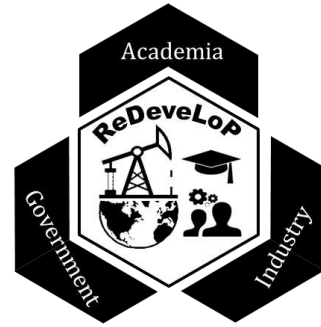


# The ReDeveLoP Challenge 2018



Responsible Development of Low-Permeability Hydrocarbon Resources  
[ucalgary.ca/science/redevelop](http://ucalgary.ca/science/redevelop)



## ENHANCED JOB-SKILLS DEVELOPMENT THROUGH COLLABORATION



*"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 2018**, the 1<sup>st</sup> Annual Innovation Conference on the responsible development of low-permeability hydrocarbon resources. This conference is the inaugural progress update and general meeting of academics, government and industry stakeholders supporting a new 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 benefits 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 and government will rely upon technical knowledge that crosscuts traditional disciplines, together with business acumen, a deep understanding of pertinent sociopolitical factors, including issues that particularly affect indigenous communities, and real-world practical experience.

ReDeveLoP is a 6-year program for enhanced training of highly qualified personnel (HQP) at five Canadian universities, within the interdisciplinary area of responsible development of low-permeability of hydrocarbon resources. In addition to existing programs offered at each institution, students will participate in activities that will provide exceptional industry networking opportunities as well as greatly enhanced learning opportunities with other disciplines. 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 inaugural ReDeveLoP Annual Innovation Program (April 29 - May 4, 2018) promises to be an exciting and thought-provoking experience for all participants, including 28 highly qualified personnel and 11 faculty members from five Canadian universities, as well as diverse representation from stakeholder groups including 3 Dragon's Den judges who have volunteered their time and expertise to make this program a success.

**Dr. David Eaton**  
Chair of ReDeveLoP  
an NSERC CREATE Initiative

## The Academic Team



David Eaton, Chair  
[eatond@ucalgary.ca](mailto:eatond@ucalgary.ca)



Mirko Van der Baan  
[mirko.vanderbaan@ualberta.ca](mailto:mirko.vanderbaan@ualberta.ca)



Maurice Dusseault  
[mauriced@uwaterloo.ca](mailto:mauriced@uwaterloo.ca)



Nancy Chen  
[snchen@ucalgary.ca](mailto:snchen@ucalgary.ca)



Chris Clarkson  
[clarksoc@ucalgary.ca](mailto:clarksoc@ucalgary.ca)



Burns Cheadle  
[bcheadle@uwo.ca](mailto:bcheadle@uwo.ca)



Jennifer Winter  
[jwinter@ucalgary.ca](mailto:jwinter@ucalgary.ca)



Jeff Priest  
[japriest@ucalgary.ca](mailto:japriest@ucalgary.ca)



Bernhard Mayer  
[bmayer@ucalgary.ca](mailto:bmayer@ucalgary.ca)



Karlis Muehlenbachs  
[kmuehlen@ualberta.ca](mailto:kmuehlen@ualberta.ca)



Giovanni Grasselli  
[Giovanni.grasselli@utoronto.ca](mailto:Giovanni.grasselli@utoronto.ca)



Celia Kennedy, Project Manager  
[celia.kennedy@ucalgary.ca](mailto:celia.kennedy@ucalgary.ca)

[ucalgary.ca/science/redevelop/team-1](http://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 CO<sub>2</sub> 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 <sup>18</sup>O 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. Grasselli'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.

## Table of Contents

	<b>The Team ..... 8</b>
	Toward a better understanding of methane emissions from individual energy wells in Canada ..... 10
	Insights into alternative policies in regulating fugitive gas emissions ..... 12
	<b>The Team ..... 14</b>
	Addressing risks of hydraulic fracturing with novel drilling and stimulation technologies ..... 16
	Hydraulic Fracturing in Canada: Risk versus Reward ..... 18
	<b>The Team ..... 20</b>
	Induced seismicity, well azimuth, and completion economics in the Duvernay ..... 22
	A Study of the Traffic Light System for Induced Seismicity ..... 24
	<b>The Team ..... 26</b>
	Supplying liquefied natural gas to remote communities: Freeze or go full steam ahead? ..... 28
	Supplying liquefied natural gas to remote communities: Freeze or go full steam ahead? ..... 30
	<b>The Team ..... 32</b>
	Pipeline versus rail: Quantitative comparison between the transportation of crude oil and the cost to society ..... 34
	Indigenous participation in Canada's oil industry: Attaining economic growth through strengthened fiscal relationships ..... 36
	<b>The Team ..... 38</b>
	Analysis of contamination, remediation and geothermal potential of orphan wells in Alberta ..... 40
	Alternative policies for managing orphan wells in Alberta ..... 42
	<b>Acknowledgments ..... 43</b>
	<b>Application for Stakeholders ..... 44</b>



## Fugitive Gas Emissions Team

Victor Gallardo (Policy)  
 Richard Li (Engineering)  
 Tiago Morais (Geoscience)  
 Jordan Phillips (Geoscience, *Project Manager*)  
 Dylan Riley (Geoscience)



*\*Not intended for public distribution or for citation\**

1<sup>st</sup> Annual ReDeveLoP Challenge | April 30 – May 4, 2018

**Jordan Phillips** is working on her MSc in Geoscience with Prof. Van der Baan at the University of Alberta. She received her BSc (2015) in Geophysics at the University of Alberta, and a GeoTech Diploma (2017) from NAIT. Jordan is currently investigating the technical and perceived risks of induced seismicity, including social implications such as public perception and communication challenges within the industry. Jordan's goal is to work in science communication and/or consulting within the industry as society moves towards increased accountability and sustainability in energy development. She is a Geoscientist In Training with APEGA, is trilingual (English, conversational French and some Spanish), and enjoys active sports activities, including figure skating and rock climbing. She is also a volunteer with Metro Cinema at Garneau Theater and with the Federation Skating Club.

**Contact:** jnphilli@ualberta.ca | **Linked-in profile:** [www.linkedin.com/in/missjordanphillips](https://www.linkedin.com/in/missjordanphillips)

**Victor Gallardo** is working on his MPP in Public Policy with Prof. Winter at the University of Calgary. He also received an MA (2008) in Economics at the University of Alberta, and a BA (2004) in Commerce at the Mexican Autonomous Institute of Technology (ITAM). Victor is currently working as an energy trader for TransAlta, covering the Midwest power market in the U.S., while working on his MPP in Public Policy. He witnessed how the evolving discourse around climate change and oil pipelines led to the resurgence of riskier and more expensive shipping methods like rail. The disconnect between the public's declared intentions and the actual effects of their demands was the impetus for his return to academia. Victor was the recipient of the Graduate Core Prize in Economics for outstanding academic achievement in 2008. He has a range of experience working energy companies in Alberta (TransAlta Corp, Capital Power Corp and TransCanada Pipelines) and France (Électricité de France). Born and raised in Mexico, Victor calls Alberta home now. He is grateful for the opportunities Alberta has given him and hopes to contribute to the success of the province in the future.

**Contact:** victor.gallardo@ucalgary.ca | **Linked-in profile:** <https://www.linkedin.com/in/vicgallardo/>

**Ruiqiang (Richard) Li** is working on his PhD in Geosciences and Geomechanics with Prof. Dusseault at the University of Waterloo. He received his MSc (2011) in Geophysics, a B-Eng (2008) in Geological Engineering, and a BA (2008) in English, at Taiyuan University of Technology in China. Richard's current work focuses on geological and geomechanical characterization of shale gas deposits in eastern Canada (Ontario, Quebec, and New Brunswick). In addition to research and teaching, Richard has actively worked on campus as a training program coordinator and graduate professional development program specialist. Off campus, Richard enjoys interacting with the community as a photographer, language interpreter and yoga instructor. Richard is open to a range of career possibilities after graduation, including: teaching and research (within and outside academia), working in industry, government or consulting. He is bilingual (English and Chinese Mandarin), and is willing to relocate for the right position.

**Contact:** ruiqiang.li@uwaterloo.ca | **Linked-in profile:** <https://www.linkedin.com/in/ruiqiangli>

**Tiago Morais** is working on his PhD in Geoscience at the University of Calgary with Prof. Ryan. He received his MSc (2017) and BSc (2015) in Geoscience at the Federal University of Rio Grande do Sul, in Brazil. Tiago's current research involves prediction and evaluation of environmental impacts potentially caused by unconventional oil and gas exploration and production. His MSc research focused on deep marine reservoir characterization. While in Porto Alegre, Tiago worked in an environmental consulting company and volunteered at the Children's Cancer Institute. His career preference is to work in research and become a professor. Tiago is bilingual (English and Portuguese). He loves photography, surfing and traveling.

**Contact:** tamorais@ucalgary.ca | **Linked-in profile:** [www.linkedin.com/in/tiago-antonio-morais](https://www.linkedin.com/in/tiago-antonio-morais)

**Dylan Riley** is working on his MSc in Geoscience with Prof. Mayer at the University of Calgary. He received his BSc (2014) in Geoscience at the University of Calgary. Dylan holds a Geoscientist-in-Training designation with the APEGA, has 2 years experience in exploration and development geology, and plans to pursue a career in environmental consulting as a hydrogeologist. Dylan is also involved with the CMC Research Institute (<http://cmcghg.com/>), where he is monitoring and characterizing CO<sub>2</sub> and CH<sub>4</sub> conditions for comparison with CO<sub>2</sub> injection and storage data. He is also involved in a gas migration study in southern Alberta. Dylan has spent his life in Alberta, enjoying the outdoors and winter sports. That said, he is partial to fieldwork and willing to travel or relocate for the right position. A former member of Canada's National Development Team, Dylan has been a competitive snowboard racer on a global scale and, on a local scale, a coach and volunteer in youth sports. Dylan is also bilingual (English and German).

**Contact:** djtriley@ucalgary.ca | **Linked-in profile:** <https://www.linkedin.com/in/dylan-riley-43744a68>

[ucalgary.ca/science/redevelop/team/student-hqps](http://ucalgary.ca/science/redevelop/team/student-hqps)

## Toward a better understanding of methane emissions from individual energy wells in Canada

Dylan Riley<sup>1</sup>, Jordan Phillips<sup>2</sup>, Tiago Morais<sup>1</sup>, Ruiqiang (Richard) Li<sup>3</sup>, Victor Gallardo<sup>1</sup>



To meet the Federal and Alberta governments' climate goals of reducing methane emissions by 45% below 2012 levels by 2025, a better quantification of methane emissions from energy sector wells is needed. The two main forms of fugitive natural gas emissions from these individual wells are gas migration (GM) and surface casing vent flow (SCVF). Emissions estimates for methane, including those employed by federal and provincial governments are under scrutiny and considered unreliable. These 'bottom-up' emission estimates are self-reported industry values and are incongruent with academia-performed 'top-down' emission estimates. A recent review of Alberta energy sector wells using the Alberta Energy Regulator's own statistics derived from 'bottom-up' industry self-reporting claim only 5.63% of all energy in the province have GM/SCVF problems. This contrasts with a 2017 'top-down' aerial survey of two regions in Alberta finding discrepancies of 17 times and 5 times greater emissions than industry self-reported data. Additionally, a 2017 'top-down' study of tight-gas Montney wells in northeast BC found 47% of wells to be leaking methane. A clear disconnect is evident with respect to emissions derived from industry and independently reported values. The disconnect is not necessarily the product of 'bottom-up' versus 'top-down' methods, but potentially, that two different groups typically perform these surveys. It is therefore recommended further studies be done to harmonize the discrepancies between 'top-down' and 'bottom-up' derived methane emission estimates. Additionally, it is recommended access to energy wells be granted to independent or regulator surveyors to potentially more accurately quantify their methane emissions.

