“Greening” Remediation - the Life-Cycle Approach

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Vision

Not to have “green” cleanups

To protect human health and the environment!

Goal- Reduce the overall impact of cleanups

To do this, we need to be comprehensive

-> Life-cycle perspective <-

Purpose

Considering sustainable principles or even “green”; how can we tell if we are doing things better (or if we are actually doing more harm than good)?

Describe the value of life-cycle perspective and Life Cycle Assessment (LCA) as a tool for evaluating and improving Remediation

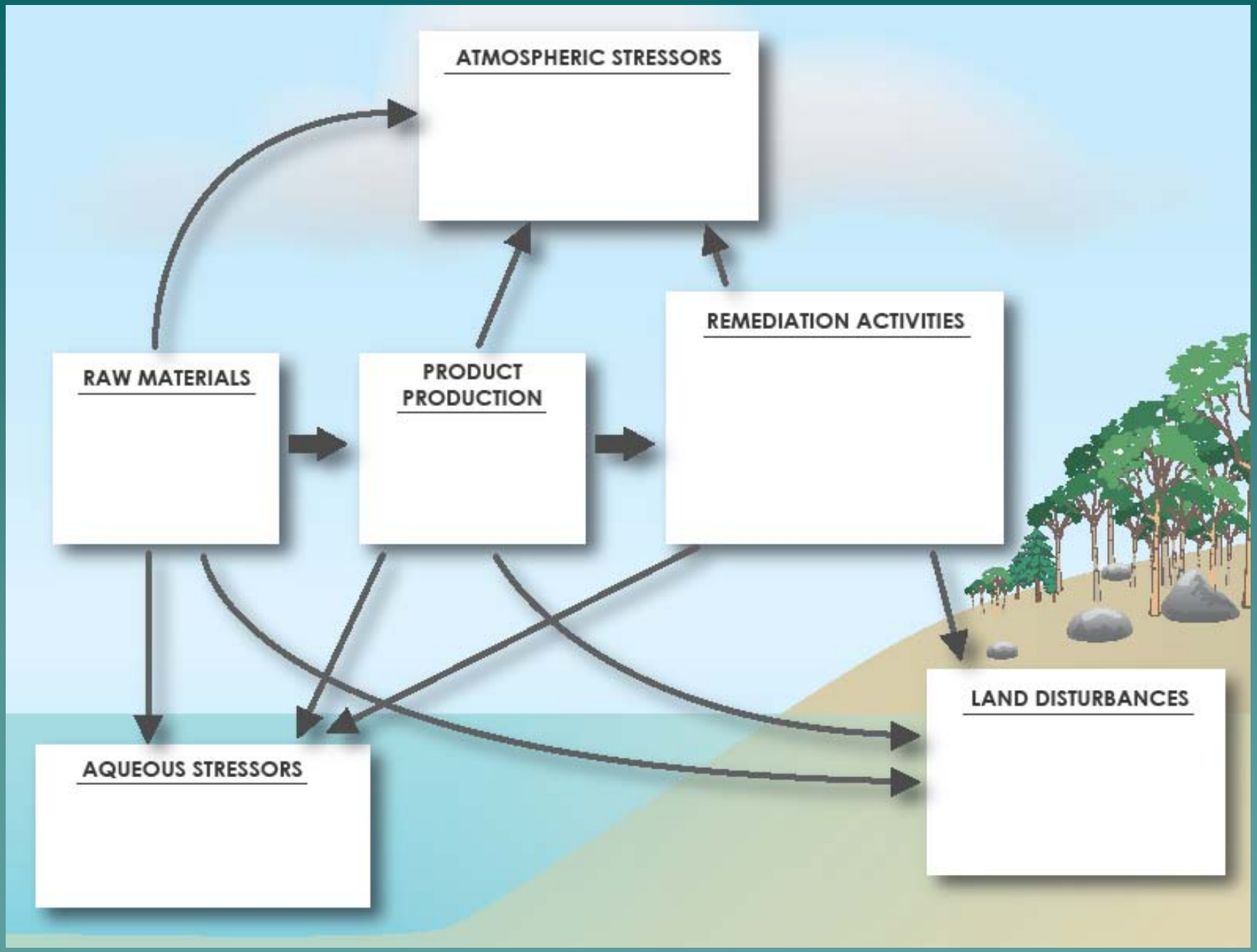
Why a Life Cycle Approach?

