dr. Chen's group focuses on developing strategies to enhance the oil/gas recovery in the unconventional tight/shale reservoirs with massive hydraulic fractures. The group has developed novel numerical simulation and mathematical optimization techniques, demonstrated to increase oil recovery and lifespan of wells. Their work will help forecast the impacts of the complex fracture network on the well after-stimulation productivity during field operational process.

Christopher Clarkson, Geoscience, University of Calgary, Professor and Assoc. Prof in Chemical and Petroleum Engineering, 2017 ASTech Award Winner for Outstanding Achievement in Applied Technology & Innovation. Dr. Clarkson is an AITF Shell / Encana Chair in Unconventional Gas and Light Oil research. The focus of his work in industry was on exploration for and development of unconventional gas (UG) and light oil (ULO) reservoirs. Since joining the University of Calgary in 2009, the focus of his research has been on advanced reservoir characterization methods for UG-ULO, such as rate- and pressure-transient analysis, flowback analysis, and core analysis. Chris is also interested in simulation of enhanced recovery processes in UG-ULO, and how these processes can be used to reduce greenhouse gas emissions. Dr. Clarkson leads an industry-sponsored consortium called "Tight Oil Consortium", focused on these research topics for unconventional light oil reservoirs in Western Canada. Chris holds a PhD in geological engineering from the University of British Columbia, and is the author of numerous articles in peer-reviewed scientific and engineering journals. He was an SPE Distinguished Lecturer for the 2009/2010 lecture season, and is the 2016 recipient of the Reservoir Description and Dynamics Award (Canadian Region) from the SPE.

Burns Cheadle, Earth Sciences, University of Western Ontario. Associate Professor and Director of Corporate Relations and Student Professional Development. Burns received his BSc from Lakehead University in 1981 and his PhD from Western University in 1986. He returned to Western in 2009, following a 23-year career in the upstream oil and gas sector in Calgary. His research focuses on reservoir characterization and petroleum system evolution of carbonaceous mudrock successions. This work extends to responsible development of tight oil and shale gas plays with a specific focus on geological controls on triggered or induced seismicity processes. In his administrative role, Burns develops and coordinates experiential and reflective learning programs aimed at developing professional competencies in undergraduate and graduate students in Western's Faculty of Science.

Jennifer Winter, Economics and School of Public Policy, University of Calgary, Assistant Professor and Scientific Director, Energy and Environmental Policy. Jennifer holds a BA, MA and PhD (2011) from the University of Calgary. She is actively engaged in increasing public understanding of energy and environmental policy issues. Recognition of her efforts include: 2014 Young Women in Energy Award, and being named one of Alberta Oil Magazine's Top 35 Under 35 in 2016. Dr. Winter's research is focused on the effects of government regulation and policy on energy development and the associated consequences and trade-offs. Current research projects are the prospects for Canadian LNG exports to Europe, social impacts of hydraulic fracturing, and comparing provincial emission-reduction policies. She also directs the Canadian Network for Energy Policy Research and Analysis. Currently, Jennifer serves on the Future Leaders Board of Directors, World Petroleum Council Canada, and is a member of Global Affairs Canada's Environmental Assessment Advisory Group.

Jeffrey Priest, Civil Engineering, University of Calgary, Professor and CRC Tier II Chair in Geomechanics of Gas Hydrates. Jeff received his B.Eng and PhD from the University of Southampton (UK) in 2000 and 2004 respectively. Dr. Priest is a geotechnical engineer, with research broadly associated with understanding the geomechanical performance of soil and rocks through laboratory and field measurements. His research has primarily focused on the behavior of gas-hydrate-bearing soils and railway foundations. Since arriving at the University of Calgary, in 2013, Jeff has started to apply his expertise in the area of hydraulic fracturing to help address some of the challenges that exist, such as: linking observed microseismicity to the geomechanical response of shale rock during hydraulic fracturing.

Bernhard Mayer, Geoscience, University of Calgary, Professor. Bernhard received his BSc, MS and PhD (1993) in Isotope Geochemistry from Ludwig Maximilian University of Munich (Germany). Dr. Mayer employs chemical and isotopic techniques to trace water, carbon, nitrogen, oxygen, and sulfur-containing compounds in surface and subsurface environments. His research applies innovative scientific approaches with the goal to reduce environmental impacts of anthropogenic activities including fossil fuel production. Bernhard served as a member of the National Scientific Review Panel on Harnessing Science and Technology to Understand Environmental Impacts of Shale Gas Extraction, coordinated by the Council of Canadian Academies (CCA), and as assistant scientific director of Carbon Management Canada (CMC), which is a Networks of Centers of Excellence (NCE), Canada, hosted at the University of Calgary. Dr. Mayer has (co-)authored >145 papers in international peer-reviewed journals and 15 book chapters on a wide variety of geochemical topics, including: geologic CO2 sequestration, shale gas development, and water sources in the Athabasca oil sands region of northeastern Alberta.

Karlis Muehlenbachs, Earth & Atmospheric Sciences, University of Alberta, Professor. Karlis is a world-renowned stable isotope geochemist, receiving his BA in Chemistry from Washington University (St.Louis) and his PhD from the University of Chicago in 1971. His doctoral thesis on the Oxygen isotope geochemistry of mid-ocean rocks was the first comprehensive study of the interaction of sea water with the oceanic crust, and his post-doctoral discovery of the low 18O isotope anomaly in Icelandic basalts resulted in methods to measure diffusion rates. His work in organic isotope geochemistry during his Humboldt Fellowship at the German Geological Survey, in 1981, led to monitoring techniques used in the coal and petroleum industries. Lately, Dr. Muehlenbachs and his students have utilized the isotopic composition of natural gases to elucidate their varied origins from biogenic to over mature shale gas. His research group also pioneered isotopic fingerprinting of fugitive gases from energy wells in order to identify their source depth, thereby facilitating remediation. Karlis' interests remain in using stable isotope analysis of natural gases to better understand the genesis and evolution of gas in tight reservoirs thus improving their production, but also to assist in minimizing gas migration from production facilities.

Giovanni Grasselli, Civil Engineering, University of Toronto, Professor, Foundation CMG Research Chair - Fundamental Petroleum Rock Physics and Rock Mechanics. Giovanni received his MSc in Civil Engineering in 1995 from the University of Parma (Parma, Italy) and his PhD from the Swiss Federal Institute of Technology EPFL (Lausanne, Switzerland) in 2001. He received the prestigious ISRM Rocha Medal (2004) for best thesis worldwide in rock mechanics and also supervised two Rocha Medal winners (2015 and 2017). Dr. Grasseli's research focuses on hybrid finite-discrete element (FDEM) numerical technology, experimental visualization techniques and geomechanics principles applied to the study of hydraulic fracturing. Through the start-up company, Geomechanica Inc., the FDEM technology is currently commercialized and translated to engineering practice.

