2008 REMEDIATION technologie symposium

October 15-17, 2008
The Fairmont Banff Springs
Banff, Alberta

Chemical Recovery via Vapor Condensation (A "Green Remediation" Approach): The Next Generation Soil Vapor Extraction Off-Gas Treatment Technology

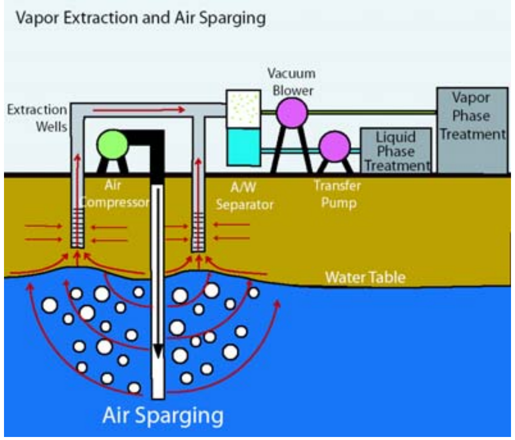
Presented by: Lowell Kessel and Carol Winell

Good Earthkeeping Organization

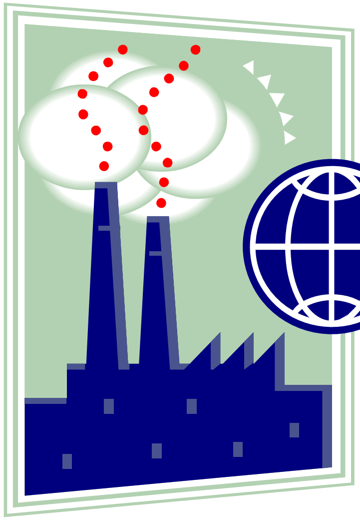
Advancing Off-Gas Treatment technology

Off-Gas Treatment

- Soil venting and groundwater remediation



- Industrial process air treatment



What off-gas treatment technology is more appropriate today?

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- Human health risk models-Emission limits are more restrictive
- Life cycle costing- reuse & recycling
- Rising fuel & energy costs
- GHG & carbon footprinting & Resource conservation
- Regulatory controls can be very different
- Public relations
  - Fortune 500 companies
  - Marketing and brand preservation

lineOtu

☐ Off-Gas Treatment Technologies Review
  - History

☐ **Technical Feasibility**

☐ **Cost Comparison – Life Cycle Costing**

☐ **Sustainability Metrics**
  - Carbon Footprint Model
  - Resource Usage & Conservation

☐ Three Case Studies

History of Soil Vapor Extraction

- 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

Off-Gas Treatment Technologies

Traditional (>95%)

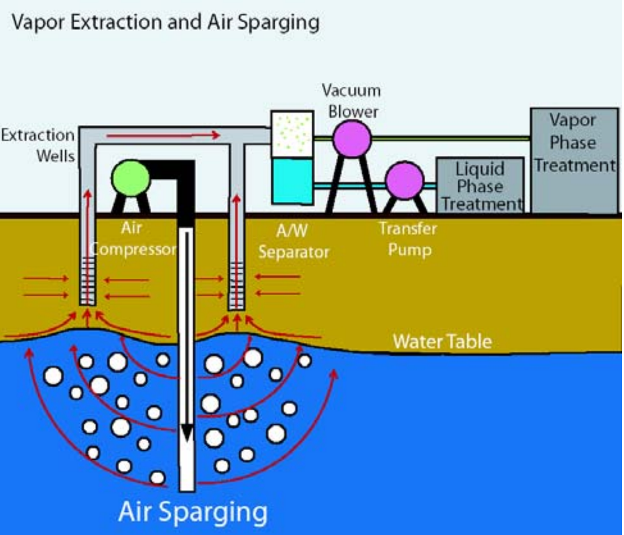
- Granular activated carbon (GAC)
- Direct-flame thermal oxidizers
- Flameless thermal oxidizers (FTO)
- Catalytic oxidizers (Cat-Ox)
- Hybrid thermal/catalytic
- Internal Combustion Engine (ICE)

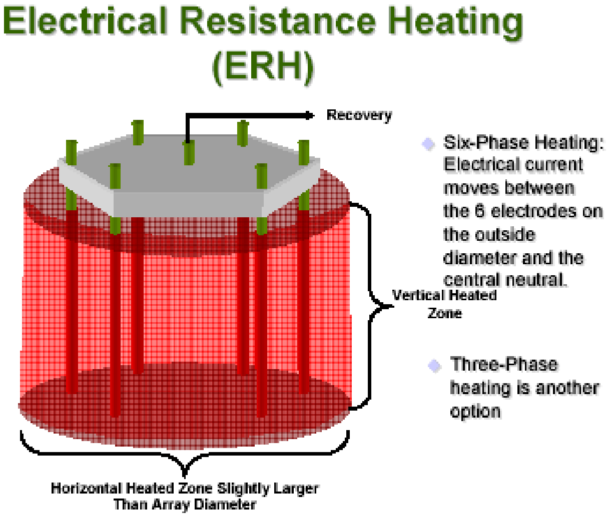
Non-traditional (<5%)