- Comprehensive -includes a breadth of environmental burdens; cradle to grave
- Accounts for temporal, spatial, and media shifts; includes “externalities” = ecosystem services
- Broader information for decision making
- Inform consumers, industry, and government on the environmental tradeoffs of products, activities or alternatives

Life Cycle Thinking

As applied to remediation, life-cycle thinking includes impacts outside the “fence line”:

- the origin of materials and energy resources consumed
- the destination of the wastes produced
- as well as the externalities


ATMOSPHERIC STRESSORS
RAW MATERIALS
PRODUCT PRODUCTION
REMEDIATION ACTIVITIES
AQUEOUS STRESSORS
LAND DISTURBANCES

Screening Framework

Table 2-4 Potential Impacts Checklist

Stressors	*Potential Impacts*	*Priority/Level of Concern*		
		Low	Medium	High
Pollution				
◦ acid emissions (e.g., SO_2, HCl, NO_x, particulates)	→ acid rain			
◦ greenhouse gases (e.g., CO_2, CFCs, methane, methyl chloride)	→ global warming			
◦ ozone precursors (e.g., CFCs, CO, methyl furan, methyl chloride)	→ ozone depletion			
◦ photochemical fog precursors and air polluters (e.g., VOCs, semi-volatile compound, PAHs, NO_x, SO_x, particulates)	→ air pollution			
◦ nutrients (C, N, P)	→ eutrophication			
◦ chemical changes to water quality (e.g., TSS)	→ stress on aquatic species			
◦ chemical changes to soil quality (e.g., nutrient levels, organic content, pH)	→ soil quality disturbances			
◦ toxic compounds in ground and surface water	→ groundwater impacts (ecotoxicity) → human health impairment (toxic effects)			
◦ toxic compounds in soil	→ soil impacts (ecotoxicity) → human health impairment (toxic effects)			
◦ toxic compounds and particulates in air	→ airborne transport to other media (ecotoxicity) → human health impairment (toxic effects)			
Disturbance				
◦ heat discharge	→ heat damage/dispersion of heat			
◦ land fragmentation	→ habitat alteration			
◦ non-remediation of land	→ land stagnation			
◦ construction, excavation	→ habitat destruction/ alteration			
◦ compaction, paving, or application of an impervious soil coverage	→ effects on soil moisture, aquifer recharge, ecosystem regeneration			

- Each stressor paired with a corresponding impact
- 'Screening level' evaluation can be performed to determine need for additional analysis or to alert a concern
- Total of impacts can help with selection or improvement actions

Metrics for Remediation

Energy consumption and climate change are of growing interest, we should leverage this effort.

Should we consider other factors?

- Air particulate emissions
- Natural resource consumption
- Acidification/ Eutrophication
- Photochemical smog formation
- Human health effects

How do we manage them?

LCA

LCA offers a method for performing an integrated interpretation of impacts

- for remedy selection
- to identify what to improve
- to provide benchmarking and targets for improvement, and measurement
- to integrate benefits of cleanups and re-use

Life-Cycle Assessment - Overview

- A standardized tool for evaluating the overall impacts of a product *or activity* throughout its lifecycle
- Theoretically, can account for all inputs and outputs for a complete system (including background processes and services)
- Results are related to a suite of impact characteristics (including the commons)

History of LCA

- 1960's: Growing concerns over stocks of raw materials and energy resources.
- 1970's: Quantify resource use and environmental releases of products and alternatives to land disposal
- 1990's:
  - Society of Environmental Toxicology and Chemistry (SETAC) builds consensus on methodology
  - ISO develops LCA standards (14040-43 Environmental Management - Life Cycle Assessment)
  - Development of TRACI – USEPA's LCA tool