### FOOTNOTES:

<sup>1</sup> University of Calgary

<sup>2</sup> University of Alberta

<sup>3</sup> University of Waterloo

### ACKNOWLEDGEMENTS:

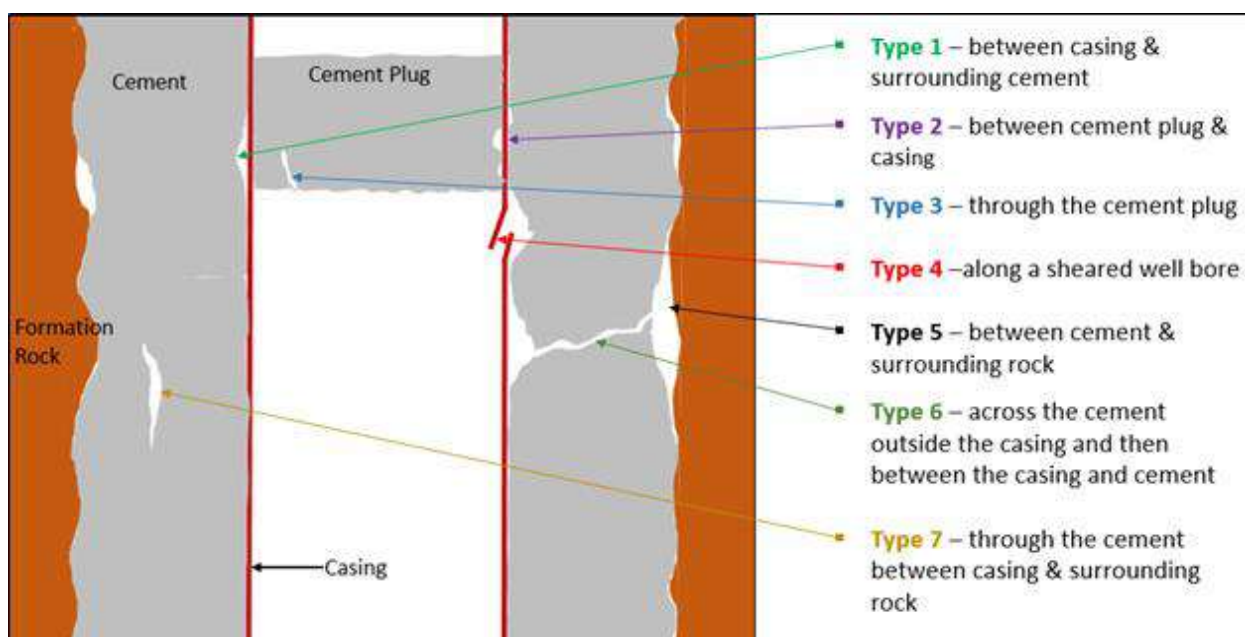
Interviews with Dr. Bernhard Mayer (Professor, University of Calgary), Dr. Cathy Ryan (Associate Professor, University of Calgary), Jason Abboud (MSc candidate, University of Calgary), Brent Bowerman (President, Baseline Water Resource Inc.), Jim Quehl (President, Adandonwell Inc.)

### REFERENCES:

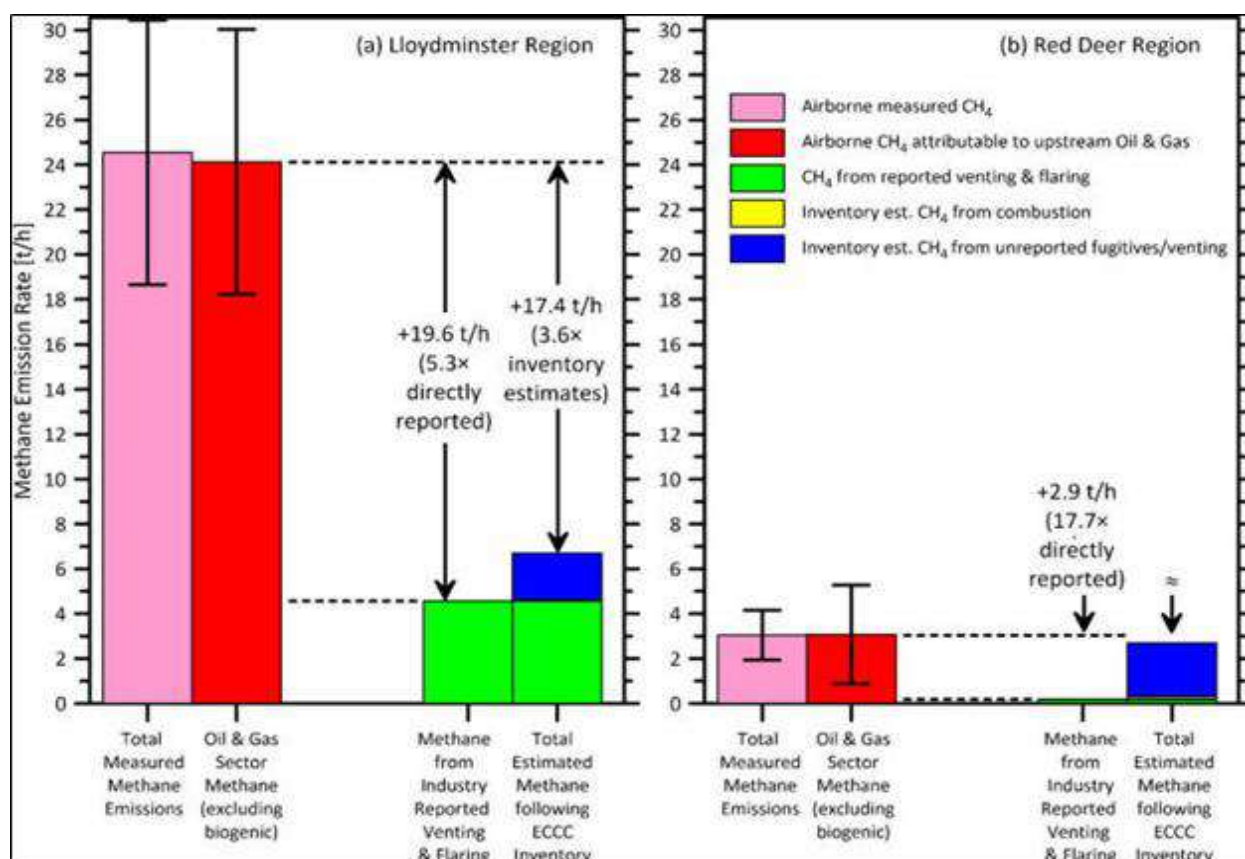
M. R. Johnson, D. R. Tyner, S. Conley, S. Schwietzke, D. Zavala-Araiza, Comparisons of Airborne Measurements and Inventory Estimates of Methane Emissions in the Alberta Upstream Oil and Gas Sector. Environ. Sci. Technol. 51, 13008–13017 (2017).

*\*Not intended for public distribution or for citation\**

1<sup>st</sup> Annual ReDeveLoP Challenge | April 30 – May 4, 2018



**Figure 1.** Conceptual diagram showing the seven main conduits in an energy well through which GM/SCVF occurs.



**Figure 2.** Flux of methane from the Lloydminster study area (a) and the Red Deer study area (b). Of note for (a), oil and gas sector methane emissions surveyed were 5.3 times greater than industry self-reported values and 3.6 times greater than Environment and Climate Change Canada's (ECCC) estimates. For (b), where GM testing is not mandatory prior to abandonment, emissions were 17.7 times greater than industry self-reported values, and in line with ECCC estimates (Johnson et al., 2017).

## Insights into alternative policies in regulating fugitive gas emissions

Victor Gallardo<sup>1</sup>, Tiago Morais<sup>1</sup>, Ruiqiang (Richard) Li<sup>2</sup>, Jordan Phillips<sup>3</sup>, Dylan Riley<sup>1</sup>



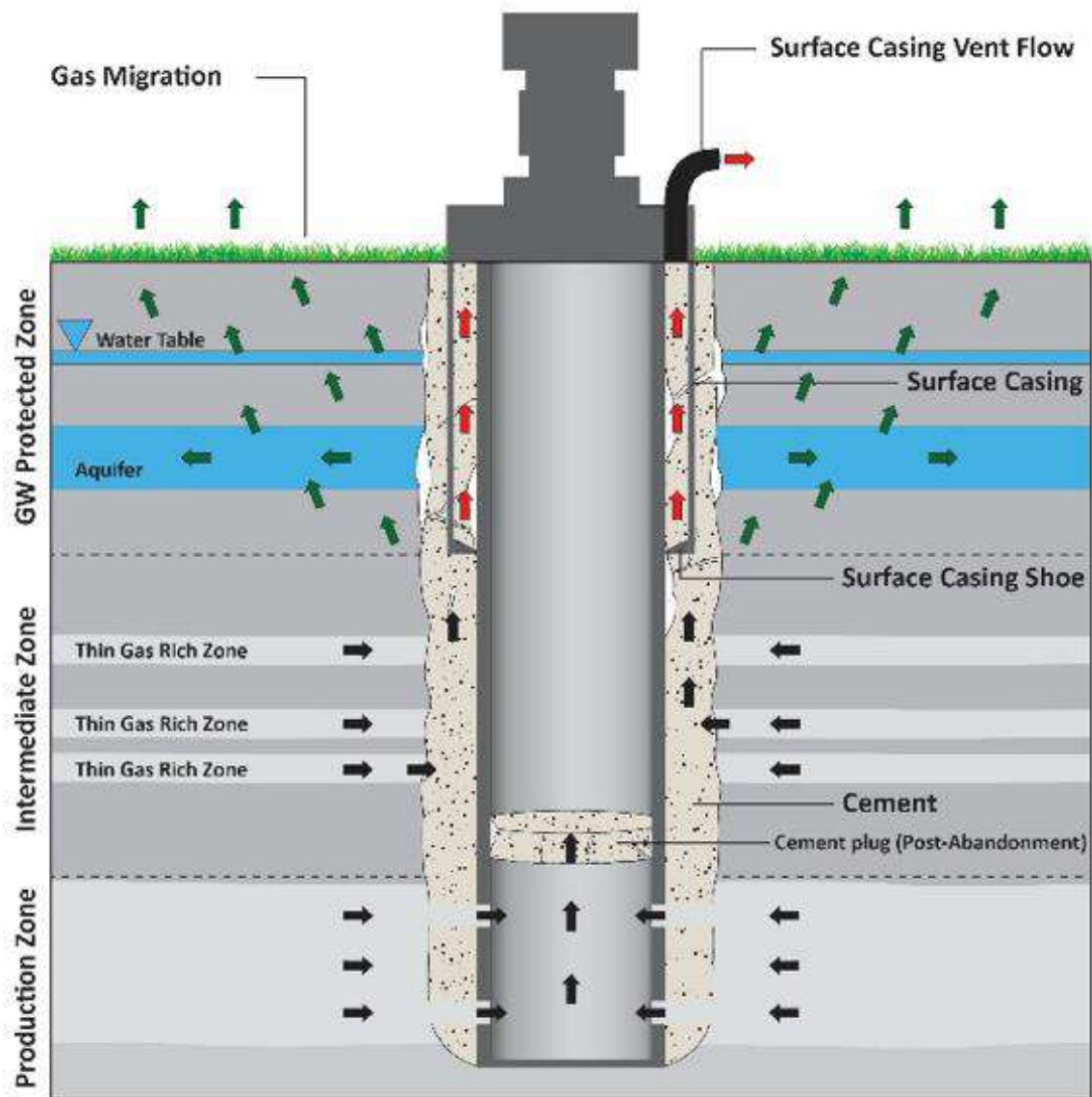
Despite the implementation of several environmental policies by federal and provincial governments intended to minimize the impact and mitigate the long-term effects of GHG emissions, regulations to account for GHG emissions are still in the preliminary stages. In addition, the lack of accurate baseline information on methane emissions and the costs required for compliance make most of the current policies ineffective. Currently, there are four potential alternatives being discussed to regulate methane emissions: market-based policies; technology-based standards policies; performance standard policies; and voluntary approaches. However, this paper proposes an alternative approach, which has not been discussed in the literature. Based on literature review, successful policies and regulations will depend on the capacity to accurately monitor and quantify GHG emissions. A series of studies and government reports have demonstrated the success of the forestry industry's third-party certification process in Canada. Thus, we suggest that research regarding a demand-based policy, combined with a voluntary approach, should be explored for this specific case. This approach could lead to an effective long-term reduction of greenhouse gas emissions from the oil and gas sector in Canada. Based on this alternative approach, both public and private resources could be used for campaigns aiming to educate consumers about the costs of adopting sustainable management practices and the importance of consuming energy from certified suppliers.

### FOOTNOTES:

<sup>1</sup> University of Calgary

<sup>2</sup> University of Waterloo

<sup>3</sup> University of Alberta



**Figure 1.** Pathways for fugitive gas emissions.



## The Hydraulic Fracturing Team

Henry Zhou (Engineering)

Jinghan Zhong (Engineering)

Germán Rodríguez-Pradilla (Geoscience, *Project Manager*)

Leah Wilson (Geoscience)

Linh Tran (Economics)



*\*Not intended for public distribution or for citation\**

1<sup>st</sup> Annual ReDeveLoP Challenge | April 30 – May 4, 2018

**Hongyuan (Henry) Zhou** is working on his MSc in Civil Engineering and Rock Mechanics with Prof. Grasselli at the University of Toronto. He received his B-Eng (2016) in Geological Engineering with a Geophysics option at University of Waterloo. Henry's research focuses on shear-induced dilation of rock joints based on quantified surface description, and stress influence of hydraulically-induced fractures using FDEM. He has completed internships in the areas of hydraulic fracturing, tunnelling, geotechnical, and road construction, and is a recipient of the Queen Elizabeth II / Robert M. Smith Memorial Graduate Scholarship.

**Contact:** hongyuan.zhou@mail.utoronto.ca

**Jinghan (Cici) Zhong** is working on her PhD in Geomechanical Engineering with Prof. Grasselli at the University of Toronto. She received her MSc (2016) in Oil and Gas Engineering at Memorial University, in Newfoundland, and her B-Eng (2013) in Resource Exploration Engineering from Xi'an Petroleum University, in China. Cici's current research involves hydraulic fracturing, micro-seismic, microscopic mechanisms and fracture modelling using FDEM simulation of unconventional reservoirs. She is also interested in drilling penetration mechanisms, drill string dynamics and well control. Cici is bilingual (English and Chinese).

