CSAP FALL 2017 PROFESSIONAL DEVELOPMENT WORKSHOP

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Parisa Jourabchi, Ian Hers, François Beaudoin

Toolkits for the Management of Petroleum Hydrocarbon Sites

Toolkits #3: Remedial Technologies
Toolkits #4: Green & Sustainable Remediation

CSAP/Shell Toolkits Project

Acknowledgments:
BC Contaminated Sites Approved Professionals (CSAP) Society
Dr. Matthew Lahvis (Shell Global Solutions)
BC Ministry of Environment and Climate Change Strategy

Golder Associates

MNA and NSZD Toolkits

#1 CSM & Case Study Toolkit

- Conceptual Site Model
- Multi-Site Database Studies
- BC Case Studies

#2 Monitoring and Prediction Toolkit

- Methods for evaluation of natural attenuation and source depletion

Toolkits 1 & 2 (Golder, 2016)*

#3 Remediation Technology Toolkit

- Screening criteria for technical feasibility & implementability and comparison to NSZD

#4 Sustainability Toolkit

- Methods & roadmap for implementing green & sustainable remediation (GSR)

*Golder Associates Ltd. 2016. Toolkits for Evaluation of Monitored Natural Attenuation and Natural Source Zone Depletion. Prepared for the Society of Contaminated Sites Approved Professionals of British Columbia (CSAP) and Shell Global Solutions, July 8th, 2016. Available on CSAP Web Site.

Toolkit 3: Outline

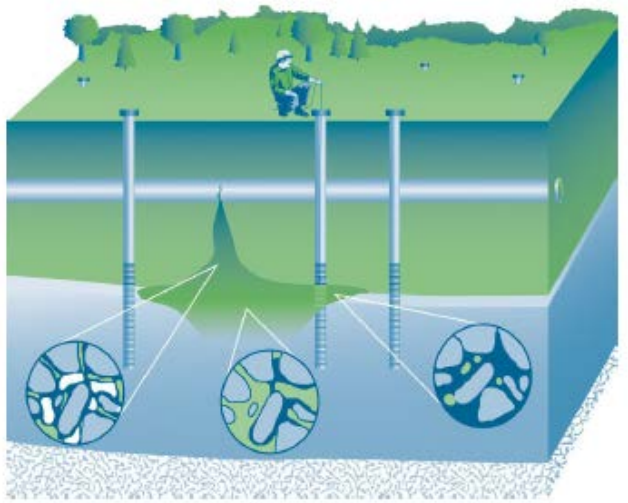
- Overview of guidance & available tools on remedial technology selection
- Conceptual site model and data collection
- Overview of remedial technologies
  - Targets
  - Objectives
  - Primary mechanism
- Technology screening process Tables A & B

GUIDANCE ON REMEDIAL TECHNOLOGY SELECTION

- Canada National Research Council (NRC)
- US Federal Remediation Technologies Roundtable (FRTR)
- US NRC (2004)
- Interstate Technology & Regulatory Council (ITRC) – (2009)
- Contaminated Land: Applications in Real Environments (CL:AIRE) – UK organization

Technical/Regulatory Guidance

Evaluating LNAPL Remedial Technologies for Achieving Project Goals

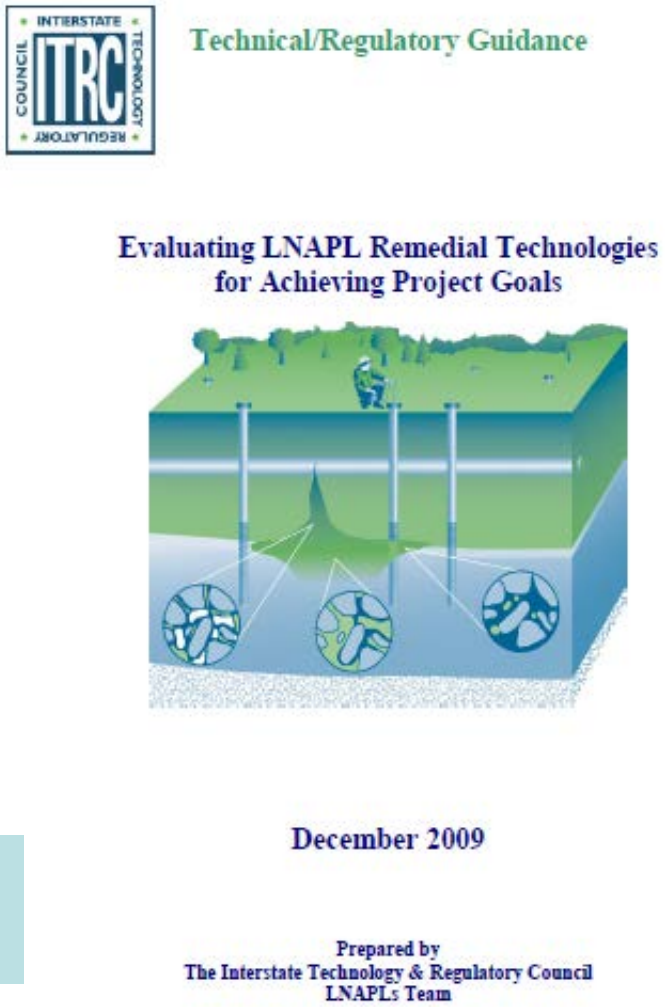


ITRC (2009)

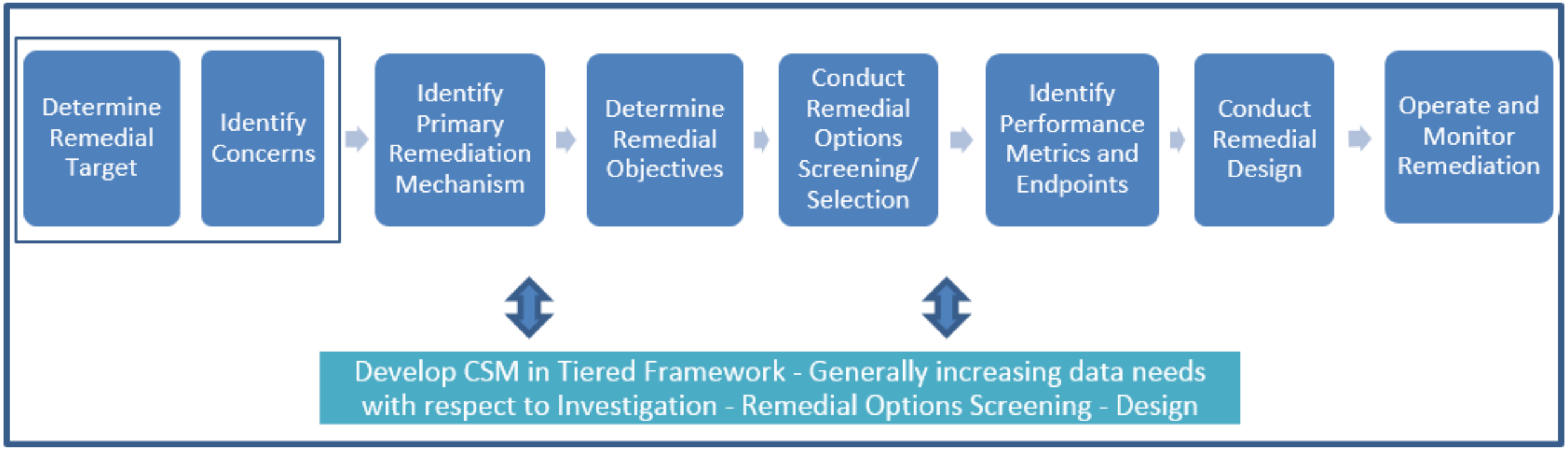
- Fundamental Steps

1. Site characterization and refinement of LNAPL conceptual site model (LCSM) with reference to ASTM (2007) for development of LCSM.
2. LNAPL remedial objectives for the site.
3. Development of remedial strategy based on remedial objectives.
4. Establish an acceptable outcome (i.e., in terms of closure and site monitoring) once objectives are met.

