HALEY & ALDRICH

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Banff, Alberta

Off-Gas Treatment Carbon Footprint Calculator:

Form and Function

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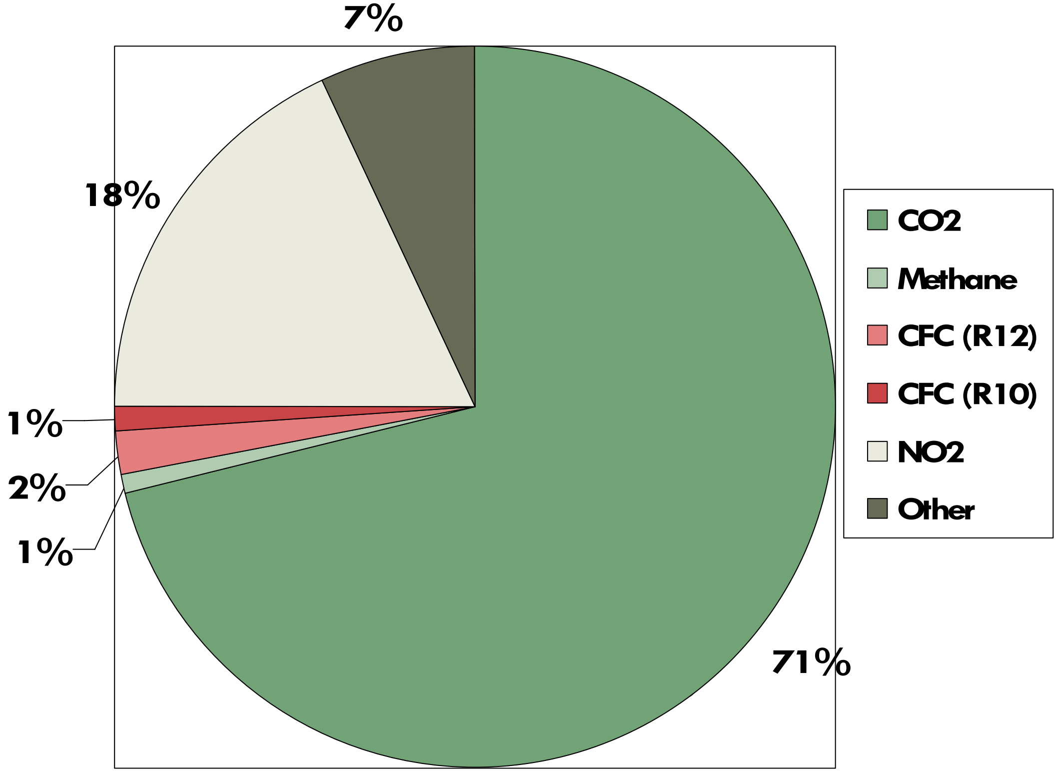
Good Earthkeeping Organization

Advancing Off-Gas Treatment technology

What is carbon footprinting?

G.E.O. Inc.

It's the measurement of the impact on the environment in terms of the amount of greenhouse gases produced, measured in units of carbon dioxide released directly and indirectly by an individual, organization, process, event or product (Carbon Trust, 2007).



Why Consider GHG Footprinting for SVE?

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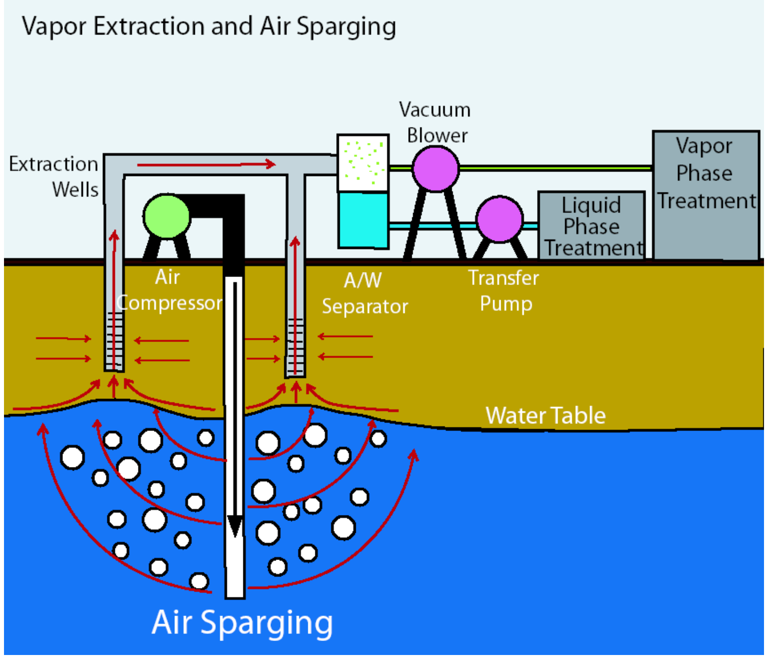
- **Conceptualize the impact to global warming**
- Regulatory requirements
- Community action groups
- Years of SVE operation- Emissions are cumulative
- Social responsibility
- Carbon credit value$$$



