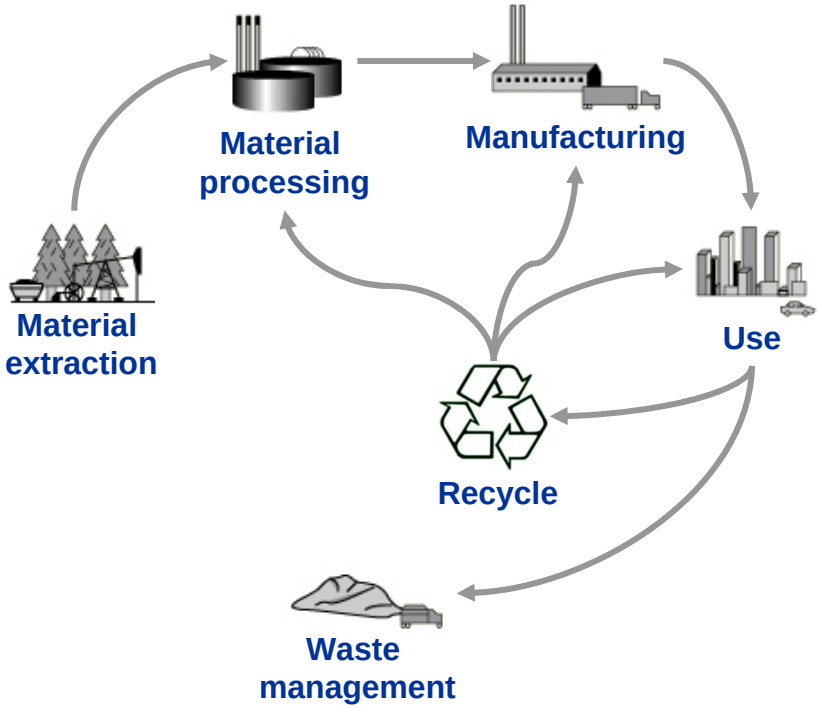
Life Cycle Assessment of an In Situ Chemical Oxidation Remedy

Angela Fisher

Sustainable Remediation 2011

Life Cycle Assessment (LCA)

Assess overall environmental impact throughout a product, process, or system's life cycle:



Quantify ins & outs

Energy
Materials
Emissions

- Fossil Fuels
- Hazardous Wastes
- Minerals
- Land Use
- Climate Change
- Ozone depletion
- Respiratory Organics
- Resp. Inorganics
- Radiation
- Acidification
- Eutrophication
- Ecotoxicity

•Carbon footprint is a subset of LCA

… including packaging and transportation

ISO guidelines 14040-44

In Situ Chemical Oxidation LCA

A Life Cycle Assessment (LCA) was performed on an in situ chemical oxidation implementation to understand where the environmental impacts from this technology arise and to identify potential impact-reduction strategies for future ISCO implementations.

- Retrospective analysis
- ISCO stage of overall site remedy included in analysis
- Objective: educational exercise to assess environmental impacts of one remedial technology

Site Clean Up Plan (two-stages):
1.Reduce VOC source mass via ISCO
2 Polish with enhanced bio

Scope & Functional Unit

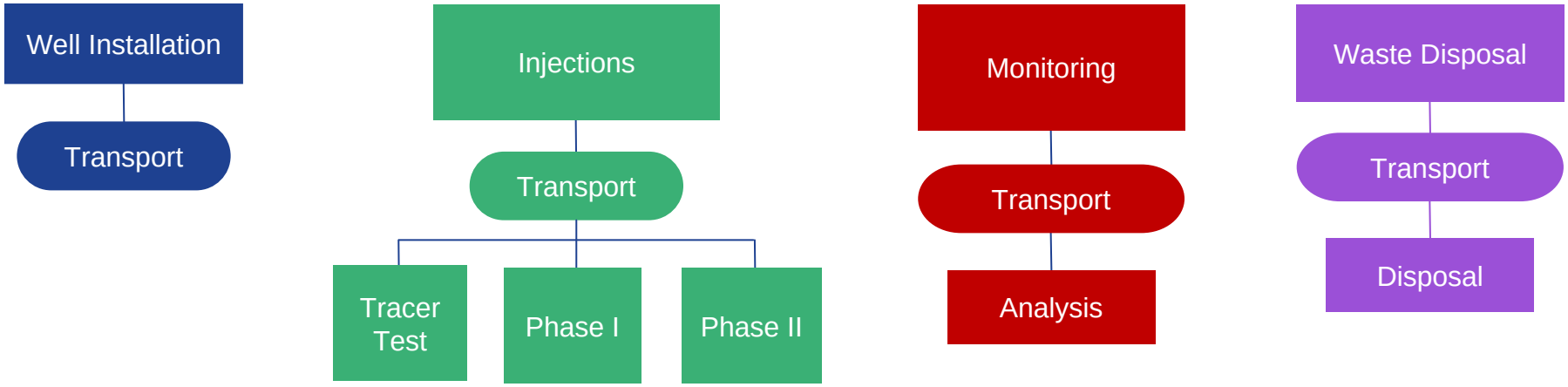
- Goal & Scope
  - To understand the broad range of environmental impacts (including carbon footprint) resulting from the implementation of the ISCO stage of the site remedy

- Functional Unit
  - The reduction of ~90% of the VOC contaminant mass in the source zone via $KMnO_4$ injection

ISCO Boundary

- Activities included (over ~1.5 years)
  - Soil Borings/Characterization (field screening)
  - Injection Well Installation & Development
  - Baseline Sampling
  - Tracer Test (organic dyes)
  - Phase I Injection ($KMnO_4$)
  - Phase II Injection ($KMnO_4$)
  - Performance Monitoring
- Activities not included (pre- or post- ISCO stage)
  - Initial Site Characterization
  - Monitoring Well Installation
  - Polishing Treatment (Stage 2: enhanced bio)
  - Long Term Monitoring
  - Site Closure & Reuse