- Biofiltration
- Vapor condensation
- C^3 Technology

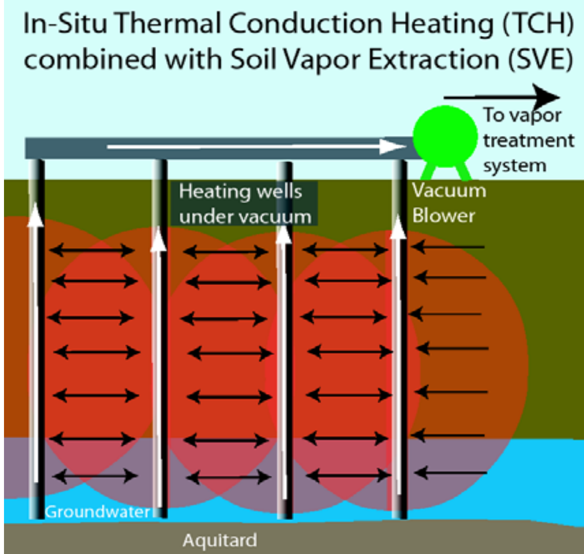
Off-Gas Treatment Applications

- 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)



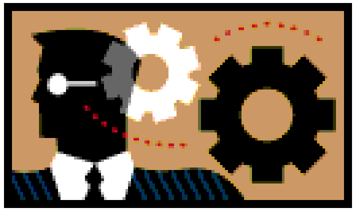


Courtesy of CES



Evaluation Criteria

- ☐ **Technical Feasibility**
- ☐ Cost Analysis - LCC
- ☐ Environmental Sustainability



Granular Activated Carbon

- More cost effective at VOC concentrations < 200 ppmv
- Adsorption Limitations:
  - ☑ CFCs
  - ☑ Vinyl Chloride
  - ☐ Chloroform
  - ☐ Chlorobenzene
  - ☑ Methylene Chloride
  - ☐ Carbon Tetrachloride
- Autoignition Concerns:
  - ☑ Aldehydes
  - ☐ Ketones (i.e., MEK)

Thermal / Catalytic Oxidation

- Therm-Ox requires dilution above 5,000 ppmv (Chlorinated solvents)
- Therm-Ox requires dilution above 10,000 ppmv (Petroleum)
- Cat-Ox limited to ~2,000 ppmv (solvents) or ~4,500 ppmv (petroleum) and less than 100ppm if CFCs are present (<25% of LEL)

Thermal / Catalytic Oxidation (cont)

- Potential formation of dioxins and furans and untreated VOCs
- CO, CO2, and nitrogen / sulfur oxides
- Uptime is low = high O&M costs
- Supplemental fuel costs are rising
- Scrubber maintenance costs are high!

C^3-Technology

- Cryogenic compression and condensation combined with regenerative adsorption
- NO UPPER LIMIT of VOC concentration
- NO DILUTION!
- >19 years in service!

C^3-Technology (cont)

- Chemical recovered as a non-aqueous phase liquid (NAPL)
- > 99.8% Removal efficiency

Recoverable Chemistries

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Chlorinated Ethenes
PCE (Perchloroethene)
TCE (Trichloroethene)
DCE (Dichloroethene)
VC (Vinyl Chloride)

Petroleum Hydrocarbons
Fuels (gasoline, diesel, jet)
Aromatics (BTEX)
4-ethyl toluene
Napthylene

Chlorinated Ethanes
TCA (Trichloroethane)
DCM (Methelene Chloride)
CT (Carbon Tetrachloride)
CF (Chloroform)
CFCs (Freon 113)