Total of 17 technologies are described along with evaluation factors, new updated guidance expected in 2018



Toolkit 3: Remediation Process & Selection Framework



Toolkit 3: Remedial Selection Categories

Remedial Target	Concern	Primary Mechanism	Remedial Objective	Performance Metrics
Saturation	Possible Migrating LNAPL Mobile LNAPL Soil Concentrations	Mass Recovery	Abate LNAPL migration Reduce saturation to acceptable threshold Meet criteria or standards	Transmissivity LNAPL recovery rate (decline curve analysis) Observational data at wells Soil concentrations
Composition	Soil Concentrations GW, SV Concentrations	Phase Change (and Mass Reduction)	Reduce concentrations/flux Abate safety issues Meet criteria or standards	Soil, GW, SV concentrations/flux
Containment	Possible Migrating LNAPL GW Concentrations	Mass Control	Abate/control LNAPL migration Abate/control dissolved plume migration	Observational data (presence/absence) Leaching (LEAF) Admixture PHC compatibility Barrier permeability
Saturation & Composition	Possible Migrating LNAPL Mobile LNAPL Soil, GW, SV Concentrations	Phase Change & Mass Recovery	Abate LNAPL migration Abate safety issues Reduce saturation to acceptable threshold Reduce concentrations/flux Meet criteria or standards[4]	Transmissivity LNAPL recovery rate (decline curve analysis) Observational data (presence/absence) Soil, GW, SV concentrations and flux

GW = groundwater, SV = soil vapour

Toolkit 3: CSM and Data Collection

Components	Data types for site investigation	Data sources/ references for site investigation	Data types for remedial options evaluation	Data sources/ references for remedial options evaluation
Site setting	Land use, receptors	Site investigation	More detailed assessment, as warranted	Additional investigation
Geology	Stratigraphy, soil classification, basic soil properties (moisture, grain size)	Site investigation	Detailed soil properties: capillary tests of fluid retention (oil/water), porosity, density, permeability	Specialized coring and lab tests – API 4711 – PTSLabs info
Hydrogeology	Hydrostatigraphic units, hydraulic conductivity, gradient, depth to groundwater	Single well response tests, empirical relations – BC MOE TG #8	More detailed assessment, as warranted	Estimation of groundwater velocity and transmissivity from pumping tests and tracer studies – ref
LNAPL release	Approximately when did release occur? Is it abated?	Historical and current records	More detailed assessment, as warranted	Specialized fingerprinting / forensics tests (e.g., PIANO, biomarkers) - ref
LNAPL type and composition	Fuel, crude oil, motor oil, expected additives, etc.	Historical and current records	Constituent mole/mass fractions and weathering	GC/FID/MS analyses; Routine and specialized lab analyses – GC/FID/MS; simulated distillation by ASTM D2887
LNAPL properties	Density, viscosity	Empirical relations for fuel/oil type - API 4682; API 4731; Environment Canada Database http://www.etc-cte.ec.gc.ca/databases/OilProperties/oil_prop_e.html; Mercer & Cohen (1990)	Density, viscosity, interfacial tension, vapour pressure	Specialized lab tests – ASTM D1481; ASTM D445; API 4711
LNAPL distribution	Vertical and horizontal delineation	Site investigation	More detailed assessment, as warranted	Detailed cores and lab testing, UV light; profiling method e.g., LIF (D6187-97(2000), MIP (D7352-07 (2012) ;inferred from soil vapour
Mobile LNAPL (above residual saturation)	Is it present? Based on direct and indicators	ITRC PVI Guidance, Table 3-5 http://www.itrcweb.org/PetroleumVI-Guidance/	Quantitative estimates of total and residual LNAPL saturation	Specialized coring and lab testing: pore fluids testing, lab centrifuge (1000g), water drive, f-factor approach API Bulletin 9 http://www.api.org/~/media/Files/EHS/Clean_Water/Bulletins/09_Bull.pdf
Mobile LNAPL behaviour	Confined, unconfined, perched	Hydrostratigraphic plots, DGPs – ANSR http://www.h2altd.com/ansr	More detailed assessment, as warranted	Observations from oil recovery tests – ASTM #
Potential for LNAPL migration or LNAPL body stability?	LOE's include: information on mobile LNAPL, in-well LNAPL observations, trans-missivity estimates, recovery decline curve, dye tracer test, depletion rates, inference from groundwater and soil vapour plumes, modeling	At this stage, only select LOE's typically warranted – BC MoE P16 ITRC LNAPL Guidance (2009) ASTM E2856-13	More detailed assessment and additional LOE's, as warranted	ITRC LNAPL Guidance (2009) ASTM E2856-13 API Transmissivity Guide

- The main stages in the development of the CSM and data collection efforts are:
  - Site investigation – identify concerns
  - Remedial options evaluation – identify additional data needed to evaluate technologies
  - Remedial design and performance monitoring
- CSM focused on petroleum hydrocarbon and LNAPL
- CSM should be updated as new data is obtained

Detailed CSM Component and Data Collection Table Created to Guide LNAPL Focused Investigation and Remediation

Toolkit 3: CSM Components, Data Types and Sources

Components	Data types for site investigation	Data sources/ references for site investigation	Data types for remedial options evaluation	Data sources/ references for remedial options evaluation

- Site setting
- Geology
- Hydrogeology
- LNAPL release
- LNAPL type and composition
- LNAPL properties
- LNAPL distribution
- Mobile LNAPL (above residual saturation)
- Mobile LNAPL behaviour
- Potential for LNAPL migration or LNAPL body stability?
- LNAPL recoverability information
- LNAPL depletion information
- Associated groundwater and soil vapour plumes
- Preferential pathways
- Potential for complete exposure pathways
- Safety concerns
- Geotechnical concerns

Toolkit 3: Remedial Technologies

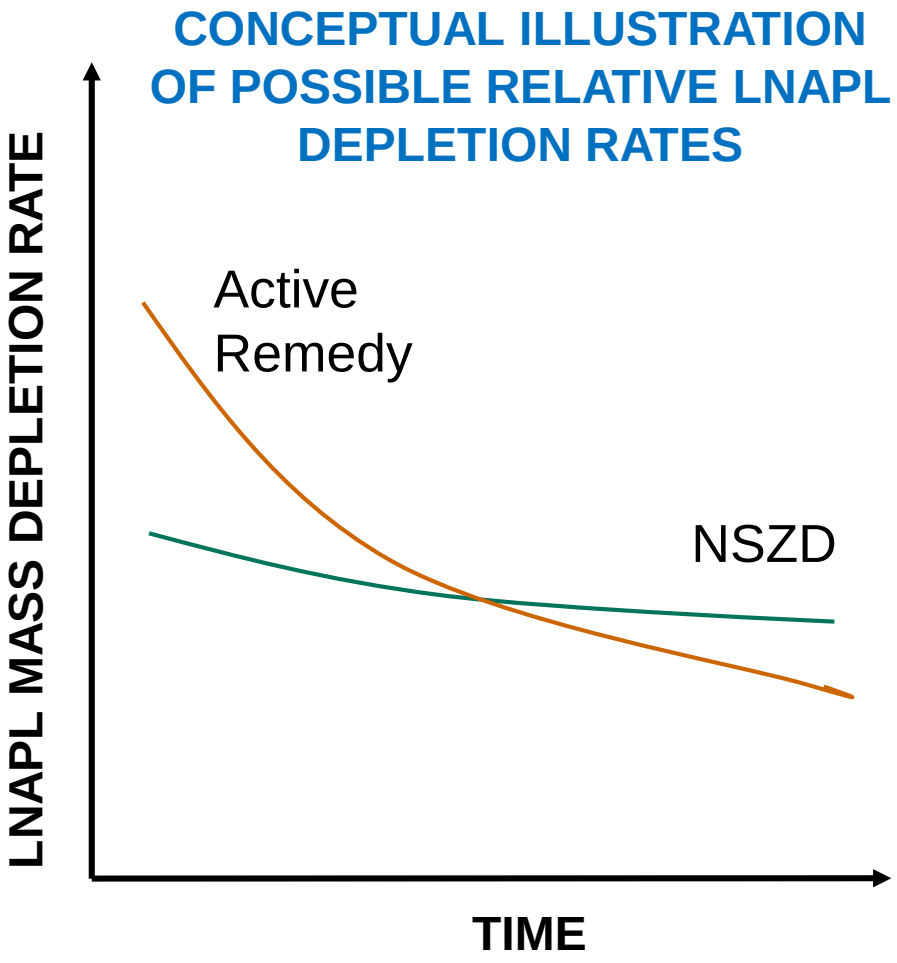
Primary Mechanism	Technologies Available
LNAPL Mass Recovery	▪ Excavation ▪ MPE / DPE / DPLE (or two-phase extraction; total fluid recovery) / AirSweep® ▪ LNAPL recovery (pumping, skimming)
Mass Control	▪ PRB ▪ French drain ▪ Impermeable/slurry walls ▪ Trenches ▪ Hydraulic containment (Ankeny moat) ▪ In-Situ Containment-Capping and Solidification-Stabilization (including vitrification) ▪ Ex-situ solidification-stabilization (including vitrification) ▪ Groundwater Pump & Treat
Phase Change & Mass Recovery	▪ Bioslurping & enhanced fluid recovery (vacuum enhanced recovery & bioventing) ▪ In-situ thermal (radio frequency heating, electrical resistance heating, thermal conductive heating) ▪ Solvent, surfactant, or steam/hot air enhanced hydraulic recovery ▪ Water, supersaturated water injection, or hot water flooding for enhanced recovery