Outline

- Off-Gas Treatment Technologies Review
  - History
- Carbon Footprint Model
  - Form and Function
  - Parameters
  - Assumptions
  - Calculations
  - Off-Gas Treatment Applications
- Resource Conservation
- Three GHG Footprint Case Studies

History of Soil Vapor Extraction

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- Duane Knople one of the first to use SVE in 1972 (Thornton and Wootan, 1982)
- 25% of most U.S. soil remediation utilizes SVE (EPA, 2000)
- 15% of U.S. superfund sites utilizes SVE (FY 82-02; EPA, 2004)
  - 70% of which uses GAC
  - 25% uses Therm-Ox or Cat-Ox

Carbon Footprint Model

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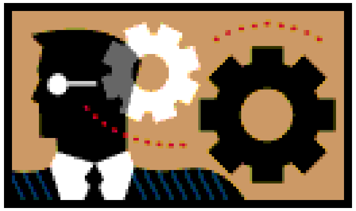
- **Form and Function**
- Parameters
- Assumptions
- Calculations
- Applications



GHGs Emission Calculations for Off-Gas Treatment Technology Process

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Carbon Dioxide

On-Site Combustion

Fuel	Fuel Consumption cu ft/yr	Fuel Consumption gallons/cu ft yr	Emission Factor (kg CO_2/gallon)	metric tons/kg CO_2	CO_2 Emissions Subtotal
Diesel		0	10.15	0.001	0
Propane		0.02278	5.70	0.001	0.00
Motor Gasoline		0	8.87	0.001	0

Fuel	Fuel Consumption cu ft/yr	Fuel Consumption MMBTU/cu ft	Emission Factor (kg CO_2/MMBTU)	metric tons/kg CO_2	CO_2 Emissions Subtotal
Natural gas	881882	0.0010300	52.78	0.001	48
		Stationary Combustion Emissions Subtotal =			48

Mobile Combustion

Fuel	Annual Miles driven	Vehicle MPG	Emission Factor (kg CO_2/gallon)	metric tons/kg CO_2	CO_2 Emissions Subtotal
Vehicle - weight 6,000 lbs and less - gas	1733	16.8	8.55	0.001	0.9
Vehicle - weight 6,000 lbs and less - diesel		16.6	9.96	0.001	-
Vehicle - weight 6,001 - 10,000 lbs - gas		13.7	8.55	0.001	-
Vehicle - weight 6,001 - 10,000 lbs - diesel		13.7	9.96	0.001	-
Vehicle - weight 10,001 - 14,000 lbs - gas		10.4	8.55	0.001	-
Vehicle - weight 10,001 - 14,000 lbs - diesel	600	11.8	9.96	0.001	0.5
Vehicle - weight 14,001 - 16,000 lbs - gas		8.9	8.55	0.001	-
Vehicle - weight 14,001 - 16,000 lbs - diesel		10.3	9.96	0.001	-
Vehicle - weight 16,001 - 19,500 lbs - gas (mid-size truck)		8.6	8.55	0.001	-
Vehicle - weight 16,001 - 19,500 lbs - diesel (mid-size truck)	1733	9.3	9.96	0.001	1.9
Vehicle - weight 19,501 - 26,000 lbs - gas		7.5	8.55	0.001	-
Vehicle - weight 19,501 - 26,000 lbs - diesel		8.3	9.96	0.001	-
Vehicle - weight 26,001 - 33,000 lbs - gas (full size truck)		7.0	8.55	0.001	-
Vehicle - weight 26,001 - 33,000 lbs - diesel (full size truck)	3333	7.5	9.96	0.001	4.4
Vehicle -weight 33,001 lbs and up - gas (big rig)		6.5	8.55	0.001	-
Vehicle -weight 33,001 lbs and up - diesel (big rig)		5.9	9.96	0.001	-
		Mobile Combustion Emissions Subtotal =			7.7