Select Project Summaries

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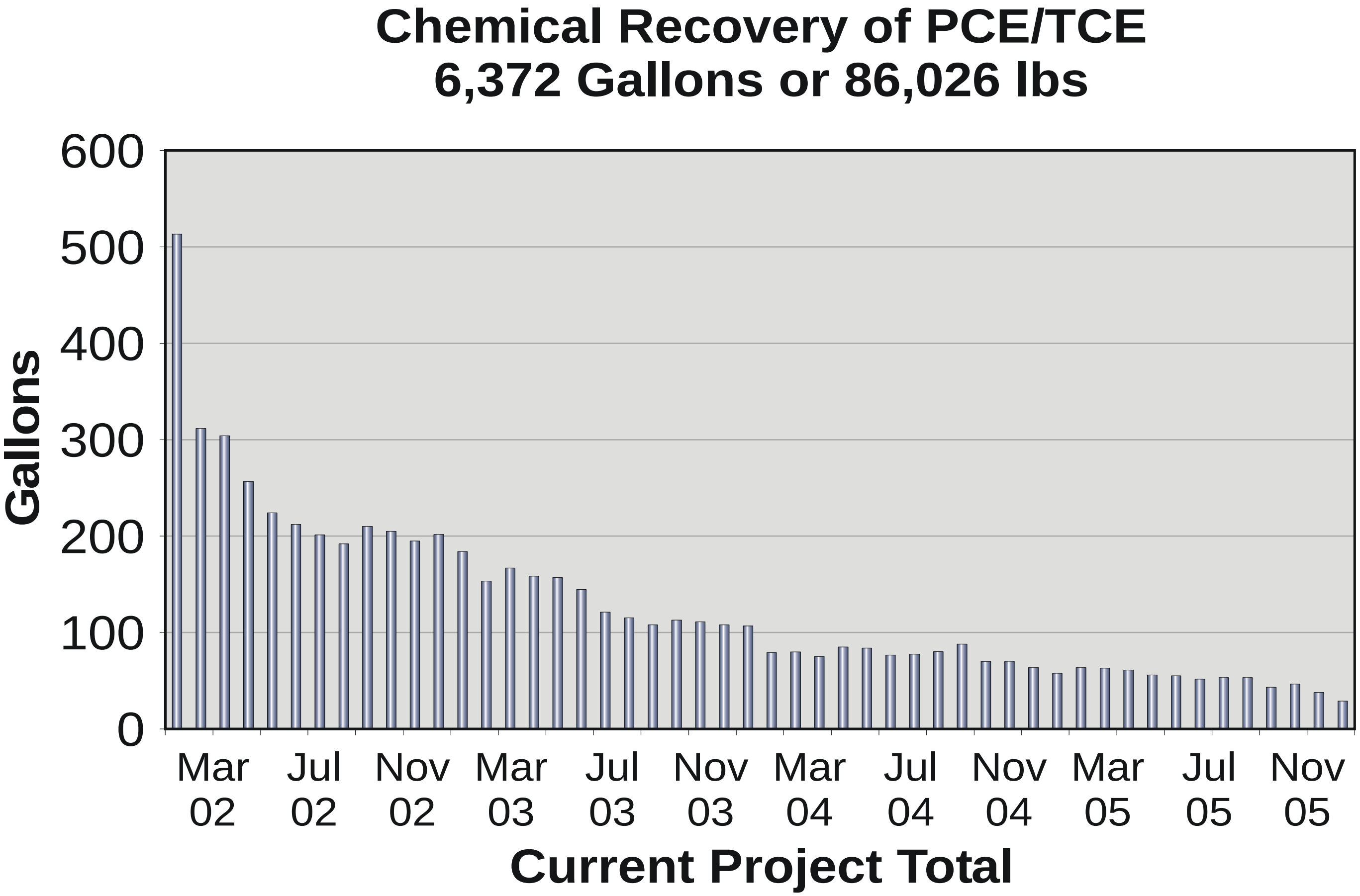
Location	Constituents of Concern	Initial Concentrations in ppmV	Remediation Time	Chemical Recovered in pounds (lbs)
California	CFC's, Chloroform, Carbon Tet, HCFCs, 1,1,1-TCA	25,000	3.5 years	110,000
California	PCE	28,000	3 years	39,000
California	1,1-DCA, R-113, cis 1,2-DCE, Methelene Chloride	16,000	1 year	16,000
Arizona	CFC's, 1,1-DCE, Methelene Chloride, TCE,	24,000	1 year	60,000
California	BTEX, MTBE, TCA, DCA, MeCl	26,000	32 days	14,080
California	PCE	18,000	1 year	13,500
California	TCE and Methelene Chloride	27,000	3 months	15,120

Case Example



(Site In California)

4,500 Gallon Recovery Tank

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Evaluation Criteria

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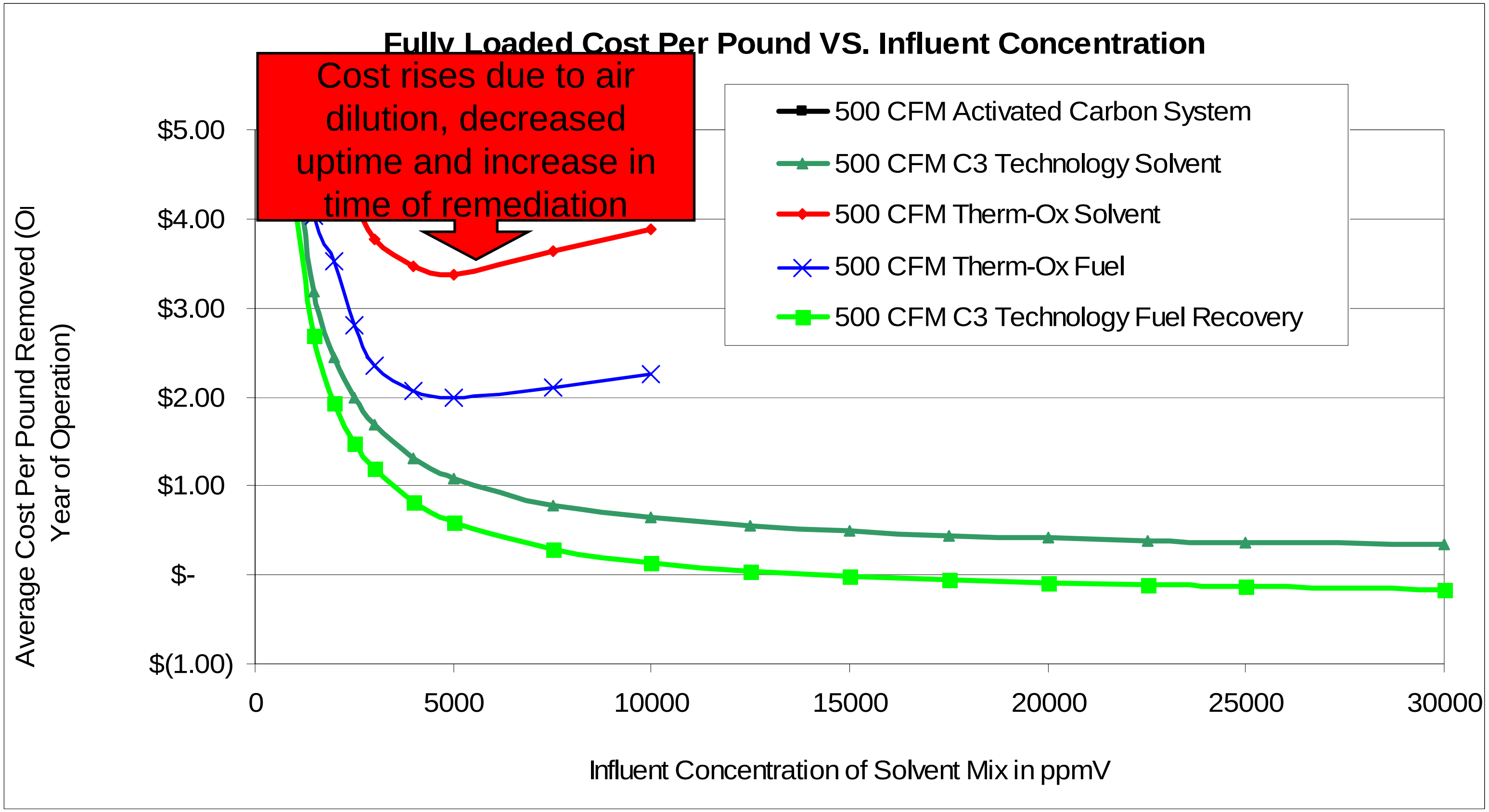
- ☐ Technical Feasibility
- ☐ **Cost Analysis - LCC**
- ☐ Environmental Sustainability

