The evolution of regulatory practice for CCS projects in Canada

Patricia Larkin*, William Leiss and Daniel Krewski

McLaughlin Centre for Population Health Risk Assessment, University of Ottawa, Room 216A, 600 Peter Morand Crescent, Ottawa, Ontario, K1G 5Z3, Canada
Email: plarkin@xplornet.com
Email: leissw@queensu.ca
Email: dkrewski@uottawa.ca
*Corresponding author

Abstract: Carbon capture and storage (CCS) pilot and demonstration projects began in Canada in the 1990s. This review of publicly available documentation considers the regulatory application and approval practice for four large Canadian projects that are either under construction or in operation. Results find that oversight of CCS projects is value chain specific and obtaining documentation can be challenging. However, technical risk assessment supporting approvals is moving forward, with an increasing range of chain component health and environmental risks being assessed using referenced approaches. Monitoring remains the primary risk management approach. Global risk estimation is not completed and unresolved issues about transparency in risk communication could have the potential to negatively impact broad public acceptance of CCS and therefore project viability in the long run.

Keywords: carbon capture and storage; regulatory practice; Canada; risk assessment; risk management; risk communication; Canadian Environmental Assessment Act; Saskatchewan Environmental Assessment Act; Alberta Energy Regulator.

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Biographical notes: Patricia Larkin is a Post-Doctoral Fellow at the University of Ottawa. Her field of research, population health, considers structural and intermediary determinants of health and their interactions, with a goal to protect or improve human health. With a focus on applied risk management, she is undertaking research, writing and project management at the McLaughlin Centre for Population Health Risk Assessment and the Institute for Science Society and Policy. She is an active member of the Society for Risk Analysis. She holds her Master in Geography and Graduate Diploma in Population Health Risk Assessment and Management.

William Leiss is a Fellow and Past-President (1999–2001) of the Royal Society of Canada and an Officer in the Order of Canada. He is currently a Scientist at the McLaughlin Centre for Population Health Risk Assessment, University of Ottawa. From 1999 to 2004 he held the NSERC/SSHRC/Industry Research

Chair in Risk Communication and Public Policy at the Haskayne School of Business, University of Calgary. From 1994 to 1999, he held the Eco-Research Chair in Environmental Policy at Queen's University (Ontario). He is the author of *Risk and Responsibility* (1994), *Mad Cows and Mother's Milk: The Perils of Poor Risk Communication* (1997, 2004); in the *Chamber of Risks: Understanding Risk Controversies* (2001), all from McGill-Queen's University Press.

Daniel Krewski is a Professor of Epidemiology and Community Medicine at the University of Ottawa, where he also serves as Scientific Director of the McLaughlin Centre for Population Health Risk Assessment. His research interests include epidemiology, biostatistics, health risk assessment and risk management. He is a Fellow of the Society for Risk Analysis, the American Statistical Association and a national affiliate of the US National Academy of Sciences. He holds the Natural Sciences and Engineering Research Council of Canada Chair in Risk Science at the University of Ottawa.

1 Introduction

Carbon capture and storage (CCS) pilot and demonstration projects began in Canada in the 1990s and substantial geological storage potential has been identified for this climate change mitigation technology (NRCan et al., 2012). Today, three large scale integrated projects[1] (LSIP) are in operation and one is nearing completion. Three are principally carbon capture utilisation and storage [enhanced oil recovery (EOR)] project types: Saskatchewan's Weyburn-Midale Enhanced Oil Recovery (EOR) Operations and Boundary Dam Integrated CCS Demonstration Project and the Alberta Carbon Trunk Line. Alberta's Quest Carbon Capture and Storage Project is a saline aquifer geological sequestration project type.

To investigate the evolution of regulatory practice in Canada, the contents of publicly available project applications, third party submissions, review and approval documents are analysed, with emphasis on the regulatory process and considerations in risk assessment, risk management and risk communication. Findings suggest similarities and differences between provincial jurisdictions and project types, with progress evident over a 15-year study period. Potential obstacles to widespread implementation are also discussed.

A compendium of regulatory and non-regulatory risk assessment and risk management frameworks for CCS are described by Larkin et al. (2019a), particularly with respect to requirements for geologic sequestration. Differences exist in the mandatory and voluntary provisions that enable CCS, where mandatory requirements are not often elaborated and the use of guidance documents is discretionary. As well, risk assessment and risk management (RA/RM) is less prescribed in North America than in European-based regional or international jurisdictions. The Canadian policy and regulatory context is provided by Larkin et al. (2019b). In Canada, both CCS-EOR and saline sequestration project types are approved under oil and gas related legislation, regulations and directives that are in effect within the provincial jurisdiction. Three of the projects reviewed here were also subject to a screening process under the Canadian Environmental Assessment Act.

The analysis of RA/RM frameworks worldwide and the present consideration of the evolution of regulatory practice applied to Canadian projects were used to inform *An Integrated Risk Management Framework for Carbon Capture and Storage: A Canadian perspective* (Larkin et al., 2019b).

2 Regulatory review of four large Canadian CCS projects

2.1 Weyburn-Midale enhanced oil recovery (EOR) operations, Saskatchewan

The Weyburn-Midale enhanced oil recovery (EOR) operations began in 2000 and are expected to continue through 2030. The Souris Valley Pipeline transports compressed carbon dioxide (CO_2) from the Great Plains synfuels coal gasification plant in North Dakota to CO_2 miscible floods in Saskatchewan, operated by Cenovus Energy in Weyburn (through 4th quarter 2017) and Apache Corporation in Midale (through mid-2017), now Whitecap Resources Ltd. Since inception, more than 17 Mt of CO_2 have been stored in conjunction with EOR at Weyburn; at the end of operations, this site is projected to store 30-40 Mt CO_2 (IEAGHG, 2006). At one time, Cenovus Energy estimated that the infrastructure could then be used exclusively for CO_2 sequestration, providing an additional 25 Mt capacity[2]. Over 2 Mt of CO_2 have been stored in conjunction with EOR at Midale and more than 10 Mt are expected to be stored over the 30-year life of the project.

The 260 km international transport pipeline from the Canada/US border to the Weyburn field was subject to screening under the Canadian Environmental Assessment Act (CEAA), as administered by the National Energy Board (NEB). The scope of the project was restricted to the 'applied-for facility', comprising the pipeline but excluding the miscible flood project. To facilitate public awareness prior to making the decision, the Board required the proponent to publish notices in two national and seven regional newspapers. Only one letter, from Environment Canada, was received. Following the deadline, a second organisation filed a letter arguing that the miscible flood project ought to have been included in the environmental assessment (EA); however, the NEB did not find a reason to expand the scope of the review (NEB, 1998).