ISCO LCA Process Map



Inputs for Well Installation

- Materials:
  - sand
  - bentonite
  - PVC
  - concrete

- Fuel Use:
  - drill rig (transport & operation)
  - drill team travel
  - consultant travel

materials & fuels modeled 'cradle-to-gate'

Inputs for Injections

- Tracer Test:
  - tracer dyes
  - mixing tanks
  - PVC pipes
  - hoses
  - water
  - diesel (generator)
  - transport (materials)
  - transport (equipment)
  - transport (consultants)
- Phase I:
  - oxidant
  - water
  - transport (oxidant)
  - transport (consultants)
- Phase II:
  - oxidant
  - water (consultants)
  - transport (oxidant)
  - transport

materials & fuels modeled 'cradle-to-gate'

Inputs for Monitoring

- Laboratory Analyses:
  - chemicals
  - water
  - electricity (equipment & office/reporting)

- Fuel Use:
  - subcontractor travel
  - sample transport

Materials, electricity & fuels modeled 'cradle-to-gate'

Inputs for Waste Disposal

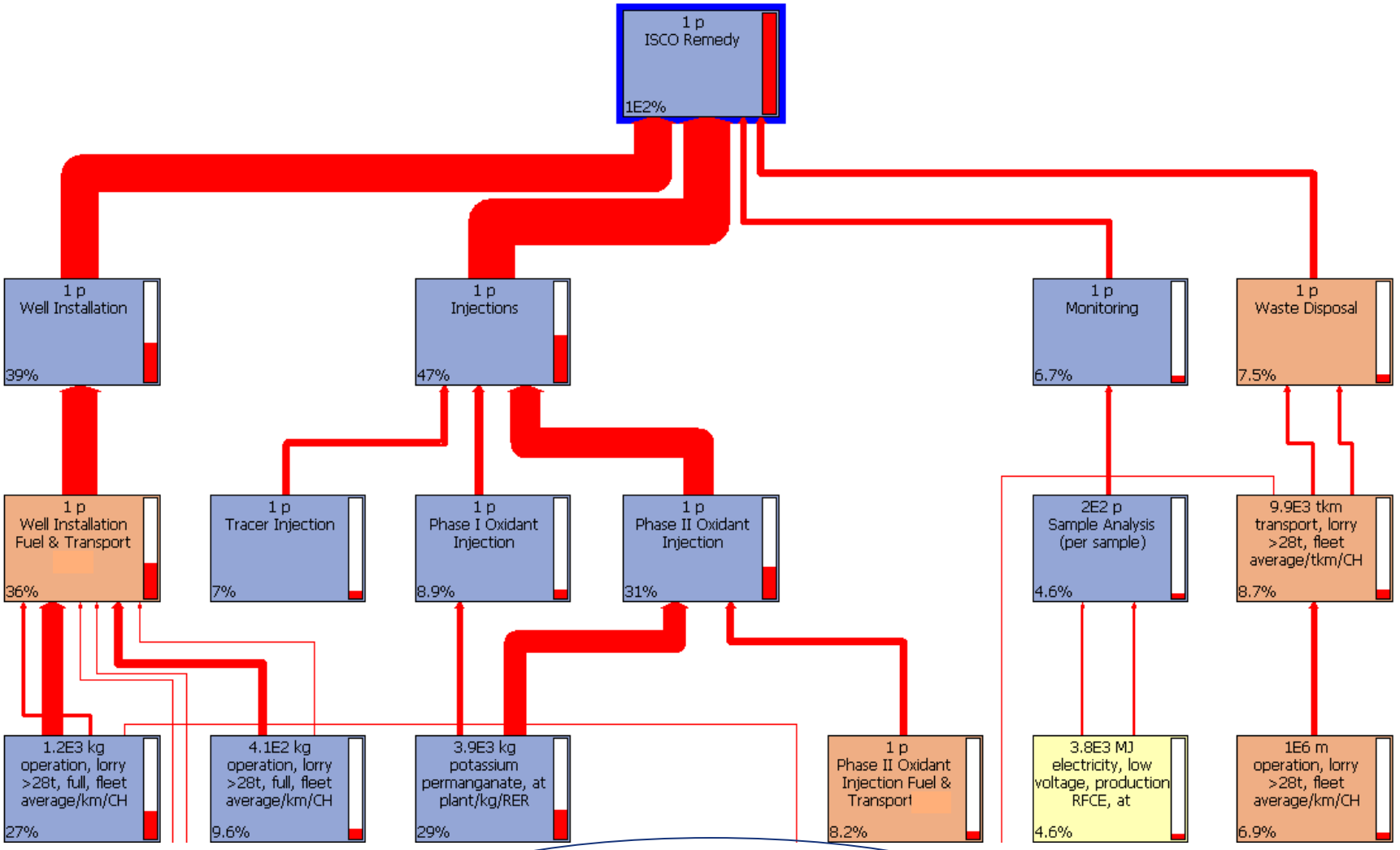
- Fuel Use:
  - waste transport to disposal
- Disposal:
  - landfill
  - incinerator
  - WWTP
  - recycling

Wastes: investigation derived wastes, soil cuttings, well development water, etc

Data Sources

- Remedy Installation Report:
  - material types and quantities
  - equipment used & duration
  - transport distances and frequencies
  - sample analysis quantities and frequencies
- Ecoinvent 2.2 & US LCI Databases:
  - materials
  - fuel production/combustion
  - electricity grid mixes
  - waste transport & disposal
- Vendors:
    - manufacturing & distribution locations (for grid mix and transport distances)
- Estimations:
    - equipment fuel consumption rate (EPA NONROAD2008a Model)
    - analytical laboratory electricity consumption rates

Sima Pro Network Diagram



LCA can identify areas that are most impactful & where to gather more/better data

- Thickness of connector lines indicates relative contribution to impacts

Interpreting the Inventory Data

- Materials and processes have environmental emissions or impacts to one or many areas of concern to human health and the environment.