**Contact:** jinghan.zhong@mail.utoronto.ca

**German Rodriguez-Pradilla** is working on his PhD in Geoscience with Prof. Eaton at the University of Calgary. He received his MSc (2014) in Geophysics and his B-Eng (2010) in Civil Engineering at Universidad Nacional de Colombia. German's current research focuses on developing robust methods for microseismic data processing and modelling applied to unconventional reservoir characterization and hazard analysis of induced seismicity. He is also interested in R&D work in microseismology associated with the exploration and development of natural resources after graduation. German is also bilingual (English and Spanish).

**Contact:** german.rodriquezprad@ucalgary.ca

**Linked-in profile:** <https://www.linkedin.com/in/germán-rodr%C3%ADguez-pradilla-9803a471>

**Leah Wilson** is working on her MSc in Hydrogeochemistry with Prof. Mayer at the University of Calgary. She received her BSc (2016) in Geology at Mount Royal University. Leah's current research focuses on nitrate (sources and distribution) within the shallow groundwater of Alberta. She has completed internships with Devon Canada (Jackfish Thermal), Encana (Exploration and EH&S), and PrairieSky Royalty Ltd. (Exploration) and is excited to rejoin Encana's EH&S team during the summer of 2018. Leah looks forward to working with the government or oil and gas industry and is most engaged when applying her skills in support of people or the environment. Leah has been an active volunteer mentor for young girls interested in STEM related fields with Cybermentor. She also dedicates her time to Hydrogeologists Without Borders (<http://hydrogeologistswithoutborders.org/wordpress/>), where she builds and manages teams of international hydrogeologists who are translating the Groundwater textbook, by Freeze and Cherry, into their mother language. When she's not studying, Leah enjoys spending time with her cats and dog, creating pottery, reading, and planning her next travel adventure. Leah's first language is English; she also has an intermediate level of German and Swiss German from her year living in Switzerland as a Rotary Youth Exchange Student.

**Contact:** leah.wilson@ucalgary.ca | **Linked-in profile:** [www.linkedin.com/in/leahjwilson](http://www.linkedin.com/in/leahjwilson)

**Linh Tran** is working on her MA in Economics at the University of Calgary. She received her MBA (2017) at the University of Alberta, and her BA (1998) in Economics at the University of Economics, in Hochiminh City. Linh also has an Advanced Computer Security Certification (2017) from Stanford University. Linh is the recipient of numerous academic scholarships and has >10 years experience working as a professional accountant in both Alberta and Vietnam. Linh is interested in the interaction between the decisions made by policy makers and regulated parties. Linh's research is primarily in the field of environmental economics. She has a particular interest in the enforcement of environmental regulations and the use of warnings and the increasing reliance on public complaints to enforce environmental standards.

**Contact:** linh.tran1@ucalgary.ca | **Linked-in profile:** <https://www.linkedin.com/in/linh-lynn-tran-753b8b77>

[ucalgary.ca/science/redevelop/team/student-hqps](http://ucalgary.ca/science/redevelop/team/student-hqps)

*\*Not intended for public distribution or for citation\**

1<sup>st</sup> Annual ReDeveLoP Challenge | April 30 – May 4, 2018

## Addressing risks of hydraulic fracturing with novel drilling and stimulation technologies

Hongyuan Zhou<sup>1</sup>, Jinghan Zhong<sup>1</sup>, Germán Rodríguez-Pradilla<sup>2</sup>, Leah Wilson<sup>2</sup>, and Linh Tran<sup>3</sup>



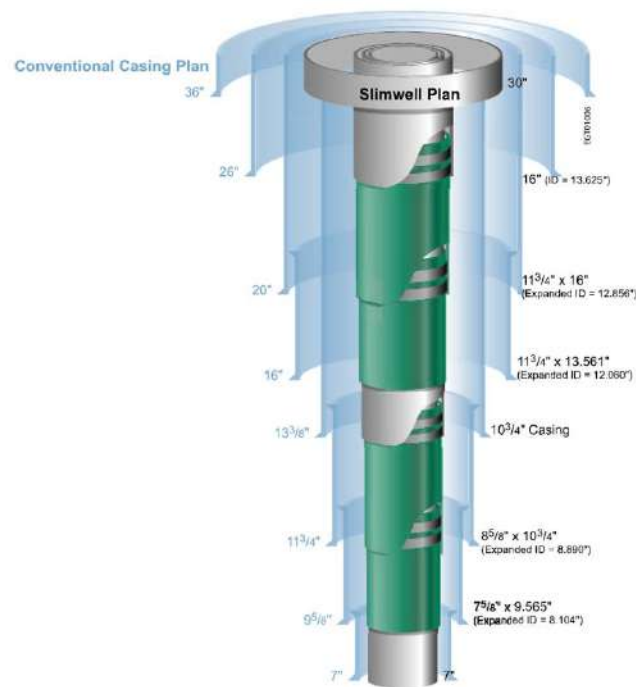
Large scale commercial shale gas development was made possible through the advancement in hydraulic fracturing by combining horizontal drilling with multi-stage hydraulic fracturing. With the increase in hydraulic fracturing operations, occurrence of incidence concerning environment and public health and safety also increased. These concerns mainly focused on water and air quality, fresh water availability, well integrity, and induced seismicity. As a result, technologies in drilling and hydraulic fracturing discussed in this paper have been centered on addressing the concerns and reducing the risks and impacts of environmental and public health and safety. The seven drilling technologies mentioned focus on improving wellbore stability in different drilling environments which in turn can prevent environmental contaminations. Seven stimulation technologies mentioned focus on replacing the usage of water and reducing resource requirements during hydraulic fracturing. This relieves pressure on water availability and minimizes the quantity of material exposed to the environment.

### FOOTNOTES:

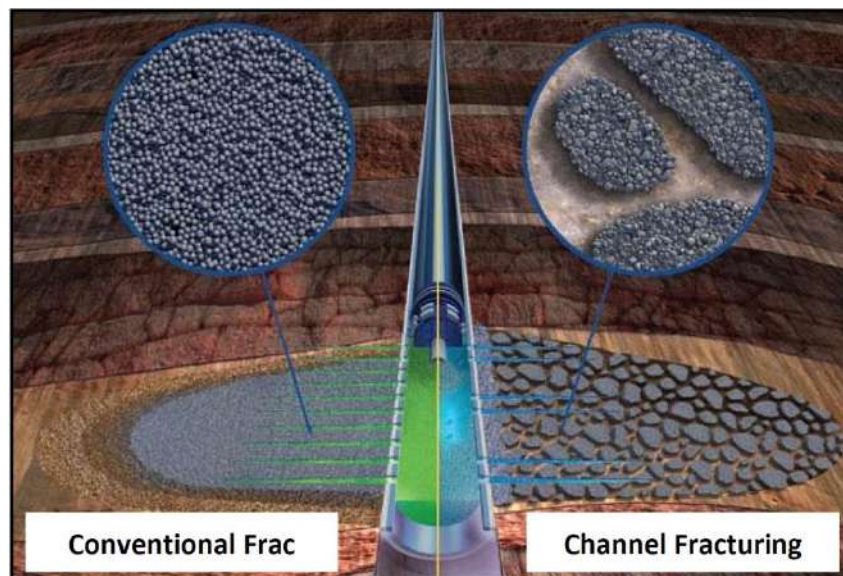
<sup>1</sup> University of Toronto – Department of Civil Engineering

<sup>2</sup> University of Calgary – Department of Geoscience

<sup>3</sup> University of Calgary – Department of Economics



**Figure 1.** Example drilling technology, monodiameter drilling line (Williams et al., 2003).



**Figure 2.** Example stimulation technology, impulse sand fracturing (Gillard et al., 2010).

#### ACKNOWLEDGEMENTS:

Data source: Dr. C. Kennedy, Dr. N. Chen of University of Calgary. James Armstrong, Matt Gobson, Al Viscotto of Encana Corp. Cecilia Brooks of New Brunswick First Nation communities representative.

#### REFERENCES:

Gillard, M. R., Medvedev, O. O., Hosein, P. R., Medvedev, A., Peñacorada, F., & d'Huteau, E. (2010). A New Approach to Generating Fracture Conductivity. In SPE Annual Technical Conference and Exhibition. Society of Petroleum Engineers. <https://doi.org/10.2118/135034-MS>

Williams, C., Filippov, A., Cook, L., Brisco, D., Dean, B., & Ring, L. (2003). Monodiameter Drilling Liner - From Concept to Reality. In SPE/IADC Drilling Conference. Society of Petroleum Engineers. <https://doi.org/10.2118/79790-MS>

## Hydraulic Fracturing in Canada: Risk versus Reward

Germán Rodríguez-Pradilla<sup>1</sup>, Leah Wilson<sup>1</sup>, Linh Tran<sup>2</sup>, Hongyuan Zhou<sup>3</sup>,  
and Jinghan Zhong<sup>3</sup>



Hydraulic fracturing is a reservoir stimulation technique that increases the reservoir permeability and its connectivity with the producing wellbore by injecting a pressurized fracturing fluid mostly comprising water and sand. It has been implemented in the oil and gas industry since the 1940s and has undergone a constant evolution ever since, with a sharp increase during the last decade in areas of rich low-permeability hydrocarbon reservoirs. Canada has vast resources of these type of reservoirs, mostly concentrated in the Western Canada Sedimentary Basin (WCSB) and with the remaining resources distributed in north-western and eastern provinces (Figure 1). Hydraulic fracturing has been massively practiced in some WCSB formations, sustaining the country's natural gas production and exporting more than 50 percent of its production to Midwest and Western U.S. (Figure 2). This practice, together with all other industrial activities related to oil and gas developments, is tightly regulated at both federal and provincial levels (Green & Jackson, 2015).

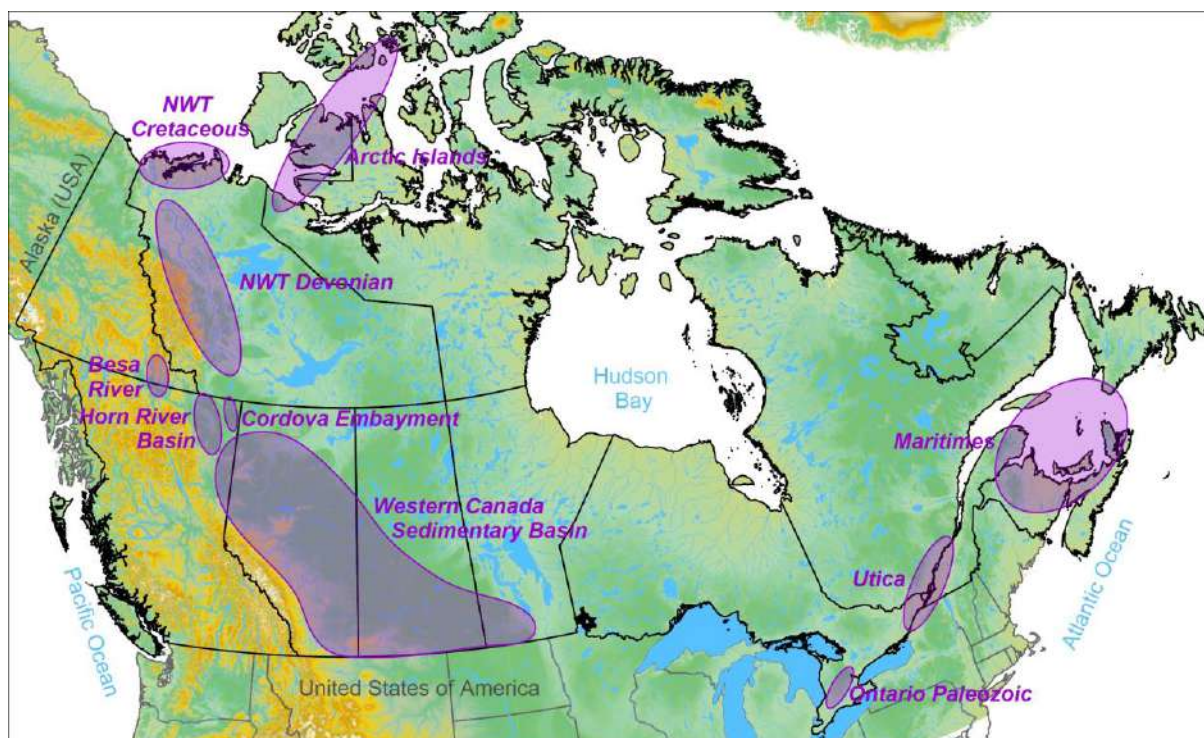
However, the public concern regarding the environmental and public health impacts of large-scale hydraulic fracturing practices has also increased across the country to the point of forcing the establishment of moratoria by the provincial governments of Quebec, Nova Scotia, New Brunswick, and Newfoundland and Labrador (Winter, Dobson, & Lorefice, 2016). This has not been the case with local and First Nation communities located in the WCSB, where public concerns have also arisen among them but have also been more receptive as they've cohabitated with the traditional oil and gas industry for decades. The major gaps between currently implemented hydraulic fracturing technologies, applicable federal and provincial regulations, and the negative public perception among some communities, represents major challenges for the oil and gas industry, the government, and the academia. This requires a careful, updated, and unbiased review of the economic and environmental impacts of current hydraulic fracturing practices and its future implications.