Celia Kennedy, Geoscientist and **NSERC CREATE ReDeveLoP Project Manager**, University of Calgary. Celia received her BSc.(Hon) in Environmental Science from Carleton University (2005). She received her MSc in Environmental Biology (2010) and PhD in Hydrogeology (2017) from the University of Guelph. While managing the ReDeveLoP Program, Celia is also the Research Coordinator for the Gas Migration Field Research Project and working on publications from her PhD research in groundwater - surface water interaction in bedrock rivers. Dr. Kennedy is the mother of two engineers and had a prior 10-year career as a paralegal working in criminal and property law during the early years of implementation of environmental law in property development in Ontario.

Conference at a Glance

Monday, May 27

St. Louis Rooms I & II, 2nd Floor, Hilton Garden Inn

8:00 AM - 8:45 AM	**BREAKFAST Buffet -** *David Eaton, moderator*
	Welcome to The ReDeveLoP Challenge, by Prof. David Eaton, U.Calgary and ReDeveLoP Chair
8:45 - 9:10	**Science and Public Perception,** by Dan Allan, P.Geo., President, CSUR
9:15 - 9:45	**Greater than the Sum of Its Parts: Toward Integrated Management of Natural Resources Management in Canada,** by Jérôme Marty, PhD, Project Director, CCA, and Martin Olszynski, Law Professor, U.Calgary
9:50 - 10:20	**Indigenous Engagement #1,** by Arthur Cunningham, President, Round Table Consulting
10:30- 10:40	***Health Break -*** *Jennifer Winter, moderator*
10:40- 11:00	**Rebirth of Social Licence,** by Kristen van de Biezenbos, Law Professor, U.Calgary
11:05- 11:35	**Translational Outreach for Shale Energy Stakeholders,** by Tom Murphy, Director, MCOR at Penn State Cooperative Extension
11:40 AM - 12:00 PM	**Listening to Advocates #1,** by Brad Hayes, PhD, P.Geo., President, Petrel Robertson Consulting Ltd., Secretary-Director of CSUR, and Adjunct Professor at U.Alberta.
12:00- 12:10	***Health Break***
12:10- 12:30	**Listening to Advocates #2,** by Brad Hayes
12:35- 12:55	**How to Network and Build a Meaningful Community of Contacts,** by Hamreet Sekhon, MPP, Senior Advisor, School of Public Policy, U.Calgary

1:00 - 1:20	***Health Break*** *- Giovanni Grasselli, moderator* *St. Louis Room III opens, Appetizer Buffet & Cash Bar will remain open until **5:00 PM*** Introduction of Dragons and Exhibitors Challenge videos on continuous loop
1:20 PM	 ***POSTER SESSION - Round #1*** 
1:20- 2:00	Introduce **Induced Seismicity** Teams Dragons evaluate posters Q & A from general audience
2:00 - 2:10	***Networking Break***
2:10 - 2:50	Introduce **Hydraulic Fracturing** Teams Dragons evaluate posters Q & A from general audience
2:50 - 3:00	***Networking Break*** *- Celia Kennedy, moderator*
3:00 - 5:00	***Speed-Dating with Industry,*** followed by open networking.

Tuesday, May 28

St. Louis Rooms I & II, 2nd Floor, Hilton Garden Inn

8:00 AM	**BREAKFAST Buffet -** *Jeff Priest, Moderator*
8:25 - 8:45	**Environmental Risk Assessment,** by Dan Soeder, Director of Energy Resources Initiative, SDSMT
8:50 - 9:15	**The Western Canadian Sedimentary Basin: A Confluence of Science, Technology, and Ideas,** by Paul McKay, PhD, P.Geo., President – Shale Petroleum Ltd., and Adjunct Professor at the U.Calgary.
9:20 - 9:35	**Collaborative Research & Student Training,** by Oba Harding, Business Director, Mitacs.
9:40 - 9:50	***Health Break*** *- Introduce Dragons, Draw names for order of presentations*
9:50 AM	 ***PRESENTATIONS - Round #2*** 
9:50- 10:40	Introduce **Induced Seismicity Team A** (5 min) Presentation (15 min), followed by 2 rounds of Q&A. Dragons will each have 5 min per round (30 min).
10:40- 10:55	***Networking Break***
10:55- 11:45	Introduce **Induced Seismicity Team B** (5 min) Presentation (15 min), followed by 2 rounds of Q&A. Dragons will each have 5 min per round (30 min).
11:45- 12PM	***Networking Break*** *- Bernhard Mayer, moderator*
12:00- 12:45	**LUNCH Buffet**
12:45- 1:35	Introduce **Hydraulic Fracturing Team A** (5 min) Presentation (15 min), followed by 2 rounds of Q&A. Dragons will each have 5 min per round (30 min).
1:35 - 1:50	***Networking Break***
1:50 - 2:40	Introduce **Hydraulic Fracturing Team B** (5 min) Presentation (15 min), followed by 2 rounds of Q&A. Dragons will each have 5 min per round (30 min).

Health Break *- David Eaton, moderator*

2:40 - 2:55 ***Introduce Energy Champ Panel Discussions***

Each panelist will have 5 min to present a slide, followed by 15 min of Q&A

Energy Champ Panel #1:

2:55 - 3:40 **Public perception and the future sustainability of the oil/gas industry in Canada**

PANELISTS: (1) **Brad Hayes**, Geologist & President of Petrel Robertson Consulting, (2) **Donna Phillips**, EVP Corporate Development, Canbriam Energy, (3) **Ramez Hanna Alla,** Mechanical Engineer at Chevron, (4) **Bill Whitelaw**, President & CEO of JWN Energy, and (5) **Dave Browne**, Director of IP & Public Affairs at Trican Well Service.

Energy Champion Panel #2:

3:40 - 4:25 **Orphan wells, legacy pipelines, climate change and the carbon tax**

PANELISTS: (1) **Mike Johnson,** Technical Lead at the National Energy Board, (2) **Heather Lemon,** Exec.Advisor at the Alberta Energy Regulator, (3) **Brian Schulte**, Geophysical Advisor at Schiefer Reservoir Consulting, (4) **Jim Reimer**, Petroleum Geologist for 37 years, and (5) **Lars DePauw,** Environmental Engineer & Exec. Director of the Orphan Well Assoc.

Networking Break *- St. Louis Room III opens, Appetizer Buffet and Cash Bar.*

4:25 - 6:00 Dragons return from deliberation.

Presentation of awards and networking.

Invited Speaker Abstracts

Greater than the Sum of Its Parts: Toward Integrated Natural Resource Management in Canada

Jérôme Marty, PhD, Project Director at the Council of Canadian Academies (Ottawa), and Martin Olszynski, Assistant Professor, University of Calgary.

Natural resources constitute a key element of Canada's identity. The ongoing debates and division regarding how these resources are being developed underscore the importance and timeliness of this report, which explores integrated natural resources management in Canada. In the last few decades, the health of many of Canada's diverse ecosystems has been increasingly threatened and there has been a loss of public confidence in our system of natural resource management. The limitations of project-level management practices are becoming more evident, leading to conflict and delays. Several significant court cases in recent years have challenged the status quo approach to resource management. At the same time, there is real concern over the competitiveness of Canada's resource industries. It is clear that Canada needs to shift the way it plans and manages natural resource development away from siloed project-level processes toward more integrated approaches. The Expert Panel on the State of Knowledge and Practice of Integrated Approaches to Natural Resource Management in Canada hopes this report will support enhanced implementation of INRM in Canada to strengthen the sustainability and legitimacy of our systems of resource management.