Cost Per Pound Comparison

- PCE, TCE and BTEX

*Greater than 90% uptime



Fully Loaded Cost Per Pound VS. Influent Concentration

Cost rises due to air dilution, decreased uptime and increase in time of remediation

*Inclusive of all labor, materials, equipment, expendables, consulting fees, reporting, and permits.

Cost Per Pound Comparison

G.E.O. Inc.

- PCE, TCE and BTEX

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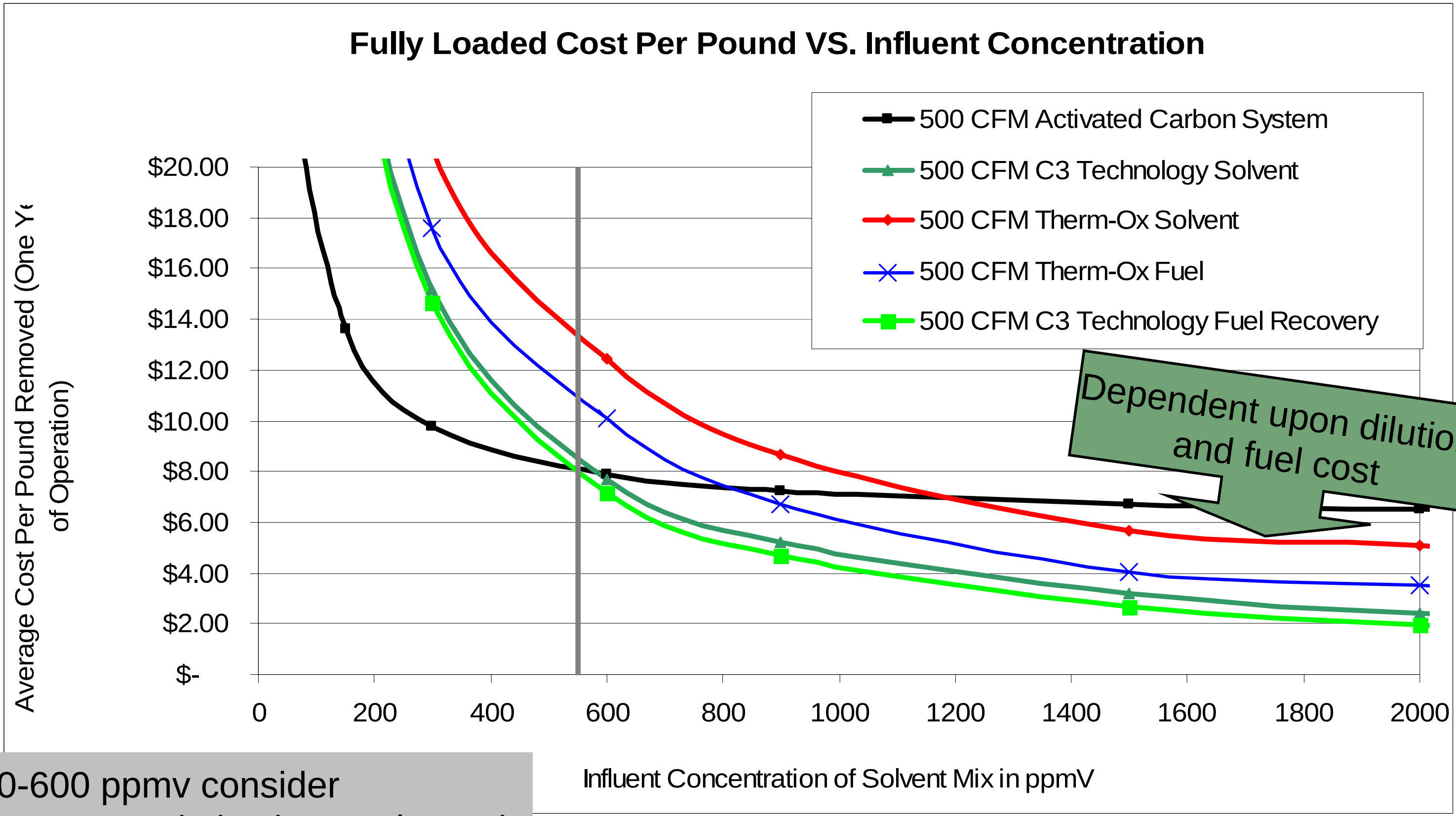