The CEAA review considered the estimated potential consequences of accidental airborne releases of CO_2 and hydrogen sulphide (H_2S) due to pipeline leaks or ruptures and quantified the potential probability of impacts at receptor points along the route. The results determined the level of protection required for human health and safety such that these would be incorporated into the Emergency Response Plan (ERP). The NEB accepted Souris' recommendation that the Emergency Planning Zone (EPZ) within the ERP be based on an exposure threshold concentration of 100 ppm H_2S, as was then determined as the concentration Immediately Dangerous to Life or Health (IDLH) (NEB, 1998). The EPZ then comprised the area within 1.5 km of the pipeline alignment. Proposed risk management of malfunctions and accidents included preparation of a draft ERP which discussed pre-emergency planning and education, operational safety precautions, emergency response procedures and agency coordination (NEB, 1998).

CO_2 stream composition was also assessed in order to lower risks of contamination from residual substances if there was leakage into potable groundwater. The normal composition of the pipeline gas mixture was described as 97% CO_2 and 0.8% H_2S, with not more than 2% by volume of nitrogen or methane (NEB, 1998). The NEB public

hearing addressed the adequacy of the public consultation process; the potential environmental and socio-economic effects of the proposed project; and the safety of the design and operation of the proposed facilities.

A second CEAA application to the NEB was in made in 2005 for a custody transfer and metering station needed to supply CO_2 from the Weyburn facilities to the Midale pipeline. This was subject to a public notification and consultation program commensurate with the scale and nature of the Project (NEB, 2005); the scope of this screening was limited to impacts associated with the station and not with the Midale pipeline as a whole (NEB, 2005). The sole affected landowner was the only person engaged in the process as it was deemed unnecessary to conduct further notification to the next nearest residence located over 2.8 km from the project site. The proponent also notified the administrator of the Rural Municipality.

Both NEB screenings concluded that surface impacts on the environment were not significant and approval certificate conditions addressed environmental and general safety mitigation measures for pipeline design, pre-construction, construction and post construction (operational) periods (NEB, 1998, 2005). Specifics included mitigation of topsoil erosion or compaction; a maximum 2.0 mole percent H_2S in the product stream; a maximum moisture concentration entering the pipeline; pipeline inspection at the time of construction (but without a monitoring or follow-up program); performance data for the leak detection system prior to commencement of construction; criteria for the emergency protection zone; and ongoing examination of the emergency response plan as part of ongoing safety auditing function.

At the provincial level, several applications were made under the Saskatchewan Environmental Assessment Act (EAA) (Government of Saskatchewan, 2013): the 1984 Midale CO_2 Flood Pilot Project, the 1991 Midale field scale demonstration project and the 2005 Midale EOR project and associated pipeline (IEAGHG, 2010). The single Weyburn EAA application in 1997 was for the 260 km pipeline, compressors, flow lines, injection wells and other project infrastructure. In each case, the EAA concluded that environmental impacts were not significant and that the projects did not constitute a 'development' under the EAA. Applications were approved by clearance letter. The decisions also found that existing regulatory licensing requirements were sufficient to ensure that all components of these projects would be appropriately implemented (IEAGHG, 2010).

Details in the licensing application under the Saskatchewan Oil and Gas Conservation Act (OGCA) regulations in force at the time required characterisation of the geology of the area; injection summaries of various research experiments and simulations; information on new and upgraded facilities; project monitoring and data collection; well location; construction and design (1997 only); internal and external corrosion protection plans; project schedule and expectations; emergency response plan (1991 only); and predicted costs (1997 only). These provided the basis for an analysis of projected recovery rates and behaviour of injected CO_2. No specific OGCA requirements were established for injection, potential for leakage and storage activities.

Midale 1991 and Weyburn 1997 approvals required operation of the project in accordance with the plans filed with the Ministry; approval of a field representative of the ministry prior to commencement of CO_2 injection and subsequent to any modifications to such installations; and annual progress reports. The Midale 2005 approval included additional conditions: to operate the project to minimise the possibility of negative impact on adjacent non-unit producing properties; to measure solution gas composition in

production wells monthly and inject tracer to determine reservoir flow characteristics prior to CO_2 injection; to provide appropriate impact mitigation to adjacent units if required; and to undertake specific measures at identified wells, although details of this requirement are not documented. While the OGCA licensing approval applied to injection and EOR activities, there was no regulatory provision at the time for 'waste' disposal (storage) and none was envisioned for EOR operations at inception (IEAGHG, 2010).

Additional provincial regulatory approval for the Weyburn and Midale projects included Pipeline Act regulations, shoreline permits, occupational health and safety regulations, waste handling, litter control and Clean Air Act and Regulations (IEAGHG, 2010).

2.2 Boundary dam integrated CCS demonstration project, Saskatchewan

The Boundary Dam Integrated Carbon Capture and Storage Demonstration Project (BD) has been described as the first and largest integrated carbon capture demonstration project in the world (SaskMOE, 2013b). The goals of the project are to extend the operating life of the SaskPower coal-fired electricity plant unit by 30 years, increase efficiency, reduce SOx and NOx emissions and capture approximately 1 Mt CO_2 per year. The key project operators are SaskPower for the capture facility at their Boundary Dam electricity generating station and Whitecap Resources Ltd. (formally Cenovus Energy, the original proponent for the transport pipeline from SaskPower property line to the injection/EOR operations at the Weyburn field). Some CO_2 is also provided to the Aquistore research and saline sequestration monitoring project which is not discussed in detail here because it does not meet the definition of an LSIP with respect to the storage operations. Capture was expected to account for roughly two-thirds of the power project's estimated $1.24 billion cost. Although there was federal funding for this project ($240M), a CEAA screening trigger did not apply because the contribution was established as a trust fund in the 2008 federal budget, for discretionary use by the Government of Saskatchewan for carbon capture and storage initiatives.

SaskPower submitted a capture project description for provincial EAA screening in 2009 (SaskPower, 2009). Potential capture technologies were described at a high level and the application listed considerations that would be included in an environmental impact statement (EIS) if one was to be required: a biophysical overview of the study region; a description of the socioeconomic environment; air dispersion modelling; noise assessment; hydrology; a public consultation program; as well as any other required studies. SaskPower noted that these studies would be undertaken if the project was not deemed a development under the EAA because this data collection would be required for other regulatory approvals. Ancillary activities that would not be included in the assessment were listed as the CO_2 pipeline, EOR operations and water usage (because they represented separate developments and may have other environmental approvals in place or anticipated). The application noted that decommissioning and site reclamation applications would occur at a later date.

BD project was not deemed a 'development' under the EAA and did not require an environmental impact assessment (EIA) (SaskMoE, 2009). The capture component received clearance based on the description and the environmental protection commitments of the project (SaskPower, 2009), subject to the clarifications and

restrictions suggested by other ministries as listed in the clearance letter (SaskMoE, 2009):

- Saskatchewan Watershed Authority supported a proposed hydrology study and the Industrial Branch of Ministry of Environment supported proposed air dispersion modelling (the branch anticipated changes in ambient air quality with the three different proposed technologies, partly as a result of lower stack height)
- Workplace Safety Unit regarding regulations to ensure safe use of chemicals and requirement that air concentration be kept below listed standards, particularly sulphur dioxide
- Mining and Engineering Services Branches of Ministry of Energy and Resources, regarding approvals for EOR, pipeline licensing and field operations.