Indirect Emissions

Electricity	Annual KWh		lbs CO_2/KWh	lbs/metric ton	CO_2 Emissions Subtotal
On-site	306,600		0.87	2,204.62	121
Off-site			0.87	2,204.62	-
Manufacturer			0.87	2,204.62	-
Vendor			0.87	2,204.62	-

			Indirect Emissions Subtotal =		121

Fugitive Emissions

Contaminant volatilization due to soil mixture by cubic yards	Carbon atoms /mol	Concentration (ppmV)	Cubic YD of soil x minutes of aeration	lbs/metric ton	CO_2 Emissions Subtotal
Compound Name	Carbons/Mol				
Gasoline	8			-	-
Diesel	12			-	-
			Fugitive Emissions Subtotal =		-

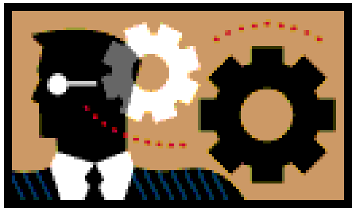
Thermal Oxidation Processing Emissions

Estimated Time of Remediation (Years)	System Flow Rate (SCFM)		Constituent Concentration (ppmV)	Est. Mass of CO_2 EQ (pounds)	CO_2 Emissions Subtotal (Metric Tons)
1.00	100				
Compound Name	Carbons/Mol				
PCE (Tetrachloroethylene)	2		2,750	32,954	15
Compound Name	Carbons/Mol				
TCE (Trichloroethylene)	2		2,750	32,954	15
TCE (Trichloroethylene)	2				
Compound Name	Carbons/Mol				
Methylene Chloride (DCM; Dichloromethane)	1			-	-
Compound Name	Carbons/Mol				
HCFCs (Hydrochlorofluorocarbons)	2			-	-
Compound Name	Carbons/Mol				
DCE (Dichloroethene)	2			-	-
Compound Name	Carbons/Mol				
CFCs (Chlorofluorocarbons; Freon 113)	1			-	-
			Processing Emissions Subtotal =		30
Total CO_2 footprint					207

Other GHGs	Metric Tons	Global Warming Potential	CO2 EQ Subtotals
CH4	0.006	23	0.148
N20	0.001	296	0.23
HFCs	SEE BELOW		-
PFCs	SEE BELOW		-
SF6		22000	-
Total GHG footprint			207

Carbon Footprint Model

- Form and Function
- **Parameters**
- Assumptions
- Calculations
- Applications



Sources

- World Business Council for Sustainable Development (WBCSD) /World Resources Institute (WRI), 2004
- California Climate Action Registry (CCAR), 2007
- The Climate Registry, TCR, 2008
- GHGs listed in the Kyoto Protocol to the United Nations Framework Convention on Climate Change

Parameters

- GHGs listed in the Kyoto Protocol to the United Nations Framework Convention on Climate Change
  - Carbon dioxide
  - Methane
  - Nitrous oxide
  - Sulfur hexafluoride
  - Hydrofluorocarbons (HFCs)
  - Perfluorocarbons (PFCs)

Carbon Footprint Model

G.E.O. Inc.

- Form and Function
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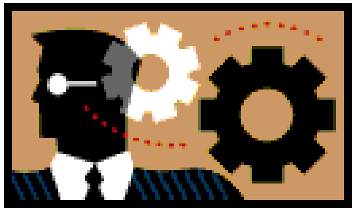


Carbon Footprint Model Assumptions

G.E.O. Inc.

- Direct emissions-emissions generated from technology and its application (e.g. thermal combustion)
- Indirect emissions- emissions consequential to the implementation of the technology (e.g. electricity)
- Focus on on-site off-gas treatment technologies and associated transport
- Complete life cycle of technologies not included (e.g. raw material extraction)
- Stationary and mobile combustion emissions, process emissions and indirect emissions
- Fugitive emissions *de minimus*

Carbon Footprint Model Assumptions continued

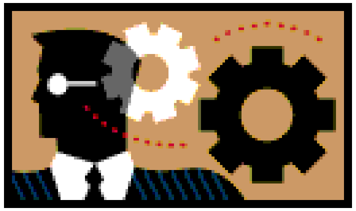
G.E.O. Inc.

Emission sources

- Stationary combustion emissions
- Mobile combustion emissions
- Indirect emissions
- Physical or chemical processing emissions
- Fugitive emissions
- De Minimus Emissions

Carbon Footprint Model

G.E.O. Inc.