Dependent upon dilution and fuel cost

At 500-600 ppmv consider performance optimization or planned transition to alternative technology

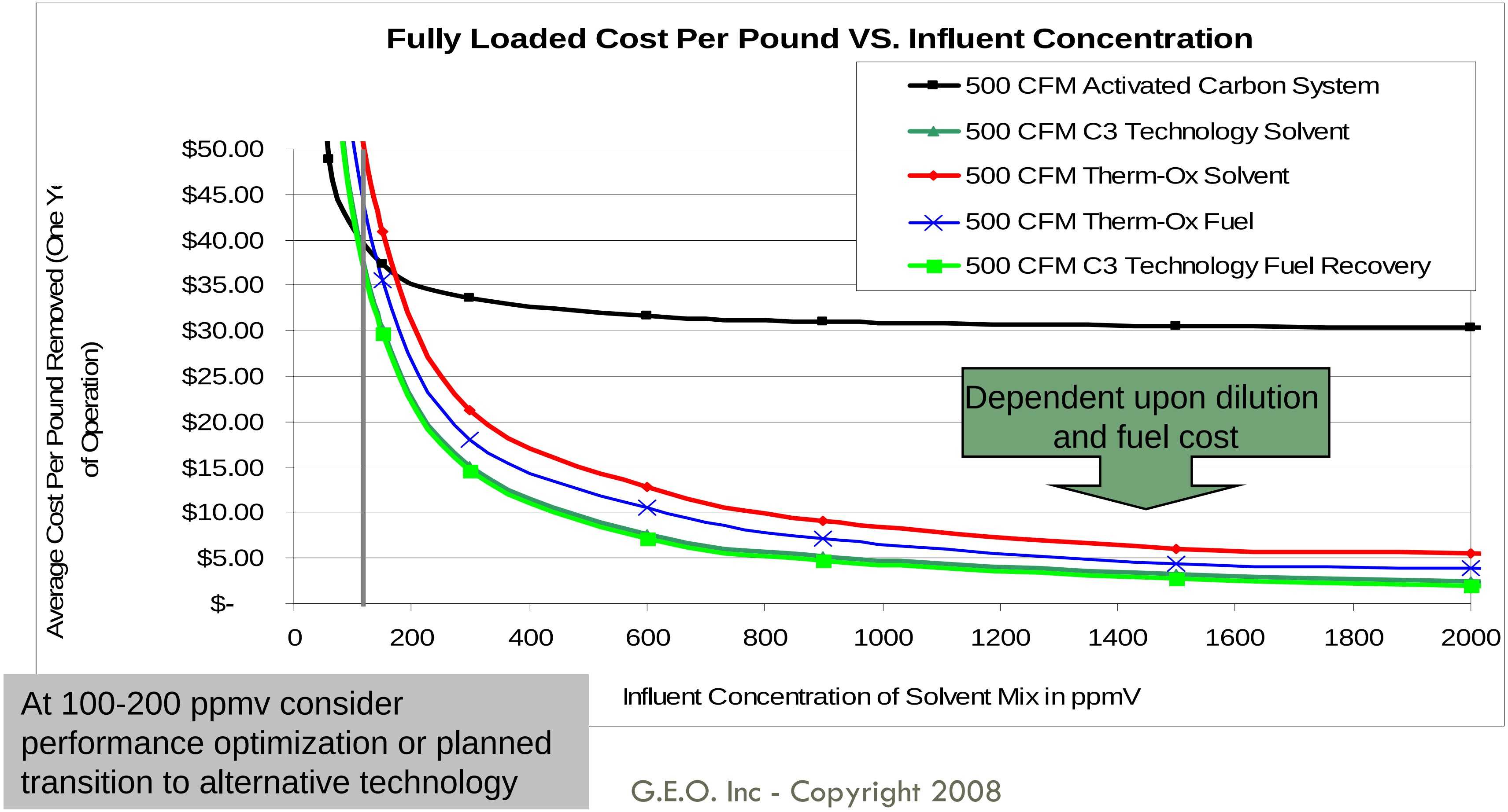
*Inclusive of all labor, materials, equipment, expendables, consulting fees, reporting, and permits.

Cost Per Pound Comparison

G.E.O. Inc.