Rebirth of Social Licence

Kristen van de Biezenbos, Assistant Professor of Law, University of Calgary.

Canada's energy industry and the agencies that regulate it are suffering a crisis of legitimacy. Both are battered by shifting public opinion, opposition from powerful NGOs, a troubled history with many communities and Indigenous groups, and the actions of political parties that consider opposition to oil and gas projects to be central to their platforms. In such an environment, the concept of social licence to operate, or simply social licence, seems more important than ever to the energy industry. This Article argues, however, that it is not the ability or inability to obtain social licence, as the term is currently used, that will allow the fossil fuel industry to maintain some measure of public good will and to lower municipal and provincial resistance to energy projects. That is because, while social licence has some value as a normative concept, it is functionally meaningless. Not only has the term itself been hollowed out by overuse and fluctuating definitions, but what it represents in popular discourse—a broad public acceptance or approval—is probably not achievable. For too long, the national debate over social licence has obscured the very real concerns over the local impacts of energy projects, and this has eroded the trust and support of communities. This Article proposes that the concept of social licence should be understood as descriptive only, and what should matter instead is what measures companies can take to earn that descriptor. This Article also argues that, in order to obtain acceptance from local and community groups and thus to obtain social licence, Canadian energy companies should follow the lead of companies in other jurisdictions and employ community agreements to demonstrate their commitment to responsible resource development and to earn local buy-in for projects.

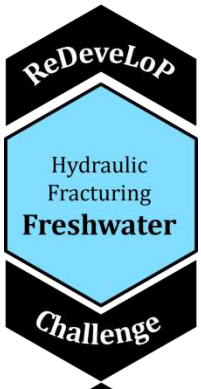
Translational Outreach for Shale Energy Stakeholders

Tom Murphy, Director, Penn State's Marcellus Center for Outreach and Research (MCOR).

There is a sustained, ongoing demand from stakeholders in the Commonwealth, ranging from landowners to elected officials, attempting to understand the trends associated with shale energy development in Pennsylvania and beyond, as they impact individuals and communities. Examples include: construction of new pipeline infrastructure, emerging research on health implications of shale energy production, revenue generation policy, new legal precedents impacting municipalities and/or landowners, water resource protections, fugitive methane emission reduction, regulatory education, and a host of other important issues. MCOR is a trusted venue for this education and provides the needed translational component as it has extensive and holistic experience with the topics and has earned credibility with a wide range of audiences. More recently, MCOR has engaged hundreds of participants in an *immersive outreach program,* providing an opportunity to view shale energy exploration first-hand, see the impact of development in the community, and learn directly from key regional voices embedded in the shale dialogue. The experience is unique for each delegation, aligned and customized to address the priorities of the group. Conducted for international embassy staff, government agency personnel, elected officials, oil & gas industry partners, media representatives, and distant university collaborators. The latest chapter in this immersive training initiative is the current use of virtual reality (VR) technologies as a new medium for stakeholders to "realistically" experience the implications of shale energy development, and impact decision making at the community level, along with influencing public policy in energy.

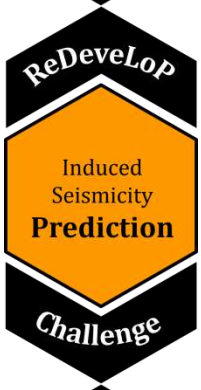
The Challengers

are *scholarship recipients and graduate students of the NSERC CREATE ReDeveLoP Program under Grant #386133824*



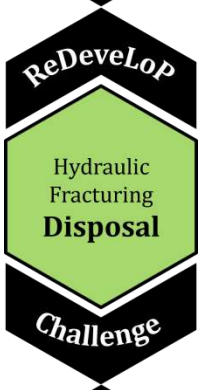
Hydraulic Fracturing - Freshwater Team

Reducing freshwater in hydraulic fracturing: An analysis of fracturing fluids used in the Montney Formation in Alberta and policy recommendations for freshwater reduction 16



Induced Seismicity - Prediction Team

Mitigation of Induced Seismicity that is Triggered by Hydraulic Fracturing 20

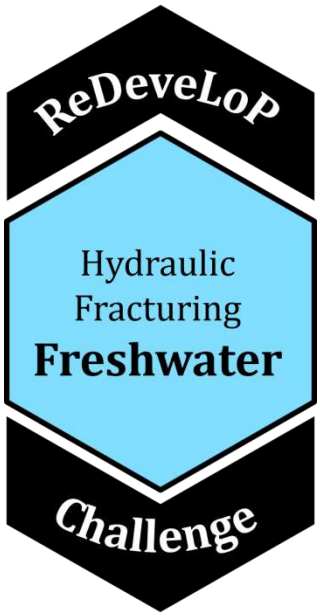


Hydraulic Fracturing - Disposal Team

Risks and Mitigations for Hydraulic Fracturing Wastewater Disposal Operations in Western Canada 24

Induced Seismicity - Traffic Team

Utilizing Ground Motion in the Traffic Light System for the Management of Induced Seismicity in Alberta 28



Hydraulic Fracturing - Freshwater Team

Mirella Chiappe *(Project Manager)*

Jorge Nustes Andrade

Paulina Wozniakowska

Rasoul Sheikhmali

UNIVERSITY OF CALGARY

Mirella Chiappe
Policy

Paulina Wozniakowska
Geophysics

Rasoul Sheikhmali
Engineering

UNIVERSITY OF ALBERTA

Jorge Nustes Andrade
Geophysics

Mirella Chiappe is working on her **MPP** in Public Policy with Prof. Winter at the University of Calgary. She received a **M-Plan** (2018) in Urban Planning at the University of Calgary, and a **BA** (2014) in Geography at McGill University. Mirella is also the **Project Manager** of her team. Mirella's research interest is in environmental and economic policy. She has been actively involved in graduate student government and is serving as VP of Internal Affairs on the MPP Student Assoc. Mirella has a global perspective, having lived in Montreal, New York and London (UK), and would be willing to relocate for the right position. In her free time, she enjoys running, travelling, and trying new foods.
Contact: mchiappe@ucalgary.ca

Jorge Nustes Andrade is working on his **MSc** in Geophysics with Prof. Van Der Baan at the University of Alberta. He received a **BSc** (2018) in Geoscience at Universidad de Los Andes Colombia. Jorge's current research interest involves the use of machine learning techniques for microseismic interpretation and event detection. He is an active volunteer at the SEG Wiki and a 2017 SEG Wiki Champion. Jorge enjoys the outdoors and sports, especially soccer and basketball. He is bilingual (English and Spanish) and willing to relocate for the right position.
Contact: nustesan@ualberta