Elements of LCA

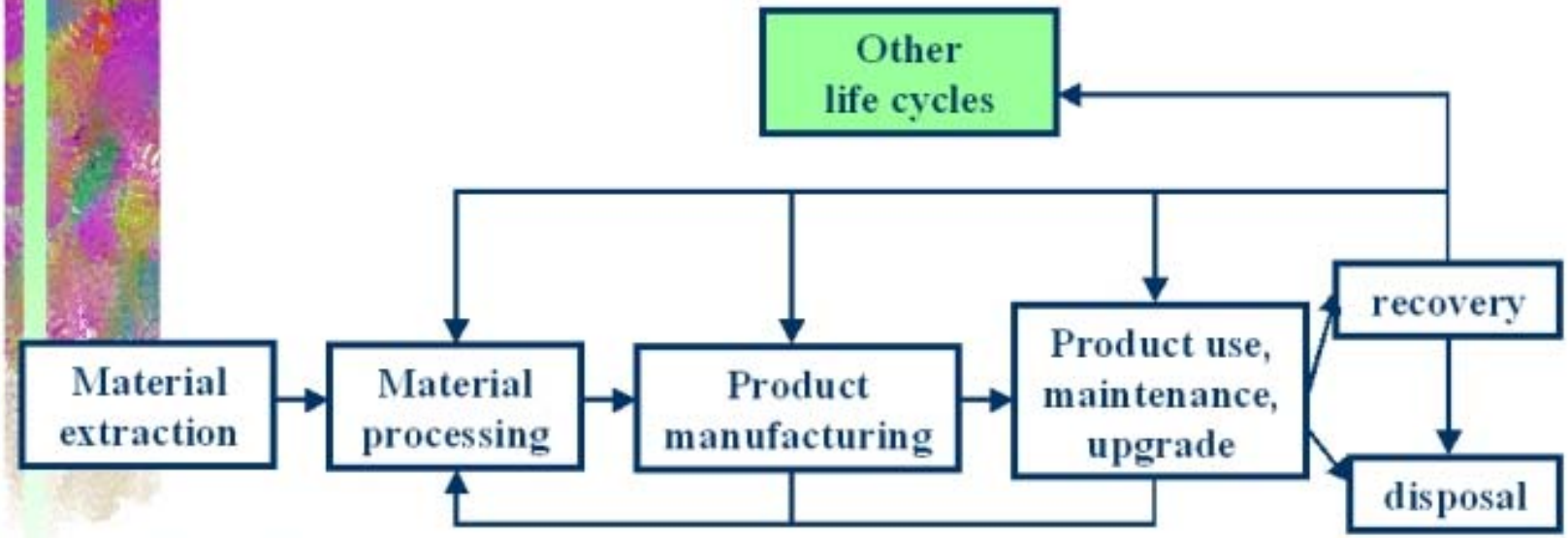
i. Define the Product Life Cycle
ii. Gather Input and Output Data
iii. Create Inventory of Data
iv. Characterize Impacts
v. Interpret results

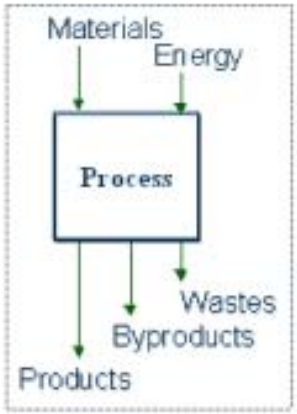
Define the Life Cycle

Remediation Project Life Cycle Stages

- Raw materials production
- Intermediate product manufacture
- Energy/fuels production
- Site processes
- Waste management
- Transportation and energy use included at each stage

Defining the Product Life Cycle





Assessment Questions:

Why? What? Who? Where? How? When?

With what environmental implications?

At what cost?

What opportunities exist for partnerships, elimination of toxics, material recovery, …..?