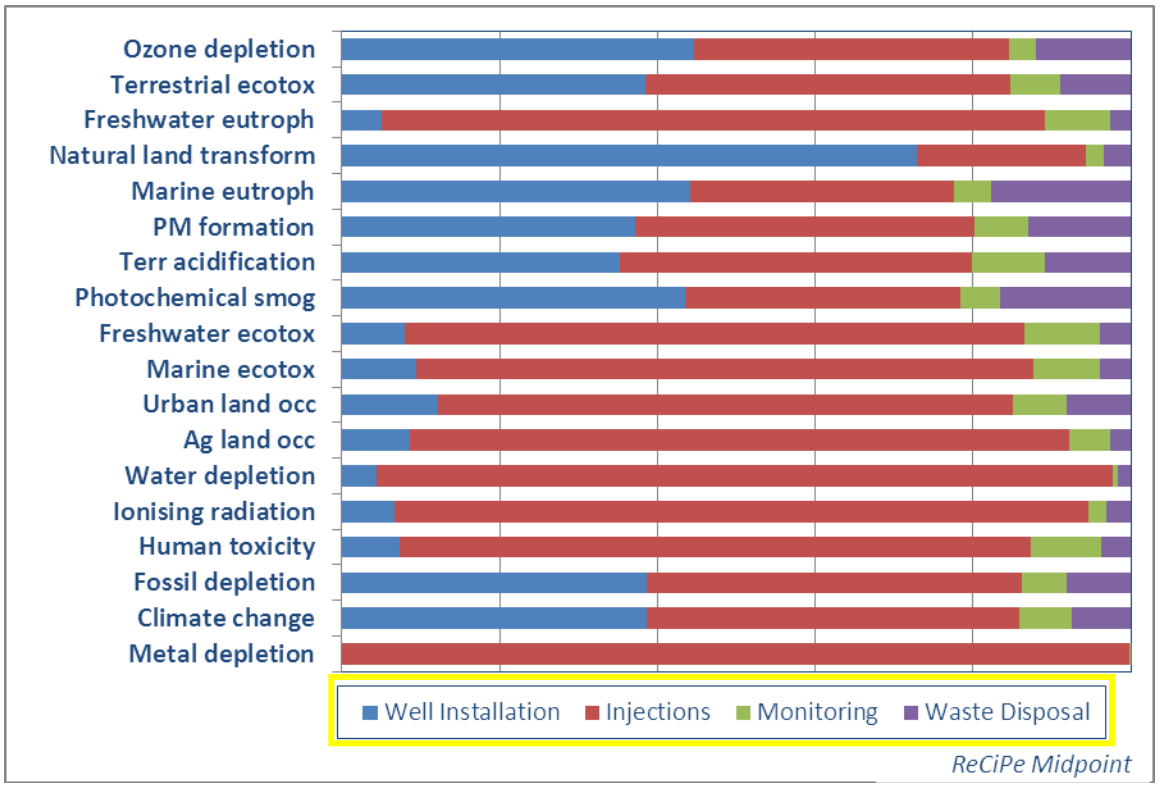
- LCA tools assign (and quantify) the inventory data into impact categories via characterization

- For example, CO_2, methane, and N_2O all contribute to climate change and are all converted into common units (CO_2 eq) and assigned to the global warming impact category.

TRACI Impact Assessment Method	
midpoint category	common unit
Ozone depletion	kg CFC-11 eq
Global warming	kg CO2 eq
Smog formation	g NOx eq
Acidification	H+ moles eq
Eutrophication	kg N eq
Carcinogens	kg benzeen eq
Non-carcinogens	kg toluene eq
Respiratory effects	kg PM2.5 eq
Ecotoxicity	kg 2,4-D eq

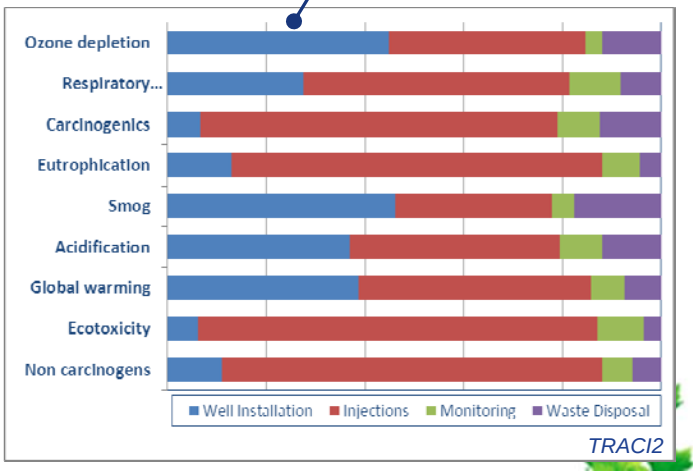
Environmental impacts cannot be compared to one another, since each impact category has separate units. However, normalization methods are available that can provide a relative basis of comparison.