Paulina Wozniakowska is working on her **PhD** in Geophysics with Prof. Eaton at the University of Calgary. She received her **MSc** (2016) and **BSc** (2015) in Applied Geophysics at the AGH University of Science and Technology in Krakow, Poland. Paulina's current research focuses on applications of machine learning in induced seismicity analysis. Before returning to academia, she worked in the Czech Republic as a junior analyst at a company specializing in microseismic monitoring of hydraulic-fracturing operations in USA and Canada. Paulina has also completed internships in Poland and Slovakia, in the areas of mining seismology and environmental monitoring using geophysical methods. She was a board member of the SEG Student Chapter in Krakow, and currently, is a member of the CSEG/EAGE/SEG Student Chapter in Calgary. In her spare time, Paulina enjoys yoga, board games and the ukulele. She speaks a number of languages, including English, Polish, Spanish and Czech.
Contact: paulina.wozniakowska@ucalgary.ca

Rasoul Sheikhmali is working on his **PhD** in Civil Engineering with Prof. Priest at the University of Calgary. He received a **MSc** in Mining Engineering (2016) at the University of Tehran, and a **BSc** (2012) in Mining Engineering at the Urmia University, in Iran. Rasoul's research interests are in the areas of numerical modelling of hydraulic fracturing and analysis of casing collapse phenomenon. After completing his MSc, Rasoul worked on an academic-industry collaborative geomechanical research project (i.e., casing collapse in the Iranian oilfields). Rasoul is trilingual (English, Persian and Azerbaijani). He loves mountaineering, traveling and music.
Contact: rasoul.sheikhmali@gmail.com

Reducing freshwater in hydraulic fracturing: An analysis of fracturing fluids used in the Montney Formation in Alberta and policy recommendations for freshwater reduction

Mirella Chiappe[1], Jorge Nustes Andrade[2], Paulina Wozniakowska[3], and Rasoul Sheikhmali[4]

Hydraulic fracturing is a water-intensive method of oil and gas extraction from unconventional reservoirs. In Alberta, hydraulic fracturing operations are performed primarily within the Montney Formation. The rapid expansion in the employment of this technique over the last few years has led to a growing demand for freshwater by industry. The extraction of large amounts of fresh water from natural sources, such as aquifers and rivers, can impact the health of these sources, especially sensitive aquatic ecosystems, and limit the availability of potable water supply to nearby communities. Many existing water management policies and regulations for the oil and gas industry were developed for conventional production methods and have been applied to hydraulic fracturing. This can be problematic since conventional methods use freshwater in different ways and in different quantities than hydraulic fracturing. Responsible and sustainable development of hydraulic fracturing projects requires solutions to reduce the necessity of freshwater use through the development of policy to encourage the use of alternative fracturing fluids.

We conducted a study on 598 stimulated wells in the Montney Formation in Alberta to assess both water usage and the efficiency of hydraulic fracturing fluids (HFF) by comparing the injected water volumes with the first 12 months of production. The HFF were divided into four categories based on their main carrier fluid: water-based, oil-based, energized gas, and energized cryogenic. According to the statistical analysis, wells using energized cryogenic HFF showed the highest barrel of oil equivalent (BOE) production among the four categories. We found that energized cryogenic wells allowed for approximately 20% higher BOE production with 80% less water consumption compared to water-based wells.

Here, we examine freshwater use in hydraulic fracturing in Alberta and relevant policy that could be introduced to support alternate technologies for the reduction of freshwater use in fracking.

Footnotes:
[1] School of Public Policy, University of Calgary, Calgary, Alberta T2N 1N4; mchiappe@ucalgary.ca
[2] Dept. of Physics, University of Alberta, Edmonton, Alberta T6G 2R3; nustesan@ualberta.ca
[3] Dept. of Geoscience, University of Calgary, Calgary, Alberta T2N 1N4; paulina.wozniakowska@ucalgary.ca
[4] Dept. of Civil Engineering, University of Calgary, Calgary, Alberta T2N 1N4; Rasoul.Sheikhmali@ucalgary.ca

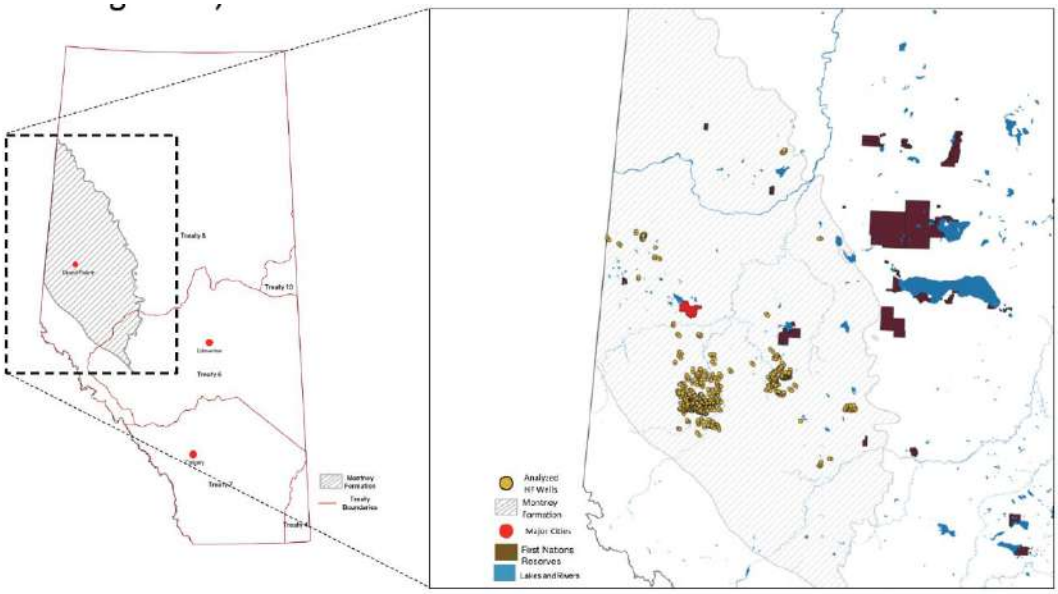


Figure 1. Hydraulic fracturing wells analyzed in the Montney Formation 1.

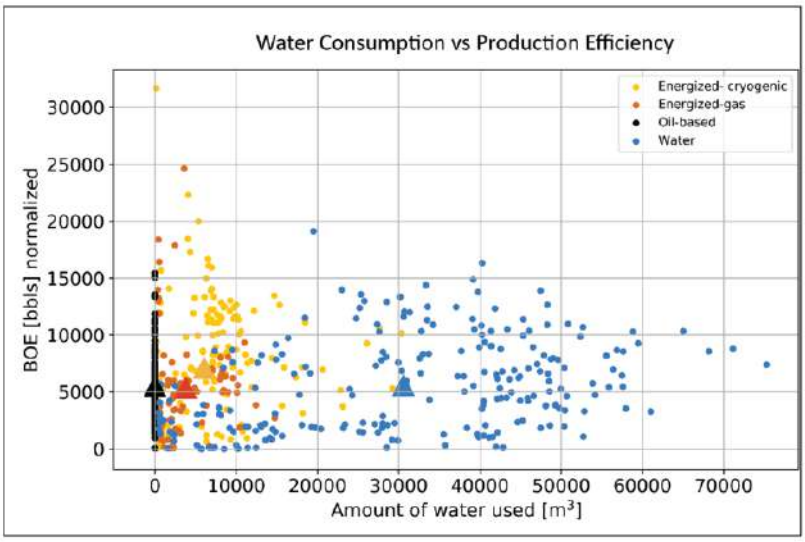


Figure 2. Comparison of resultant BOE and amount of water used. Triangles represent average normalized BOE and water use. In this study only BOE production within the first 12 months was analyzed (Data from FracFocus.ca and GeoSCOUT).