Subsequently, SaskPower completed an internal assessment of the three potential capture technologies and chose Cansolv Technologies' proprietary amine based SO_2/CO_2 post combustion capture technology. An amended EAA application was submitted in 2013 (SaskPower, 2013), providing updated information for air emissions; CO_2 storage through Aquistore sequestration research project (SaskMoE 2014a, 2014b); deep waste water disposal well storage; and operation of a sulphuric acid producing plant generated through carbon capture activities. The latter three activities, as well as coal mining, ash lagoon operations, transport pipeline, EOR facilities and operations and others, were discussed as ancillary developments requiring separate permitting.

The amendment included a brief biophysical and socio-economic overview of the local and regional environment, as well as more detail regarding air dispersion modelling concentrations for criteria air contaminants (SO_2, NOx, CO, TSP, PM_{10} and $PM_{2.5}$, Hg and Cd) and effects of the amine-based technology (SaskPower, 2013). A decrease in ground level concentrations compared with the base case for these air contaminants was expected under several alternative operating scenarios, although predicted SO_2 concentrations were greater than applicable Saskatchewan standards in all but one scenario.

The Material Safety Data Sheets for the amine-based technology were also included in the 2013 application. In the absence of CCS process nitrosamine-specific data, N-nitrosodimethylamine (NDMA) was deemed a suitable surrogate for human health exposure and toxicity assessment based on an international review of the nitrosamine guidelines (SaskPower, 2013). Maximum amine and nitrosamine ground level concentrations were evaluated for eighteen vent dispersion scenarios. With anticipated emissions of 8 t/year and 10 kg/year, respectively, assuming a 90% capacity factor, negligible ground level impacts were anticipated relative to Ministry of Environment approved guidelines of 5 ug/m^3 amine and 0.3 ng/m^3 nitrosamine. Indoor ventilation conditions were also assessed.

The amendment also included an assessment of an added water demand at Boundary Dam. Results found continued ability of the Rafferty Reservoir to supply users, including BD, the City of Estevan and future development at SaskPower's Shand Generating Station.

With respect to risk management, SaskPower committed to complete a regional baseline survey and post monitoring results online for amines and degraded products in air, water and soil. The application noted use of best management practices to avoid or mitigate minor impacts, particularly for water management at the reservoirs. A short

description of impacts and expected frequency of abnormal operating scenarios was presented in tabular format. These included stack emissions at start-up and shutdown; capture reduction to the federal regulatory target should electricity generation prove more advantageous than CO_2 sales (requiring only 60% rather than 90% capture rate); loss of CO_2 capture associated equipment (where it would be possible to run full SO_2 capture but without CO_2 capture); loss of SO_2 capture associated equipment (requiring shutdown with diversion of SO_2 contamination in order to protect CO_2 system); loss of acid plant (SO_2 emissions would return to current levels for duration of scenario); and reduced demand for the CO_2 product (off-taker demand to be managed through contractual agreements). The frequency of fluctuations in stack emissions was expected to be rare once operating stability is obtained.

Throughout the planning and development period, joint communications activities to engage and inform key audiences about all components of the project, including the CO_2 injection test well, were undertaken by SaskPower in conjunction with Petroleum Technology Research Centre (PTRC) and it's Aquistore sequestration research project (SaskMoE, 2014b). Several organisations formed the Aquistore Communications Steering Committee in 2011, including SaskPower, the PTRC, Enbridge Inc., SaskEnergy, SaskMoE, Schlumberger Carbon Services (SaskPower's consultant) and Consumers Cooperative Refinery Limited (CCRL) (SaskMoE, 2014b). Engagement efforts included kitchen table discussions with area landowners, public open houses, site tours and media communications. The amended project application noted that the majority of comments received from directly affected stakeholders and others were favourable and supportive, that the information provided addressed relevant issues and concerns and that no significant environmental impacts or concerns were identified from the public consultation process (SaskPower, 2013). An open house and grand opening of the capture plant occurred in 2014.

Based on the evaluation of the amended application against EAA project determination criteria, the global project was not deemed a development requiring an EIA. The clearance letter included terms and conditions under which the project could be undertaken and specified that environmental protection measures be implemented in the manner described in the application and that the project comply with other federal, provincial and municipal regulatory requirements and other administrative details (SaskMoE, 2013a). The reasons for this determination noted that the project would result in a net benefit to the environment (SaskMoE, 2013b). The project phase components would be subject to other regulatory requirements (pollutant emissions, transport and EOR chain component applications through the appropriate branches of the Ministry of Economy), the protection measures in the proposal and the stipulations in the determination letter (SaskMoE, 2013b).

The Cenovus Energy pipeline has been licensed (Government of Saskatchewan, 2011) and the CO_2 is being injected at the Weyburn EOR operations described above. The pipeline and injection scheme for the Aquistore sequestration research well were approved (SaskMoE 2014a, 2014b).

2.3 Alberta carbon trunk line, Alberta

The Alberta Carbon Trunk Line (ACTL) is a 240 km high vapour pressure (HVP) pipeline and connectors project. The project proponents changed hands since inception: ACTL was initiated by Enhance Energy Inc., now sold to Wolf Carbon Solutions in

2018. Enhance Energy will maintain EOR project operations. Initially, approximately 0.5 Mt/yr CO_2 were anticipated from Agrium Fertilizer, now Redwater Fertilizer facility; and 1.2 Mt/yr CO_2 from Phase 1 the North West Redwater Partnership's (NWRP) oilsands upgrader project, both located in Alberta's Industrial Heartland region. The NWRP project, at inception, had the potential to scale up to 3.6 Mt/yr CO_2 through later phases of development. The pipeline capacity was slated to be 14.6 Mt/yr.

The Wolf Carbon Solutions announcement states that initial flow rates of almost 0.3 Mt/yr were expected to begin at end 2019, increasing to 1.6 Mt/year. EOR injection is planned near Clive, Alberta, a project of Enhance Energy (Carbon Capture Journal, 2018).

At the time, the Agrium and NWRP capture projects required notification of a change in process under the Alberta Environmental Protection and Enhancement Act (EPEA) (Government of Alberta, 2010), administered by the Ministry of Environment and Sustainable Resource Development (ESRD), without additional regulatory applications. This is because pure stream CO_2 would be dehydrated and compressed to ACTL specifications. Both plants would be operating as an improvement to emissions (Alberta Energy Utilities Board, 2007; Alberta Ministry of Environment, 2006). NWRP gasification operations will also minimise water and natural gas resource use and reduce sulphur and trace metals emissions associated with conventional upgraders.