ReCiPe Results



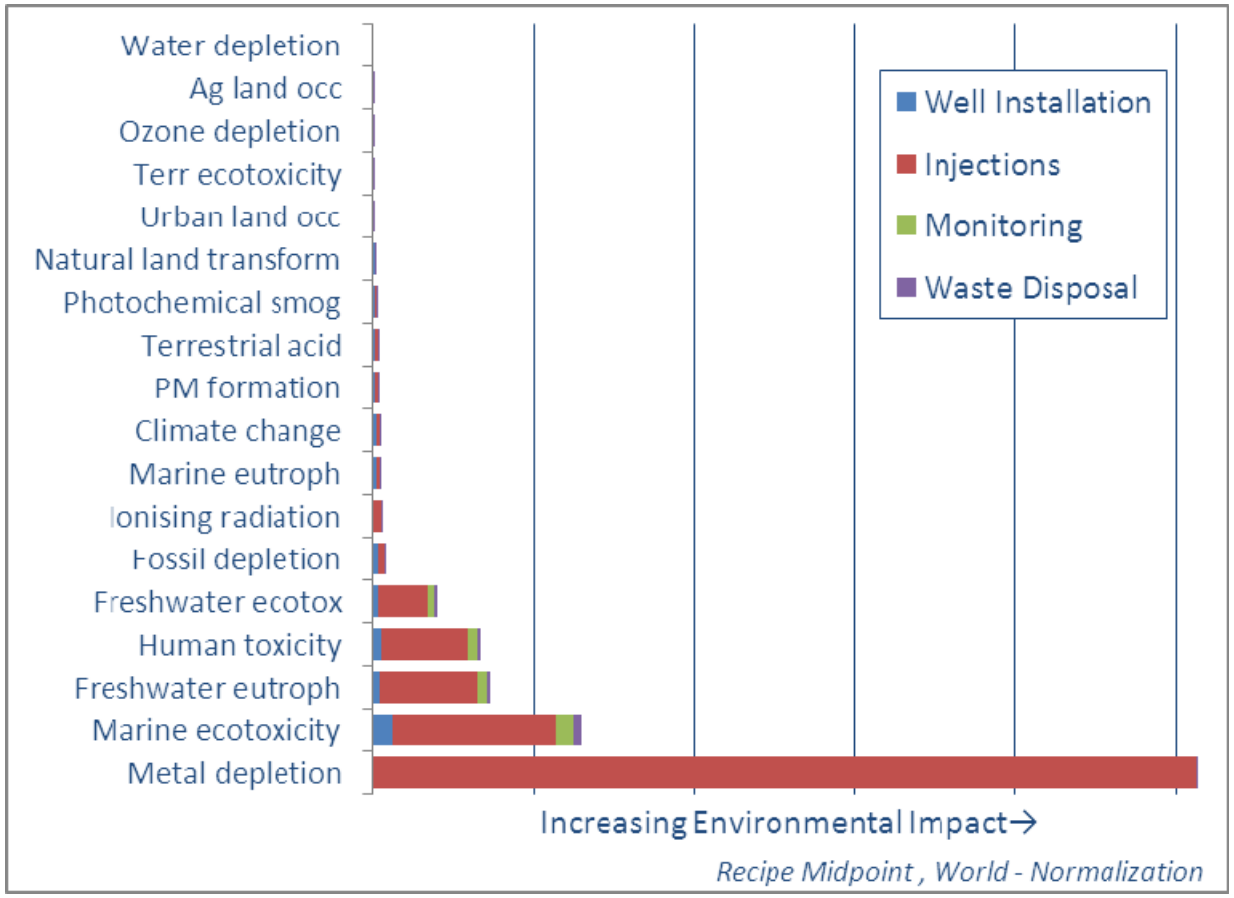
- Plot shows relative contribution of each life cycle stage to each impact category
- Across most impact categories, injection stage dominates emissions.

TRACI results for Impact Assessment method verification



GE imagination at work

Results by Life Cycle Stage



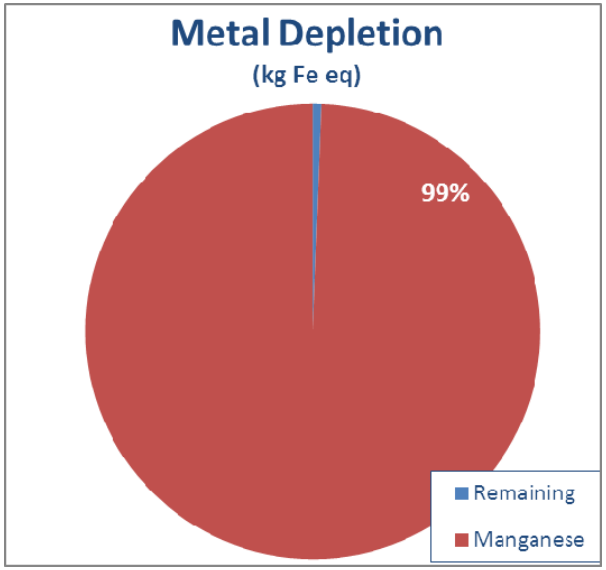
- Metal Depletion, Marine & Freshwater Ecotoxicity, Freshwater Eutrophication, and Human Toxicity categories dominate impacts