Acknowledgements:

Dr. Jeffrey Priest, Dr. Jennifer Winter, and Dr. Celia Kennedy from the University of Calgary are sincerely thanked for their constant support and guidance during the development of our project for the ReDeveLoP research program. We would like to thank Chief Jim Badger from the Sucker Creek First Nation for providing us with an Indigenous perspective of freshwater use and fracking. Melanie Popp from GeoLOGIC Systems provided help and support with the GeoSCOUT program, which allowed us to access data needed for our analysis. Derrick Britton from Ferus Inc., Dan Allen from CSUR, and Bill Whitelaw from JuneWarren-Nickle's provided valuable contributions regarding industry environmental practices and technical hydraulic fracturing processes. We would finally like to acknowledge the support and funding from the NSERC CREATE ReDeveLoP program.

Induced Seismicity - Prediction Team

Edouard Kravchinsky *(Project Manager)*

Hamzeh Ali Mohammadi

Mitchell Boyne

Zahra Esmaeilzadeh

UNIVERSITY OF TORONTO

Edouard Kravchinsky
Geomechanics

UNIVERSITY OF CALGARY

Hamzeh Ali Mohammadi
Petroleum Engineering

Mitchell Boyne
Policy

Zahra Esmaeilzadeh
Geophysics

Edouard Kravchinsky is working on his **PhD** in Geomechanics with Prof. Grasselli at the University of Toronto. He received a **MSc** in Geophysics (2018) with Prof. Van Der Baan, as well as a **BSc** (2015) in Geophysics, at the University of Alberta. Edouard is also the Project Manager of his team. During his MSc studies, Edouard's research focused on cellular automaton and simulation of earthquake sequences, and he joined the Microseismic Industry Consortium (MIC). His current research focuses on geomechanical modeling, fracture propagations and acoustic emissions. Outside of work, Edouard enjoys an active lifestyle and is a recreational trumpet player.
Contact: edouard.kravchinsky@mail.utoronto.ca

Hamzeh Ali Mohammadi is working on his **M-Eng** in Petroleum Engineering with Prof. Chen at the University of Calgary. He received a **B-Eng** (2006) and an **MSc** (2009) in Petroleum Engineering at the Petroleum University of Technology, in Iran.
Contact: hamzeh.alimohammadi@ucalgary.ca

Mitchell Boyne is working on his **MPP** in Public Policy with Prof. Winter at the University of Calgary. He received a **BSc** (2015) in Mechanical Engineering at the University of Alberta. Mitchell's current research is exploring potential regulatory frameworks for the partial upgrading of bitumen in Alberta. He is registered as an EIT with APEGA and has two years' experience working as a reservoir engineer on in-situ oil sands projects with ConocoPhillips, where he developed production forecasts and optimized operating strategies. Mitchell has completed several internships in the energy sector, including one in completions engineering and one in oilfield equipment design. During his MPP studies, he has received two academic awards. In his free time, Mitchell enjoys playing basketball, hiking, and travelling.
Contact: mitchell.boyne@ucalgary.ca

Zahra Esmaeilzadeh is working on her **MSc** in Geophysics/Seismicity with Prof. Eaton at the University of Calgary. She received a **MSc** (2009) in Reservoir Engineering at the Amirkabir University of Technology, and a **BSc** (2006) in Production Engineering at the Petroleum University of Technology, in Iran. Before returning to academia, Zahra worked 10 years for the National Iranian Oil Company, studying large oil and gas reservoirs and completing, among other things, well and reservoir evaluation and performance modelling, production optimization and forecasting, and simulation studies of enhanced recovery processes in large-scale projects. She served as a member of cross-functional teams, coordinating several projects requiring technical and economic evaluation. Zahra is currently registered as a EIT with APEGA, with a P.Eng. application under review. She is also a nature lover and enjoys charity activities and events.
Contact: zahra.esmaeilzadeh84@gmail.com

Mitigation of Induced Seismicity that is Triggered by Hydraulic Fracturing

Ali Mohammadi, H.[1], Boyne, M.[1], Esmaeilzadeh, Z.[1], and Kravchinsky, E.[2]

Development of low-permeability hydrocarbon resources has increased during the past decade. In some areas, injection-induced seismicity has become a growing concern in the application of hydraulic fracturing of low-permeability reservoirs.

We examine the current state of knowledge in evaluating the seismic hazard of a geological formation or region; focus is given to the Duvernay Formation in Alberta, Canada. In literature, we find that factors such as pre-existing faults and permeable pathways for pressure diffusion and stress transfer, proximity to crystalline basement and reefs, as well as high rates of natural seismicity and pore fluid overpressures are potential indicators of seismic susceptibility.

We utilize 2D geomechanical modeling to gain insight into the impact of fault orientation relative to the minimum (θ_{min}) and maximum (θ_{max}) stresses, along with fault reactivation through hydraulic fracturing (HF). We find that during HF treatments, fracture growth is hindered for the critically angled fault (30°N from θ_{max}) relative to the stable fault orientation (90°N from θ_{max}). Moreover, a stable fault acts as a hydraulic conduit for injected fluids, whereas a critically angled fault acts as a fluid sink. Greater displacement magnitudes occur for critically angled faulaats, thus, greater fault slip occurs.

We examine two mitigation practices of skipping stages and HF at half the injection spacing. Skipping stages reduces the total injected volumes, whereas decreasing the injection spacing reduces the length of fracture growth. We find that for the critically angled fault effectiveness of mitigation methods is greatly reduced.

Finally, we summarize current policies and outline possible policy measures that could help minimize the risk of induced seismicity. Moving forward, we suggest that regulators establish minimum pre-operation induced seismicity risk assessment criteria to form a baseline of assessment. Additionally, we recommend that regulators explore expanding induced seismicity regulations to areas near population centers and critical infrastructure to lower the risk of high impact events.

FOOTNOTES:
[1]*University of Calgary /* [2]*University of Toronto*

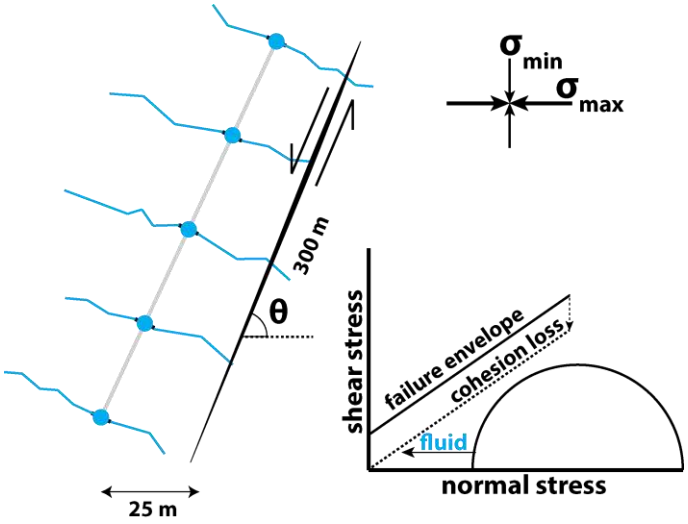


Figure 1. Plan view of model concept with a 300-meter long broken discrete fracture (fault) at an angle θ from the maximum stress orientation σ_{max}. Hydraulic fracturing is simulated through 5 injection points 25 meters away horizontally. Mohr circle represents a simplified conceptual failure criterion through fluid injection into a fault.