*Greater than 90% uptime

- Methylene or Vinyl Chloride or Freon



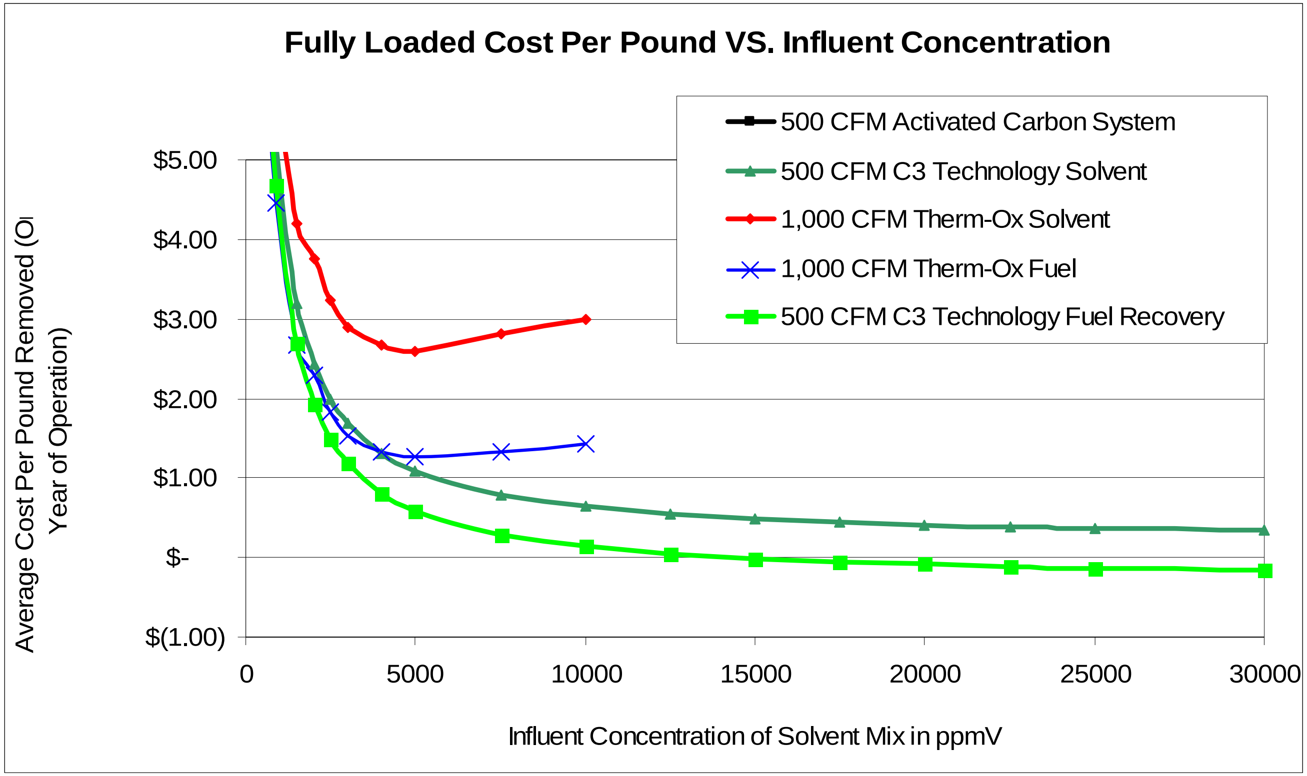
At 100-200 ppmv consider performance optimization or planned transition to alternative technology

*Inclusive of all labor, materials, equipment, expendables, consulting fees, reporting, and permits.