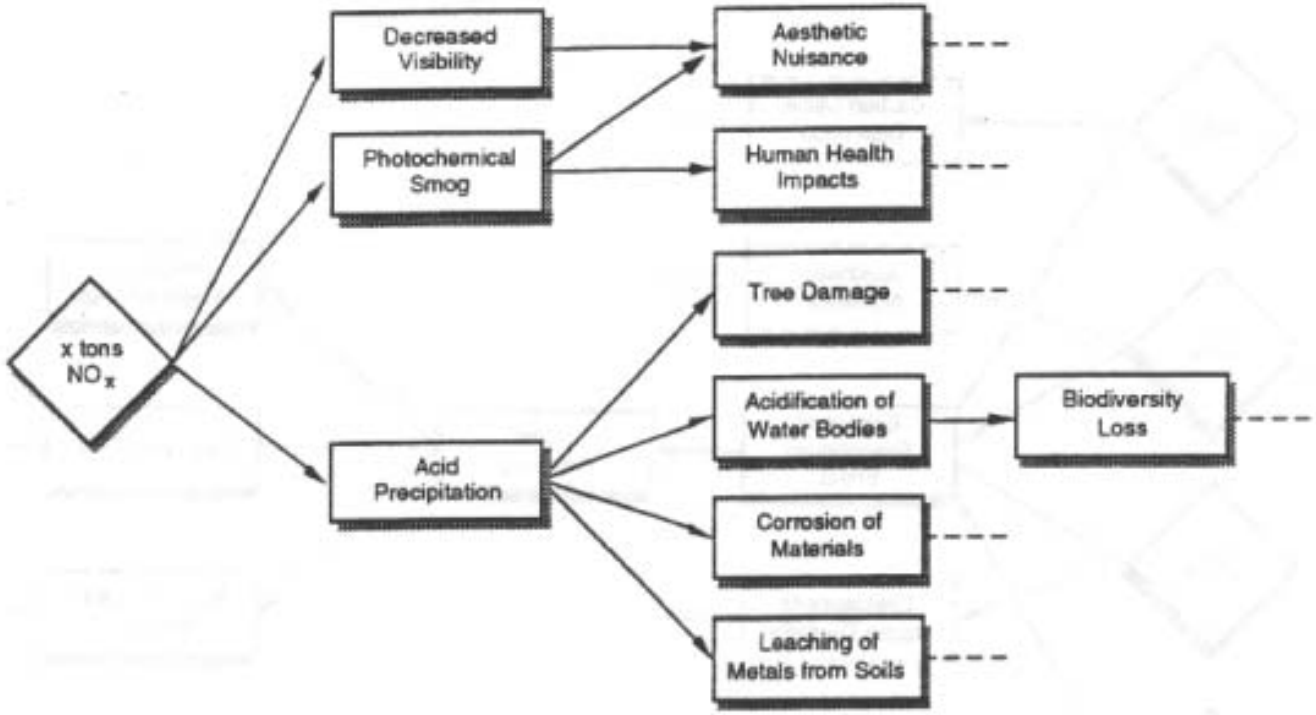
Table 4-36 Summary of life-cycle inventory data by life-cycle stage

Stressor Category	*Stressor*	LIFE-CYCLE STAGES *Raw Materials Acquisition*	*Site Processing*	*Waste Management*	*Transportation*
Pollution					
Acid Emissions / Photochemical Smog Precursors	NO_x (kg)	3 120	2 950	-	20 700
	SO_2 (kg)	800	776	-	5 545
	particulates (kg)	285	276	-	1 951
	VOC (kg)	615	597	-	3902
Greenhouse Gases	CO_2 (kg)	334 000	265 000	-	1 884 000
	C_xH_y (kg)	270	240	-	1 284
	CO (kg)	7 260	7 040	-	50 400
	NO_x (kg)*	3 120	2 950	-	20 700
Contaminants / Particulates to Air	coarse dust (kg)	-	1 400	-	-
	lead (kg)	-	3 57	-	-
Contaminants in Surface and Groundwater	fluorine (kg)	-	-	4 51	-
	silver (kg)	-	-	0 05	-
	aluminum (kg)	-	-	116	-
	arsenic (kg)	-	-	5.81	-
	cadmium (kg)	-	-	1.60	-
	chromium (kg)	-	-	0.40	-
	copper (kg)	-	-	13.5	-
	iron (kg)	-	-	550	-
	lead (kg)	-	-	91 1	-
	phosphorus (kg)	-	-	6.11	-
	zinc (kg)	-	-	13.0	-
	BOD (kg)	-	-	60.0	-
	TSS (kg)	-	-	4530	-
Disturbance					
Non-Remediated Land	contaminated land (m^2)	-	4127	-	-
Application of impervious surface	capped land (m^2)	-	2 500	-	-
Aquifer quality stressors	groundwater (kg)	-	-	8 000 000	-
Depletion					
Fossil Fuel Use / Energy Consumption	diesel (GJ)	3560	3450	-	16 700
	oil (GJ)	85.4	-	-	-
	natural gas (GJ)	11.5	-	-	-
	coal (GJ)	0.814	-	-	-
	nuclear (GJ)	1.64	-	-	-
	hydro (GJ)	0.357	-	-	-
	precombustion (GJ)	401	380	-	1 831
	other fuel (GJ)	-	1.05	-	-
	coal (raw material) (kg)	300 000	-	-	-
	crude oil (raw material) (kg)	26 100	-	-	-
Solid Waste	non-hazardous soil (kg)	-	-	12 400 000	-
	hazardous soil (kg)	-	-	50 380 000	-
	hazardous sludge (kg)	-	-	95 000	-
	hazardous water (kg)	-	-	108 000	-
	mineral waste (kg)	215	169	-	6 244
	ash (kg)	207	192	-	1 030
	inert chemicals / industrial waste (kg)	42.9	36 8	-	197
	drillings / cuttings (kg)	36.3	-	-	-
Water Use	water (kg)	195	-	3 430 000	-
Mineral / Soil Use	aggregate (kg)	235 000	-	-	-
	clean soil (kg)	67 500 000	-	-	-
	limestone (kg)	1 080	-	-	-

* Listed again for illustrative purposes.