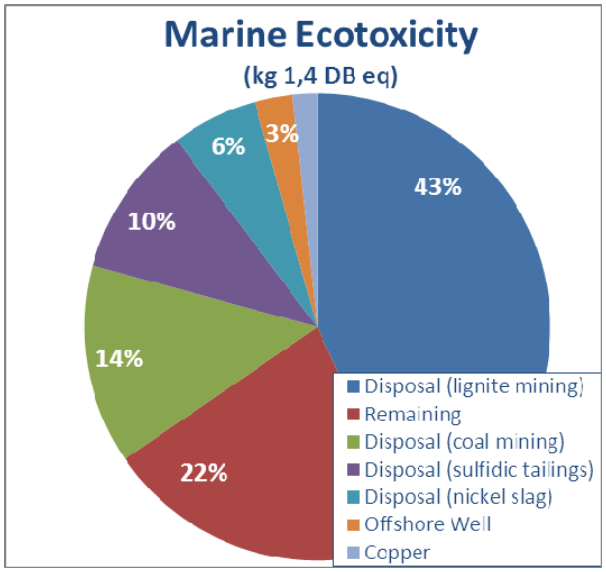
GE imagination at work

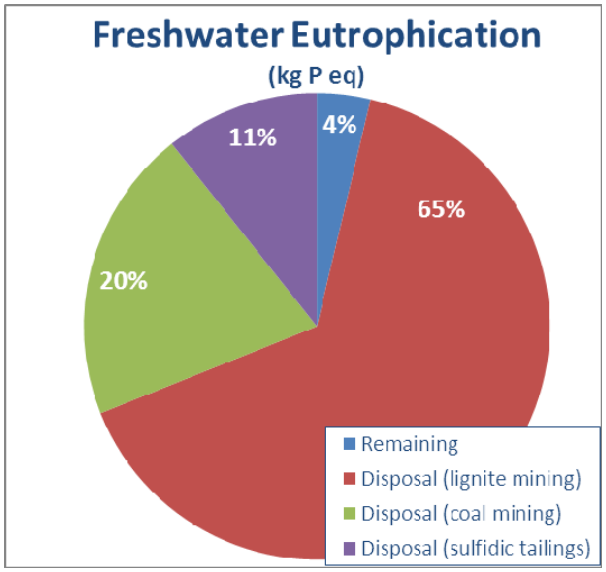
ReCiPe normalization factors are 'per substance' and impact category and based on emissions from the year 2000 from the world (Europe + USA + China).

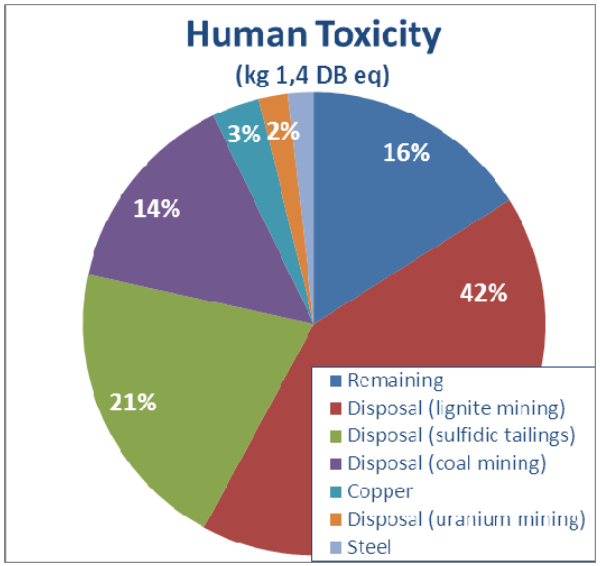
Results by Impact Category

- LCA can show the materials & processes contributing to the environmental impacts within each category
- Majority of impacts related to mining activities & disposal
- Mining activities are not just related to the oxidant; other materials, chemicals, electricity production, fuel production, etc require mining