ACTL required a screening assessment under CEAA as a result of a potential federal funding contribution by NRCan (Canadian Environmental Assessment Registry Archives, 2018). The EIS considered all of the physical works and activities required to construct, operate and decommission both the ACTL and the Clive/Bashaw injection and storage scheme (NRCan, 2012). The latter included up to 20 CO_2 EOR injection wells and 100 oil wells (converted and new). Valued ecosystem components (VECs) and the risk of potential residual adverse environmental effects from the pipeline were assessed qualitatively, based on criteria for magnitude, frequency, duration, geographic extent and reversibility. Potential impacts included atmospheric and acoustic environments; soils, terrain and land use; vegetation and wetlands; wildlife; fisheries; historical resources; and social and economic issues. Other EIS sections considered accidents and malfunctions; effects of the environment on the project; environmental protection plan; and public and First Nations consultation.

Construction and operations activities for injection and EOR were assessed, including the integrity of existing and abandoned wells (the former with regard to their suitability for conversion to CO_2 service); drilling and completion of CO_2 injection and oil production wells; construction of CO_2 distribution and oil production flow lines; compression to recycle CO_2; monitoring mass distribution and migration of CO_2 in the reservoir; ongoing simulation and history matching, comparing actual project performance to modelling predictions; and ongoing updating of risk mitigation strategies and the emergency response plan (ERP). However, no final engineering designs for injection and EOR were [online] the time of the screening.

NRCan required a 30-day comment period based on the magnitude of the project, the fact that it was a first-in-kind project and that it may be linked with additional CO_2 sources and injection sites in the future. Enhance energy received requests for the draft screening report from ten individuals and later provided copies of the final screening report.

Federal departments requested clarifications and provided comments based on their area of expertise (Canadian Environmental Assessment Agency, 2014). Health Canada

initially responded with an inability to provide expert review due to the qualitative nature of the information, especially regarding air quality, noise and human health effects. The proponent stated that as there would be no new significant sources of continuous air emissions, there was very little potential for the project to result in adverse effects on human health. NRCan commented that the level of detail for the injection and storage facility should have been as specific as that provided for the pipeline routing. The proponent initially responded that this was proprietary information, but later invited government representatives to view information on this aspect of the project at their office. The proponent also later provided a table summarising the challenge, risk and mitigation strategy for CO_2 containment; CO_2 injection wells; CO_2 injection flowlines; drilling and completions (NRCan, 2012). No further assessment detail was provided. NRCan requested more detail on the monitoring, measurement and verification (MMV) plan, but this had not been completed at the time of the screening process. The proponent noted that once plans were confirmed and negotiations were completed with the potential service providers, the company would make the MMV plan available to the public.

The CEAA screening decision found that the project was not likely to cause significant adverse environmental effects after mitigation measures for the pipeline, injection and storage facilities as normally implemented through Alberta's Energy Resources and Conservation Board (ERCB) Directives (now Alberta Energy Regulator). Nevertheless, comments were provided with respect to the pipeline, release from injection and storage facilities and accidents and malfunctions during construction, operations and decommissioning (NRCan, 2012). For instance, it was suggested that the potential environmental effects of either a sudden release or a slow leak of CO_2 on soils, surface water, groundwater, air and other environmental receptors would be negligible because of the relatively inert nature of the CO_2 being transported in the pipeline; however, CO_2 was considered a safety hazard for workers or public in the vicinity of the pipeline (NRCan, 2012). CO_2 leakage from the storage reservoir was discussed for the decommissioning (post-closure) phase: the rate of leakage and total amount of CO_2 released from the reservoir would likely be a small fraction of the CO_2 stored and effects would therefore likely be negligible.

Provincially, ACTL pipeline was also subject to the EPEA (Government of Alberta, 2010) with respect to a conservation and reclamation plan for soil, waste and water management practices and water crossings during the construction and reclamation periods (ESRD, 2013).

Lastly, ACTL and EOR activities were subject to ERCB Directives and regulations. More information is available with respect to land based than injection/EOR activities. Based on an expected pipeline flow rate of 5.475 Mt/year (the pipeline design is up to 14.6 Mt/year), a preliminary hazard assessment for CO_2 and co-materials [hydrogen (flammable) and carbon monoxide (toxic)], using dispersion modelling software (in combination with ERCB Directive 71 guidance for H2S and HVP liquids), determined a 700 m Emergency Protection Zone (EPZ) adjacent to pipeline alignment. The study considered the release rate, meteorological conditions, concentration of concern (hazard endpoint, using National Institute for Occupational Safety and Health (NIOSH) for Immediate Danger to Life and Health (IDLH) (40,000 ppm)) and release conditions. The Initial Isolation Zone was set at 20% of the EPZ and rounded to a distance of 200 m. The Emergency Awareness Zone was set at 150% of the EPZ and rounded up to 1,100 m. An H2S concentration of 100 ppm was cited in the report, but did not appear to be included in the determination of the ERP Zone. This assessment was provided by the proponent as

part of the ERCB application (Enhance Energy, 2012) and was not included with the reports and correspondence available as part of the CEAA screening (NRCan, 2012). It is unknown if this was an oversight.

The ERCB Directives also required the proponent to provide a Project Information Package to landowners and occupants in the defined EPZ and to develop a site-specific ERP with affected stakeholders.

With respect to risk management, the pipeline portion of the ACTL project would be built to meet existing standards. The pipeline integrity program should include corrosion mitigation and monitoring, leak detection and the ERP. Enhance Energy engaged another firm to provide integrated solutions for work place quality, health, safety and environmental management programs, including emergency response, integrity management and health and safety issues on a best practices basis.

The ERCB approved the application in 2011. There were no scheduled hearings because preliminary objections to the project were resolved. The ERCB determined the project was in the public interest. ESRD approval for the pipeline conservation plan was obtained in 2013 (ESRD, 2013).

2.4 Quest Carbon Capture and Storage Project, Alberta

Quest Carbon Capture and Storage Project (Quest) is the first large scale integrated CO_2 sequestration project in Canada. It was conceived as a joint venture between Shell Canada Energy (60%), Chevron Canada (20%) and Marathon Oil Canada Corporation (20%), the three companies who together formed the Athabasca Oil Sands Project. Quest value chain components include up to 1.2 Mt/yr CO_2 capture at Shell's Scotford bitumen upgrader using an activated amine process; approximately 80 km transport pipeline and connectors; injection infrastructure at 3–8 well pads; deep saline sequestration in Basal Cambrian Sands (BCS) geological formation, approximately 2 km below surface; and a measurement, monitoring and verification (MMV) program (Shell Canada Limited, 2010a, 2010b, 2010c, 2010d, 2010e). Cumulative stored volumes could exceed 27 Mt CO_2 over the life of the project (greater than 25 years) (Shell Canada Limited, 2010a) with a 35% capture rate (MIT, 2018) and overall reduction in CO_2 annual emissions of 15% relative to the existing upgrader (Shell Canada Limited, 2010b). The project cost just under the $1.35B estimate, with partial financing from the Alberta government ($745 million over 15 years) and federal Clean Energy Fund ($120 million) (Shell Canada Limited, 2010a).

