Sustainability in remediation – Calculating CO_2 emissions associated with varied remediation activities

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ABSTRACT
Various technologies are used for petroleum hydrocarbon remediation. Sustainability is playing a more important role in technology selection; however measurement of carbon emissions is poorly understood. This paper looks at the main considerations for determining greenhouse gas emissions associated with the method of remediation applied.

Degradation of petroleum hydrocarbons occurs along:

$$C_xH_y+(2x+y)O_2 = xCO_2+½yH_2O$$

A procedure will be presented to analyse the carbon dioxide generated during remediation activities. This procedure will then be applied to different remediation technologies and assorted variables in a case study of a theoretical site.

RÉSUMÉ
Une variété de technologies est utilisée pour l'assainissement d'hydrocarbures pétroliers. La durabilité joue un rôle plus important dans la sélection de technologie; mais la mesure d'émissions de carbone est mal comprise. Ce journal examine ce qu'il faut considérer pour déterminer les émissions de gaz contribuant à l'effet de serre associé avec le mode d'assainissement appliqué.

La dégradation d'hydrocarbures pétroliers se produit ainsi:

$$C_xH_y+(2x+y)O_2 = xCO_2+½yH_2O$$

Une procédure sera présentée pour analyser le dioxyde de carbone produit durant les activités d'assainissement. Cette procédure sera ensuite appliquée à de différentes technologies d'assainissement et à de variables assortis dans une étude de cas d'un site théorique.

1 INTRODUCTION

The top line objective of any sustainable project is effective marrying of economic vitality, environmental rejuvenation and social enrichment. From a project management standpoint, the cost, time, and remediation success in relation to legislated objectives are common considerations. The negative impact on the environment in the form of greenhouse gas emissions is rarely considered and then only abstractly.

To fulfill a holistic lifecycle approach, the release of greenhouse gases from the contaminant source and from the consumption of petroleum hydrocarbons involved in identifying, delineating, remediating, and confirming conditions at the site must be considered.

To provide an introduction to the sustainability considerations, a look at the greenhouse gas producing components of various technologies used in site remediation will be conducted.

2 ASSUMPTIONS

Greenhouse gases include but are not limited to water vapour, carbon dioxide (CO_2), methane, nitrous oxide, ozone, CFCs, sulphur hexafluoride, hydrofluorocarbons, perfluorocarbons and chlorofluorocarbons. For this analysis, CO_2 will be used as the surrogate under the assumption that total green house gas emissions will increase as CO_2 levels increase.

In impacted soils, petroleum hydrocarbon contaminated is often associated with detectable levels of other contaminants, (i.e., MTBE, metals, VOCs). Only the total petroleum hydrocarbon (TPH) present in the impacted soils will be included in the analysis.

3 EMISSION COEFFICENTS

The coefficients relative to remediation activities are included in Table 1.

Table 1: Emission Coefficients

Source	Emission Coefficient	
	Published	Metric Conversion
Distillate fuels (gas and diesel)	22.384 pounds CO_2 per gallon[i]	2.7 kg CO_2/L
Electricity (US average)	1.34 pounds CO_2 per kWh[ii]	0.61 kg CO_2/kWh

4 CO_2 CALCULATIONS

4.1 Impacted Soils

Determining the total CO_2 associated with the complete attenuation of the TPH contamination requires the calculation in Equation 1.

$$\text{Total } CO_2 = \frac{\text{Impacted soil weight * TPH concentration* emission coefficient}}{\text{TPH density}} \quad [1]$$

As attenuation will occur only until steady state is reached, based on experience and considering published data, it is conservative to assume that CO_2 is 80% attenuated for ex situ and in situ remediation technologies. Fifty percent attenuated will be assumed for monitored natural attenuation and risk assessment[iii].

4.2 Vehicular travel

Any contaminated site will have to be visited multiple times in order to investigate the presence of potential contamination, conduct delineation of contaminant plumes identified, mob/demob investigation and remediation equipment, and confirm acceptability of remediation activities. Fuel consumption factors for some common vehicles are included in Table 2. Unreferenced values were assumed.