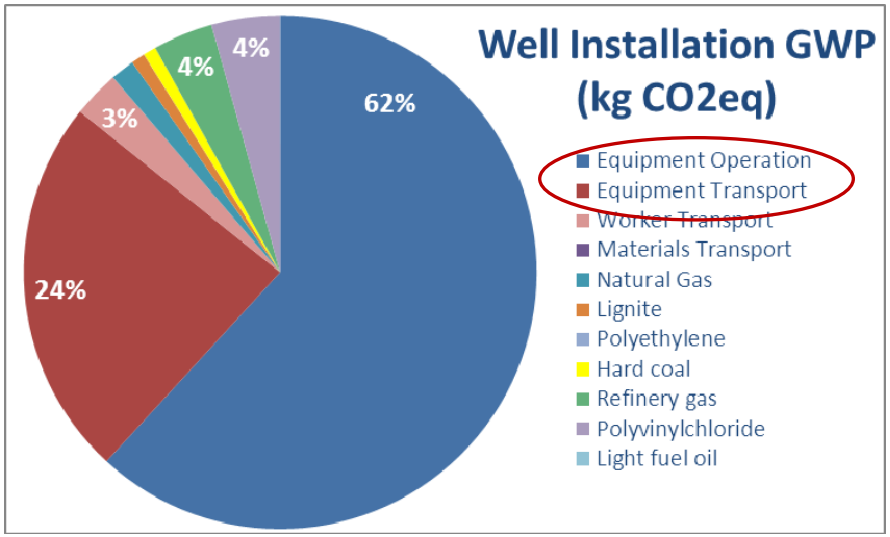


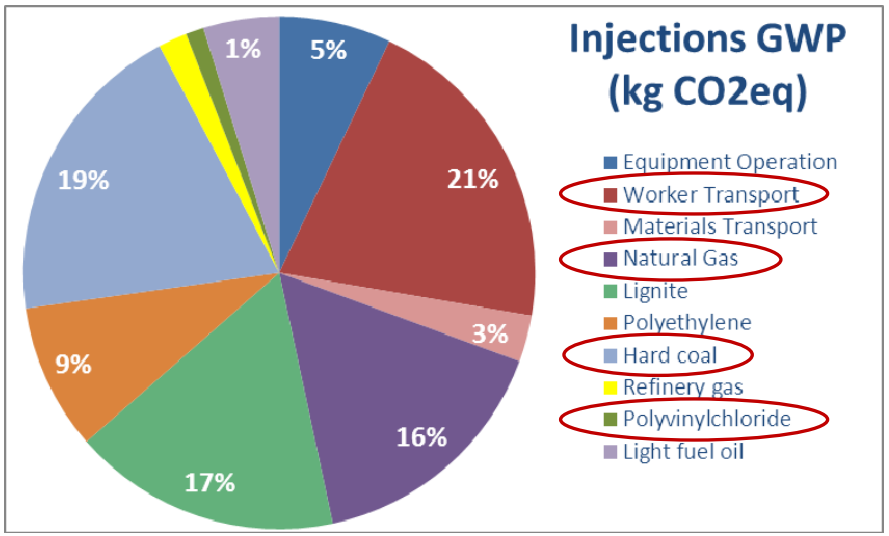




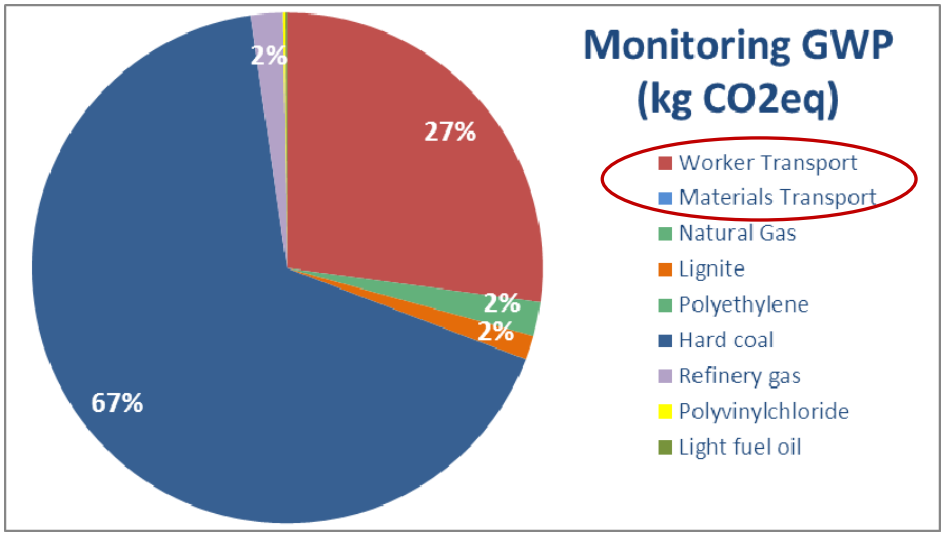
LCA can show us what materials & processes are causing the impacts.

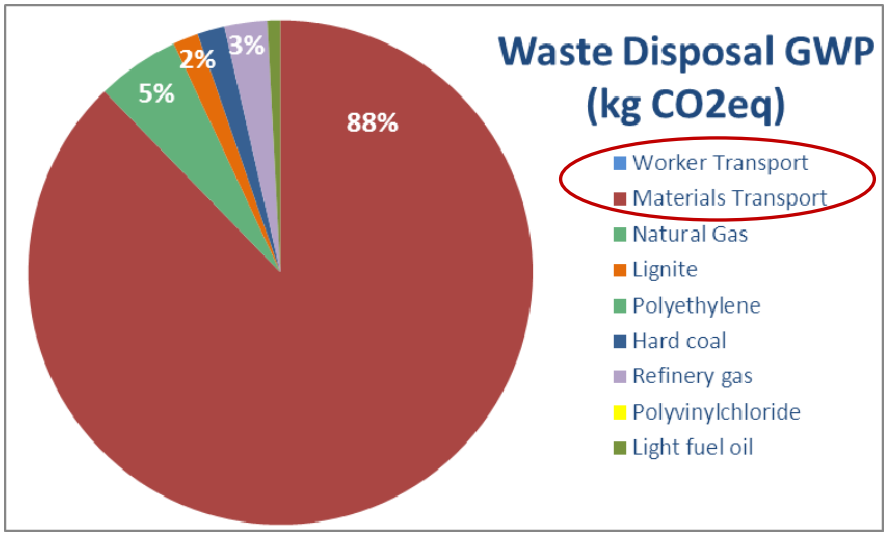
Global Warming Potential (kg CO2eq)