### FOOTNOTES:

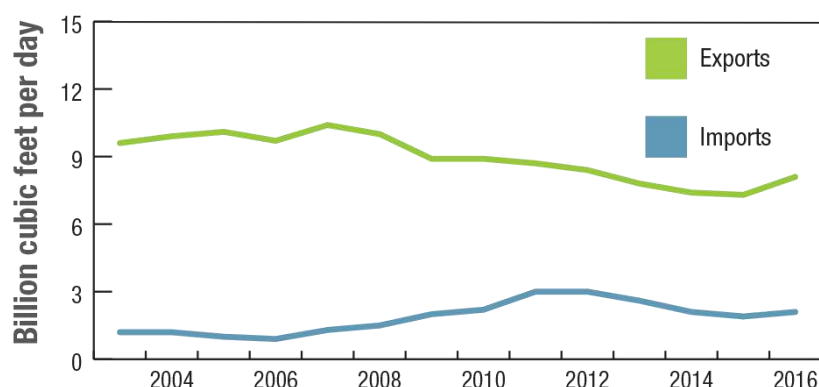
<sup>1</sup> University of Calgary – Department of Geoscience

<sup>2</sup> University of Calgary – Department of Economics

<sup>3</sup> University of Toronto – Department of Civil Engineering



**Figure 1.** Distribution of major shale gas basins in Canada (modified from CSUR, 2010).



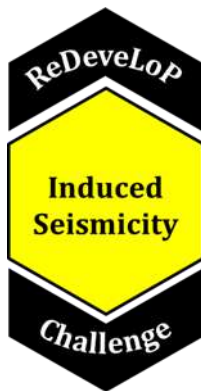
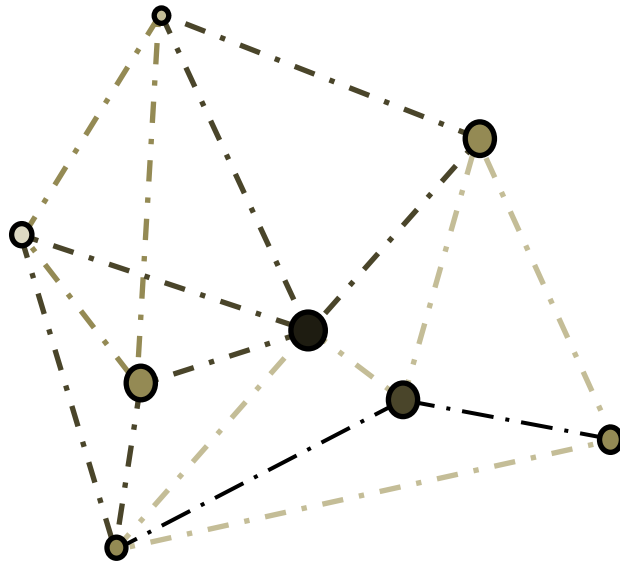
**Figure 2.** Canada trade of natural gas. In 2016, Canada produced **15.4 Bcf/d**, exported **8.1 Bcf/d**, mostly to Western and Midwest U.S., and imported **2.1 Bcf/d** from Northeast U.S. into Eastern Canada. (NRCAN, 2018).

#### ACKNOWLEDGEMENTS:

Dr. Celia Kennedy and Dr. Nancy Chen from the University of Calgary are sincerely thanked for their constant support and guidance during the development of the Hydraulic Fracturing Challenge of the ReDeveLoP research program. James Armstrong, Matt Gibson, and Al Visotto from Encana Corp. provided valuable contributions regarding the main industry environmental contingency practices, the technical hydraulic fracturing process, and collaboration with local and First Nation communities during the implementation of hydraulic fracturing stimulations in the company's operational areas in western Canada. Cecilia Brooks, representative of First Nation communities in the province of New Brunswick, shared with us the key concerns from these communities regarding the possibility of developing unconventional hydrocarbon resources in this province that would require hydraulic fracturing stimulation.

#### REFERENCES:

- CSUR. 2010. *Understanding Shale Gas in Canada*. Canadian Society of Unconventional Resources.
- Green, K. P., & Jackson, T. 2015. *Managing the Risks of Hydraulic Fracturing: An Update*. Fraser Institute.
- NRCAN. 2018. *Natural Gas Facts*. (Natural Resources Canada) Retrieved 03 21, 2018, from <http://www.nrcan.gc.ca/energy/facts/natural-gas/20067>
- Winter, J., Dobson, S., & Lorefice, S. 2016. *Final Report: Knowledge Synthesis Grant Hydraulic Fracturing and Public Policy*. Report to the Social Sciences and Humanities Research Council of Canada.



## The Induced Seismicity Team

Jieyu Zhang (Geophysics, *Project Manager*)

Sobhan Iranmanesh (Economics)

Scott McKean (Engineering)

Suzie Jia (Engineering)

Yu Wang (Engineering)



*\*Not intended for public distribution or for citation\**

1<sup>st</sup> Annual ReDeveLoP Challenge | April 30 – May 4, 2018

**Jieyu Zhang** is working on her MSc in Geophysics with Prof. Van der Baan at the University of Alberta. She received her BSc (2013) in Geophysics at the China University of Petroleum, in Beijing. The focus of Jieyu's research is the ecological analysis of fault reactivation and the statistical study of fault reactivation in different models. During her undergraduate studies, Jieyu spent a semester as an exchange student studying geology at the University of Tulsa, in Oklahoma. Previously, she worked on improving coherency methods to identify subsurface discontinuities. Jieyu is bilingual (English and Chinese) and is willing to relocate for the right position. She also enjoys running and community volunteer work.  
**Contact:** jieyu@ualberta.ca

**Sobhan Iranmanesh** is working on his MA in Economics at the University of Calgary. He also has an MSc (2013) in Environmental Engineering from the University of Calgary, and a B-Eng (2009) in Chemical Engineering from the University of Isfahan, in Iran. Sobhan's current research straddles environmental engineering and economics and he is a registered EIT with APEGA. His previous MSc thesis research dealt with removal of naphthenic acid from water using biomass-based activated carbon.  
**Contact:** siranman@ucalgary.ca

**Scott McKean** is working on his PhD in Geoscience-Engineering with Prof. Priest at the University of Calgary. He received his MSc (2017) in Geophysics and his B-Eng in Civil Engineering at the University of Calgary. Scott's current research focuses on numerical modelling of hydraulic fracturing and induced seismicity. Before returning to academia, he worked as a consulting geoenvironmental engineer for >8 years. Scott is passionate about sustainability and accredited as a LEED AP and ENV SP and works with Engineers Without Borders to effect systems change and poverty elimination. He loves mountain sports and is roughly proficient in French.  
**Contact:** scott.mckean@ucalgary.ca | <https://www.linkedin.com/in/scotthmckean/>

**Suzie Jia** is working on her PhD in Petroleum Engineering with Professors Wong and Eaton at the University of Calgary. She received her MSc (2015) at the University of Alberta, and her BSc (2012) at the University of Waterloo. Her interest focuses on investigating the failure mechanisms and stress evolution during hydraulic fracturing. Her research integrates different methodologies, such as MATLAB programming, numerical modeling, laboratory tests and geophysical data analysis to better characterize the stimulated reservoir volume.  
**Contact:** qing.jia@ucalgary.ca | **Linked-in profile:** <https://www.linkedin.com/in/suziejia/>

**Yu Wang** is working on her MASc in Geotechnical Engineering with Prof. Grasselli at the University of Toronto. She received her B-Eng in Petroleum Engineering at the University of Alberta. Yu's research focus includes geomechanical modeling using FDEM and lab testing focusing on effect of gas in pores during the rock deformation process. She has completed internships in the oil and gas industry (TransCanada and Trican Well Service Ltd.), involving well performance enhancement design and field QA/QC work on standard conformance for pipeline construction. Yu enjoys reading, swimming and Sichuan cuisine.  
**Contact:** yuu.wang@mail.utoronto.ca | **Linked-in profile:** [www.linkedin.com/in/YuWANG9925](https://www.linkedin.com/in/YuWANG9925)

[ucalgary.ca/science/redevelop/team/student-hqps](https://ucalgary.ca/science/redevelop/team/student-hqps)

## Induced seismicity, well azimuth, and completion economics in the Duvernay

Scott McKean<sup>1</sup> and Suzie Jia<sup>1</sup>



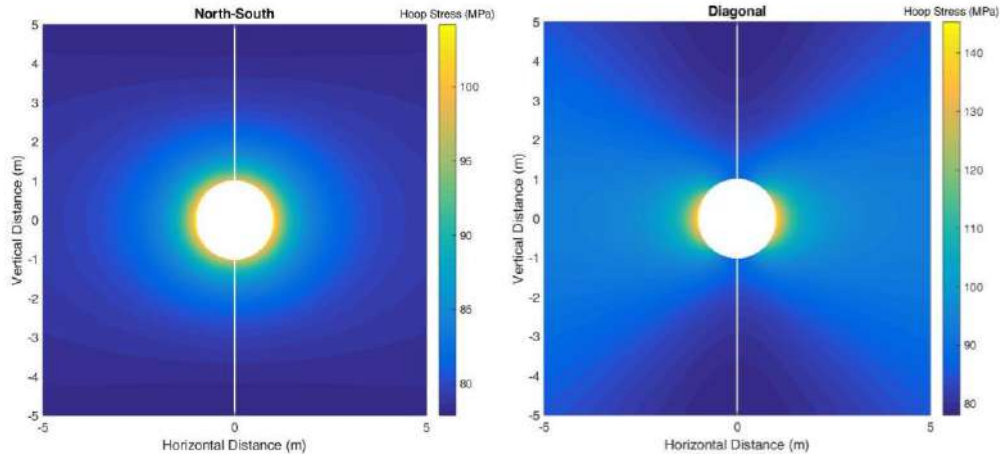
Induced seismicity is a major challenge for the Canadian energy sector, especially in the Duvernay Formation. This study uses the Mohr-Coulomb criterion to investigate induced seismicity mechanisms, which principally consist of hydraulic and total stress perturbations. It proposes two structural models for optimally oriented faults and shows that faults in the Duvernay are very sensitive to triggering. It then looks at the influence of wellbore azimuth on wellbore stability, induced seismicity, operations, and economics – both theoretically and through a statistical comparison of north south and diagonal laterals in the Kaybob area of the Duvernay. The study argues that the presence of north-south wells may exacerbate total and hydraulic stress perturbation and that it may be economically advantageous to drill wells north south as opposed to diagonally.

### FOOTNOTES:

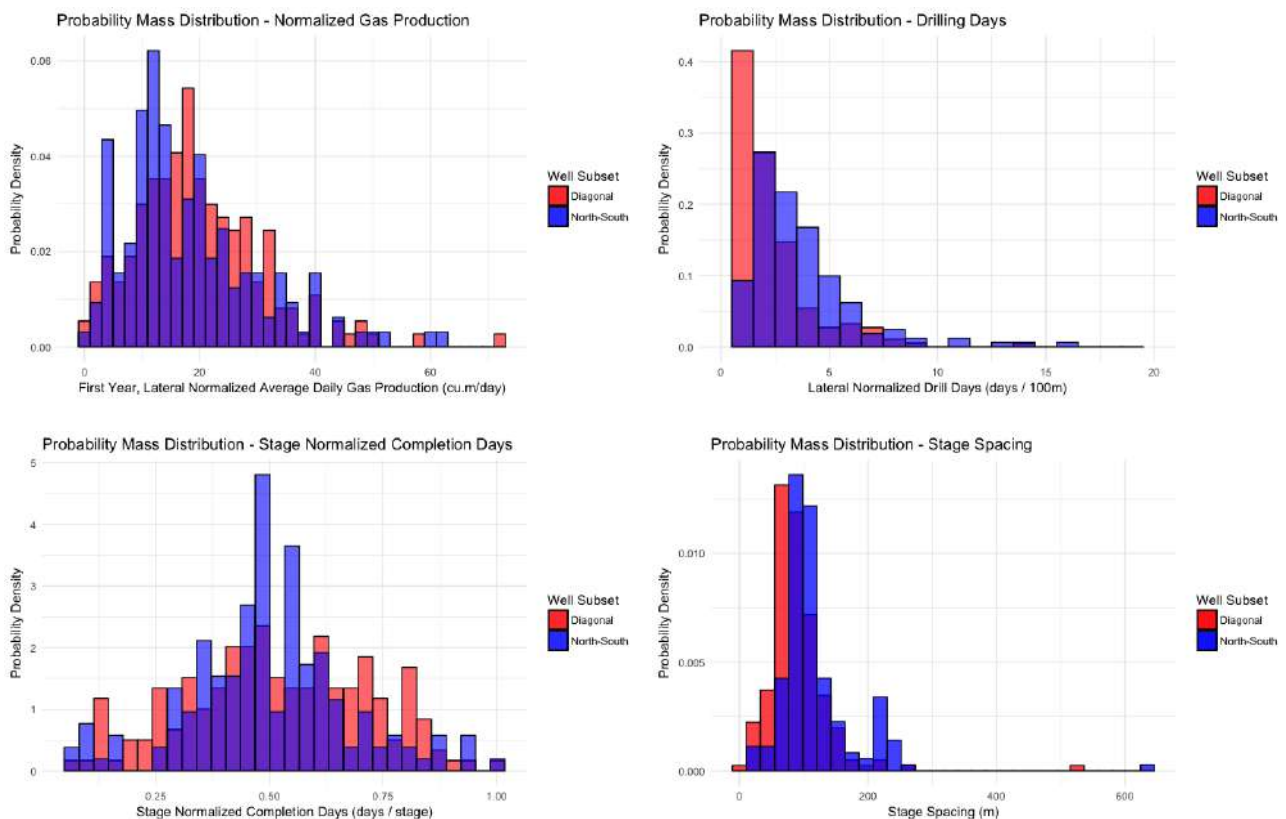
<sup>1</sup>University of Calgary

*\*Not intended for public distribution or for citation\**

1<sup>st</sup> Annual ReDeveLoP Challenge | April 30 – May 4, 2018



**Figure 1.** A plot of hoop stress around a north-south lateral (left) and diagonal lateral (right). The colour scale shows the hoop stress in MPa. Stress concentrations are clearly visible in the diagonal lateral.