Cost Per Pound Comparison

- ☐ PCE, TCE and BTEX
- ☐ Oversize the Therm-Ox System

*Assumes Greater than 90% uptime

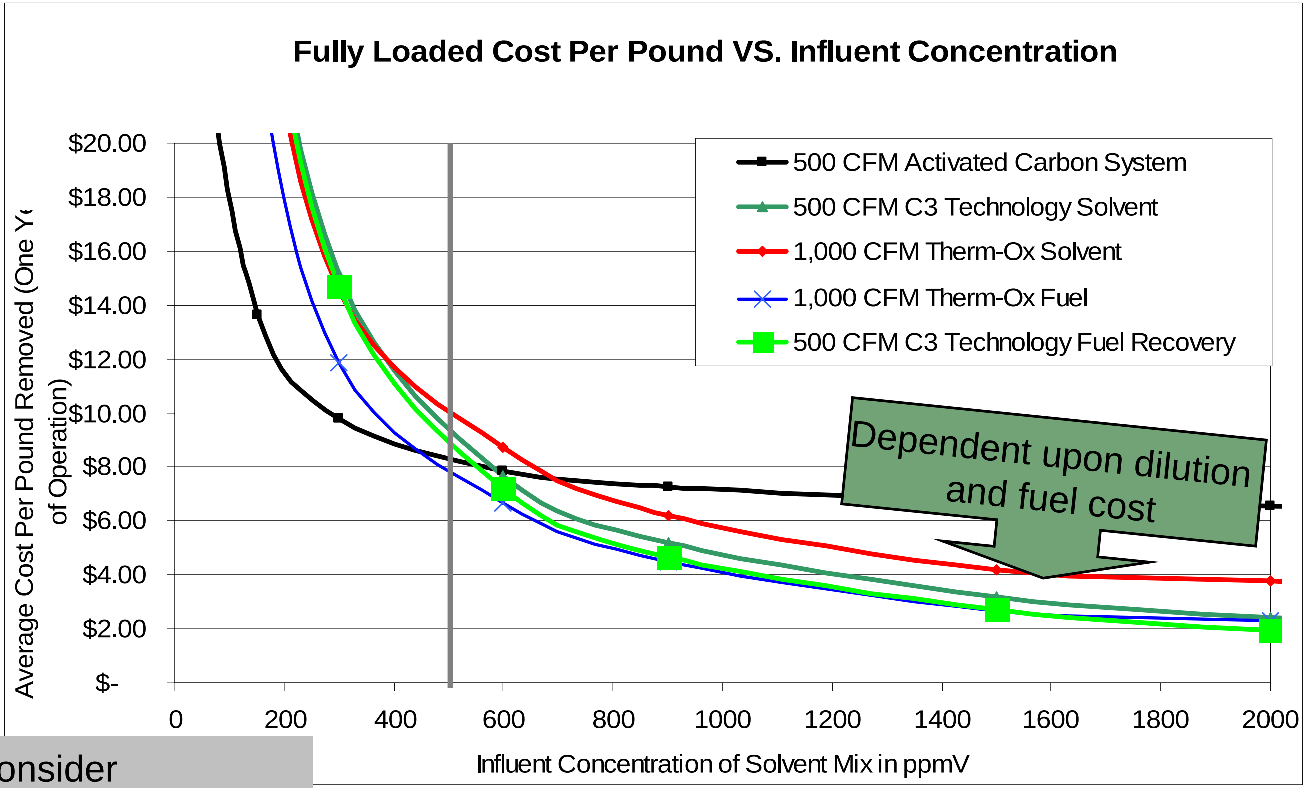


*Inclusive of all labor, materials, equipment, expendables, consulting fees, reporting, and permits.

Cost Per Pound Comparison

- ☐ PCE, TCE and BTEX
- ☐ Oversize the Therm-Ox system

*Assumes Greater than 90% uptime


Fully Loaded Cost Per Pound VS. Influent Concentration

Dependent upon dilution and fuel cost

At 500-600 ppmv consider performance optimization or planned transition to alternative technology

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Fuel Recovery Economics

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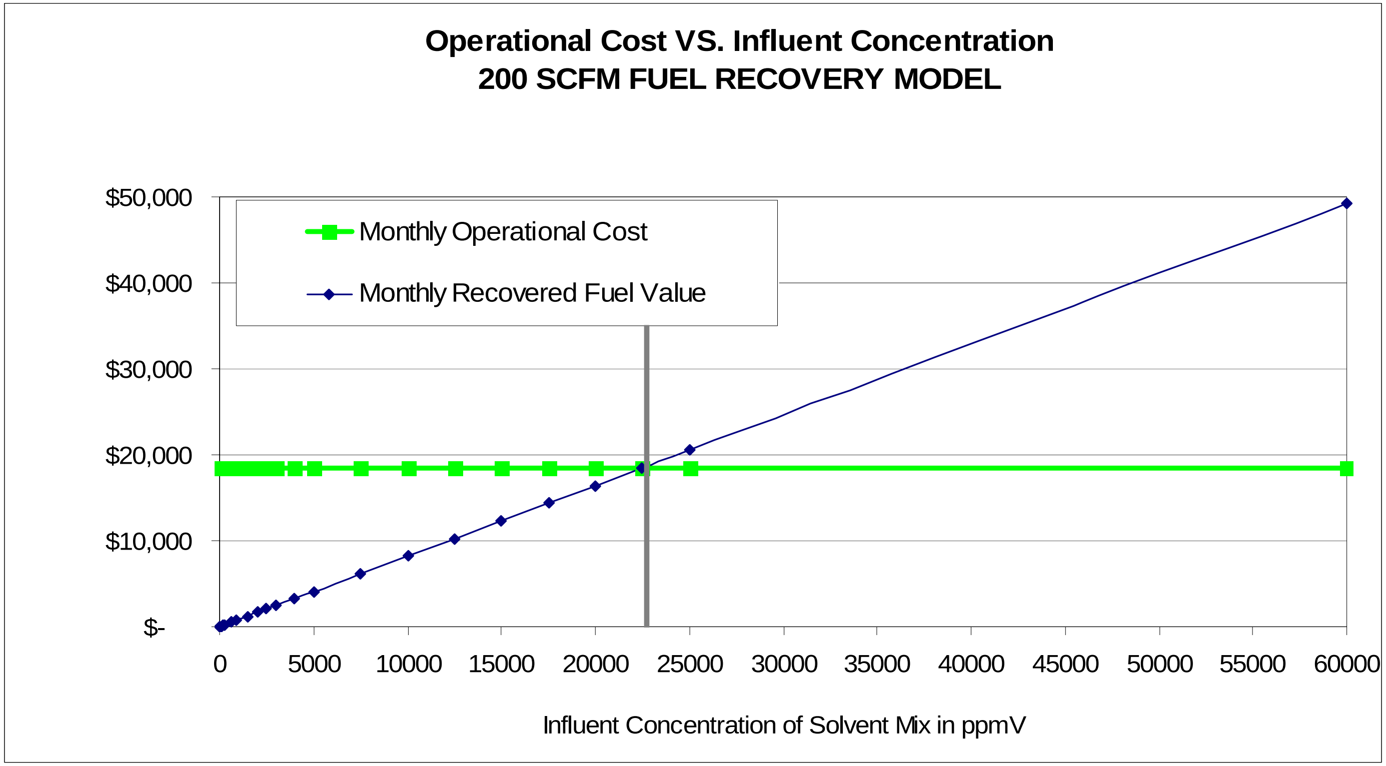
- 200 SCFM Fuel Recovery System
- $1.50 per gallon after market value