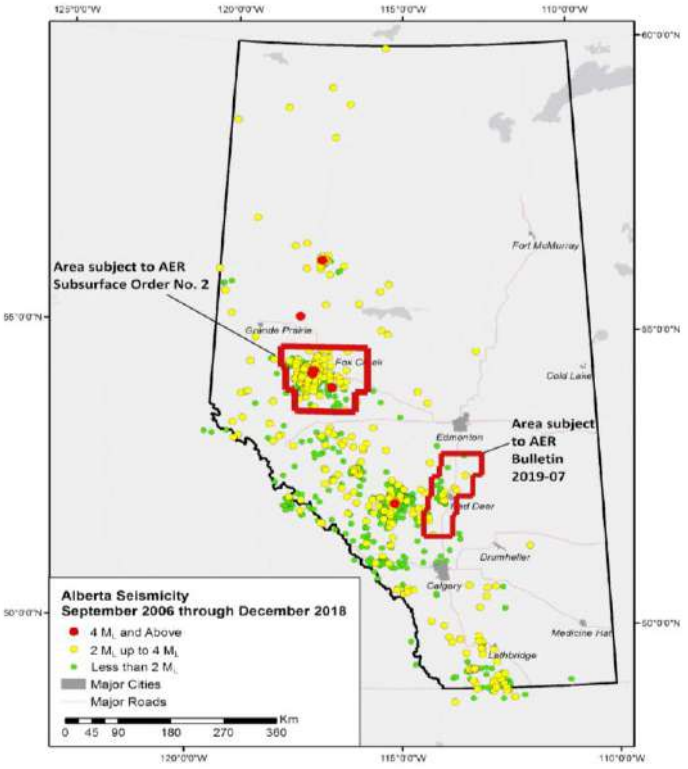
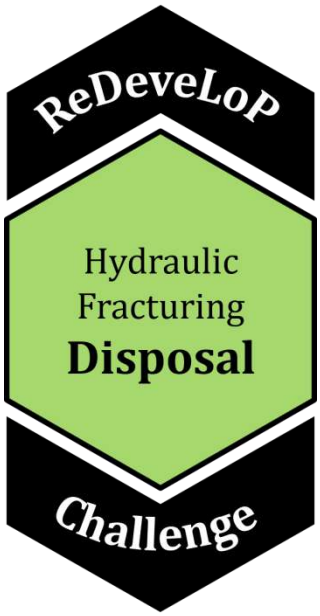


Figure 2. Areas subject to induced seismicity regulation in Alberta overlaying seismic activity in Alberta from September 2006 through to December 2018.
(Adapted from AGS, n.d.)

ACKNOWLEDGEMENTS: We would like to express our special thanks to Tim Tyrrell (XTO Energy Canada), Sobhi Alhashwa (Encana), Stuart Venables (BC Oil and Gas Commission), John Evans (Chevron), Ryan Segstro (Repsol), and Melanie Popp (geoLOGIC systems) for their support.

Data Source: Geomechanica's FDEM software Irazu



Hydraulic Fracturing - Disposal Team

Rabia Ladha *(Project Manager)*

Mauricio Reyes Canales

Melissa MacDonald

Wayne Park

UNIVERSITY OF CALGARY

Rabia Ladha
Policy

Melissa MacDonald
Geochemistry

UNIVERSITY OF ALBERTA

Mauricio Reyes Canales
Geophysics

UNIVERSITY OF WATERLOO

Wayne Park
Civil Engineering

Rabia Ladha is working on her **MPP** in Public Policy with Prof. Winter at the University of Calgary. She received her **BSc** (2016) in Chemical Engineering from the University of Alberta. Rabia is also the Project Manager of her team. During her BSc studies, Rabia completed 3 co-ops (20 months in total), where she worked in distribution design at ATCO Gas, on a terminal expansion engineering project with Enbridge, and in air policy research with Alberta Environment and Parks (previously Alberta Environment and Sustainable Resource Development). Rabia is currently taking French as a Second Language and plans to pursue a career in energy-sector policy. She is interested in community outreach, and served two terms as Chair (Strategy, Operations & Partnerships) for Edmonton's NextGen. Rabia also has an interest in visual artwork.
Contact: rabia.ladha@ucalgary.

Mauricio Reyes Canales is working on his **PhD** in Geophysics with Prof. Van Der Baan at the University of Alberta. He received a **B-Eng** (2015) in Geophysical Engineering at the Universidad Simon Bolivar, Venezuela. During his undergraduate studies, Mauricio was an exchange student at the Norwegian University of Science and Technology for one year, where he completed a thesis on seismic Interpretation in the Barents Sea. Mauricio is a member of the Microseismic Industry Consortium (MIC), and his research is focused on hazard analysis for induced seismicity, combining geostatistics and geomechanics into probabilistic seismic hazard analysis. He is bilingual (fluent in Spanish and English) and currently learning French. Mauricio is an active volunteer at the UoA with both the UAGGS and the ISS.
Contact: reyescan@ualberta.ca

Melissa MacDonald is working on her **MSc** in Geochemistry and Petroleum Hydrogeology with Prof. Mayer at the University of Calgary. She received her **BSc. Hon** (2017) in Geology from the University of Alberta. Melissa's current research is focusing on characterizing of gases, condensates and flowback fluids from hydraulically-fractured wells in the Montney Formation. Past research projects involved fingerprinting formation waters with geochemical techniques to identify fluid flow and potential borehole leaks. Melissa volunteers with the CSPG and enjoys running, skiing and hiking.
Contact: melissa.macdonald1@ucalgary.ca

Wayne Park is working on his **MASc** in Civil Engineering with Profs. Dusseault and Leonenkoat the University of Waterloo. He received a **BASc** (2017) in Geological Engineering at the University of Waterloo (with Honours). Wayne's current research focuses on evaluating the feasibility of creating geothermal energy storage in deep georepositories that store waste heat or solar heat on a seasonal basis. Wayne also spent 3 years in the oil sands working in mine planning/design and geotechnical investigation for residential and commercial buildings and infrastructures. In his spare time, Wayne enjoys training in martial arts.
Contact: s76park@uwaterloo.ca

Risks and Mitigations for Hydraulic Fracturing Wastewater Disposal Operations in Western Canada

Ladha, R.[1], MacDonald, M. [1], Park, W.S.[2], and Reyes-Canales, M.[3]