Multiple acts, regulations and directives applied to the review and approval of Quest under several applications (Table 1). Value chain components were subject to CEAA screening (because of federal funds) and the EPEA, applied jointly under the federal/provincial agreement for environmental assessment cooperation. Furthermore, the EIA, together with requirements under Acts and Directives of the ERCB, formed the complete application to the ERCB (Alberta Energy Regulator, 2010), including: project description, impact assessments, measurement, monitoring and verification (MMV) plan and details about stakeholder consultations, among other sections. Throughout the 20-month review and approval process, subsequent documentation provided updates, amendments, errata, supplementary information requests (SIRs) by regulators, intervener submissions and responses to these, totalling approximately 4,000 pages within 400 documents. Documents remain posted on Shell Canada's Quest webpages (https://www.shell.ca/en_ca/about-us/projects-and-sites/athabasca-oil-sands-project.html)

or can be obtained through Alberta Energy Knowledge Sharing website (http://www.energy.alberta.ca/CCS/3848.asp) or from Alberta Energy Regulator by written request (formally ERCB).

Table 1 Shell Quest regulatory framework[1]

Regulator	*Regulatory application – chain component*			
	Capture	*Transport*	*Injection*	*Storage*
Agreement for environmental assessment cooperation Alberta Environment – *Environmental Protection and Enhancement Act* Natural Resources Canada/Canadian Transportation Agency – *Canadian Environmental Assessment Act*	Three amine absorber towers, amine regeneration unit, multistage CO_2 compressor with coolers and separators and a triethylene glycol dehydration unit; To increase nitrogen oxide limits from HMUs.	80 km steel pipeline from upgrader to proposed injection wells, including conservation and reclamation plan	Environmental impact assessment report for injection wells and storage	
Alberta Energy Resources Conservation Board (Now Alberta Energy Regulator)	To amend approval Section 13, *Oil Sands Conservation Act*	Part 4, Pipeline Act Directive 056: Energy Application for construction and operation of the pipeline	Directive 056 for well development Directive 051 for injection	Section 39*, Oil and Gas Conservation Act* Directive 065: Resource Application for Oil and Gas Reservoirs

Note: [1]For details about the legislation, regulations and directives, see Larkin et al. (2019b).

Source: Excerpts from Shell Canada Limited (2010a, 2010b, 2010c)

The EIA focused on the project's area of interest (AOI) – namely the sections of land for which a tenure lease agreement had been reached under Alberta's Carbon Sequestration Tenure Regulation (Government of Alberta, 2011). Within the AOI delineation, six risk issues were assessed: air quality, public health and safety, emergency response planning (transport and injection pads), injection well integrity, acid gas storage scheme and accidents, malfunctions and unplanned events. Table 2 identifies the methodology, risks assessed and conclusions for the human and environmental health issues considered (Shell Canada Limited, 2010d). We make the following observations:

- qualitative, semi-quantitative and quantitative risk assessment methodologies were used, often with a multi-step risk assessment (RA) approach
- CO_2 was initially excluded from the air quality RA at the capture facility

- quantitative RA for the pipeline and injection wells was made available later in the process, in response to a SIR
- although the quest acid gas storage scheme RA is not available publicly, an independent panel review (IPR) of the RA for this was made available later in the approval process in response to an SIR (Shell Canada Limited, 2010f);
- Det Norske Veritas (now DNV GL) issued the world's first certificate of fitness for safe CO_2 storage to quest.

The MMV plan (Shell Canada Limited, 2010e) development was ongoing throughout the approval process and continues through project development and implementation (Shell Canada Limited, 2015). Monitoring measures include three (shallow) non-saline groundwater monitoring wells for each injection well; at least three deep injection wells into the upper part of the storage complex; repeated 3-D seismic plume monitoring; and InSAR radar based technology to measure any ground deformation (ground heave).

Shell began outreach and consultation activities in 2008 (Shell Canada Limited, 2010a) and retained Pembina Institute's consulting arm (Pembina Corporate Consulting) to evaluate their program. Recommended enhancements were subsequently implemented.

Under CEAA, NRCan required that public and aboriginal consultation activities be conducted, in part because the magnitude of the facility was considered a new technology (NRCan and CTA, 2012). No direct comments were received (NRCan and CTA, 2012). Federal authorities determined that the project was not likely to cause significant adverse environmental effects and that a ten-year follow up was required in order to verify predictions (NRCan and CTA, 2012). This will be based on the proposed MMV Plan and was delegated to the proponent in consultation with others (NRCan and CTA, 2012).

Under the ERCB regulatory process, consultation and notification continued through the decision-making process for property owners within varying distances of the proposed activities (Shell Canada Limited, 2011a). As all community concerns were not settled through the ERCB's Appropriate Dispute Resolution (ADR) process, public hearings were required. Direct public participation at ERCB hearings is limited to accredited interveners based on the location of land holdings and having identified a direct and adverse potential effect. Five interveners representing three properties participated. Concerns included pipeline routing, safety and containment, injection, well water contamination, the effect of the project on future plans and property value and compensation (ERCB, 2012).

Quest was approved with conditions (ERCB, 2012). The ERCB found the underground reservoir a suitable location for the long-term storage of CO_2 and that the combination of geological conditions, engineering design, operational practices and extensive monitoring program would mitigate any potential risks of project development (ERCB, 2012). The decision discussed risk regarding third party industry activity in the AOI; legacy wells; long term integrity of injection wells; non-saline groundwater contamination affecting oil and gas industry activities; ground heave impacts on fracturing or increasing permeability of surface strata, potentially affecting potable water supply; loss of containment; and public safety (risk of fatality) for pipeline right of way, injection wells and sequestration formation.