Table 2: Fuel Consumption

Vehicle	Fuel Consumption Rate (L/100km)
Prius Hybrid	5[iv]
Camry Hybrid	7[i]
Float Truck	35
Ford F250	27[i]
Dump Truck	35
Vacuum Truck	35
Sakai 400 Compactor	22[v]

Determining total CO_2 associated with travel requires calculating in accordance with Equation 2.

$$\text{Total } CO_2\text{=Fuel consumption rate * total distance * emission coefficient} \quad [2]$$

4.3 On Site Operation

Site investigation and remediation equipment create CO_2 through the burning of fuel. Fuel consumption factors for some equipment commonly used on site is included in Table 3. Unreferenced values were assumed.

Table 3: Fuel Consumption Factors (L/hr)

Vehicle	Fuel Consumption Rate
Volvo EC360B Excavator	25[vi]
Drill Rig	25
Dump Truck	25
Vacuum Truck	25

A straight forward calculation is shown in Equation 3.

$$\text{Total } CO_2\text{=Fuel consumption rate * operating hours * emission coefficient} \quad [3]$$

A direct correlation exists between additional hours of operation and amount of CO_2 produced.

The efficiency of the production of electricity from fossil fuels is limited (30-35%), resulting in electricity generation being a significant contributor to CO_2 production. In situ remediation systems generally rely on electricity for their operation. A reduction in green house production associated with electricity generation is only seen when the total consumption of electricity is reduced. Sourcing electricity from a “green” source (i.e. water, wind, solar) for remediation activities adds to consumption preventing the “green” energy to be used to replace existing green house gas emitting sources.

Determining CO_2 associated with electricity consumption requires use of Equation 4.

$$\text{Total } CO_2 = \text{Years operation * Electrical Consumption * emission coefficient} \quad [4]$$

There is a direct correlation between how long the system is operated and how much CO_2 is produced.

5 CASE STUDY

The case study looks at CO_2 produced from an ex situ (excavate and replace), an in situ (vapour extraction), and a risk assessment scenario. It includes the work associated with remedial activities as it is assumed that the Phase I/II, detailed site investigation, and confirmation of remediation will result in the same CO_2 emissions for each method.

5.1 CO_2 from Impacted Material

The total amount of soils impacted with petroleum hydrocarbons is assumed to be 1 000 tonnes with an average TPH concentration of 10 000 ppm. A density of 0.85 kg/L is assumed for the TPH.

Applying Equation 1:

1000 tonnes *10 000 ppm/0.85 kg/L*2.7 kg CO_2/L

=31 765 kg CO_2

An 80 % attenuation (ex situ, in situ) results in 25 412 kg CO_2. A 50% attenuation (risk assessment, monitored natural attenuation) results in 15 882.5 kg CO_2.

5.2 CO_2 from Vehicular Traffic

5.2.1 Ex Situ Remediation

If the site is assumed to be 5 km from the consultant's office and 10 km from the contractor's facility and the analytical laboratory, the total travel distances for each of the vehicles, considering multiple trips for some vehicles, is included in Table 4.

Table 4: Ex Situ Travel Distances (local)

Activity	Total
Mob/demob field tech	110km
Mob/demob supervisor	10km
Mob/demob excavator	20km
Mob/demob excavator operator	100km
Mob.demob dump truck	220km
Mob/demob vac truck	60km
Mob/demob compactor	20km

Using Equation 2, the total amount of CO_2 produced would be 385 kg.

If the site is assumed to be 500 km from the consultants office and 50 km from the contractors facilities and analytical laboratory, the total travel distances for each of the vehicles, again considering some multiple trips, is included in Table 5.

Table 5: Ex Situ Travel Distances (remote)

Activity	Total
Mob/demob field tech	1500km
Mob/demob supervisor	1000km
Mob/demob excavator	100km
Mob/demob excavator operator	500km
Mob/demob dump truck	1100km
Mob/demob vac truck	300km
Mob/demob compactor	100km

Using Equation 2, the total amount of CO_2 produced for a more remote site is 2233 kg.

The difference in CO_2 production for the more remote site is 1848 kg.

5.2.2 In Situ Remediation

Using the same assumptions for distance from the consultant's office and contractor's facilities for a local and a more remote site, the total travel distances for each of the vehicles is included in Tables 6 and 7. It is assumed that the vapour extraction system is being sourced from a location 500 km away. In addition, the system will be inspected by the field technician on a monthly basis for two years.

Table 6: In situ Travel Distances (local)

Activity	Total
Mob/demob Field Tech	290km
Mob/demob supervisor	10km
Mob/demob vapour extraction system	1000km
Mob/demob drill operators	100km
Mob/demob drill rig	20km

The total amount of CO_2 produced according to Equation 2 would be 1078 kg.