Toolkit 3: Remedial Technologies

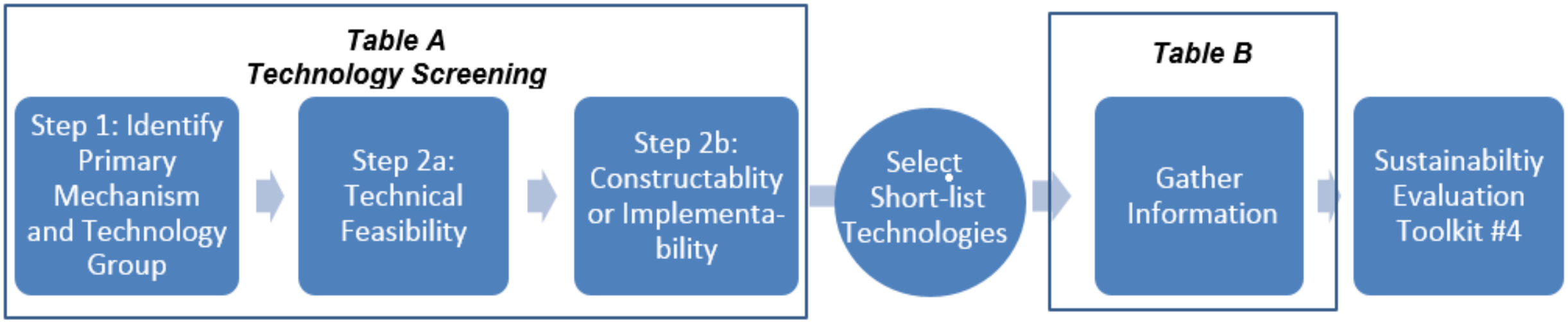
Primary Mechanism	Technologies Available
Phase Change & Mass Reduction	*In-situ* ▪ NSZD (MNA and/or institutional controls) ▪ Air Sparging ▪ SVE / TEVET ▪ Bioventing ▪ Biosparging ▪ ISCO ▪ In-situ bioremediation (active or enhanced: biostimulation or bioaugmentation; aerobic or anaerobic; thermally enhanced (e.g., solarization) ▪ Activated carbon ▪ Phytoremediation ▪ Chemically enhanced electrokinetics *Ex-situ* ▪ Ex-situ thermal (desorption, pyrolysis) ▪ Ex-situ bioremediation (biopiles, landfarming, composting) ▪ Ex-situ physical/chemical treatment (soil washing, UV, adsorption)

Toolkit 3: Technology Transition and Treatment Trains

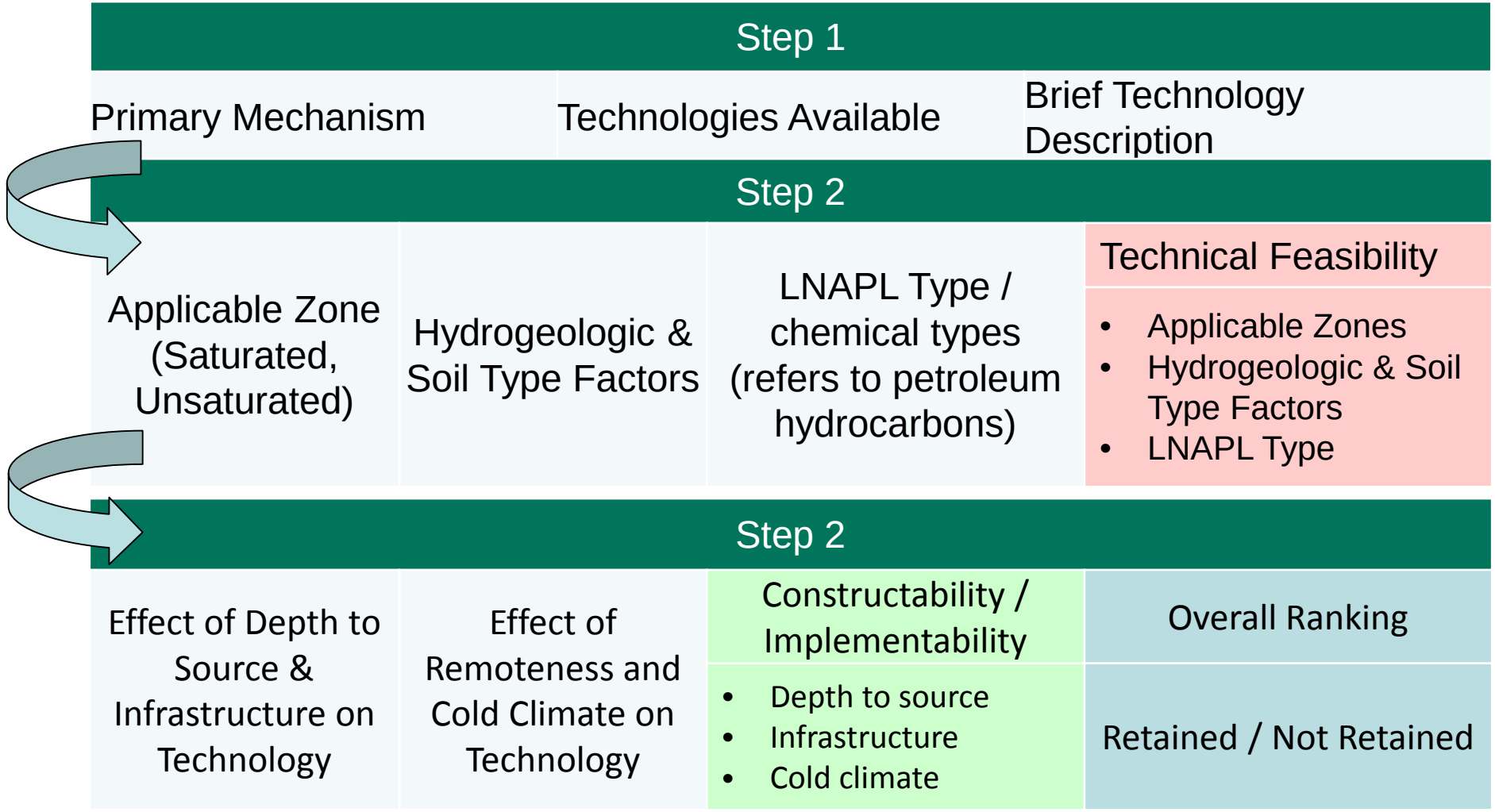
- NSZD results in longer-term mass depletion and compositional change
- Methods for estimation of NSZD have been developed (Toolkit 2)
- Database of NSZD rates have been compiled (typically 500 to 1,500 Gal/Acre/yr) (Toolkit 2)
- Case studies show later stage active LNAPL recovery rates for technologies such as LNAPL pumping, SVE, and MPE can be comparable to or less than NSZD depletion rates
- Baseline NSZD depletion rates and comparisons to active recovery technologies may be used to inform decisions for technology transition over the project life-cycle as a more sustainable approach
- Treatment train approach may be warranted, e.g., LNAPL recovery, enhanced bioremediation (bioventing, biosparging), NSZD)



Toolkit 3: Remedial Selection Process



Toolkit 3: Remedial Selection Process



Toolkit 3: Step 1 of Selection

Step 1		
Primary Mechanism	Technologies Available	Brief Technology Description
LNAPL Mass Recovery	1. Excavation	LNAPL body is physically removed and properly treated or disposed.
	2. LNAPL recovery (pumping, skimming)	LNAPL is hydraulically recovered from the top of the groundwater column within a well.
In-Situ Phase Change & Mass Reduction	3. NSZD (MNA and/or institutional controls)	LNAPL constituents are naturally depleted from the LNAPL body over time by volatilization, dissolution, absorption and degradation.
	4. Bioventing	Similar process to SVE except air/oxygen is injected more slowly (not extracted like SVE) to stimulate biological degradation of petroleum in the unsaturated zone.

Toolkit 3: Step 2a Technical Feasibility

	Applicable Zone (Saturated, Unsaturated)	Hydrogeologic & Soil Type Factors	LNAPL Type / chemical types (refers to petroleum hydrocarbons)	Technical Feasibility * Applicable Zones * Hydrogeologic & Soil Type Factors * LNAPL Type
Excavation	Both	potential stability concerns; easier to excavate unconsolidated soil and less practical for bedrock	all types	
LNAPL recovery (pumping, skimming)	Saturated	greater efficiency for higher permeability soils and lower residual LNAPL saturation in coarser grained soils (i.e., lower capillary pressure)	all types, more efficient for lower viscosity LNAPL	
NSZD (MNA and/or institutional controls)	Both	permeability, grain size and soil moisture content in the vadose zone; higher mass loss through dissolution at higher groundwater flow velocities	all types; greater efficiency for higher fractions of soluble and/or volatile components	
Bioventing	Unsaturated	more efficient in higher permeability soil	all types	

Toolkit 3: Step 2b Implementability & Overall Ranking

LNAPL Mass Recovery	Effect of Depth to Source & Infrastructure on Technology	Effect of Remoteness and Cold Climate on Technology	Implementability * Depth to source * Infrastructure * Cold climate * Remoteness	Overall Ranking Retained / Not Retained
Excavation	may be impracticable for deep sources and where access is limited by infrastructure	disposal options potentially limited; relatively short window for implementation		
LNAPL recovery (pumping, skimming)	generally not impacted by presence of infrastructure or depth to source	potential limitations in access to utilities or local operations & maintenance labour; groundwater freezing; deep frost or permafrost; potentially long periods without collected product removal		

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Toolkit 3: Step 2b Implementability & Overall Ranking