- Form and Function
- Parameters
- Assumptions
- **Calculations**
- Application

Calculations

Calculation of Mass Removal Rate for SVE

- M = Q* (L/ft^3) *VOC conc*T
- M = Mass of recoverable contaminant in source area
- Q = Flow Rate in liters
- VOC = influent VOC concentration in lbs (convert to lbs by multiplying the VOC in ppmV by the number of moles 165.8 for PCE and 131.4 for TCE) / (mole ratio 24.45)* 0.0000000022
- T = time in minutes

Calculations cont.

G.E.O. Inc.

Calculation for Natural Gas Requirement for thermal oxidizer

- $Q = \dfrac{Dw\ Qw\ [Cp(1.1Tc - The - 0.1Tr) - Hw]T}{Dsf\ [Hsf - 1.1Cp\ (Tc - Tr)]}$
- Dw = density of waste air stream (usually 0.0739 lb / scf)
- Q = total volume of supplementary fuel, CF of methane
- Cp = Mean heat capacity
- Tc = combustion temperature
- The = temperature of waste air stream
- Tr = reference temperature, 77degree F
- Hw = heat content of waste air stream, Btu/lb (2,141 for PCE and 3,140 for TCE)
- T = total time of operation, minutes
- Dsf = density of supplementary fuel, lb/scf (0.0408 lb/scf for methane)
- Hsf = heating value of supplementary fuel, Btu/lb (21,600 Btu/lb for methane)

Calculations cont.

Calculation for Fuel Combustion

Total GHG emissions	= emission factor	x fuel consumed	x 0.001
(metric tons)	(kg / gallon)	(gallons)	(metric tons/kg)

Where,

kg = kilogram

0.001 metric ton = 1 kg

Calculation for Electricity

Total GHG emissions	= electricity use	x electricity emission factor	/ 2,204.62
(metric ton)	(kWh)	(lbs /kWh)	(lbs/metric ton)

Where,

kWh = kilowatts hour

lbs = pounds

2,204.62 lbs = 1 metric ton

Carbon Footprint Model

G.E.O. Inc.

- Form and Function
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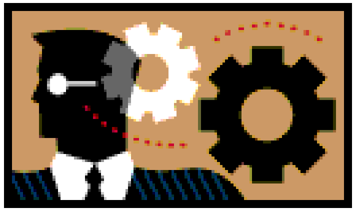
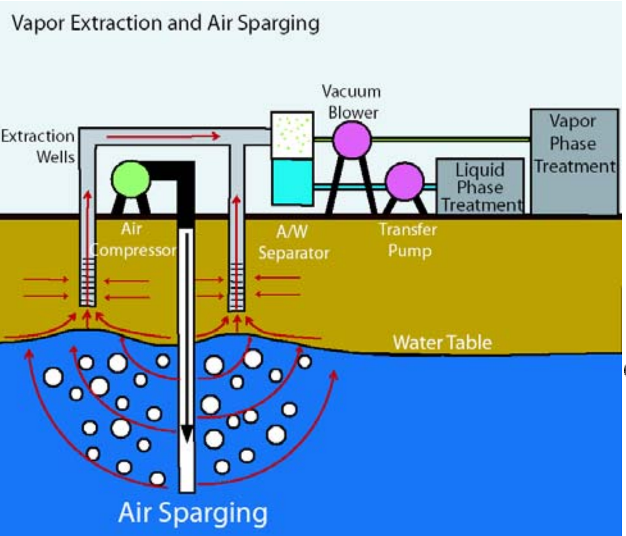
- **Applications**