Table 2 Shell Quest human health and environmental risk assessment and management

Issue	*Approach*[1]	*Risks assessed*	*Conclusions*
		Capture	
Air quality	'Standard assessment approach' – based on TOR, existing AENV guidelines and criteria. Consistent with other AQ assessments in region	NOx, NOx as precursors to $PM_{2.5}$, PAI deposition, nitrogen deposition, ozone formation, regional haze	Increased NOx 3.1 t/d (1.9% in RAA) Compliant with Alberta ambient air quality objectives (AAAQO) and guidelines under normal operating conditions
Public health and safety	Quantitative human health risk assessment – 4 step RA methodology endorsed by a number of regulators	Increased NOx, NOx as precursors to $PM_{2.5}$	Increased predicted concentrations of NOx and $PM_{2.5}$ are not expected to result in adverse health effects.[1]
		Transport and injection	
Emergency response planning (ERP)	Quantitative risk assessment used published exposure limits, modelling, risk acceptability based on land use – 7-step RA	CO_2 release into atmosphere in the event of accident or upset for Pipelines and Injections Wells	ERP 450m Maximum risk of fatality within pipeline ROW calculated to be two chances in a million/yr (Energy Resources Conservation Board, 2012)
Injection well	Oxand risk management solutions Static and dynamic modelling for proposed Well #3	Plume migration along wellbore CO_2 mass leakage through well Well degradation	Risk-based quantification of 17 scenarios shows that all scenarios have a low or very low risk score, according to Shell's risk criteria. No concern for long-term containment over 200 year period.
		Storage	
Acid gas storage scheme	Qualitative assessment of site selection and characterization criterion (Shell, 2010a) from Review and Synthesis Draft Report to IEA IEAGHG (2009)	Safety and security of CO_2 storage in the BCS	Shell's risk assessment is not apparently publicly available. Refers to DNV IPR.
	DNV Independent Panel Review (IPR) (Shell Canada Limited, 2010f) Based on CO_2Qualstore (DNV, 2010)	Storage site characterization Risk and uncertainty assessment and management	The risk assessment activities have been carried out in a very comprehensive and systematic manner. Some deficiencies identified.
	DNV Independent Panel Review (IPR) (Shell Canada Limited, 2011c) Based on CO_2Qualstore (DNV, 2010)	Storage development plan	Evaluated and certified to be fit-for-purpose Includes actions to establish/maintain confidence in five metrics

Note: [1]Regarding $PM_{2.5}$, Evans (2013) shows that any increase will affect health.

Source: Excerpts from Shell Canada Limited (2010a, 2010b, 2010c, 2010d, 2010e, 2010f, 2011a, 2011b, 2011c, 2011d)

Table 2 Shell Quest human health and environmental risk assessment and management (continued)

Issue	*Approach*[1]	*Risks assessed*	*Conclusions*
		Capture, transport, storage	
Accidents, malfunctions, unplanned events (AMUE)	Qualitative risk assessment Combination of literature review and professional judgement. If available, quantitative analysis conducted – 4-step RA	Effect of • Process upsets in CO_2 capture infrastructure • CO_2 pipeline rupture or injection well head failure • Release of CO_2, BCS brine or CO_2 saturated brine from the storage complex or injection wells on valued ecosystem components (VEC) including public health and safety, aquatic resources	No significant effects for all assessed VECs for each assessed AMUE
		Measurement, monitoring and verification (MMV)	
MMV plan for acid gas storage scheme	Conceptual semi-quantitative systematic risk-based approach to inform MMV Ongoing development throughout process based on ERCB Directives, CO_2 Qualstore (DNV, 2010)	Loss of conformance (Discrepancy between modelled and observed migration) Loss of containment (CO_2 and Brine migration)	RM in passive and active safeguards No interaction expected between non-saline groundwater and the project during decommissioning and abandonment

Note: [1]Regarding $PM_{2.5}$, Evans (2013) shows that any increase will affect health.

Source: Excerpts from Shell Canada Limited (2010a, 2010b, 2010c, 2010d, 2010e, 2010f, 2011a, 2011b, 2011c, 2011d)

Twenty one of the 23 conditions in the decision relate to monitoring activities. The ERCB emphasised that MMV needed to be adaptive. Shell was warned that additional requirements might be imposed as the project evolved, depending on how the plume performed (Bankes, 2012). Bankes (2012) also noted that the MMV conditions were a result of a dialogue between Shell and the Board.

Other ERCB decision comments relate to protecting the potable water supply through injection well completion requirements. Furthermore, Bankes (2012) assessment of the decision found that the Board was satisfied that there was little risk of the injected substances migrating and reaching the legacy wells and if it did that there was little risk that the induced pressure increases would lift the brine to reach protected groundwater aquifers.

3 Comparative analysis of regulatory practice

This review of publicly available documentation describes the ways in which human health and environmental hazards and risk issues were considered in the application, review and approval of four large scale Canadian CCS projects: Saskatchewan's Weyburn-Midale enhanced oil recovery (EOR) Operations and Boundary Dam Integrated CCS Demonstration Project; and Alberta's Carbon Trunk Line and Quest Carbon Capture and Storage Project. The comparative analysis first considers general aspects of regulatory oversight, including document availability, project boundaries and the range of risk issues assessed. Progress and deficiencies in risk assessment, risk management and risk communication are then discussed.

3.1 Regulatory oversight and approach

In Canada, project development related to the oil and gas industry falls primarily within provincial jurisdiction. Regulatory oversight for the four large scale Canadian projects was therefore based on provisions contained within Alberta or Saskatchewan oil and gas- and environment-related legislation, regulations and directives. Three projects were also assessed under the Canadian Environmental Assessment Act where a trigger was caused by an international pipeline development or a federal program funding contribution. Table 3 summarises the provisions with respect to risk assessment and management, some of which have been updated over the period of these project approvals (Larkin et al., 2019b).

Regulatory oversight of CCS projects is value-chain specific, where activities in capture, transport, injection, EOR, or storage determine the types of required applications and assessments. Identifying and accessing relevant assessment documentation for all value chain activities is therefore challenging. Furthermore, application and approval documents may be obtained from the proponent or regulator, depending on the project; some from web-based archives, some by direct contact and some requiring payment for an information request.

Overall, Canadian Environmental Assessment Act screenings were more comprehensive in terms of multiple value chain activities and ease of access to the document trail than those completed under provincial legislation, regulations and directives. Additionally, Saskatchewan's Environmental Assessment Act (EAA) applications are not posted. The Ministry of Environment posts the Ministerial

Determination and Reasons for Determination, but applications and review documentation require direct contact with a number of government offices and/or the project developer.

Table 3 Primary regulatory oversight of Canadian projects

Project and goal	*Primary regulatory oversight*			
	CEAA screening	*Alberta or Saskatchewan Provincial EIA*	*Alberta ERCB*	*Saskatchewan licensing*
Approved 1997, 2005 Weyburn and Midale EOR operations	Yes transport	Clearance letter Transport	NA	Pipeline EOR
Approved 2009, 2013 Boundary Dam integrated CCS demonstration project EOR; some research	No	Clearance letter Global Project	NA	Pipeline EOR
Approved 2010-2013 Alberta Carbon Trunk Line EOR operations	Transport injection EOR	Transport C&R	Approved without hearings	NA
Approved 2012 Quest Carbon Capture and Storage Project	Joint application federal/provincial capture, transport, injection, storage		Approved with hearings	NA
Sequestration				

Notes: Acronyms: CEAA – Canadian Environmental Assessment Act; C&R – Conservation and Reclamation Plan; EIA – Environmental Impact Assessment; EPEA – Alberta Environmental Protection and Enhancement Act; ERCB – Alberta Energy Resources Conservation Board; OGCA – Saskatchewan Oil and Gas Conservation Act

With respect to approach, Quest was based on the proponent's and regulator's defined 'area of interest' (AOI). Bankes (2012) suggested that neither the AOI nor its subset 'zone of interest' (ZOI) are "legal terms of art and … are not used in any of the relevant legislation or the key [ERCB] Directives" (Section 3). Bankes (2012) also suggested that the term is evidently important because it "controls the geographical scale of such things as lease configuration, the provision of notice, identification of legacy wells, geological characterisation etc and the scale (as one might expect) is much larger than that provided for cognate operations such as acid gas disposal projects" (Section 3). In Saskatchewan, if regulators deem a proposal not to be a development under the EAA based on specific review criteria, then a clearance letter is issued rather than requiring an environmental impact assessment. Proponents then proceed to value chain activity licensing and permitting applications where documentation is not readily available and RA/RM is not detailed further.