In-Situ Phase Change & Mass Reduction	Effect of Depth to Source & Infrastructure on Technology	Effect of Remoteness and Cold Climate on Technology	Constructability / Implementability * Depth to source * Infrastructure * Cold climate * Remoteness	Overall Ranking Retained / Not Retained
NSZD (MNA and/or institutional controls)	remediation effectiveness generally not impacted, except where infrastructure significantly affects oxygen transport to the subsurfface; potential challenges in monitoring and data interpretation for deep source	potential reduction in effectiveness during extreme cold conditions; potential limitations for access and labour related to monitoring activities		
Bioventing	generally not impacted by presence of infrastructure or depth to source; less practical where source is mainly below the water table	power requirements; extreme cold in shallow soil can impact biodegradation and volatilization		

Toolkit 3: Data Gathering

Key Factors (set 1/2)

Example Excavation

Waste Generation	soil and seepage water; characterization and treatment/disposal required; additional requirements for hazardous waste
Remedial Timeframe	short (weeks to months)
Design Data Requirements	Extent of source zone; soil type; dewatering and slope stabilization requirements (i.e., cut-off walls)
Special Considerations	potential dust generation and air quality concerns; potential for mobilizing contamination through pumping for groundwater dewatering

Toolkit 3: Data Gathering

Key Factors (set 2/2)

	Example Excavation
Performance Metrics	soil; groundwater; and possibly soil vapour concentrations; LNAPL presence
Applicable Models	none
Safety Concerns	moderate * construction related concerns for excavation, dewatering * tranportation related concerns
Cost	* Low to high dependent on extent of excavation/disposal; * Likely no O&M associated cost
BC Context	remote locations: high mobilization and monitoring costs; northern locations: short work windows

Toolkit 4: Green & Sustainable Remediation

- Starting with a short-list of applicable remedial technologies (e.g. up to four) selected using Toolkit #3
- Green & Sustainable Remediation (GSR) as the integration of:
  - Sustainable Development: Triple bottom line

  &

  - Green remediation: greater focus on environmental net benefit; lesser focus on social and economic aspects
- Overall impact of remedial activities on human and ecological receptors and society

ITRC (2011)

optimization of triple bottom line = sustainable remediation

Toolkit 4: Introduction & Outline

- GSR Concepts & Principles
- Review of Key Guidance
- GSR methods and tools
  - Best management practices
  - Life cycle analysis
  - Environmental footprint
  - Multi-criteria analysis (MCA) tools to support practitioners in finding optimal solution(s)
- Roadmap for the implementation of GSR
- GSR Dashboard

Common obstacles to implementation of GSR*

- Lack of regulatory driver
- Perceptions/lack of agreement on what is and what is not sustainable
- Lack of consistent standards
- Lack of training and/or resources
- Cost considerations

* highlighted in different surveys conducted within the remediation community (Ellis and Hadley, 2009, Hou, 2016)

Toolkit 4: GSR Concepts & Principles

Core elements of GSR (linked to sustainable development)

- Air pollution (e.g., particulates, volatile organic compounds (VOCs))
- Water use
- Waste generation
- Greenhouse gas (GHG) emissions
- Surface soil degradation (e.g., erosion, nutrient depletion, geochemical change)
- Ecological impacts
- Energy use
- Stewardship of resources
- Local community vitality

GSR themes found in guidance worldwide (various guidance)

- Balanced decision-making process
- ⋮
- Best Management Practices (BMPs)
- Total cost approach
- Non-technical risk management
- Project life cycle & life cycle analysis
- Record keeping and transparent reporting
- Safe working practices
- Social justice
- Net Environmental Benefit Analysis (NEBA)

Common thread: overall impact of remediation effort & evaluation of the environmental footprint of the project (at minimum)

Toolkit 4: Key Guidance & GSR Tools

- ITRC (2011) Green & Sustainable Remediation Guidance
- US EPA (2008) Green Remediation Primer
- Sustainable Remediation Forum (SuRF) Organizations
  - CL:AIRE (UK)
- Federal Contaminated Sites Action Plan (FCSAP)

Core Elements of Green Remediation

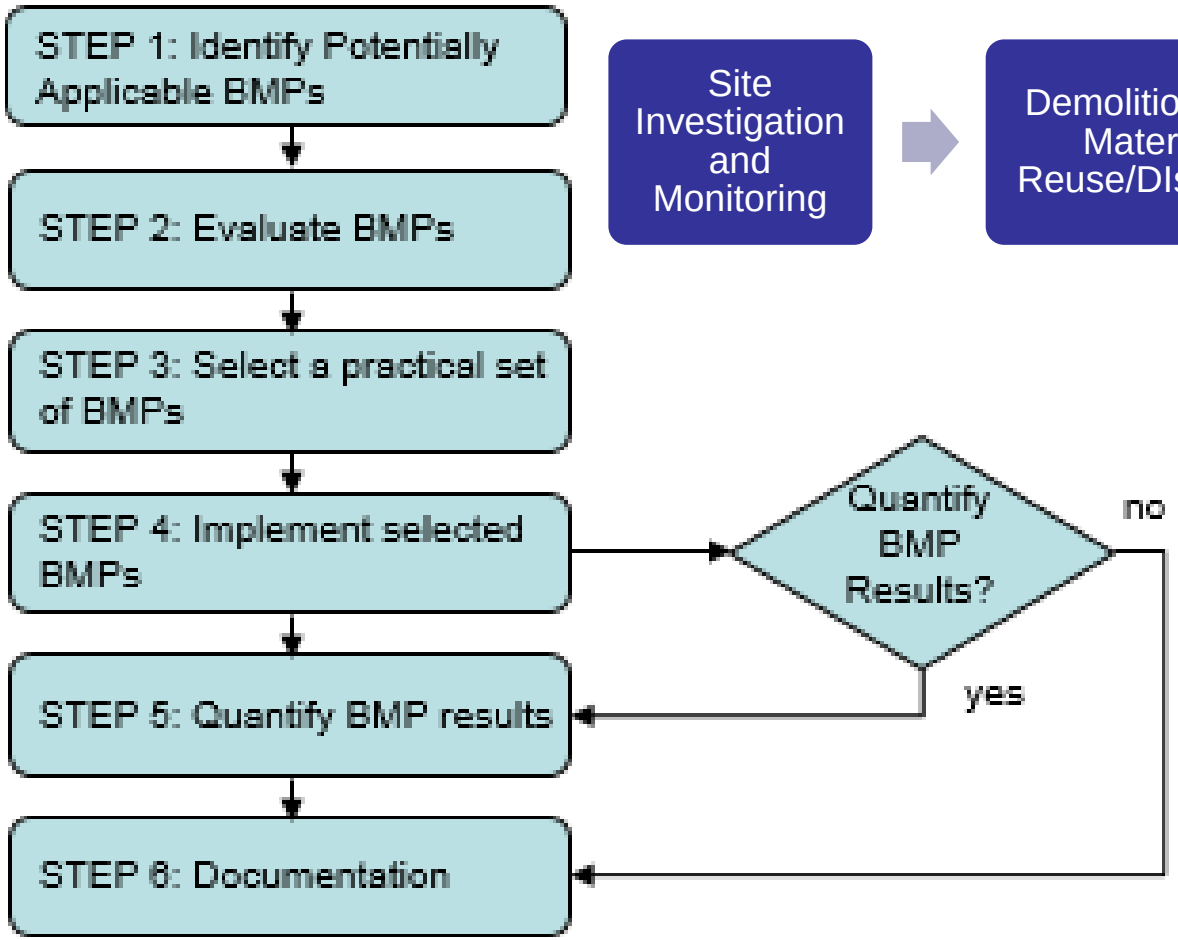
- *Reducing total energy use and increasing renewable energy use*
- *Reducing air pollutants and greenhouse gas emissions*
- *Reducing water use and negative impacts on water resources*
- *Improving materials management and waste reduction efforts, and*
- *Enhancing land management and ecosystem protection*

US EPA (2008)

GSR Methods & Tools

1. Best management practices (BMPs) or sustainable management practices (SMPs)
2. Quantifying environmental impacts or footprint analysis (LCA tools) and carbon footprint analysis (CFA)
3. Multi-criteria analysis (MCA) of sustainability

Toolkit 4: Best Management Practices



BMP implementation steps from ASTM E2876-13

Site Investigation and Monitoring → Demolition and Material Reuse/DIsposal → Site Remediation and Waste Management → Site Re-development, Risk-based measures → Long-term Stewardship and Oversight (where needed)

- All phases of site investigation and remediation
- Site-specific GSR measures
  - GHG Emmissions
  - Energy efficiency
  - Waste management

Toolkit 4: Best Management Practices

Energy Efficiency

- Alternate or renewable energy sources (e.g., landfill gas, wind, solar power)
- Consideration of passive sampling methods, smaller drill rigs or technologies such as bioventing or other low intensity enhanced bioremediation methods
- Appropriate sizing of equipment and operational efficiency through for example pulsed operation and energy efficient equipment
- Sequencing of work to improve efficiency
- Telemetry and advanced data collection and processing methods to improve monitoring and operational efficiency
- Equipment and materials local to the site

Waste Reduction

- Reduction of investigation derived wastes
- Use of water efficient equipment and water re-cycling where feasible
- Re-cycling or reclamation of materials, and use of products with re-cycled content
- on-site reuse of excavated and treated materials (with due consideration for potential residual risk)