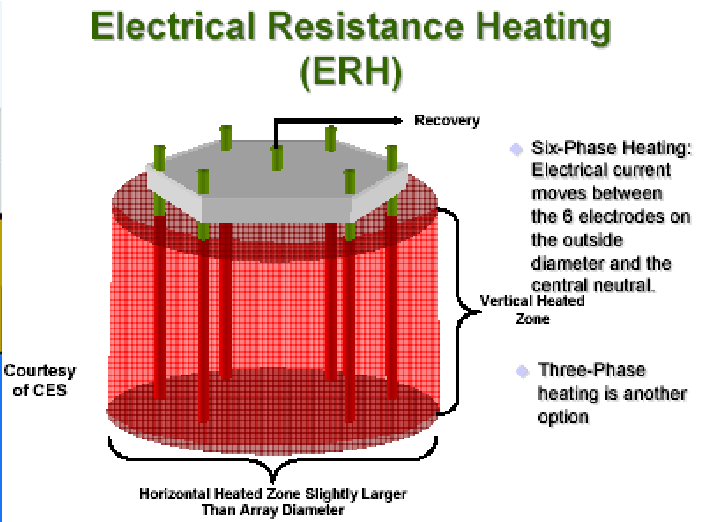


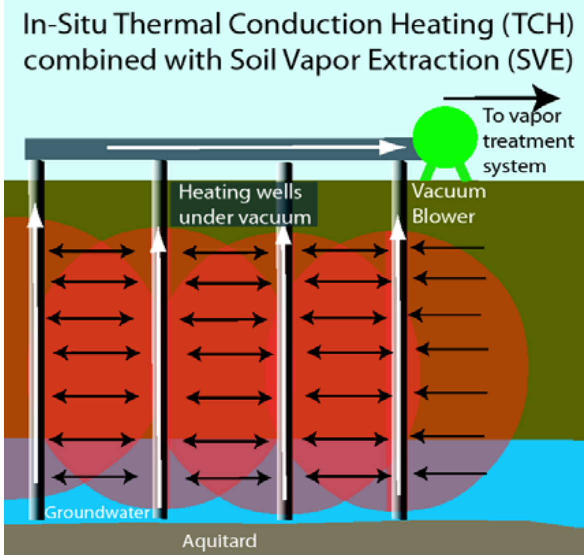
Off-Gas Treatment Applications

G.E.O. Inc.

- Soil Vapor Extraction (SVE)
- Multi-phase extraction (MPE)
- Air/ozone sparge/SVE
- In-Situ Thermal Remediation (ISTR) using electrical resistance heating (ERH) or thermal conduction heating (TCH)







Off-Gas Treatment Technologies

G.E.O. Inc.

Traditional (>95%)

- Granular activated carbon (GAC)
- Direct-flame thermal oxidizers
- Flameless thermal oxidizers (FTO)
- Catalytic oxidizers (Cat-Ox)
- Hybrid thermal/catalytic
- Internal Combustion Engine (ICE)

Non-traditional (<5%)

- Biofiltration
- Vapor condensation
- C^3 Technology

GHG Footprint Case Studies

G.E.O. Inc.

	Case Study 1	Case Study 2	Case Study 3
GAC	400	1,300	1,800
TO	200	300	800
C3	150	300	600

Case Study 1

- ***C3 has lowest footpr*** ***rt***
- Equivalent size systems

Case Study 2

- ***C3 and TO have equivalent footprint***
- Equivalent size systems

Case Study 3

- ***C3 has lowest footprint***
- Thermal system oversized to 600 scfm

System Size:	100 SCFM	200 scfm	200 scfm

*Annual footprint estimates do not include equipment and component manufacturing

Case Study 3 Footprint Analysis

G.E.O. Inc.

- **TABLE 1. Carbon Footprint Evaluation**

Off-Gas Technology	Carbon Footprint in metric tons of CO_2	Potential for Resource Conservation
200 SCFM GAC system	~1800	Limited, footprint for mining and consumption of natural resources not quantified
600 SCFM Thermal Oxidation	~800	Limited, footprint for disposal of acid waste not quantified
200 SCFM C3-Technology	~600	Moderate to high, if recovered chemical was recycled it would provide a credit to the footprint

GAC Environmental Impact

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- Derived from coal mining (**i.e. natural resource**) or carbonization of other organic materials
- Transported from distant countries, processed, distributed and delivered to sites
- GAC regeneration energy is significant
- Out of State transportation

= Large carbon footprint

Thermal Oxidation Env. Impact

G.E.O. Inc.

- Supplemental fuel usage is most significant carbon footprint lever
- Direct incineration results in CO_2 emissions
  - Potential formation of dioxins and furans and untreated VOCs
  - CO, CO_2, and nitrogen / sulfur oxides
- Salts collected from acid scrubber
- Moderate carbon footprint can be high

C3 Technology Env. Impact

G.E.O. Inc.

- Electricity use on-site is most significant factor
- Low to Moderate carbon footprint
- No incineration of organics on-site
- VOCs containerized for transport off-site for **recycling, reuse or incineration**

GAC

Raw materials mining and consumption

Thermal Oxidation

Supplemental fuel required to operate

C3 Technology

* Electricity usage

***** Opportunity for reuse / recycle or fuel replacement***

Conclusion

- Carbon Footprint Model
  - Calculator with standard calculations
  - Clearly defined assumptions with boundaries
- Resource Conservation
  - Reduce
  - Reuse or recycle or sell$$

Questions

G.E.O. Inc.