The range of risk issues assessed during regulatory review and approval has grown over the past fifteen years – from air emissions (H_2S) that determine the emergency planning zones for a pipeline alignment (Weyburn Midale), through to six identified risk issues in Quest: air quality; public health and safety; emergency response planning (transport and injection pads); injection well integrity; acid gas storage; and accidents, malfunctions and unplanned events. Table 4 illustrates the issues assessed for each project. In the three more recent projects – Boundary Dam, ACTL and Quest – where

each project includes more than one assessed value chain activity, publicly available documentation normally contained a detailed discussion about impacts and mitigation of surface-based activities and less information about potential effects of injection and EOR/storage. This may reflect two issues. First, operators and regulators have more experience with the assessment of industrial process emissions and pipeline hazards compared with less but growing experience in injection and storage phase activities (Koornneef et al., 2012; Pawar et al., 2015). Pawar et al. (2015) described the progress being made in risk assessment and risk management methodologies for CO_2 sequestration. Second, this may be indicative of the proprietary nature of geological information within the industry. Regulators may be provided additional information verbally during the approval process (eg ACTL, Quest), but the specifics are not part of the documentation provided in a public document registry.

3.2 Risk assessment

This review found a growing use of formal, systematic protocols for RA/RM in characterising hazards, estimating risks and specifying robust monitoring regimes. Nevertheless, the choice of methodologies and transparency is inconsistent across jurisdictions and across the different dimensions of CCS projects (siting, capture, transport, injection, storage and monitoring). As noted above, overall the level of detail in RA of surface-based activities such as air emissions modelling and transport pipeline development remains high and is greater than that provided for injection and storage activities. For example, Shell provided a description of the storage site characterisation and selection, but did not provide the risk assessment publicly. ACTL only provided a summary table checklist of injection and storage risks, but without supporting documentation. Again, this may reflect the extensive experience operators and regulators have with the assessment of industrial process emissions and pipeline hazards compared with less but growing experience in injection and storage phase activities

Second, while Shell did not assess CO_2 leakage as a hazard initially and the RA of the pipeline and injection pads was not made available until later in the review process, Quest is the only project that calculated a risk of fatality within the pipeline right of way [maximum two chances in a million/year (ERCB, 2012)]. Interestingly, the pipeline emergency protection zone has decreased over the years: Weyburn-Midale Souris pipeline was 750 m; ACTL was 700 m; and Quest was 450 m. The Boundary Dam amended application included assessment of the change in air emissions at the capture plant, but the off-take pipeline licensing application was not made available and the associated EOR activities fall within the original Weyburn-Midale EOR Operations approval.

3.3 Risk management

While CCS projects are approved within a regulatory framework, achieving and monitoring safe and effective operations is dependent on wide ranging risk management options, including regulatory, economic, advisory, community-based and technological approaches (Krewski et al., 2007; Krewski et al., 2014). Examples of these are evident in this review of the four large scale Canadian projects. These and additional options for CCS are discussed fully in Larkin et al. (2019b).

Table 4 Summary of environmental and health risk assessment in CCS value chain activities for large Canadian projects

Project	*Capture*	*Transport*	*Injection*	*EOR/Storage*
Weyburn-Midale EOR	NA	CEAA screening H2S, CO_2 stream		
		EAB clearance with defined EPZ (750m)		
Boundary Dam EOR	No CEAA screening			
	Provincial EAB global clearance letter			
	Clearance letter conditions	Best practices		
	NOx, SOx, PM_{10} and $PM_{2.5}$, other criteria contaminants	Reclamation		
	Amines and by-products			
	Water usage			
Alberta carbon trunk line EOR	NA	CEAA screening		
	None	Detailed information		Little information
		Effect on valued ecosystem components	Drilling and completions	Existing and abandoned wells
		Air and noise, soils and landuse, vegetation, wetlands, wildlife, historical resources, social and economic issues		Flow lines
				If leakage in decommissioning, CO_2 not inherently toxic; no contamination
		Accident and malfunction		
	Alberta EPEA	Alberta EPEA C&R		
	None required (improvement to current operations)	ERCB		
		Hazard assessment re EPZ (700 m)		
		CO_2, hydrogen, CO, H2S, HVP		
		RM – pipeline to meet regulatory standards and monitoring		
Quest sequestration	Joint Fed/Prov Environmental Assessment (EPEA and CEAA Screening) in conjunction with ERCB Regulations and Directives			
	EIA			
	Accidents, malfunctions and unplanned events			
	Effects on valued ecosystem components, public health and safety, aquatic resources			
	EIA/ERCB	EIA/ERCB		ERCB
	Air quality	Emergency response planning		Site characterisation and selection for acid gas storage scheme
	NOx, NOx as precursors to $PM_{2.5}$, PAI, nitrogen, ozone formation, regional haze, CO_2	Transport and injection pads – (EPZ 450m)		(Not publicly available)
	Public health and safety	Monitoring	ERCB Injection well integrity	
	NOx, NOx as precursors to $PM_{2.5}$		Measurement, monitoring and verification plan to detect loss of conformance and loss of containment	
	Monitoring			

Notes: Acronyms: CEAA – Canadian Environmental Assessment Act; C&R – Conservation and Reclamation Plan; EAB – Environmental Assessment Branch; EIA – Environmental Impact Assessment; EPEA – Alberta Environmental Protection and Enhancement Act; ERCB – Alberta Energy Resources Conservation Board (now Alberta Energy Regulator).

In these four projects, developers and regulators point to meeting the requirements of existing provincial guidelines or directives as sufficient to mitigate or manage project activities at each phase of development. This review found that airshed air quality monitoring is proposed for capture projects, whereas pipeline monitoring and Emergency Response Plan (ERP)/Emergency Protection Zone are primary risk management activities for CO_2 transport. In Alberta, ERP documents are deemed operational and therefore approved by the ERCB (now AER) after a decision has been made to approve a project. Indeed, the Quest ERP was not finalised until operations began. It was also determined that ESRD, through the EPEA, are not involved in planning for spill response (for instance, they are not provided the ERP during its development), but they must respond to an incident. Lastly, some regulatory approvals require notification and reporting although follow up is not always required. The specifics of these submissions, if existing, are deemed operational and are not part of applications or approval processes.