Impact Classification: assigning of inventory data to impact categories

First, qualitatively associate, or link, inventory items with subsequent impacts.



From Research Triangle Institute, 1999, *Life Cycle Impact Assessment: A Conceptual Framework, Key Issues, and a Summary of Existing Methods.*

Characterization: modeling of the inventory data within impact categories

- Use of Impact Potentials
  - global warming potential (kg CO_2 eqv.)
  - photochemical smog potentials (kg C_2H_4-eqv.)
  - acidification potentials (kg SO_2- eqv.)
  - eutrophication potentials (kg NO_3- eqv.)
  - toxicity potentials (???)

Interpret Results

- Perform comparative review of impacts and determine course of action.

- Considering trade-offs, interpretation depends largely on the value system, eg

  - Value human health over economic gain?
  - Value short-term benefits over long-term benefits?

LCA CASE STUDIES
Remediation

Cadotte, et al, J LCA 12(4) 2007

"Selection of a Remediation scenario for a Diesel Contaminated Site using LCA"

- A well-documented paper addressing specific contaminants and remedies
- Compared 4 in-situ and ex-situ scenarios to remove LNAPL and to treat soil and groundwater
  - 10,000 ppm diesel in soil
  - 0.1 to1-m thick layer of LNAPL on groundwater
  - Residual contamination in soil and groundwater
- Remediation Goal: Reduce diesel to 700ppm in soil and 0.1mg/l in waters

Technologies Considered

1. LNAPL Removal
   - Pumping
   - Bioslurping
2. Soil Treatment
   - Natural Attenuation
   - Bioventing
   - Excavation and On-Site Biopiles
3. Groundwater Treatment
   - Pump & Treat
   - Biosparging
   - Chemical Oxidation
   - Natural Attenuation

Analysis and Interpretation

- Classification and characterization of impacts performed using USEPA's TRACI method.
- Then, impacts were 'normalized' to roll primary (short-term) and secondary (long-term) impacts into one value that could be compared.
- "Normalization" performed using Impact 2000+ method…

Results

Scenario	Remedy Description	Remedy Duration	Normalized "Impacts"
1	◆ Oil Removal (pumping) ◆ Natural Attenuation ◆ Pump and Treat	302 yrs	
2	◆ Biosparging (oil removal) ◆ Bioventing ◆ Biosparging	38 yrs	
3	◆ Bioslurping (oil removal) ◆ Bioventing ◆ Chemical Oxidation	11 yrs	
4	◆ Bioslurping (oil removal) ◆ Excavation ◆ Biopiles	8 yrs	

Results

Scenario	Remedy Description	Remedy Duration	Normalized Primary and Secondary "Impacts"
1	◆ Oil Removal (pumping) ◆ Natural Attenuation ◆ Pump and Treat	302 yrs	116
2	◆ Biosparging (oil removal) ◆ Bioventing ◆ Biosparging	38 yrs	8
3	◆ Bioslurping (oil removal) ◆ Bioventing ◆ Chemical Oxidation	11 yrs	20
4	◆ Bioslurping (oil removal) ◆ Excavation ◆ Biopiles	8 yrs	28

Cadotte: Findings Relative to "Greening" Remediation

- The greatest impacts resulted from– resource acquisition, transportation, processing
- Some impacts not well quantified – land use/stagnation, residual waste, habitat alteration
- Low-impact remedies require time, fast remedies have high impacts but for a short time.
- LCA results help to inform remedy selection

Canadian Framework

- LC thinking screening matrix developed specifically for remediation
- Before their time- 1998
- Explored full LCA on 6 specific options

Environmental Toxicology and Chemistry, v 18, n 4, pp788-800 and 801-810

Conclusion

Goal- to protect human health and the environment

It is especially important to understand and minimize remediation impacts with the life-cycle perspective in mind

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