**Figure 2.** Histograms of the four comparisons of north south (blue) and diagonal (red) wells. A histogram of lateral normalized gas production is shown in the upper left. A histogram of lateral normalized drilling days is shown in the upper right. A histogram of stage spacing normalized completions days is shown the bottom left. A histogram of stage spacing is shown in the bottom right.

#### ACKNOWLEDGEMENTS:

The work presented here is part of a research project supported by the Canada First Research Excellence Fund (CFREF), the Microseismic Industry Consortium (MIC), and the ReDevelop program. The authors thank Dr. Dave Eaton, Dr. Ron Wong, Dr. Jeff Priest, and Dr. Celia Kennedy for their technical guidance. The advice of Dr. Schultz was invaluable in scoping out this project. Matt Graham of Vesta Energy Ltd. provided detailed guidance for the comparison of north south vs. diagonal laterals.

*\*Not intended for public distribution or for citation\**

1<sup>st</sup> Annual ReDeveLoP Challenge | April 30 – May 4, 2018

## A Study of the Traffic Light System for Induced Seismicity

Sobhan Iranmanesh<sup>1</sup>, Yu Wang<sup>2</sup> and Jieyu Zhang<sup>3</sup>



Induced seismicity is mainly due to various industrial operations, such as hydraulic fracturing and wastewater injection during oil and gas production. Even though these seismic events are generally low in magnitude ( $< M_L 1$ ) and hardly felt, unexpected large induced earthquakes can still happen. One of the possible reasons is operating near fault zones. These large induced seismic events damage property and cause panic among the public. Hazard analysis is used to study the potential risks of induced seismic events. Possible damage an earthquake can cause, such as infrastructure damage, and human anxiety are considered as factors in the risk analysis of induced seismicity. The Traffic Light System (TLS) is the mitigation method implemented for operations in Alberta and British Columbia, Canada. The operators are required to react differently depending on the recorded magnitude and if the magnitude reaches certain thresholds. Reports show that TLS partially mitigates the impact of induced seismicity, but large earthquakes still occur at operation sites. In this paper, we studied the possible causes of these large induced earthquakes and the possible risks of induced seismicity and gave our opinions on the policy regarding the current TLS. We first examined the effectiveness of TLS based only on magnitudes. Then we analyzed the practicability of including other parameters in TLS, such as peak ground velocity and peak ground acceleration, specific regions, and population density. Based on our study, we gave some suggestions to improve the evaluation and mitigation of induced seismic events.

### FOOTNOTES:

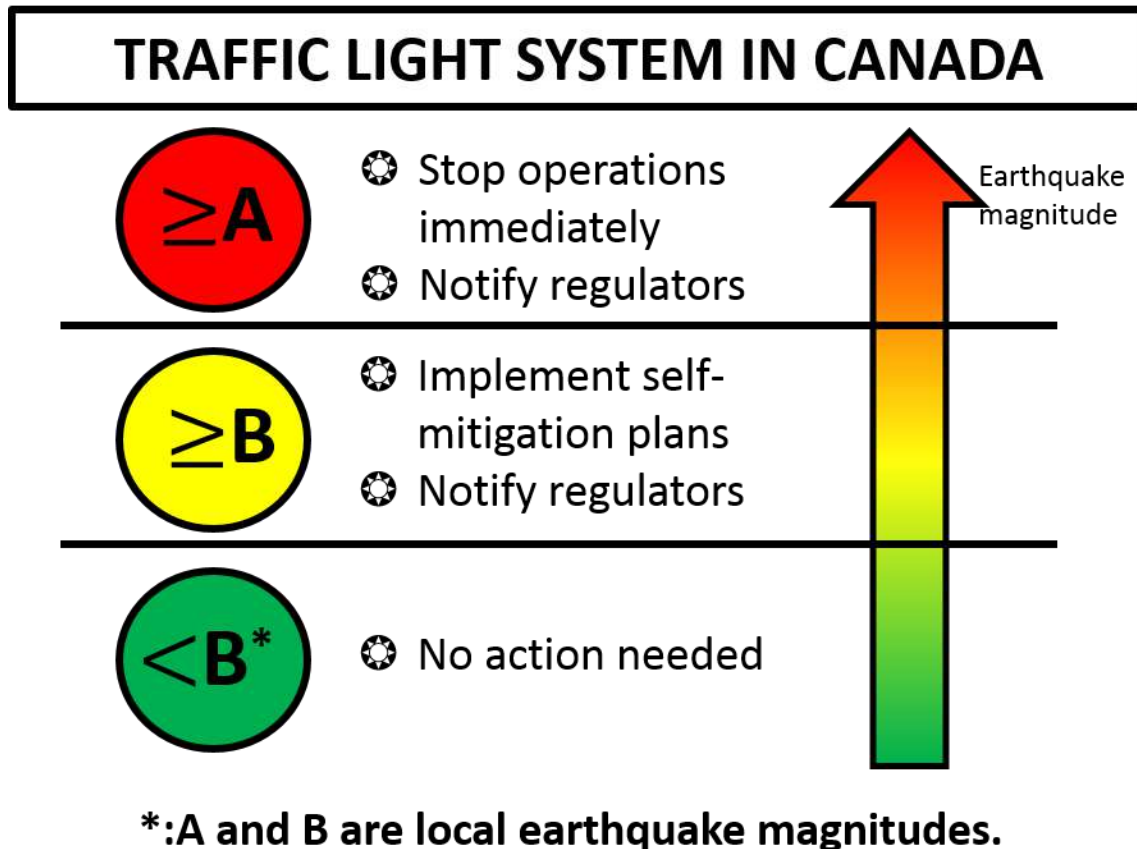
<sup>1</sup> University of Calgary

<sup>2</sup> University of Toronto

<sup>3</sup> University of Alberta

*\*Not intended for public distribution or for citation\**

1<sup>st</sup> Annual ReDeveLoP Challenge • April 30 – May 4, 2018



**Figure 1.** An illustration of Traffic Light System in Canada

#### ACKNOWLEDGEMENTS:

The work presented here is part of a research project supported by the Canada First Research Excellence Fund (CFREF), the Microseismic Industry Consortium (MIC), and the ReDeveLoP program. The authors thank Dr. Dave Eaton, Dr. Jennifer Winter and Dr. Celia Kennedy for their guidance. The advice of Rebecca Donnell was invaluable in scoping out this project.

*\*Not intended for public distribution or for citation\**

1<sup>st</sup> Annual ReDeveLoP Challenge • April 30 – May 4, 2018



# SUPPLYING LIQUEFIED NATURAL GAS TO REMOTE COMMUNITIES



**Aly Abdelaziz**

Department of Civil Engineering  
University of Toronto



**Jake Fuss**

The School of Public Policy  
University of Calgary



**Sarah Saad**

Geoscience Department  
University of Calgary



**Hanh Bui Thi**

Physics Department, Faculty of Science  
University of Alberta

**Aly Abdelaziz** is working on his PhD in Civil Engineering with Prof. Grasselli at the University of Toronto. He received his B-Eng (2007) in Civil Engineering (Structures) at Benha University in Egypt. Between 2007 and 2015, Aly worked in geotechnical investigation, construction monitoring and laboratory materials testing in Dubai, United Arab Emirates. He returned to academia to expand his knowledge and make connections between that knowledge and industry. His current research interests include generating synthetic samples using Voronoi tessellations and understanding the influence on shape tolerances on rock strength. Aly is a running fanatic on the verge of running his first half marathon, and a hobby-baker.

**Contact:** aly.abdelaziz@mail.utoronto.ca | **Linked-in profile:** <https://www.linkedin.com/in/engalyabdelaziz>

**Jake Fuss** is working on his MPP in Public Policy with Prof. Winter at the University of Calgary. He received his BA (2017) in Commerce - Finance at University of Calgary. Jake's research focus is economic and fiscal policy, primarily concentrating on evaluating the federal equalization program and the inclusion of resource revenues. Jake completed an internship for a mortgage company in downtown Calgary and worked as a Teaching Assistant in the Haskayne School of Business. He plans to work in the fields of energy, government or politics. For 3 years, Jake received Dean's List recognition by the Haskayne School of Business (GPA >3.7). He is also an active volunteer with Habitat for Humanity, enjoys travelling the globe, and a range of amateur sports, such as: tennis, football, and soccer.

**Contact:** jafuss@ucalgary.ca | **Linked-in profile:** <https://ca.linkedin.com/in/jake-fuss/>

**Hanh Bui Thi** is working on her MSc in Geophysics with Prof. Van der Baan at the University of Alberta. She also has an MSc in Earthquake and Seismology Engineering (2017) from the University of Grenoble Alpes in France, and a B-Eng (2015) (Cum Laude) in Geophysical Engineering from the Hanoi University of Mining and Geology in Vietnam. Hanh enjoys R & D and would, ideally, like to work in petroleum exploration or earthquake engineering. Hanh is bilingual (English and Vietnamese) and she is willing to relocate for the right position. After graduating from Hanoi University of Mining and Geology, she worked as a researcher at Geophysics department, Vietnam Petroleum Institute. She won the Erasmus Mundus plus scholarship and study in the Master of Earthquake Engineering and Engineering Seismology. Her interest is oil and gas exploration and earthquake engineering. Hanh is a young enthusiastic person.

**Contact:** hbui@ualberta.ca | **Linked-in profile:** <https://www.linkedin.com/in/hanh-bui-8aaab285/>

**Sarah Saad** is working on her MSc in Geochemistry with Prof. Mayer at the University of Calgary. She received her BSc (2010) with a double major in Petroleum and Environmental Geology from the University of Calgary. Sarah's current research is in isotope geochemistry, focused on the Montney Formation, an unconventional low-permeability hydrocarbon reservoir located in western Canada. Sarah's past work experience includes researching under-developed basins in the Arctic with the Geological Survey of Canada, logging Alberta oil sands cores for various major oil company projects, mapping in conventional Alberta Deep Basin plays, and oilfield operations in English and French. Most recently, she completed a project with a busy E&P company applying her isotope geochemistry knowledge to solve issues involving fracking.

**Contact:** sarah.saad2@ucalgary.ca | **Linked-in profile:** <https://ca.linkedin.com/in/sarah-saad-a97161112>

[ucalgary.ca/science/redevelop/team/student-hqps](https://ucalgary.ca/science/redevelop/team/student-hqps)

*\*Not intended for public distribution or for citation\**

1<sup>st</sup> Annual ReDeveLoP Challenge • April 30 – May 4, 2018

## Supplying liquefied natural gas to remote communities: Freeze or go full steam ahead?



Jake Fuss<sup>1</sup>, Aly Abdelaziz<sup>2</sup>, Sarah Saad<sup>1</sup>, Hanh Bui Thi<sup>3</sup>

Liquefied natural gas (LNG) may be a better alternative for diesel fuel in remote communities due to its low greenhouse gas (GHG) emissions, smaller storage capacity and increased safety. However, the costs associated with production, liquefaction, transportation, and storage limits the interest of private investors and stakeholders in such projects. In this paper we introduce the current obstacles surrounding the adoption of LNG and analyze the hamlet town of Fort Chipewyan, Alberta as a case study. We specifically address the obstacles considering the environmental, safety, economical, and political aspects. Environmental and safety factors favor the adoption of LNG technology to power remote communities. Economically, the challenge is presented in the high capital expenditure and operational costs, combined with the lack of proper distribution networks, all-season roads, and the fall in the global LNG price. Additionally, the multi-layered political structure associated with the geographic location of the remote communities may present the biggest challenge. Under these considerations, implementing such technology in Fort Chipewyan is unlikely. Accordingly, we propose additional policy options that would favor the adoption of such technology by introducing conditional government funding for energy infrastructure to lure private investors, while stressing the importance of improving the communication between the various levels of government and public agencies with the First Nations communities.

