Online Resource: Supplementary Materials

Integrated Risk Management Framework for Carbon Capture and Storage
in the Canadian Context

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CCS Hazard taxonomy and risk management options

	Consideration of Risk Management Context[1] Risk management principles; Economic analysis; Socio-political considerations; Risk perception				
Hazard	Risk Management Options[2]				
	Regulatory	Economic	Advisory	Community-based	Technological
All Chain Activities					
Project basis	Environmental Assessment		Cross-industry learning and knowledge sharing Best management practices		Integrated hazard management
Capture Chain					
Air emissions Local, regional	• Emissions regulations • Monitoring requirements (NPRI) • Reporting requirements (NPRI) • Siting specifications (setbacks)	CEPA/Provincial Penalties/Fines	Notification process - exceedances local public health (or other agency)	Siting (position, features) Emergency response zone	• Process technologies and operations • Design specifications • Alarm and shut down • Monitoring
Amine/criteria contaminant deposition	• Emissions regulations • Monitoring	CEPA/Prov Penalties/Fines	Notification process	Siting (position, features)	• Process technologies and operations • Design specifications

[1] A framework for the next generation of risk science (Krewski et al., 2014)
[2] Integrated framework for risk management and population health (Krewski et al., 2007)

Local, regional	requirements • Reporting requirements • Alberta flagged amines RA uncertainty				• Monitoring

	Risk Management Options				
Hazard	Regulatory	Economic	Advisory	Community-based	Technological
Transport Chain					
Pipeline failure Associated systems failure [CO_2 or CO_2 stream impurities] Inhalation occupational health and safety (OHS), public	Setbacks (AB CO2 pipeline class not required to identify Emergency Response Zone delineation) ERP/EPZ Shut down device interval Reporting Stream composition	Payments to municipal or provincial emergency response	Emergency response plan dissemination Training and qualifications ISO/CSA	Pipeline routing Emergency response plan development (inclusions) and implementation Site specific Emergency Response Zone Surveillance	Pipeline Integrity Management Plan • Design • Operations • Inspection • Monitoring • Maintenance Pressure control devices Alarm and shut down device/procedures
Injection Chain					
Injection wellhead or well casing failure CO_2 or CO_2 stream impurities Inhalation OHS	• Area of Review • Setbacks • Development plan • Permitted operational guidelines • Stream composition • Inspection, maintenance • Emergency Response Plan/EPZ • Drilling plan • Disposal plan (fluids) • Ignition plan (gases)		Emergency response plan dissemination Procedures Training	Siting Emergency response plan development (inclusions) and implementation	• Site characterization (subsurface hazardous substances in flowback) • Well design, development • Operating strategies • Responsive MMV programs • Pressure control, alarm, and shut down devices

	Risk Management Options				
Hazard	Regulatory	Economic	Advisory	Community-based	Technological
Injection Chain (con't)					
Induced seismicity	Permitted operational guidelines Performance-based guidelines for MMV Transparent reporting	Contingency fund	Emergency response plan dissemination	Emergency response plan development (inclusions) and implementation EPZ	Site characterization and selection Responsive MMV programs Pressure control, alarm, and shut down devices
Surface uplift	Permitted operational guidelines Performance-based guidelines for MMV[3]		Information and education for 3rd parties	Surveillance	Site characterization and selection Responsive MMV programs Pressure control, alarm, and shut down devices
Caprock Fracture	Permitted operational guidelines Performance-based guidelines for MMV		Safety procedures Training		Site characterization and selection Responsive MMV programs Pressure control, alarm, and shut down devices

[3] Project specific operating conditions, a principle followed by the AER (Golder, 2011).

	Risk Management Options				
Hazard	Regulatory	Economic	Advisory	Community-based	Technological
Capture, Transport, Injection Chain					
Accidents, Malfunctions, Unplanned Events (AMUE) (Process Upsets)	• CO2 stream specification • mix of Mandatory and Voluntary requirements • Spill response plan • ERP/EPZ	CEPA/Provincial Penalties/Fines	• ERP dissemination • Off specifications notification • BMP – eg natural ventilation • Training	• Siting (position, features) • ERP development and implementation • Includes EPZ • 3rd party monitoring	• CO2 competency management system • Stream specifications • Operating strategies • Alarm and shut down device(s) • Monitoring
Injection or Storage Chain					
Near or far field	• Siting, separation • Stream specification • Design specifications (operating well – EPA UIC Class VI) • Inspection, maintenance • Performance-based guidelines for MMV • ERP/EPZ		Operations Training Information and education for 3rd parties	Siting Surveillance	Site characterization and selection Well development, design, materials Responsive MMV programs Pressure control, alarm and shut down devices
From direct, diffuse or lateral transport process Near or far field	• Site selection • Characterization of baseline conditions • Stream specification • Performance-based guidelines for MMV • ERP/EPZ • Reporting	Sampling, Inspection Contingency fund	Information and education for 3rd parties	Site characterization Emergency response plan development (inclusions) and implementation Surveillance monitoring	Site characterization and selection Integrity testing of known wells in vicinity Injection well development, design Biophysical environmental monitoring Responsive MMV programs

	Risk Management Options				
Hazard	Regulatory	Economic	Advisory	Community-based	Technological
Storage Chain					
Diffuse leakage Near or far field	Renewable permit process and monitoring requirements Performance-based guidelines for MMV				Site characterization and selection Responsive MMV programs
Lateral leakage Far field	Renewable permit process Performance-based guidelines for MMV Setbacks			ERP/EPZ	Site characterization and selection Responsive MMV programs
Direct free-phase CO_2 Near field Short or long term	• Setbacks • Development plan • Renewable permit process • Performance-based guidelines for MMV • Fit for purpose certification • Closure plan • Post closure plan	Payments into contingency fund Penalty structure	Reporting DNV 2012 storage: Specifications and performance requirements to be clearly defined, quantified and documented	ERP/EPZ	Site characterization and selection Responsive MMV programs