Table 7: In situ Travel Distances (remote)

Activity	Total
Mob/demob Field Tech	25 200km
Mob/demob supervisor	1000km
Mob/demob vapour extraction system	1000km
Mob/demob drill rig	1000km

The total amount of CO_2 produced according to Equation 2 would be 5481 kg.

The difference in CO_2 produced for the more remote site is 4403 kg.

5.2.3 Risk Assessment

Assuming a definable plume, acceptable depth to impacted materials, acceptable contaminant concentrations (non hazardous), and no offsite migration, this conceptual project meets the requirements to allow risk assessment.

Additional site specific information will have to be collected for the risk assessment model. Using the same assumptions for distance from the consultant's office and contractor's facilities for a local and a more remote site, the total travel distances for each of the vehicles is included in Tables 8 and 9.

Table 8: Risk Assessment Travel Distances (local)

Activity	Total
Mob/Demob Daylighter and Operators	20km
Mob/Demob Field Tech	90km
Mob/Demob Supervisor	10km
Mob/Demob Drill Operators	100km
Mob/Demob Drill Rig	20km

The total amount of CO_2 produced according to Equation 2 would be 125 kg.

Table 9: Risk Assessment Travel Distances (remote)

Activity	Total
Mob/Demob Daylighter and Operators	1000km
Mob/Demob Field Tech	1350km
Mob/Demob Supervisor	1000km
Mob/Demob Drill Operators	1000km
Mob/Demob Drill Rig	1000km

The total amount of CO_2 produced according to Equation 2 would be 2990 kg.

The difference in CO_2 produced for the more remote site is 2865 kg.

5.3 CO_2 from Remediation Technology

The remedial work that occurs on site is the same whether a site is local or remote.

5.3.1 Ex Situ Remediation

The amount of time that equipment would need to operate to remove the impacted soil at the site and replace it with clean fill is shown in Table 10.

Table 10: Ex situ Site Work

Activity	Total
Excavator operation	65 hours
Dump truck operation	20 hours
Vacuum truck operation	13 hours
Compactor operation	8 hours

The CO_2 produced through the operation of this equipment in accordance with Equation 3 is 7155 kg.

5.3.2 In Situ Remediation

For the in situ remediation, installation of the vapour extraction system will require operation of a drill rig on site for 50 hours. The amount of CO_2 produced is accordance with Equation 3 is:

50 hours*25 L/hour*2.7 kg CO_2/L

=3375 kg CO_2

Operation of a simple vapour extraction system composed of a blower to extract combustible vapours and an oxidizer to burn them, will require 500 000 kWh/year.

Considering operating a vapour extraction system for two years, Equation 4 results in:

2 year*500 000 kWh/y*0.61 kg CO_2/kWh

= 610 000 kg CO_2

The total CO_2 emissions associated with the in situ system operation is 613 375 kg CO_2.

5.3.3 Risk Assessment

The operation times for the daylighter and the drill rig used to collect site specific information for the risk assessment is 5 hours and 40 hours respectively. As the rate of fuel consumption is the same, the total amount of CO_2 produced in accordance with Equation 3 is:

45hours*25 L/hour*2.7 kg CO_2/L

=3037.5 kg CO_2

6 CONCLUSIONS

In addition to presenting total CO_2 associated with remediation activities for ex situ, in situ, and risk assessment, the CO_2 offset cost is also presented. A reasonable average cost is $5.00 /tonne CO_2.

6.1 Ex Situ

Considering the CO_2 attenuated from the impacted soil, vehicular travel, and site activities, the total CO_2 emissions associated with remediation of a local and remote site are 32 952 kg CO_2 and 34 800 kg CO_2 respectively. This translates into an additional cost of $165 or $174 respectively.

6.2 In Situ

Considering the CO_2 attenuated from the impacted soil, vehicular travel, and the site activities, the total CO_2 emissions associated with the installation and operation of an in situ system for a local and remote site are 639 865 kg CO_2 and 644 268 kg CO_2. This translates to an additional cost of $3200 or $3220 respectively.

6.3 Risk Assessment

Considering the CO_2 attenuated from the impacted soil over time, vehicle travel, and the site activities, the total CO_2 emissions associated with collecting the site specific information required to perform a risk assessment for a local and remote site is 19 045 kg CO_2 and 21 910 kg CO_2. The additional costs are $95 or $110 respectively.

REFERENCES

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