In western Canada, most hydraulic fracturing wastewater is disposed of in deep injection wells. Risks associated with the disposal activity concern both the public and the petroleum industry, as these risks may impact the surface environment. The objective of this study is to suggest technical and policy measures to mitigate the risks associated with groundwater contamination during wastewater disposal activities related to hydraulic fracturing. To identify and evaluate the risks, we have performed extensive scientific and policy literature reviews. Also, we conducted interviews with professionals in the oil and gas industry for this study. Risks associated with the disposal activity are identified and further categorized into hydrogeological, geological, and mechanical risks. In Alberta, the geological risks are considerably low, and the mechanical risks are well-controlled with current regulations and legislation. Hydrogeological risks, however, are difficult to quantify and may lack control measures because the level of uncertainty in long-term groundwater transport is high. The hydraulic fracturing water cycle is then studied to determine practices that can reduce the risks associated with water contamination. This water cycle is composed of four stages, including water sourcing, hydraulic fracturing and well completion, treatment of flowback water, and recycling or disposal of water. Decisions for each stage are made primarily based on regulatory and economic factors, including the cost of transport, storage, and treatment of water. By analyzing the water cycle, we have concluded that the most effective and feasible practices to reduce the risks are intensive monitoring of groundwater in the vicinity of disposal sites, and increasing the recycled water ratio in hydraulic fracturing operations. To promote the latter practice, we recommend updating regulations to encourage water recycling and implementing government-initiated water recycling incentive programs in hydraulic fracturing operations.

FOOTNOTES:
[1]University of Calgary / [2]University of Waterloo/ [3]University of Alberta

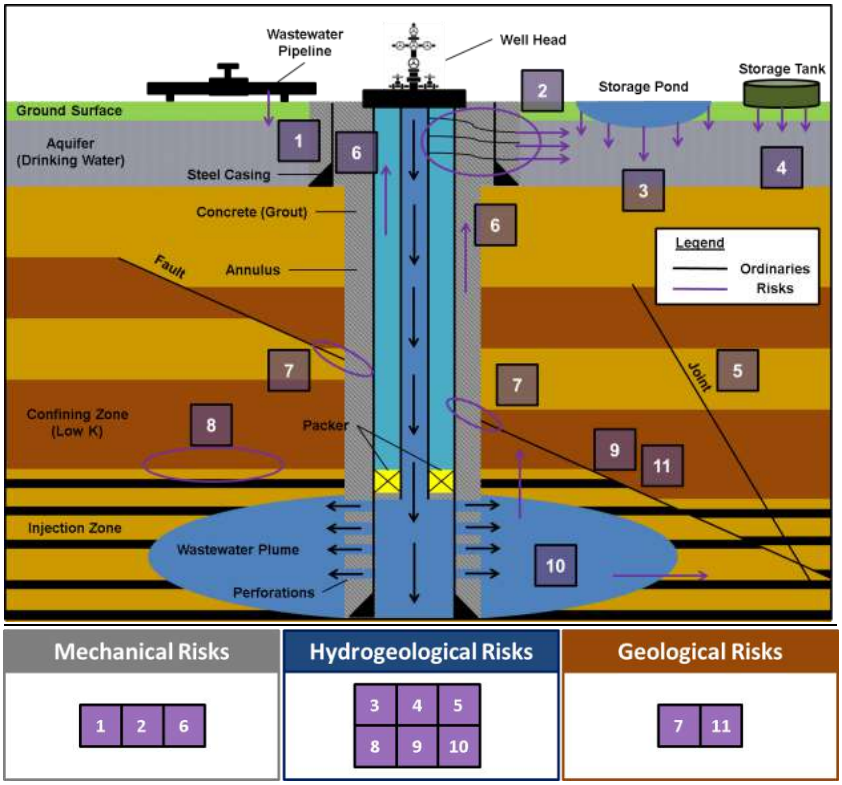


Figure 1. Identified risks associated with injection of wastewater via disposal wells.

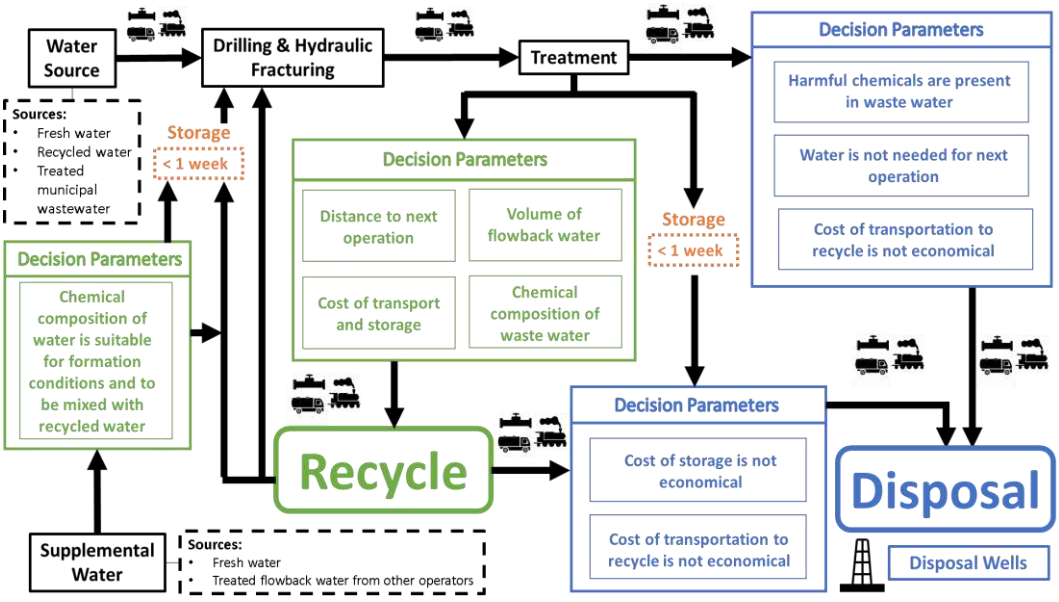


Figure 2. The hydraulic fracturing water cycle and decision flowchart.

ACKNOWLEDGEMENTS:
The authors are scholarship recipients and graduates of the NSERC CREATE ReDeveLoP Program. We would like to acknowledge support received from our academic advisor, Dr. Bernhard Mayer, our policy advisor, Dr. Jennifer Winter, and multiple industry advisors throughout the process.