### FOOTNOTES:

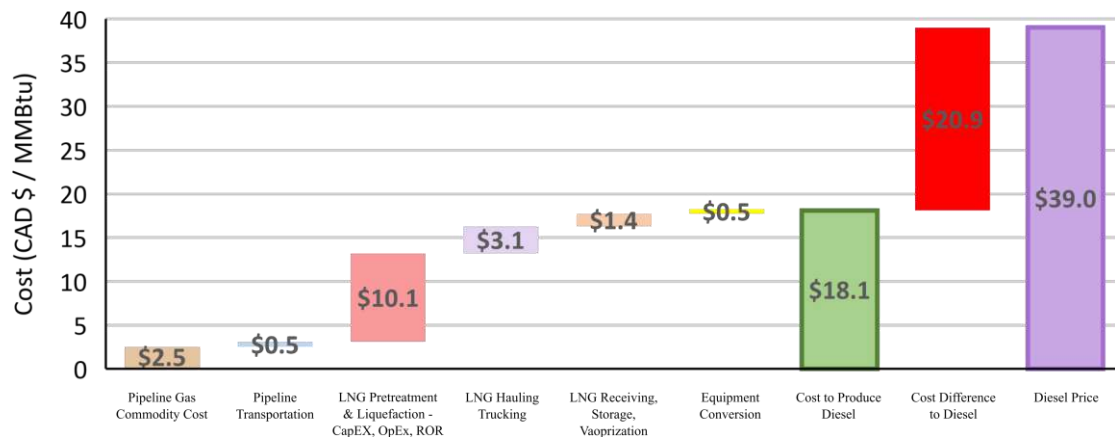
<sup>1</sup>University of Calgary

<sup>2</sup> University of Alberta

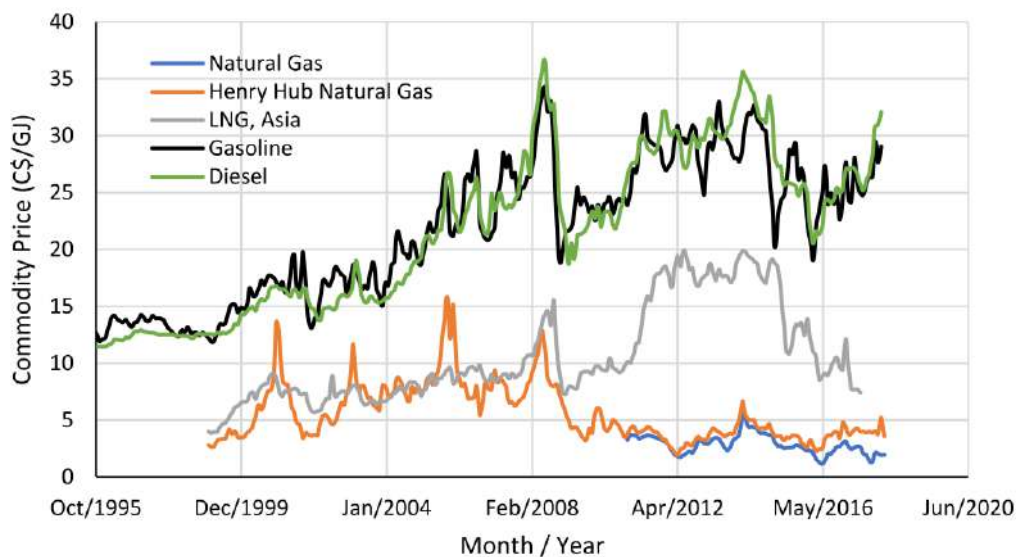
<sup>3</sup> University of Toronto

*\*Not intended for public distribution or for citation\**

1<sup>st</sup> Annual ReDeveLoP Challenge • April 30 – May 4, 2018



**Figure 1.** Breakdown of LNG Supply chain vs. Diesel costs [1].



**Figure 2.** Fluctuation of various fuel prices: Natural Gas [2]; Henry Hub Natural Gas [3]; LNG Asia [4]; Consumer Gasoline [5]; and Consumer Diesel [5].

#### ACKNOWLEDGEMENTS:

The authors would like to express their gratitude to the Project Instructor, Dr. Jeff Priest who provided insights to achieve the goals of this manuscript. The authors would also like to thank the following industry professionals who provided vast knowledge, insight and information that helped tremendously for this project: Paul Miller (Sonoma), Colin Nikiforuk (PTX Technologies), Matt Sveinbjornson (ATCO), Robert Walker (Ferus), Kevin Force (NRCAN), Mike Johnson (NEB), Chris Doleman (NEB). In addition, the contributions from the Fort Chipewyan Indigenous contacts were paramount for our ability to understand the community, including: Lisa Tssassaze (AFCN), Jule Asterisk (Keepers of the Athabasca), and Mikisew Cree Group of Companies. The work presented here is part of a research project supported by NSERC.

#### REFERENCES:

- [1] James Knowles. Power Shift: Electricity for Canada's Remote Communities; 2016.
- [2] Canadian Gas Association. Gas Stats: Natural Gas Prices.
- [3] U.S. Energy Information Administration. Henry Hub Natural Gas Spot Price [MHHNGSP].
- [4] International Monetary Fund. Global price of LNG, Asia [PNGASJPUSDM].
- [5] Statistics Canada. Table 326-0009: Average retail prices for gasoline and fuel oil, by urban centre, monthly.

*\*Not intended for public distribution or for citation\**

## Supplying liquefied natural gas to remote communities: Freeze or go full steam ahead?



Sarah Saad<sup>1</sup>, Hanh Bui Thi<sup>2</sup>, Aly Abdelaziz<sup>3</sup>, Jake Fuss<sup>1</sup>

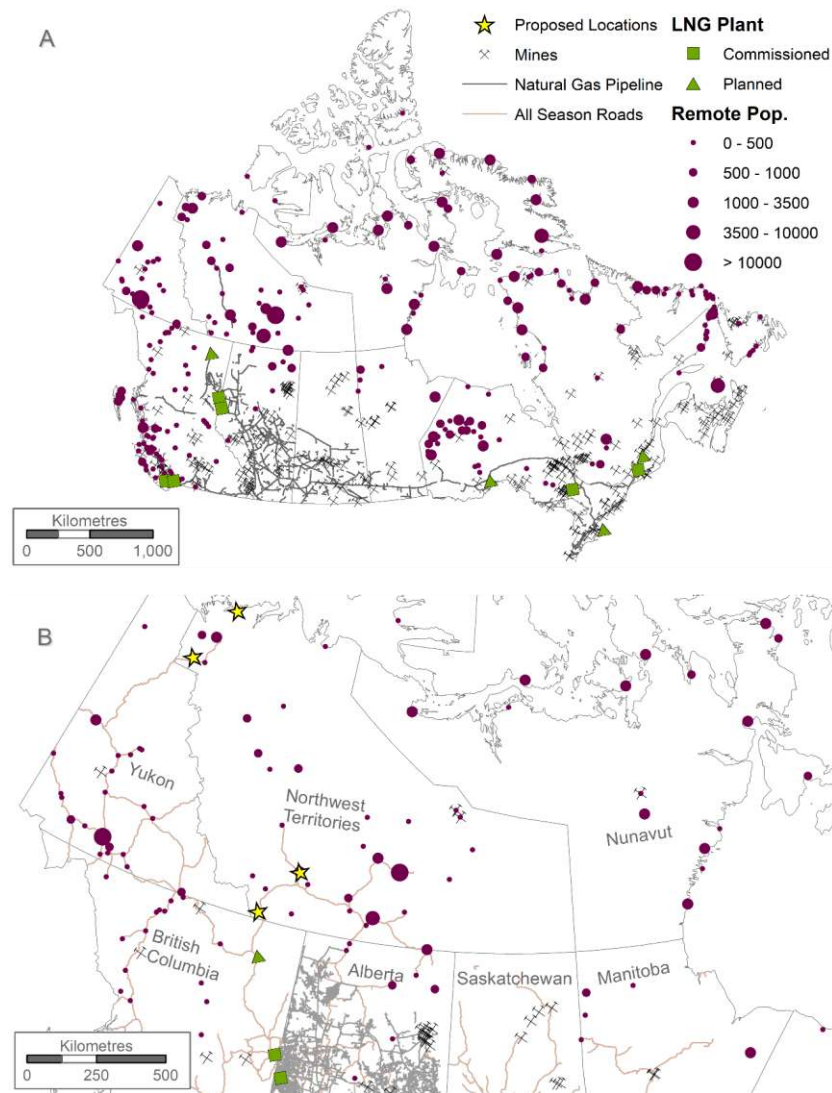
In remote Canadian communities, diesel is widely used as a reliable fuel source. However, this also comes with accompanying disadvantages including high greenhouse gas (GHG) and criteria air contaminant (CAC) emissions, the risk of environmental damage due to spills and leaks, and high market pricing. Therefore, the need for a diesel substitute is nowhere more evident than in these communities. Liquefied natural gas (LNG) is an option worthy of consideration as it is a reliable yet cleaner fuel, with much lower harmful emissions and contamination risks. Canada is one of the world's largest producers of natural gas [1] and with the advent of new horizontal drilling technologies production numbers continue to increase. Expanding the market to new end users in these communities would be beneficial to all. In this paper, we examine the possibility of supplying remote communities in Western Canada with LNG and compare this to the use of renewable energies, such as solar, wind, and geothermal. Fort Chipewyan, Alberta's largest remote community, will be used as a case study to determine the feasibility of converting to LNG as the primary fuel source and exploring options to reduce dependence on diesel.

### FOOTNOTES:

<sup>1</sup>University of Calgary

<sup>2</sup> University of Alberta

<sup>3</sup> University of Toronto



**Figure 3** – (A) Shows the location of remote communities, mines, LNG plants (square: existing; triangle: planned) and NEB regulated natural gas pipelines. (B) Shows Western Canada overlaid with Alberta gas pipelines and all-season roads. Stars indicate locations of proposed communities where LNG may be feasible. Map resource obtained from [2-5].

#### ACKNOWLEDGEMENTS:

The authors would like to express their gratitude to the Project Instructor, Dr. Jeff Priest who provided insights to achieve the goals of this manuscript. The authors would also like to thank the following industry professionals who provided vast knowledge, insight and information that helped tremendously for this project: Paul Miller (Sonoma), Colin Nikiforuk (PTX Technologies), Matt Sveinbjornson (ATCO), Robert Walker (Ferus), Kevin Force (NRCAN), Mike Johnson (NEB), Chris Doleman (NEB). In addition, the contributions from the Fort Chipewyan Indigenous contacts were paramount for our ability to understand the community, including: Lisa Tssassaze (AFCN), Jule Asterisk (Keepers of the Athabasca), and Mikisew Cree Group of Companies. The work presented here is part of a research project supported by NSERC.

#### REFERENCES:

- [1] National Energy Board. Natural Gas.
- [2] Alberta Energy Regulator. Products and Services Catalogue: Enhanced Pipeline Graphics File.
- [3] Statistics Canada. Intercensal – Road network files.
- [4] Natural Resources Canada. Liquefied Natural Gas Terminals: North American Cooperation on Energy Information.
- [5] DMTI Spatial. MADGIC GIS Data: Pipelines.

*\*Not intended for public distribution or for citation\**

1<sup>st</sup> Annual ReDeveLoP Challenge • April 30 – May 4, 2018

# PIPELINE



VS



# RAIL



**Karen Grey** is working on her PhD in Petroleum Geology with Prof. Cheadle at the University of Western Ontario. She received her BSc (Hon) (2010) in Geology at the University of New Brunswick. Karen spent several years working in the mineral exploration and mining industry after completing her undergraduate degree, before pursuing her interest in petroleum geoscience. The focus of her current research is modelling mechanical stratigraphy in a low-permeability reservoir, under the broader scope of induced seismicity processes. Although Karen enjoys research, she is eager to get back into industry and is open to relocating for the right position. Born and raised on the east coast, Karen's first language is English and she has intermediate-level French proficiency.

**Contact:** kgrey2@uwo.ca | **Linked-in profile:**

**Hossein Ahmadi** is working on his PhD in Petroleum Engineering with Prof. Clarkson at the University of Calgary. He received his MSc (2017) and B-Eng (2014) in Petroleum Engineering at the University of Tehran, in Iran. Hossein is also a research assistant with the Tight Oil Consortium (<http://www.tightoilconsortium.com/index.html>). His research interests are rate transient analysis, unconventional reservoirs, and well testing.

**Contact:** hossein.ahmadi1@ucalgary.ca | **Linked-in profile:**

**Jade McLean** is working on her MPP in Public Policy with Prof. Winter at the University of Calgary. She received her BA (2016) in Commerce of Natural Resources, Energy and the Environment at the University of Alberta. Jade completed an internship in the Environment and Energy Section of the Embassy of Canada in Washington, D.C., where she conducted research to support policy development on trans-boundary resource issues, such as: species at risk, fisheries, and mining. Jade also completed an internship as a Climate Change Liaison in the Métis Nation of Alberta, where she assisted in the planning, development and implementation of 18 Climate Change Workshops throughout Alberta. During her undergraduate studies, Jade worked as a research assistant where she examined corporate tax structures, multi-national tax law, and international tax avoidance strategies implemented by Apple Inc., Google, Starbucks and Burger King. Jade is also the recipient of two Public Policy scholarships and an active volunteer in her community.

**Contact:** jade.mclean@ucalgary.ca | **Linked-in profile:** <https://www.linkedin.com/in/jade-mclean-b8a011156/>

**Volodymyr Vragov** is working on his MSc in Geophysics with Prof. Eaton at the University of Calgary. He received his BSc (2014) in Geophysics (with Distinction) from the University of Alberta. Volodymyr is currently conducting research in the area of hydraulic fracturing induced seismicity near Town of Fox Creek, Alberta. He has almost 2 years of industry experience in geoscience workflow development and deployment, unconventional reservoir characterization and frontier offshore exploration with Shell Canada and Nexen Energy. Volodymyr is also an active volunteer on campus, as President of the CSEG/EAGE/SEG student chapter, where he helps to facilitate geoscience students' development through organizing Talk Series, industry courses, networking events and student geoscience competitions.