Metrics based on resource intensity per mass (kg) of contaminant treated

Socio-economic

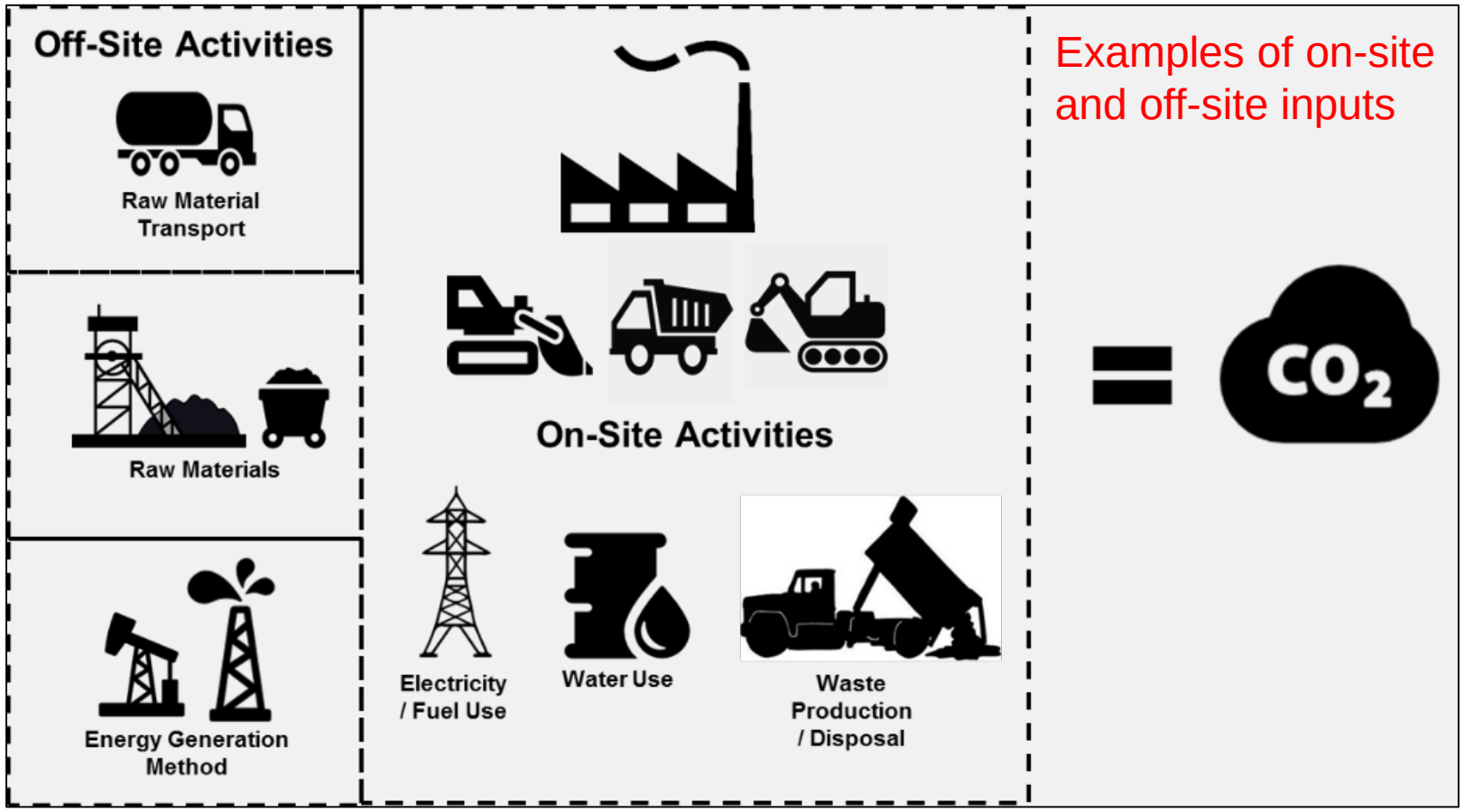
- Modify approach to address concerns about disruptions & disturbances to local residents & businesses
- Communicate site activities to stakeholders & community in a manner that public health risk are understood

Toolkit 4: Environmental Impacts (Footprint)

- Identify Environmental Metrics
- Establish System Boundaries
- Environmental Inventory
- Footprint Calculation
- Documentation

Tools Available:

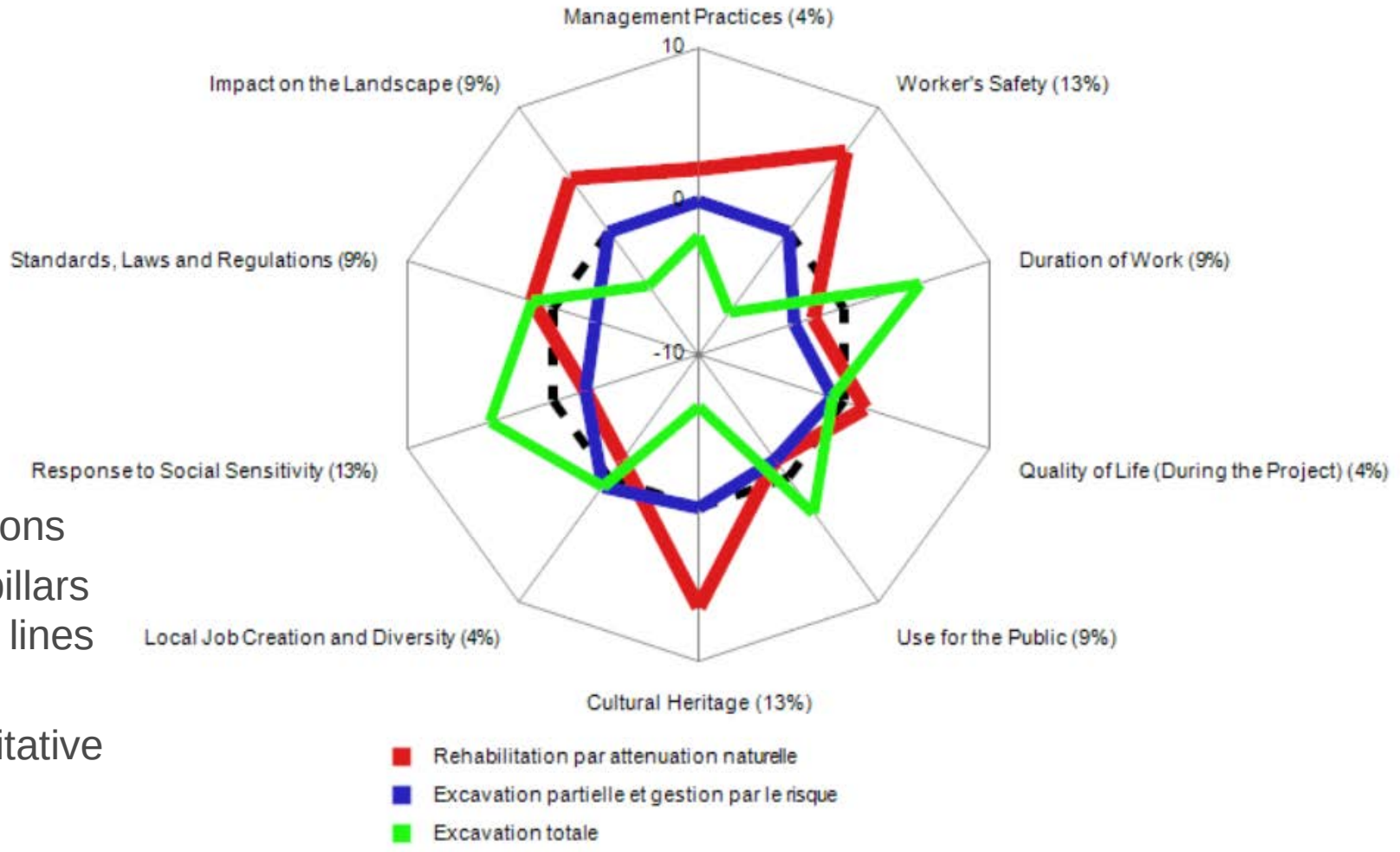
- SiteWise Tool
- US EPA SEFA
- SMARTTool
- SoFi TS Tool
- Toolkit 4: GSR Dashboard