Induced Seismicity - Traffic Team

Neil Fleming *(Project Manager)*

Mei Li

Ryan Green

Yiru Zhou

Neil Fleming
Geoscience

Ryan Green
Policy

Yiru Zhou
Geophysics

Mei Li
Civil Engineering

Neil Fleming is working on his **MSc** in Geoscience with Profs. Mayer and Ryan at the University of Calgary. He also received a **BSc** in Environmental Geoscience (2016) at the University of Calgary (with Distinction). Neil is also the Project Manager of his team. Neil's current research involves an applied, field-scale investigation of gas migration around leaking energy wells, involving active collaboration with several oilfield producers and service companies. Neil's career interests include hydrogeology and resource management, monitoring and remediation. Neil is an avid backcountry skier, backpacker and mountain biker, with an aptitude for organization, resourcefulness, and understanding challenging environments. Neil is willing to travel for the right position, ideally including a mix of field and office work.
Contact: naflemin@ucalgary

Mei Li is working on her **PhD** in Civil Engineering with Prof. Grasselli at the University of Toronto. She received a **M-Eng** (2016) in Petroleum and Natural Gas Engineering and her **B-Eng** (2013) in Petroleum Engineering, both at Southwest Petroleum University in China. Mei's research focus includes numerical modeling using self-developed FEM code and lab testing focusing on the effect of acid on tight sand. She has completed several internships in the oil and gas industry (Sinopec), involving hydraulic fracturing design and field fracturing implementation. Mei is bilingual (English and Chinese) and is willing to relocate for the right position.
Contact: nclimei@outlook.com

Ryan Green is working on his **MPP** in Public Policy with Prof. Winter at the University of Calgary. Ryan is a P.Geo, registered with APEGA. He received his **BSc** (2014) in Environmental Earth Sciences (with Distinction) at the University of Alberta. Before returning to academia, Ryan worked in environmental consulting on energy wellsite remediation projects in Western Canada. He also completed several summer internships in the energy sector, including operation of a remote sour gas plant in northern Alberta. He is also an active volunteer at the UoC, serving as VP of External Affairs on the MPP Student Assoc. In his free time, Ryan can often be found hiking, camping and skiing in the mountains.
Contact: ryan.green1@ucalgary.ca

Yiru Zhou is working on her **MSc** in Geophysics and Geomechanics, with Profs. Van Der Baan and Currie at the University of Alberta. She received a **BSc** (2018) in Geophysics from the University of Toronto. Yiru previously worked on the source mechanism inversions of hydraulic fracturing induced seismicities within the Western Canada Sedimentary Basin. Her current research interests focus on the geomechanical modelling of rock failure based on the bonded particle method. Yiru is trilingual (English, Mandarin and Korean) and willing to relocate for right position.
Contact: yiru4@ualberta.ca

Utilizing Ground Motion in the Traffic Light System for the Management of Induced Seismicity in Alberta

Fleming, N.A.[A], Green, R.S.[A], Li, M.[B], and Zhou, Y.[C]

The increased use of hydraulic fracturing in recent decades has resulted in public concern over induced seismicity. Studies have identified that these man-made earthquakes can be caused by either wastewater disposal or hydraulic fracturing, with the latter being an increasingly common source in Western Canada. Induced seismicity is regulated in Western Canada through programs such as the Traffic Light System, which informs operational responses to induced seismic events depending on the local magnitude.

While the structure of these regulations focuses on the seismic magnitude, it is increasingly evident that determination of ground motion is more important for estimating potential psychological or physical damages. We completed seismic wave propagation simulations within the Western Canada Sedimentary Basin that confirmed previous findings in scientific literature, demonstrating the importance of considering ground motion as opposed to magnitude in the regulation of induced seismic events. The propagation of historic induced seismic events was simulated utilizing the modelling software SPECFEM 3D Cartesian. The model took varying sediment types and thicknesses into consideration to generate shaking maps and waveforms at receivers, demonstrating the variations in potential damages. This technique theoretically demonstrates that induced seismic activity causes different levels of ground motion, and therefore damages, depending on the impedance and thickness of sediments. A potential application of this technique is to improve the existing induced seismicity regulations in Western Canada.

We present recommendations to utilize ground motion as a parameter for determining thresholds for the Traffic Light System instead of earthquake magnitude. Thresholds that account for the exposure and vulnerability of individuals to ground shaking will provide more protection to personal well-being compared to the current system. Our recommendations would provide greater protection in more vulnerable areas, and higher tolerances for shaking in remote areas. This flexibility provides benefits to both private industry and the public.

FOOTNOTES:
[A]University of Calgary / [B]University of Toronto/ [C]University of Alberta

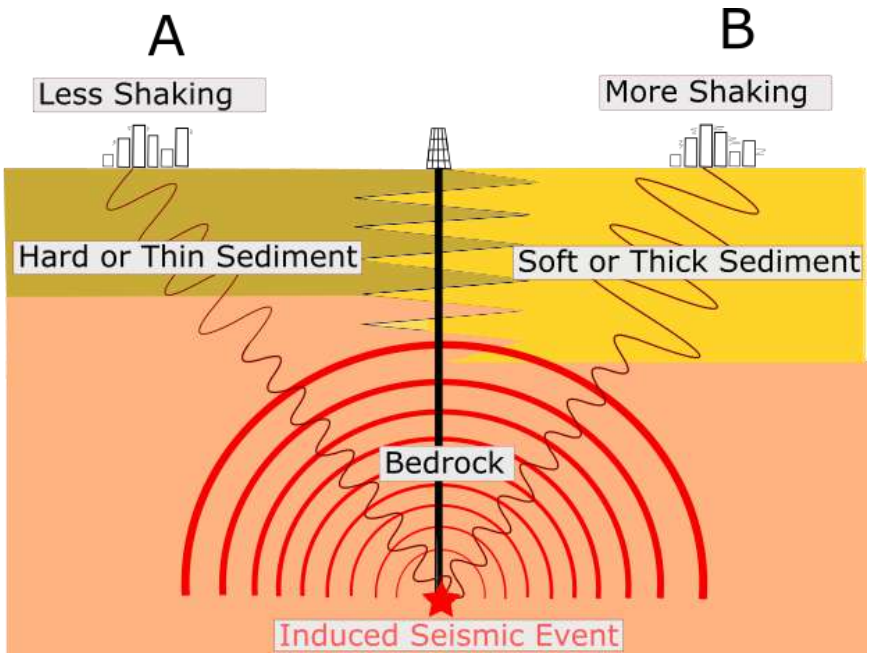


Figure 1. Cross-sectional view of conceptual model of induced seismicity, demonstrating potential variability in 'felt' shaking on the surface (ground motion) due to local variations in surficial sediment thickness and impedance.

Figure 2. Conceptual overview of the current Traffic Light System for management of induced seismicity, with basis in measuring local source magnitude, and the proposed revised system which would manage surface ground motion (peak ground acceleration) at the nearest affected residence. (After Alberta Energy Regulator)

Acknowledgements/Data Sources:
Computational Infrastructure for Geodynamics (http://geodynamics.org)
Crust Model: Crust 1.0 (https://igppweb.ucsd.edu/~gabi/crust1.html)
Incorporated Research Institution for Seismology (IRIS)

Acknowledgments

CSUR Canadian Society for Unconventional Resources
INFORMATION ABOUT CANADA'S EMERGING ENERGY RESOURCES

National Energy Board | Office national de l'énergie
Canada

CAPP
CANADIAN ASSOCIATION OF PETROLEUM PRODUCERS
Canada's Oil and Natural Gas Producers

PennState
MCOR
Marcellus Center for Outreach and Research

INDIAN RESOURCE COUNCIL
IRC Inc.

Northwest Territories

TRICAN WELL SERVICE

CALFRAC WELL SERVICES

PSAC
working energy

Round Table Consulting Inc.

CMC RESEARCH INSTITUTES

Chevron

Shale Petroleum

ITP METRICS
Growing your people and ours

MITACS

NSERC CRSNG

SUCKER CREEK BAND 1904
SUCKER CREEK FIRST NATION

"When you become a leader,
success is all about growing others."
J. Welch