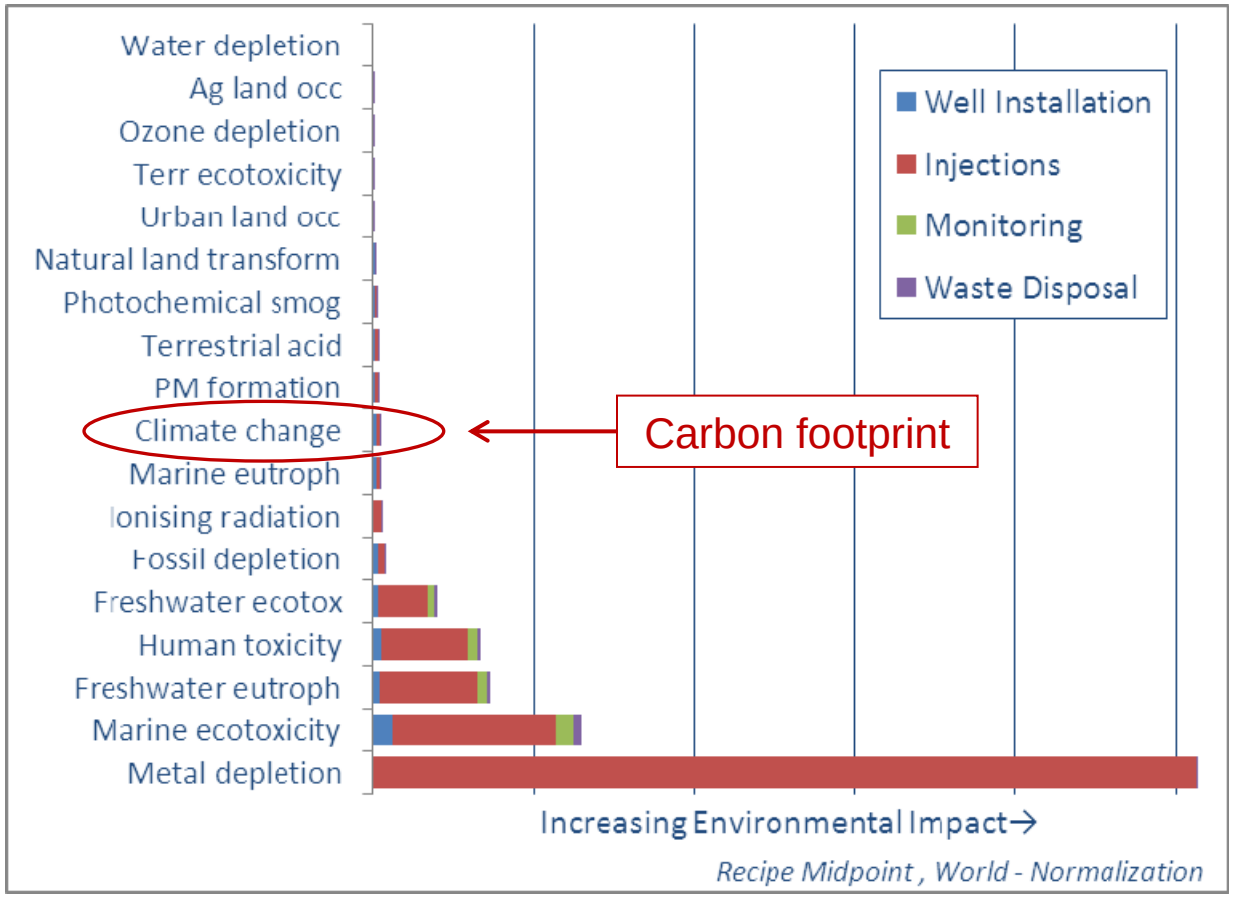


•GWP impacts primarily due to transport & equipment operation activities (fuel production & combustion)





ReCiPe Midpoint - Normalized



- A sole focus on carbon footprint would have missed many impact categories that may be more important/relevant to this remedy installation.

Some Numbers

- Nonrenewable energy: ~280,000 MJ eq
  - Equivalent to electricity use by ~7 US homes per year
- PM Formation: ~25 kg PM2.5 eq
- GWP: ~16 metric tons CO_2 eq
  - CO_2 emissions from the electricity use of ~2 homes per year
  - Annual greenhouse gas emissions from 3 passenger cars

FU = The reduction of ~90% of the contaminant mass in the source zone via KMnO4 injection; ~33,000ft^3 of contaminated media

There are numerous similar chlorinated-solvent-contaminated sites across the country

Areas for Improvement

- Mineral/Metal Depletion: injection stage
- Majority of impacts due to oxidant use

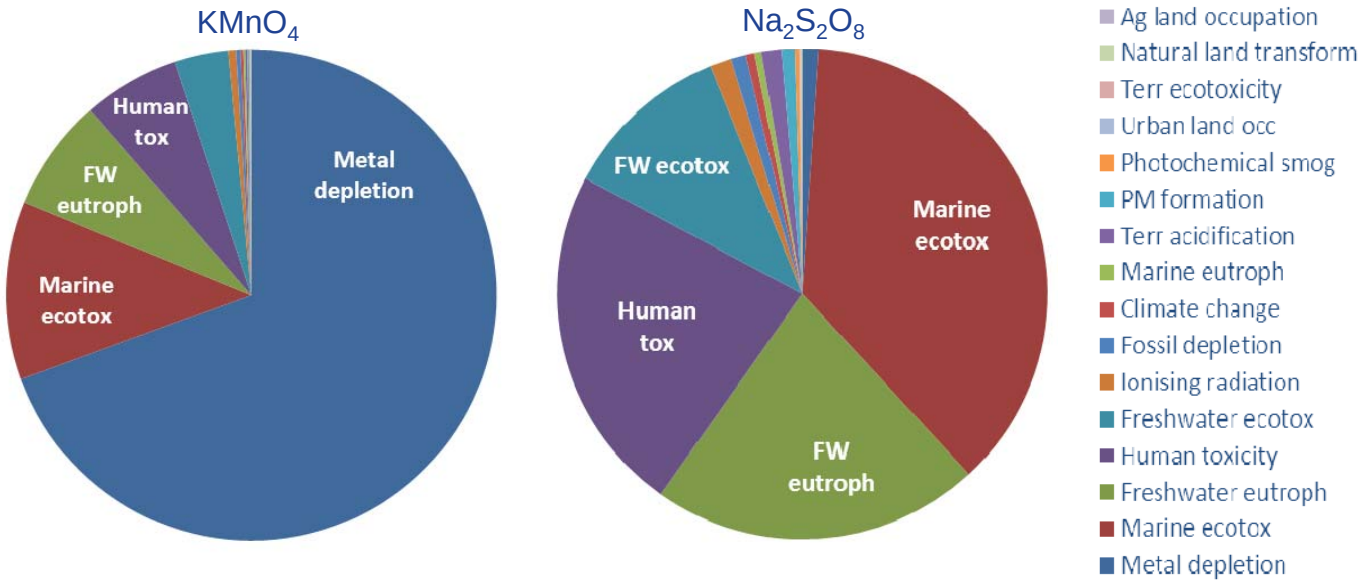
- GWP: well installation & injection stages
- Majority of impacts due to fossil fuel use for equipment & transport