**Contact:** volodymyr.vragov1@ucalgary.ca | **Linked-in profile:** <https://www.linkedin.com/in/volodymyrvragov/>

[ucalgary.ca/science/redevelop/team/student-hqps](http://ucalgary.ca/science/redevelop/team/student-hqps)

*\*Not intended for public distribution or for citation\**

1<sup>st</sup> Annual ReDeveLoP Challenge • April 30 – May 4, 2018

## Pipeline versus rail: Quantitative comparison between the transportation of crude oil and the cost to society

Volodymyr Vragov<sup>1</sup>, Hossein Ahmadi<sup>4</sup>, Karen Grey<sup>3</sup>, and Jade Mclean<sup>2</sup>



The movement of petroleum products over the last decade, particularly crude oil, has received enormous public and media attention. Most of this attention has focused on major oil spills and accidents, raising the need to have a comprehensive assessment of the costs associated with the petroleum products that are transported to society. This paper combines the most recently available estimates of air pollution, greenhouse gases, and spill and accident costs associated with long-distance movement of petroleum products. The purpose of this paper is to provide a comprehensive quantitative cost-to-society comparison between transporting petroleum products by rail versus pipeline. For the movement of crude oil by rail, the cost of greenhouse gases is 200 CAD per million-barrel mile, which is twice the cost compared to pipeline (100 CAD). The air pollution damages are larger for crude-by-rail compared to damages associated with pipelines (563 CAD vs 347 CAD). These values are Canada and USA wide averages and need to be reassessed for individual projects that need to be evaluated based on the population density. Spills and accident costs are also significantly higher for rail compared to pipelines due to more expensive consequences associated with train disasters, as well as more frequently occurring spills (483 CAD vs 63 CAD). Finally, total cost to society per million-barrel miles transported amount to 510 CAD for pipeline and 1248 CAD for rail.

---

<sup>1</sup>University of Calgary – Department of Geoscience

<sup>2</sup>University of Calgary – School of Public Policy

<sup>3</sup>University of Western Ontario – Department of Earth Sciences

<sup>4</sup>University of Calgary - Schulich School of Engineering

**Table 1.** Summary of the cost to society for the transportation of crude oil via pipeline and rail.

Type of cost	Pipeline (million-barrels miles)	Rail (million-barrel miles)
Greenhouse Gases	99.73 CAD	200.69 CAD
Air Pollution	347.13 CAD	563.88 CAD
Spills and Occurrences	63.63 CAD	483.87 CAD
<b>Total cost to society</b>	<b>510.49 CAD</b>	<b>1248.44 CAD</b>

**Table 2.** Rail vs Pipeline occurrences per Mboe transported

Total for the Years 2008-2016	Pipeline	Rail
Occurrences	590	268
Petroleum products transported (Mboe)	15,980	1,645.67
Occurrences per Mboe	0.037	0.162

**ACKNOWLEDGEMENTS:**

Mike Johnson (National Energy Board)

Kevin Olson (Fluor Corporation)

**Data Source:**

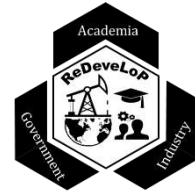
Transport Canada

National Energy Board

*\*Not intended for public distribution or for citation\**1<sup>st</sup> Annual ReDeveLoP Challenge • April 30 – May 4, 2018

## Indigenous participation in Canada's oil industry: Attaining economic growth through strengthened fiscal relationships

Jade McLean<sup>2</sup>, Karen Grey<sup>3</sup>, Volodymyr Vragov<sup>1</sup>, and Hossein Ahmadi<sup>4</sup>



At large, Canadians have a vested interest in the development and sustainability of a strong energy sector. As such, closing the gap between the financial interests of Indigenous groups and the economic objectives of industry and government regarding oil sands development, has reached a critical point. Canada's petroleum sector is challenged by limited export capacity, resulting in transportation bottlenecks and decreased investor confidence. Delays in pipeline development have been in part due to legal challenges related to the Crown's duty to consult and accommodate Indigenous peoples. While some Indigenous groups remain in opposition to petroleum development, others are taking advantage of the economic opportunity and pursuing wider involvement by seeking equity partnerships in major projects. Despite the willingness of Indigenous communities to participate in the energy sector, many experience significant financial and educational barriers to achieving economic prosperity. This paper explores how the Government of Canada can better reconcile the economic and environmental interests of Indigenous groups regarding resource development in Canada. Establishing federal loan guarantees for large-scale projects can ensure that Indigenous groups receive equitable opportunity to participate in pipeline and rail development projects that impact their land, and secure long-term economic benefits. Secondly, strengthening the fiscal capacity of Aboriginal Financial Institutions will increase support to Indigenous businesses that serve the industry. Finally, supplying training and employment opportunities through an environmental and monitoring program can allow for Indigenous peoples to play a larger role in environmental protection.

<sup>1</sup>University of Calgary – Geoscience Dept. / <sup>2</sup>University of Calgary – School of Public Policy

<sup>3</sup>University of Western Ontario – Earth Sciences Dept / <sup>4</sup>University of Calgary - Schulich School of Engineering

### ACKNOWLEDGEMENTS:

Matt Vickers (Generating for Seven Generations – G7G)

Dale Swampy (Swampy Consulting Services)

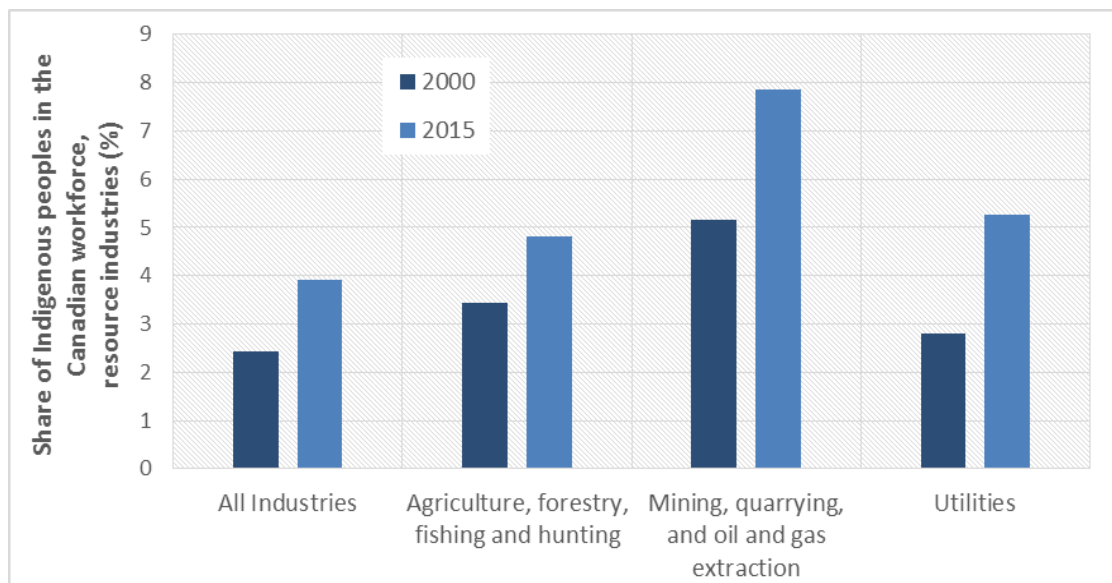
### REFERENCES:

Statistics Canada (2001). Labour Force Characteristics, Aboriginal Identity Data (table), 2001 Census of Population, Statistics Canada Catalogue no. 97F0011XCB2001045.

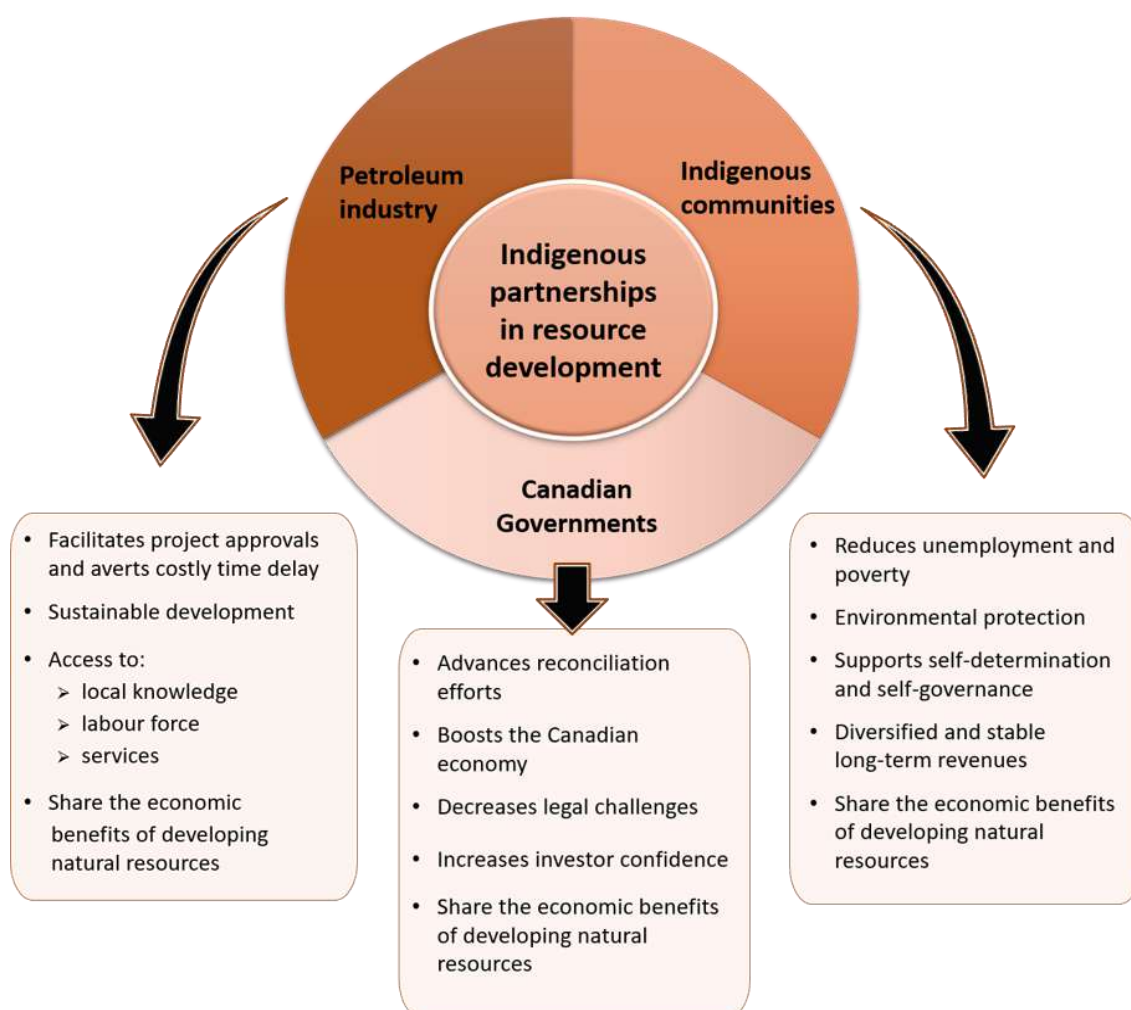
Statistics Canada (2018). Employment population by Industry – North American Industry Classification System, Aboriginal Identity Data (table), 2016 Census of Population, Statistics Canada Catalogue no. 98-400-X2016359.

*\*Not intended for public distribution or for citation\**

1<sup>st</sup> Annual ReDeveLoP Challenge • April 30 – May 4, 2018



**Figure 1.** Share of Indigenous peoples working in the Canadian resource industries in 2000 (dark blue) and 2015 (lighter blue). *Source of data: Statistics Canada, Census of Population Programs 2001 and 2016.*



**Figure 2.** Summary of how Indigenous partnerships in resource development can benefit federal and provincial governments, Canada's oil and gas industry, and Indigenous communities.



## The Orphaned Wells Team

Earl Magsipoc (Engineering)

Zhengru Yang (Geoscience)

Gang Hui (Engineering)

Michael Lim (Public Policy, *Project Manager*)

Daniela Becerra (Geoscience)



*\*Not intended for public distribution or for citation\**

1<sup>st</sup> Annual ReDeveLoP Challenge • April 30 – May 4, 2018

**Daniela Becerra** is working on her PhD in Geoscience with Prof. Clarkson at the University of Calgary. She received her MSc (2017) in Geology at University of Oklahoma, and her BSc (Cum Laude) (2013) in Geology at Universidad Industrial de Santander, in Colombia. Along with her PhD work, Daniela is also a research assistant with the Tight Oil Consortium (<http://www.tightoilconsortium.com/index.html>). Her current research focus is the integrated petrophysical and reservoir characterization of the Montney Formation in Western Canada. Daniela grew up in a small city in Northern Colombia. At age 15 she started her undergraduate studies, moving to a bigger city where she thoroughly enjoyed living in and experiencing a different culture. Daniela has lived in five cities across three different countries, and plans to continue pursuing opportunities abroad following the completion of her doctoral studies. In her spare time, she enjoys hosting friends and family for her home-made traditional Colombian cuisine.