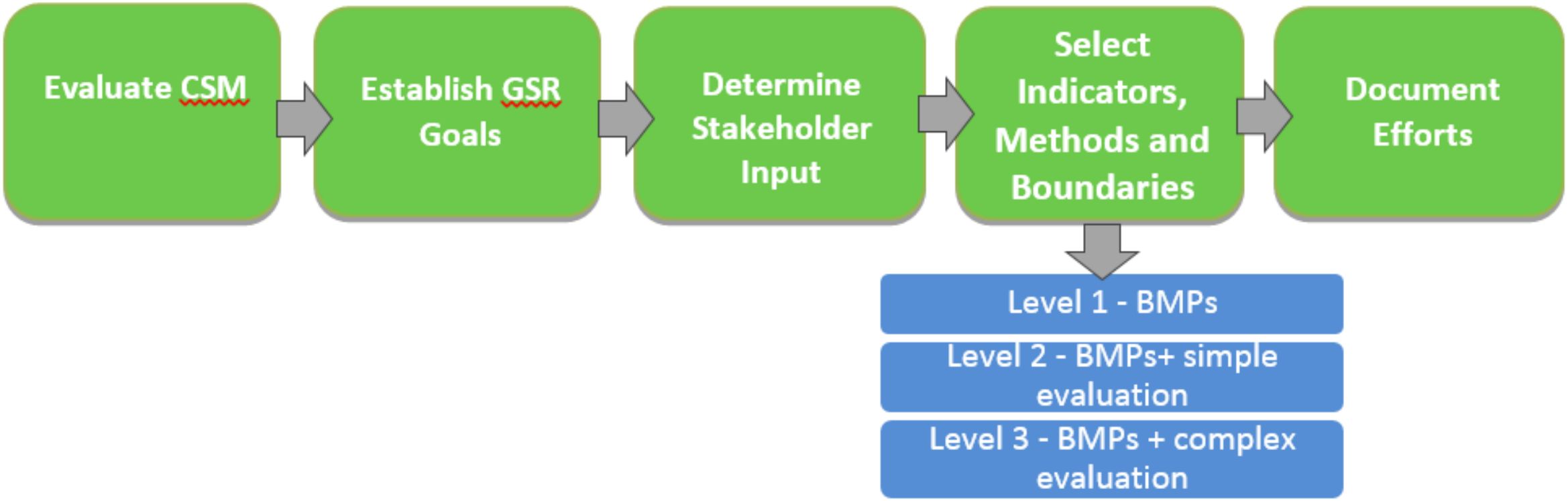
Simplified life cycle analysis (LCA) can be used to guide the analysis

Toolkit 4: MCA Methods

- Select indicators
  - Qualitative
  - Semi-quantitative
  - Quantitative (metrics and measurement units)
- Indicator weighting
- Scoring & evaluation
- Analysis, presentation and documentation of results
- Range of complexity, tools and options
  - Intend to encompass all three pillars of sustainability or triple bottom lines
  - Scoring & evaluation across indicators is challenging (quantitative & qualitative)



Toolkit 4: Roadmap



Toolkit 4: GSR Dashboard

DRAFT GSR DASHBOARD (*V1.0 - Golder Associates*) - Not for Distribution				
FOOTPRINT INFORMATION				
	Indicator (add/subtract as warrented)	**Metric**	**Measurement Unit**	**Data Sources and Calculators**
Environmental	GHG	1. GHG Emissions (CO_2, CH_4, N_2O)	Tonne CO_2e	US EPA Calculators[1,3] US EPA SEFA[2] SiteWise: Table A-3, App B BC MoE[9]
	Energy	1. Total energy use (direct and indirect) 2. Energy from renewable resources	MMBtu	SiteWise: Table A-2, App B; EPA[8], BC MoE[9]
	Air Pollutants[10]	1. NOx emissions 2. SOx emissions 3. PM10 emissions	Kilograms	SiteWise: Table A-2, App B
	Waste[11]	1. Hazardous waste disposed of offsite 2. Non-hazardous waste disposed of offsite	Tonnes or Litres	Site-specific estimate
	Materials	1. Water use 2. Other raw materials (minerals, cement, steel)	Tonnes or Litres	Site-specific estimate
	Land and Ecosystem	1. Environmental quality 2. Biota (animals and plants) and habitat 3. Soil fertility effects	Qualitative Qualitative Qualitative	Site-specific assessment

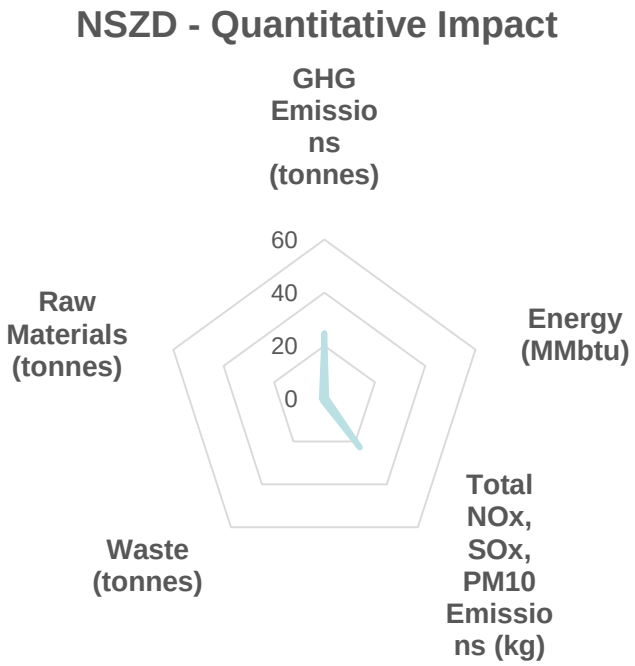
Indicator
GHG
Energy
Waste
Air Pollutant
Materials
Land and Ecosystem
Community
Safety
Time
Cost

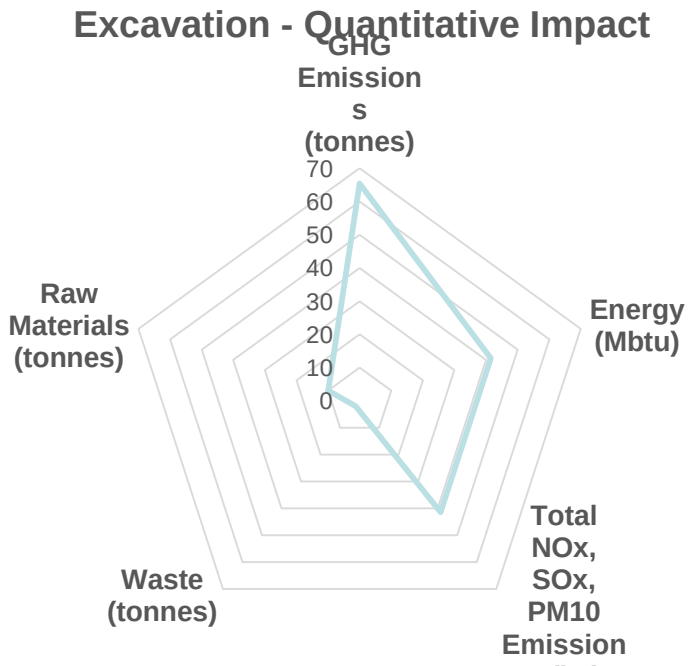
Toolkit 4: GSR Dashboard

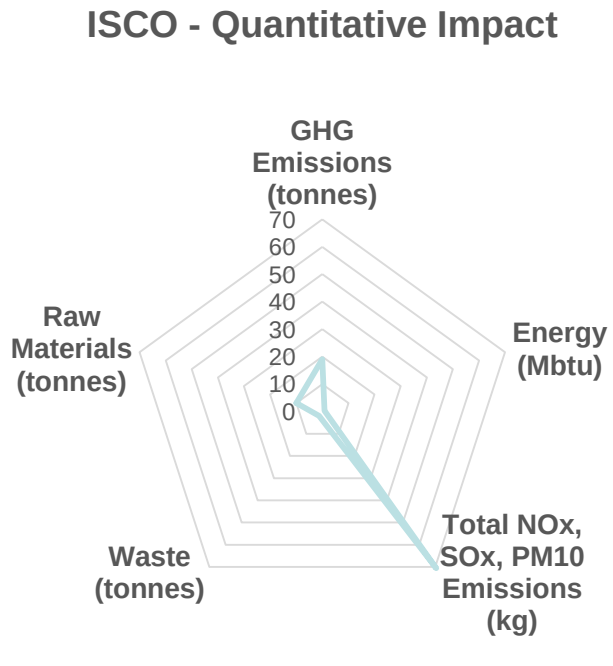
GSR DASHBOARD		
Indicator	**Metric**	**Measurement Unit**
Community	1. Revitalization (economic, social)	Qualitative
	2. Noise, dust, traffic, visual	Qualitative
	3. Land use access	Qualitative
Safety	1. Worker Safety On-site	Qualitative
	2. Public Safety Near-site	Qualitative
	3. Vehicle Accident Risk	Accidents per km
Time	1. Time of remediation	Years
Cost	1. Capital	$
	2. Operation & maintance	$ (NPV)

Toolkit 4: GSR Dashboard Footprint Example Output

Indicator
GHG
Energy
Waste
Air Pollutant
Materials







All options assume baseline LNAPL recovery option (skimming)

Toolkit 4: GSR Impact & MCA

Example indicator

COMPARISON OF FOOTPRINT & MCA FOR MULTIPLE					
Indicator (add/subtract as warrented)	**Metric**	**Measurement Unit**	**Impact Result**		
			NSZD	**ISCO**	**Excavation**
GHG	1. GHG Emissions (CO_2, CH_4, N_2O)	Tonne CO_2e	10	30	100