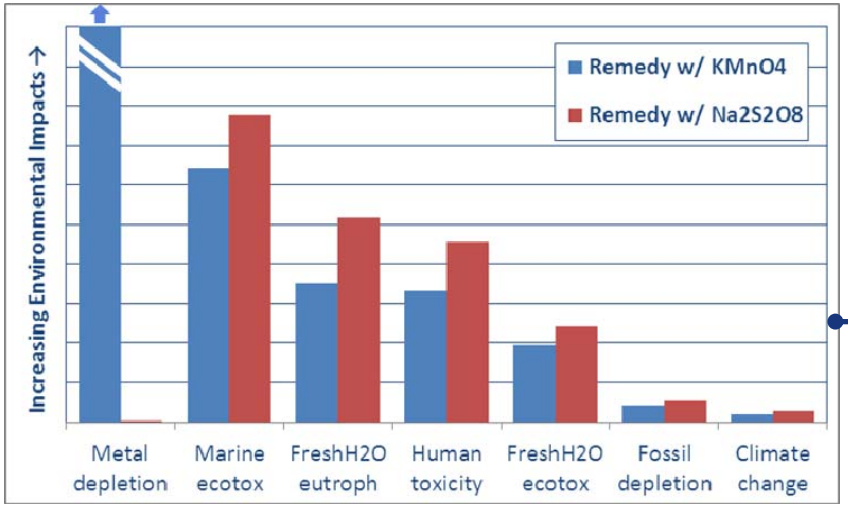
- Fossil energy: well installation & injection stages
- Majority of impacts due fuel production/combustion and electricity generation

Potential for Reducing Impacts?

- Substitute oxidant?

Shift the burden?





LCA can inform us of burden shifting if different choices are made.

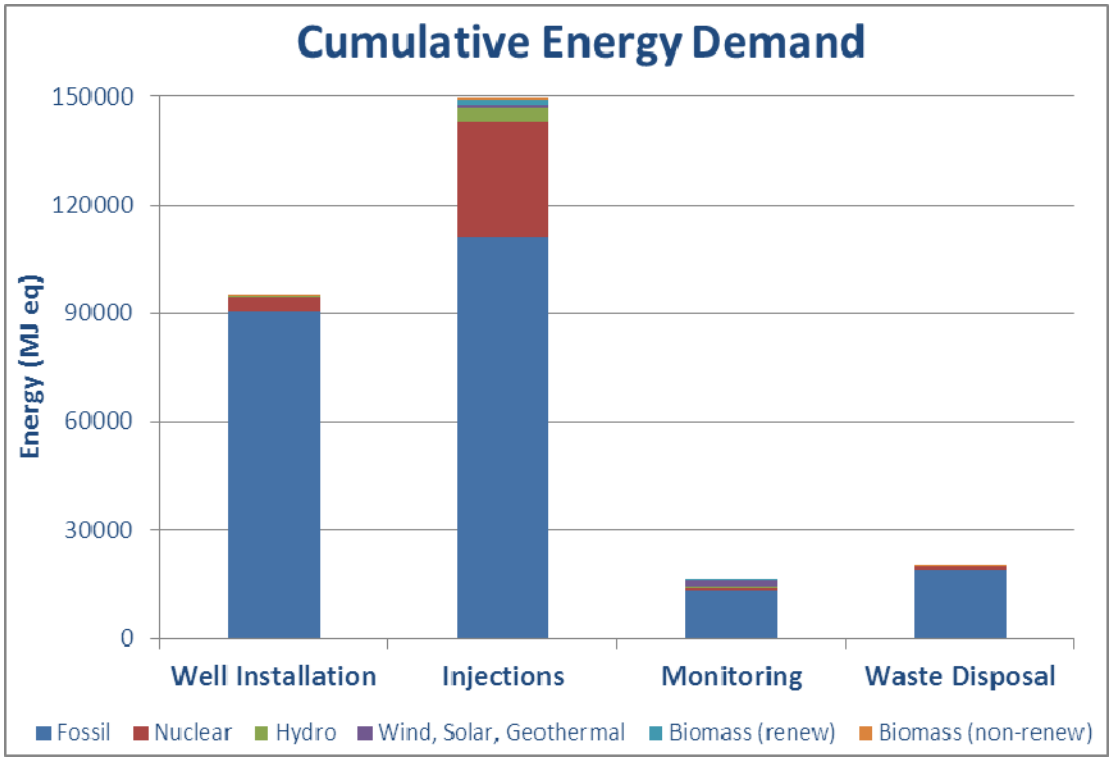
Note: For comparison purposes here, the stoichiometric requirement to degrade 1 mole of PCE was used to determine the oxidant amount. In reality many other factors affect the quantity and choice of oxidant. Oxidant quantities modeled: $KMnO_4$ = 210g; $Na_2S_2O_8$ = 472g

Take Aways

- LCA helps provides a more holistic view of all the inputs and emissions that should be considered when evaluating the environmental impacts of our remedies.
- Results indicated which environmental emissions (categories) were most impacted by the implementation of the ISCO remedy.
- Results pinpointed the materials and processes that contributed most to the environmental impacts and identified the areas to focus improvement.
    - Materials (oxidant), fuel production & combustion
- Allows for estimate of trade-offs or burden shifting if different input choices had been made.
- An evaluation of carbon footprint alone would have missed many potentially important impact categories.

SuRF 2011. "Guidance for Performing Footprint Analyses and Life-Cycle Assessments for the Remediation Industry"

Cumulative Energy Demand



•CED is a single issue impact assessment method that quantifies the energy demand of the product/service over its lifetime.

- Results indicate well installation & injection stages were dominating the energy demand of the remedy
- Crude Oil and Hard Coal (fossil) largest contributors.