**Contact:** [daniela.becerrarondo@ucalgary.ca](mailto:daniela.becerrarondo@ucalgary.ca)

**Linked-in profile:** <https://www.linkedin.com/in/daniela-becerra-43a84242>

**Earl Magsipoc** is working on his MASc in Civil Engineering with Prof. Grasselli at the University of Toronto. He received his B-Eng (2017) in Civil Engineering with an Environmental Engineering option at the University of Waterloo. After completing an internship at a geotechnical software development company, he was inspired to pursue a career in geotechnical engineering and tackle the complexity it presents. He has also completed several internships in municipal engineering, highway transportation design, and tunnelling design. The focus of Earl's research is numerical geomechanics modelling with an interest in rock tunnelling, and he is also interested in exploring the use of computer technology for engineering applications.

**Contact:** [e.magsipoc@mail.utoronto.ca](mailto:e.magsipoc@mail.utoronto.ca) | **Linked-in profile:** <https://www.linkedin.com/in/earl-magsipoc/>

**Zhengru Yang** is working on his MSc in Geoscience with Prof. Clarkson at the University of Calgary. Zhengru also has a BSc (2017) in Geology from the University of Calgary, and another BSc (2017) in Petroleum Geology from the University of Petroleum, in Beijing, China. Zhengru's research interests concern unconventional tight reservoir evaluation, with a focus on permeability / diffusivity determination, gas adsorption capacity simulation and geological controls on reservoir characteristics within the Montney and Duvernay Formations. He is also a research assistant with the Tight Oil Consortium (<http://www.tightoilconsortium.com/index.html>). Zhengru completed an internship with the PetroChina Company Limited (Liaohe Oil Company), working in sandy reservoirs distribution analysis in a fault-subsidence lake basin. Zhengru is also bilingual (English and Mandarin).

**Contact:** [zhengru.yang@ucalgary.ca](mailto:zhengru.yang@ucalgary.ca)

**Linked-in profile:** <https://www.linkedin.com/in/zhengru-yang-530681155/>

**Hui Gang** is working on his PhD in Petroleum Engineering with Prof. Chen at the University of Calgary. He received his MSc (2011) in Oilfield Development Engineering at Graduate School of RIPED, PetroChina, and his B-Eng (2008) in Petroleum Engineering at the China University of Geoscience. Hui previously worked for 6 years in RIPED (CNPC) as a reservoir geology engineer, concentrating on fractures characterization and reservoir description for low permeability reservoirs. His current research is focused on fracture propagation and simulation, integrating geomechanics, geology and reservoir engineering to simulate hydraulic and natural fractures. He would like to move into R&D work in this area after graduation. Hui enjoys an active lifestyle of basketball, badminton and swimming.

**Contact:** [hui.gang@ucalgary.ca](mailto:hui.gang@ucalgary.ca)

**Michael Lim** is working on his MPP in Public Policy with Prof. Winter at the University of Calgary. He received his BSc (Hon) (2015) (First Class Honours) in Chemistry at the University of Calgary. Michael is interested in energy, environmental and economic policies, with a focus on renewables. He is particularly interested in the Alberta energy market and participates in local policy symposiums with the CD Howe Institute and Alberta Chamber of Resources. Michael is also the recipient of numerous academic awards and scholarships. During his undergraduate studies, he conducted an NSERC-funded research project exploring energy storage materials, namely redox flow battery applications for grid-level electricity storage. Michael is bilingual (English and Korean) and possesses dual citizenship (Canada and South Korea).

**Contact:** [milim@ucalgary.ca](mailto:milim@ucalgary.ca) | **Linked-in profile:** <https://www.linkedin.com/in/michael-lim-mpp/>

[ucalgary.ca/science/redevelop/team/student-hqps](http://ucalgary.ca/science/redevelop/team/student-hqps)

*\*Not intended for public distribution or for citation\**

1<sup>st</sup> Annual ReDeveLoP Challenge • April 30 – May 4, 2018

## **Analysis of contamination, remediation and geothermal potential of orphan wells in Alberta**

Magsipoc, E.<sup>1</sup>; Yang, Z.<sup>2</sup>; Hui, G.<sup>3</sup>; Lim, M.<sup>4</sup>; Becerra, D.<sup>2</sup>



Orphan wells are oil and gas wells that are not properly abandoned due to economic factors, politics, mismanagement, etc. They pose a potential environmental risk to their surroundings if left unchecked. In Alberta, orphan wells continue to proliferate as unfavourable economics hinder the Canadian oil and gas industry. Although this problem is largely a regulation issue, solutions made on a regulatory level should have a technical basis. Public well data from the Alberta Energy Regulator (AER), Orphan Well Association (OWA) and well information database from GeoSCOUT® is presented in this study.

This work reviews the current orphan well distribution in Alberta and discusses current environmental impacts and controlling factors. Well abandonment procedures and practices by the AER are also discussed. Finally, the potential for converting oil and gas orphan wells for geothermal energy is discussed.

### **FOOTNOTES:**

<sup>1</sup>*University of Toronto – Department of Civil and Mineral Engineering*

<sup>2</sup>*University of Calgary – Department of Geoscience*

<sup>3</sup>*University of Calgary – Schulich School of Engineering*

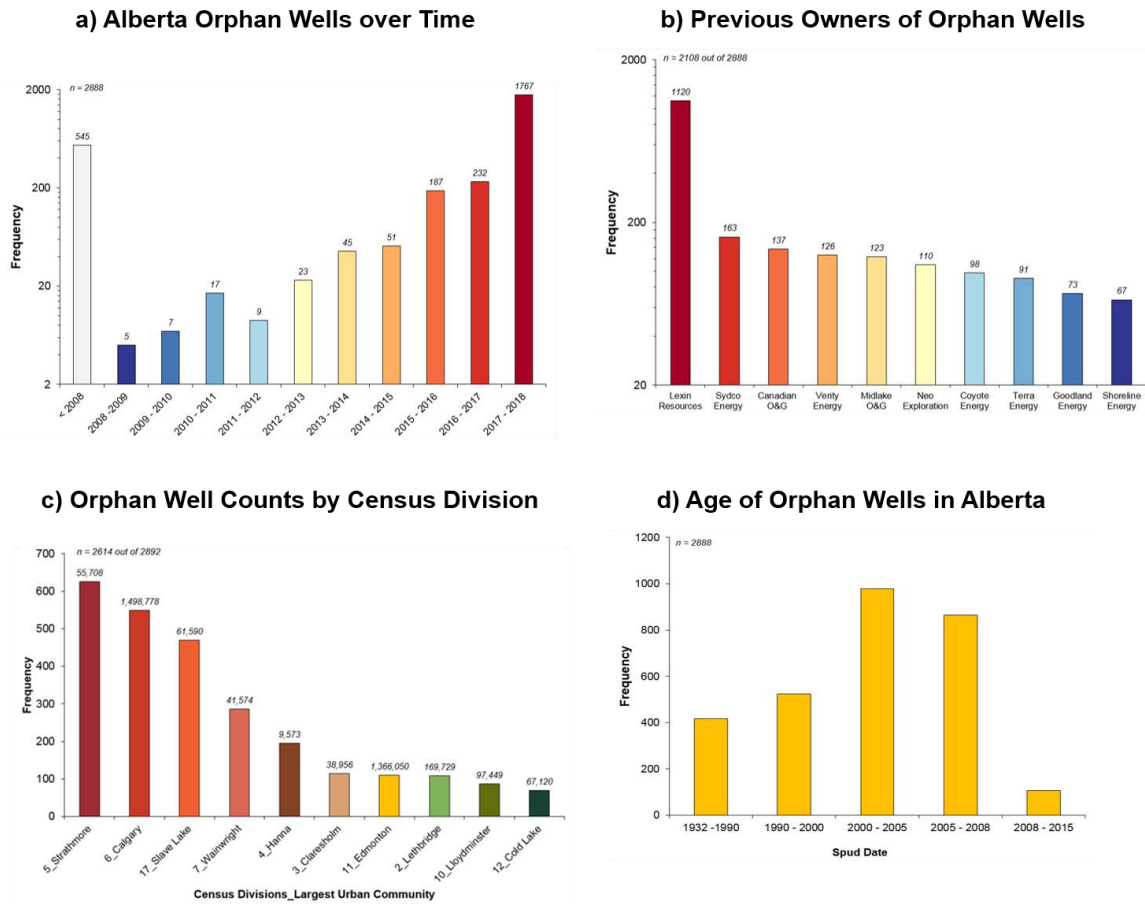
<sup>4</sup>*University of Calgary – School of Public Policy*

### **ACKNOWLEDGEMENTS:**

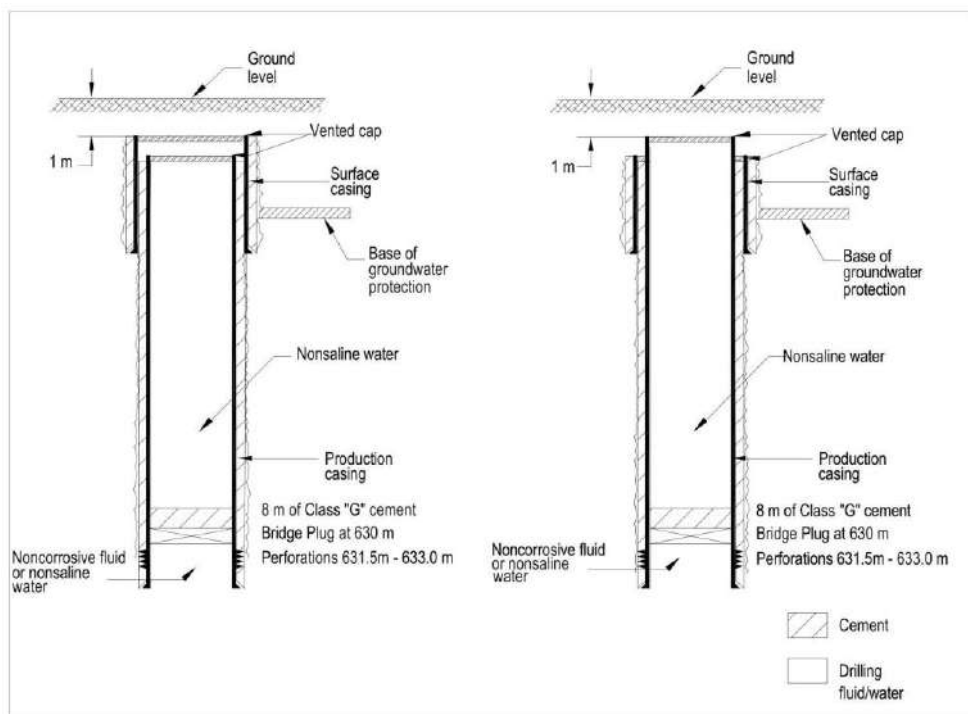
The authors acknowledge with appreciation: Dr. Karlis Muehlenbachs from University of Alberta and Pat Payne (P.Eng., Manager) from OWA for their valuable suggestions. Sincere thanks for access to GeoSCOUT® software is extended to the Centre for Applied Basin Studies (CABS), University of Calgary.

*\*Not intended for public distribution or for citation\**

1<sup>st</sup> Annual ReDeveLoP Challenge • April 30 – May 4, 2018



**Figure 1.** Histograms summarizing several aspects of orphan wells: a) Alberta orphan wells over time. b) Previous owners of orphan wells. c) Orphan well counts by census division. d) Age of orphan wells in Alberta.



**Figure 2.** Plug placement examples for Central Plains (Alberta Energy Regulator, 2016).

## Alternative policies for managing orphan wells in Alberta

Magsipoc, E.<sup>1</sup>; Yang, Z.<sup>2</sup>; Hui, G.<sup>3</sup>; Lim, M.<sup>4</sup>; Becerra, D.<sup>2</sup>



Orphan wells are non-producing or inactive assets left behind by bankrupt oil and gas producers without proper plugging or reclamation. With the current industry downturn, there are 2,888 orphan wells in Alberta, and the number is growing. The Orphan Well Association (OWA) is a responsible entity for plugging or properly abandoning orphan wells. The current mechanism for funding OWA is insufficient to deal with the growing number of orphan wells. The insufficiency imposes significant risks to landowners, indigenous communities, and taxpayers. This paper looks at reforming the current orphan well policies; it only deals with conventional and hydrofracturing assets. The proposed options are cyclically adjusted levy, blanket bond, adoption, accelerated inactive well closure, and direct government subsidy.

### FOOTNOTES:

<sup>1</sup>University of Toronto – Department of Civil and Mineral Engineering

<sup>2</sup>University of Calgary – Department of Geoscience

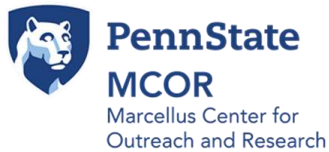
<sup>3</sup>University of Calgary – Schulich School of Engineering

<sup>4</sup>University of Calgary – School of Public Policy

### ACKNOWLEDGEMENTS:

The authors acknowledge with appreciation: Dr. Karlis Muehlenbachs from University of Alberta and Pat Payne (P.Eng., Manager) from OWA for their valuable suggestions.

## Acknowledgments



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

J. Welch