MCA							
Raw Score			**Scoring Rationale**	**Weight (3 high, 1 low)**	**Weighted Score = Raw Score x Weight**		
NSZD	**ISCO**	**Excavation**			**NSZD**	**ISCO**	**Excavation**
4	2	1	Describe rationale & uncertainty	3	12	6	3

Scoring System

- Qualitative Indicators: 5 = very positive impact, 4 = positive impact, 3 = neutral, 2 = negative impact, 1 = very negative impact
- Qualitative Scale: 5 = excellent, 4 = very good, 3 = good, 2 = fair, 1 = poor

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Toolkit 4: GSR Dashboard - Footprinter

DRAFT GSR DASHBOARD (*V1.0 - Golder Associates*) - Not for Distribution

GSR TOOL - FOOTPRINT IMPACT - CONSIDER LIFE CYCLE (INVESTIGATION - CONSTRUCTION (REMEDIATION) - OPERATION / MONITORING - DECOMMISSIONING)

TECHNOLOGY: LNAPL Recovery (skimming) followed by Natural Source Zone Depletion

Site: moderate sized source (50x100 m), 5000 m^3 contaminated soil; **Investigation:** 10 wells; **Construction (remediation):** 10 passive skimmers, 5 NSZD wells; **Operation/Monitoring**: Skimmers 2 yrs, NSZD 30 yrs total, 1st yr quarterly, annual monitoring for 5 yrs, every 5 yrs thereafter; **Decommissioning**: Abandon wells. 50 miles roundtrip to site from consultant/vendors/contractors

CATEGORIES		INFORMATION				ENERGY CONSUMPTION				GHG EMISSIONS				AIR EMISSIONS							
		Activity Data (AD)	Fuel Type (FT)[1]	Energy Efficiency (G) (can be site specific)		Energy Coefficient (E)		Efficiency Factor (EFF)	Energy Consumption (EC) EC = ADxGxExEFF	Emission Factor (EF)	Emission Factor Source (EF)	GHG Emissions (GHG) GHG = ADxGxL	e-equivalent i.e., includes CH_4,N_2O?	NOx Emission Factor		NOx Emission	SOx Emission Factor		SOx Emission	PM10 Emission Factor		PM10 Emission Factor
Mobile Sources - On Road (vehicles, light trucks)		mile		US gallon-fuel/mile		Btu/US gallon		unitless	MJ	kg CO_2/US gallon		tonne-CO_2		g-NOx/mile		kg-NOx	g-SOx/mile		kg-SOx	g-PM10/mile		kg-PM10
Investigation	*Install 10 wells, 2 days, light truck*	*100*	*Gasoline*	*0.05264465*	*1*	*10.633*		*1*	0.059	*9.005*	*2*	0.0474	e	*0.141*		0.0141	*0.005*		0.00050	*0.029*		0.00290
Investigation	*Soil & gw sampling, 3 days, light truck*	*150*	*Gasoline*	*0.05264465*	*1*	*10.633*		*1*	0.088	*9.005*	*2*	0.0711	e	*0.141*		0.0212	*0.005*		0.00075	*0.029*		0.00435
Construction (remediation)	*Install 5 NSZD wells/gas probes 1 day, light truck, monthly*	*1250*	*Gasoline*	*0.05264465*	*1*	*10.633*		*1*	0.735	*9.005*	*2*	0.5925	e	*0.141*		0.1763	*0.005*		0.00625	*0.029*		0.03625
Operation/Monitoring	*Quarterly 1st yr, annual for 5 yr, every 5 yr, 2 day event*	*1400*	*Gasoline*	*0.05264465*	*1*	*10.633*		*1*	0.823	*9.005*	*2*	0.6637	e	*0.141*		0.1974	*0.005*		0.00700	*0.029*		0.04060
Decommissioning	*Decommission 15 wells, 2 days, light truck*	*100*	*Gasoline*	*0.05264465*	*1*	*10.633*		*1*	0.059	*9.005*	*2*	0.0474	e	*0.141*		0.0141	*0.005*		0.00050	*0.029*		0.00290
Mobile Sources - On Road (heavy trucks)		mile		US gallon-fuel/mile		Btu/US gallon		unitless	MJ	g CO_2/mile		tonne-CO_2		g-NOx/mile		kg-NOx	g-SOx/mile		kg-SOx	g-PM10/mile		kg-PM10
Investigation	*Describe*	*Site specific*	*Site specific*	*SW T6b*		*SW T2a*		*1*			*SW T6b*			*SW T6b*			*SW T6b*			*SW T6b*		
Construction (remediation)	*Describe*	*Site specific*	*Site specific*	*SW T6b*		*SW T2a*		*1*			*SW T6b*			*SW T6b*			*SW T6b*			*SW T6b*		
Operation/Monitoring	*Describe*	*Site specific*	*Site specific*	*SW T6b*		*SW T2a*		*1*			*SW T6b*			*SW T6b*			*SW T6b*			*SW T6b*		
Decommissioning	*Describe*	*Site specific*	*Site specific*	*SW T6b*		*SW T2a*		*1*			*SW T6b*			*SW T6b*			*SW T6b*			*SW T6b*		
Mobile Sources - Off Road (excavators, dozers, etc)		hrs		US gallon-fuel/hrs		Btu/US gallon		unitless	MJ	g CO_2/hour		tonne-CO_2		g-NOx/hr		kg-NOx	g-SOx/hr		kg-SOx	g-PM10/hr		kg-PM10
Investigation	*Describe*	*Site specific*	*Site specific*	*SW T3b*		*SW T2a*		*SW T3a*			SW T3b			*SW T3b*			*SW T3b*			*SW T3b*		
Construction (remediation)	*Describe*	*Site specific*	*Site specific*	*SW T3b*		*SW T2a*		*SW T3a*			SW T3b			*SW T3b*			*SW T3b*			*SW T3b*		
Operation/Monitoring	*Describe*	*Site specific*	*Site specific*	*SW T3b*		*SW T2a*		*SW T3a*			SW T3b			*SW T3b*			*SW T3b*			*SW T3b*		
Decommissioning	*Describe*	*Site specific*	*Site specific*	*SW T3b*		*SW T2a*		*SW T3a*			SW T3b			*SW T3b*			*SW T3b*			*SW T3b*		
Stationary Sources - Fuel Combustion (drill rigs)		hrs		US gallon-fuel/hrs		Btu/US gallon		unitless	MJ	kg CO_2/US gallon		tonne-CO_2		g-NOx/gal		kg-NOx	g-SOx/hr		kg-SOx	g-PM10/hr		kg-PM10
Investigation	*Install 10 wells, 2 days, auger rig*	*20*	*Diesel*	*7.6*	*5*	*135847*	*6*	*1*	21681.181	*10.955*	*6*	1.6652	not e	*46.6*	*7*	7.0832	*2.1*	*7*	0.31920	*1.4*	*7*	0.21280
Construction (remediation)	*Install 5 wells, 1 day, auger rig*	*10*	*Diesel*	*7.6*	*5*	*135847*	*6*	*1*	10840.591	*10.955*	*6*	0.8326	not e	*46.6*	*7*	3.5416	*2.1*	*7*	0.15960	*1.4*	*7*	0.10640
Operation/Monitoring	*Describe*	*Site specific*	*Site specific*	*SW T3c*		*SW T2a*	*6*	*1*		*10.955*	*6*		not e	*46.6*	*7*		*2.1*	*7*		*1.4*	*7*	
Decommissioning	*Remove 15 wells, 2 days*	*20*	*Diesel*	*7.6*	*5*	*135847*	*6*	*1*	21681.181	*10.955*	*6*	1.6652	not e	*46.6*	*7*	7.0832	*2.1*	*7*	0.31920	*1.4*	*7*	0.21280
Stationary Sources - Fuel Combustion (generators, other)		hrs		US gallon-fuel/hrs		Btu/US gallon		unitless	MJ	g CO_2/hr		tonne-CO_2		g-NOx/hr		kg-NOx	g-SOx/hr		kg-SOx	g-PM10/hr		kg-PM10
Investigation	*Describe*	*Site specific*	*Site specific*	*SW T4b, T5, T6*		*SW T2a*		1			SW T4b, T5, T6			*SW T4b, T5, T6*			*SW T4b, T5, T6*			*SW T4b, T5, T6*		
Construction (remediation)	*Describe*	*Site specific*	*Site specific*	*SW T4b, T5, T6*		*SW T2a*		1			SW T4b, T5, T6			*SW T4b, T5, T6*			*SW T4b, T5, T6*			*SW T4b, T5, T6*		
Operation/Monitoring	*Describe*	*Site specific*	*Site specific*	*SW T4b, T5, T6*		*SW T2a*		1			SW T4b, T5, T6			*SW T4b, T5, T6*			*SW T4b, T5, T6*			*SW T4b, T5, T6*		
Decommissioning	*Describe*	*Site specific*	*Site specific*	*SW T4b, T5, T6*		*SW T2a*		1			SW T4b, T5, T6			*SW T4b, T5, T6*			*SW T4b, T5, T6*			*SW T4b, T5, T6*		
Stationary Sources - Electricity Use		hrs		KW		unitless		unitless	MJ	tonne-CO_2/GW-hr		tonne-CO_2										
Investigation	*Describe*	*Site specific*	*N/A*	*Site specific*		*1*		*1*			BC T3, SW T4a			*			*			*		
Construction (remediation)	*LNAPL skimming, 10 wells, 2-5 HP compressors, 2 y op's*	*17520*	*N/A*	*7.5*		*1*		*1*	473040.000	10.67	*8*	1.4020	e	*			*			*		
Operation/Monitoring	*Describe*	*Site specific*	*N/A*	*Site specific*		*1*		*1*			BC T3, SW T4a			*			*			*		
Decommissioning	*Describe*	*Site specific*	*N/A*	*Site specific*		*1*		*1*			BC T3, SW T4a			*			*			*		
Materials (well pipe, bentonite, sand, fill, cement, amendments)		kg		unitless		MJ/kg		unitless	MJ	kg-CO_2/kg		tonne-CO_2		g-NOx/kg		kg-NOx	g-SOx/kg		kg-SOx	g-PM10/kg		kg-PM10
Investigation	*Well pipe , 2 inc dia, 200 ft*	*65.5*	*N/A*	*1*		*67.5*	*9*	*1*	4418.182	*3.11*	*9*	0.2036	e	*6*	*9*	0.392727273	*9.7*	*9*	0.63491	*1.4*	*9*	0.09164
Investigation	*Bentonite*	*500*	*N/A*	*1*		*3*	*9*	*1*	1500.000	*0.22*	*9*	0.1100	e	*0.44*	*9*	0.22	*0.88*	*9*	0.44000	*0.176*	*9*	0.08800
Investigation	*Sand*	*500*	*N/A*	*1*		*0.1*	*9*	*1*	50.000	*0.005*	*9*	0.0025	e	*0.02*	*9*	0.01	*0.025*	*9*	0.01250	*0.01*	*9*	0.00500
Construction (remediation)	*Well pipe , 2 inc dia, 100 ft*	*32.72727273*	*N/A*	*1*		*67.5*	*9*	*1*	2209.091	*3.11*	*9*	0.1018	e	*6*	*9*	0.196363636	*9.7*	*9*	0.31745	*1.4*	*9*	0.04582
Construction (remediation)	*Bentonite*	*250*	*N/A*	*1*		*3*	*9*	*1*	750.000	*0.22*	*9*	0.0550	e	*0.44*	*9*	0.11	*0.88*	*9*	0.22000	*0.176*	*9*	0.04400
Construction (remediation)	*Sand*	*250*	*N/A*	*1*		*0.1*	*9*	*1*	25.000	*0.005*	*9*	0.0013	e	*0.02*	*9*	0.005	*0.025*	*9*	0.00625	*0.01*	*9*	0.00250
Waste Water Treatment		US gallons		unitless		Btu/US gallon		*unitless*	MJ	kg CO_2/US gallon		tonne-CO_2		g-NOx/USGal		kg-NOx	g-SOx/USGal		kg-SOx	g-PM10/USGal		kg-PM10
Investigation	*Describe*	*Site specific*	*N/A*	*1*		*SW T7d*		*1*			SW T7d			*SW T7d*			*SW T7d*			*SW T7d*		
Construction (remediation)	*Describe*	*Site specific*	*N/A*	*1*		*SW T7d*		*1*			SW T7d			*SW T7d*			*SW T7d*			*SW T7d*		
Operation/Monitoring	*Describe*	*Site specific*	*N/A*	*1*		*SW T7d*		*1*			SW T7d			*SW T7d*			*SW T7d*			*SW T7d*		
Decommissioning	*Describe*	*Site specific*	*N/A*	*1*		*SW T7d*		*1*			SW T7d			*SW T7d*			*SW T7d*			*SW T7d*		
Laboratory Analyses		$		unitless		Btu/$		unitless	MJ	kg-CO_2/$		tonne-CO_2		g-NOx/$		kg-NOx	g-SOx/$		kg-SOx	g-PM10/$		kg-PM10
Investigation	*Soil and groundwater investigation*	*6000*	*N/A*	*1*		*6490*	*10*	*1*	40887.000	*0.455*	*10*	2.7273	e	*0.0048*	*10*	0.0288	*0.0036*	*10*	0.02160	*0.0004*	*10*	0.00240
Construction (remediation)	*Additional NSZD testing*	*4000*	*N/A*	*1*		*6490*	*10*	*1*	27258.000	*0.455*	*10*	1.8182	e	*0.0048*	*10*	0.0192	*0.0036*	*10*	0.01440	*0.0004*	*10*	0.00160
Operation/Monitoring	*14 events x $2,000/event*	*28000*	*N/A*	*1*		*6490*	*10*	*1*	190806.000	*0.455*	*10*	12.7273	e	*0.0048*	*10*	0.1344	*0.0036*	*10*	0.10080	*0.0004*	*10*	0.01120
Decommissioning	*Describe*	*Site specific*	*N/A*	*1*		*SW T7e*		*1*			SW T7e			*SW T7e*			*SW T7e*			*SW T7e*		
								Total	**795147.989**	**Total**		**24.7339**		**Total**		**19.2475**	**Total**		**2.58**	**Total**		**0.91**
								Total (MMJ)	**0.80**	**Total (tonnes)**		**25**		**Total NOx, SOx, PM10 (kg)**								**22.7396**