In Alberta, measurement, monitoring and verification (MMV) is the principle RM approach discussed in detail, whereas in Saskatchewan monitoring is approved as RM, but detailed plans are not readily available. A variety of monitoring technologies have been proposed and approved for injection and EOR/storage. Given Alberta's requirement for a MMV Plan and Closure Plan under the Carbon Sequestration Tenure Regulation (Government of Alberta, 2011), development of the MMV Plan was a principal activity for Quest in which risk management is being informed by a semi-quantitative risk-based approach. Refinement of Quest MMV continues through project implementation, in part based on the large number of approval conditions that are focused on monitoring (Section 2.4). This is an example of the regulatory RM framework requiring sufficient capabilities in monitoring as a technological RM approach. As stated in the ERCB decision (2012, p.54), "Shell submitted that it designed its project to minimise risk to the environment and the public and it believes its MMV plan provides early detection of potential problems and verification of the effectiveness of corrective measures taken." A detailed closure plan will also be developed as the project progresses.

Measurement and reporting of EOR project performance and containment has not been required; project developers are again concerned with safeguarding proprietary information with respect to the use of CO_2 as a cost to be avoided in accessing oil and gas in the miscible flood operations (Dixon et al., 2015; Jenkins et al., 2015). As suggested above, geological information remains closely guarded by project developers.

In terms of decision content, regulators review and accept the proponent's assessments of hazards, with or without clarifications. In ACTL, there was some frustration evident in the federal departmental review where many details were provided for transport risks and few regarding injection and storage. For Quest, the ERCB accepted Shell's proposed spatial boundary of the study zone (area of interest), an important delineation as discussed above. In Boundary Dam, the RA use of surrogate NDMA for amines and by products was accepted, although further research by the proponent continued as the project was being implemented. With respect to decommissioning and closure, proponents indicate and regulators agree that these project phase details will be developed at a later date.

3.4 Risk communication

In terms of risk communication and public outreach, proponents undertook and reported on regulatory requirements for public consultation about project activities. This normally

included a selection of mechanisms to notify and consult with property owners and identified stakeholders within pre-determined (regulatory-based) distances. Local and regional public outreach was initiated and continues for both Quest and the Boundary Dam project.

As the first LSIP saline sequestration project in Canada, the review of Quest documentation demonstrated a number of risk communication issues. In terms of process, the Shell Quest application, review and approval was complicated to follow. The number of applications under two regulatory regimes (environmental assessment and ERCB applications) was likely demanding, confusing and frustrating for the proponent, regulators and the public as well. Risk topics were difficult to track through mixed topic supplementary information requests (SIRs) for each chain component (examples at Shell Canada Limited, 2010f, 2011a, 2011b, 2011c) and the content of each document was not well described by the titles.

Transparency, described as

1 ease of access to information

2 the fullest possible disclosure of all decision inputs in risk assessment and management decision-making, is also viewed as problematic.

An industry association suggested that Shell's outreach had been exemplary (Fink, 2010); however, the analysis presented here finds that some risk information was either not well presented, not provided in a timely manner, or not made [online] all. For instance, the Quantitative RA for Pipeline and Injection Wells and DNV's Independent Panel Review (IPR) Report of Shell's RA of Acid Gas Storage Scheme were both made available approximately one year into the ERCB review, in response to two SIRs. The document dates and their purpose in Shell's preliminary project assessment indicate they were completed much earlier. As well, although the proponent selected and explained their choice of risk assessment methodologies, the presentation of results varied and did not always promote public understanding. One example, the aforementioned presentation of risk of fatality within the pipeline right of way, was illustrated in graphs and figures within Shell's application and described numerically by the ERCB in its decision. On a separate matter, one might question the noted Independent Panel Review of Quest, given the known relationship between the proponent and the IPR manager, Det Norske Veritas (now DNV GL). In Saskatchewan, on the other hand, there appears to be no central repository/availability of project documentation, although requests are usually responded to positively when made to either project developer or regulator. We also note that Alberta has an ongoing requirement for the proponents to share technical information and lessons learned such that there is further global benefit from the province's investment in the two projects described here (Alberta Energy, 2018).

One final comment concerns the language used to describe the benefits of CCS in project announcements. Projects often equate the amount of CO_2 captured in terms of the equivalent number of cars taken off the road (between 200–500 thousand cars per project per year). This may or may not be meaningful to the public debate about CCS as a mitigation strategy. As well, CO_2-EOR project descriptions generally include estimates of the number of barrels of crude oil that can be developed in a miscible flood. This contrasts with the interests of those advocating for absolute decreases in fossil fuel production/dependency through alternative energy sources and energy conservation.

4 Conclusions

This review of publicly available documentation describes the regulatory practice for four large Canadian CCS projects either under construction or in operation: Weyburn-Midale enhanced oil recovery (EOR) Operations, Boundary Dam Integrated CCS Demonstration Project, Alberta Carbon Trunk Line and Quest Carbon Capture and Storage Project. As CCS develops, integrated projects will continue to be approved through a combination of existing, amended and new laws and regulations aimed at specific components of the CCS value chain, as outlined by Larkin et al. (2019a) and expected by international agencies (European Commission, 2014; IEA, 2010). Nevertheless, narrow regulatory interests form an apparent disconnect between the announcement of integrated projects and the nuts and bolts of assessment and approval processes.

Conclusions that can be drawn from this review find that RA/RM is 'moving forward' in approvals technically: an increasing range of chain component health and environmental risks are being assessed using referenced approaches. However, while proponents explained their choice of risk assessment methodologies and there is an increasing range of risks being assessed, documentation can be scattered rather than presented comprehensively across risk topics and the presentation of results would not always promote public understanding. Hence, individual risk assessments are deemed acceptable, without project developers or regulators discussing comprehensive risk estimation. An integrated RA/RM framework of the type proposed by Larkin et al. (2019b) has not been used as a guide.

Furthermore, documented approval processes experienced slow and/or incomplete public release of risk assessment information. Indeed, unresolved issues about transparency in risk management decision-making for CCS may have a negative impact in the future on public acceptance and therefore on project viability in the long run. This issue is discussed in detail by Leiss and Larkin (2019).

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Notes

1 LSIPs are defined as projects involving the capture, transport and storage of CO_2 at a scale of at least 800,000 tonnes of CO_2 annually for a coal-based power plant, or at least 400,000 tonnes of CO_2 annually for other emissions-intensive industrial facilities (including natural gas-based power generation) [GCCSI, (2018), P.25].

2 With the sale of Cenovus' interest in the Weyburn operations to Whitecap Resources Ltd. in late 2017 (Section 2.2), these figures cannot be confirmed.