Data Sources

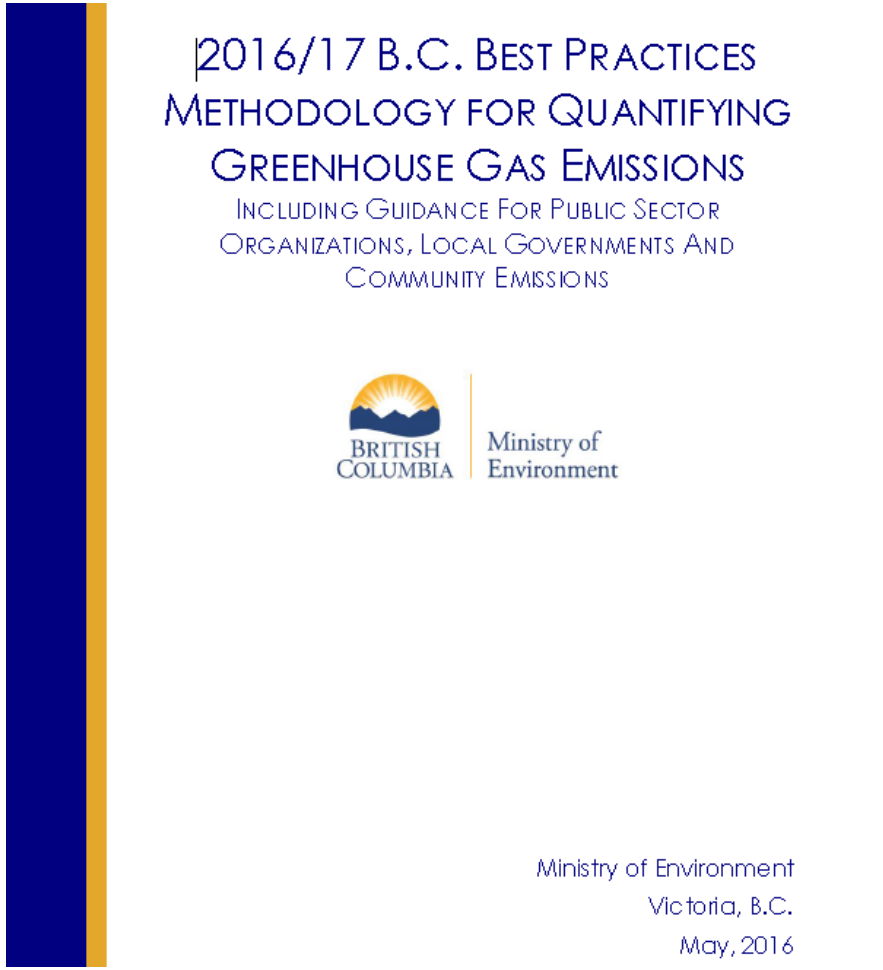
1. BC MoE (2016) Table 10

The laboratory CO2 emission rate is under review as it appears to be too high

Golder Associates

Toolkit 4: GSR Dashboard - Summary

- The GSR Dashboard, is a new tool provides a structured approach to conducting footprint evaluations based on environmental, social and economic indicators.
  - Impact information sources,
  - Footprint impact summary
  - MCA calculator based on indicator weighting /scoring scheme
- Footprinter tool enables GHG emissions, energy use and air emissions to be quantified based on a life cycle approach, which includes BC specific defaults
- Footprinter analysis is implemented in a workbook format that is practical, transparent and focuses on key metrics
- Dashboard integrates the three pillars of sustainability, a footprint analysis and option for MCA in a flexible approach found in few other tools.



Toolkits: Next Steps

- Toolkits 3 and 4 are currently being reviewed – anticipated release in early 2018
- Additional aspects considered for development
  - GSR Dashboard
  - Show case of best in practice technology case studies for greening of remediation
  - Technology factsheets

Parisa Jourabchi
pjourabchi@golder.com

Ian Hers
ihers@golder.com

Francois Beaudoin
fbeaudoin@golder.com