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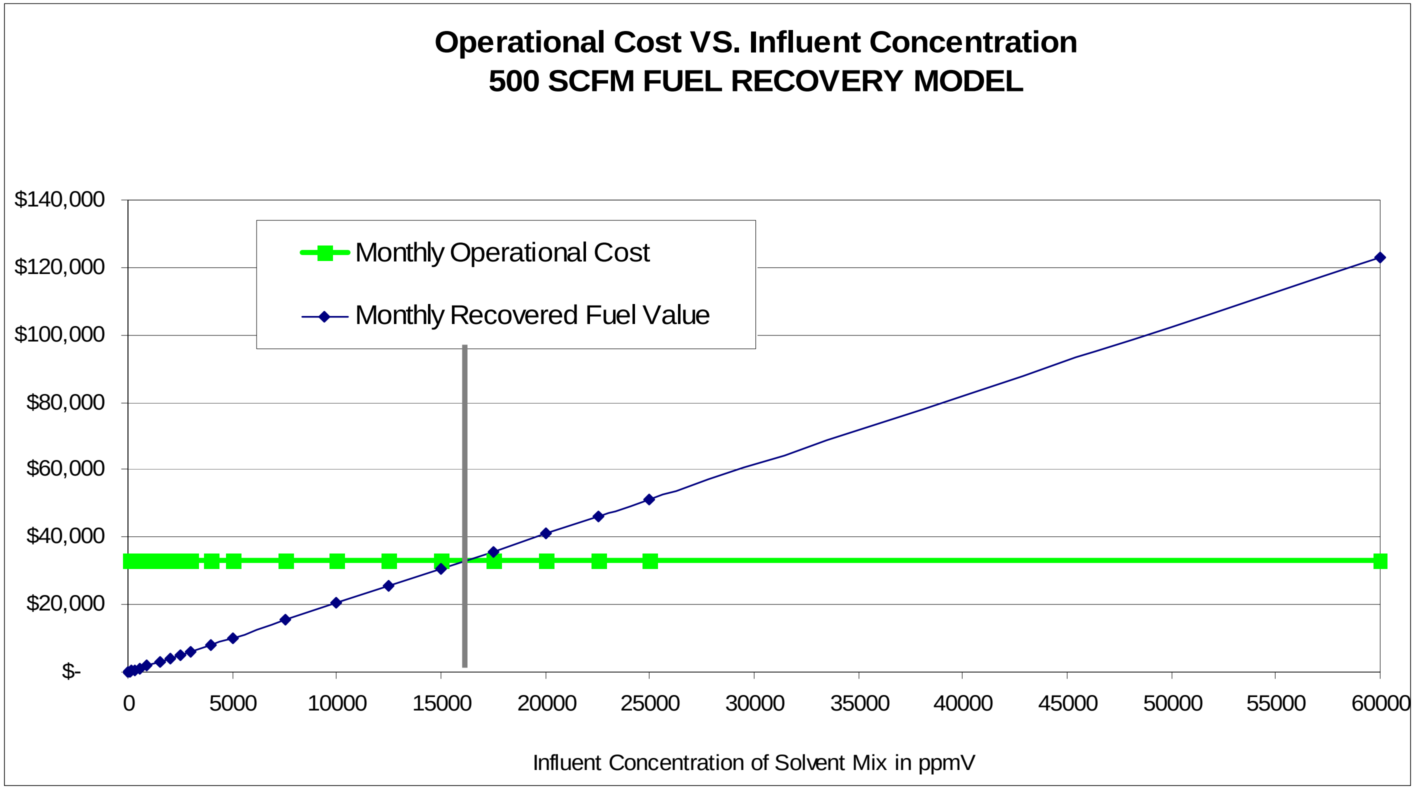

Sizing and Phase Planning

- Phase I source removal- C3
- Modular units allow for
  - Focused source area removal
  - Efficient use of technology benefits
  - Reduced remediation life cycle time
- Phase II rebound and closure performance testing- GAC

Evaluation Criteria

- Technical Feasibility
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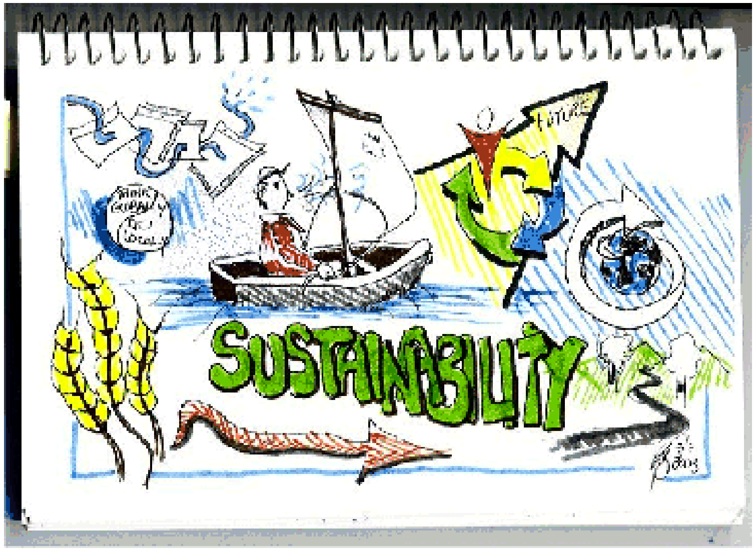
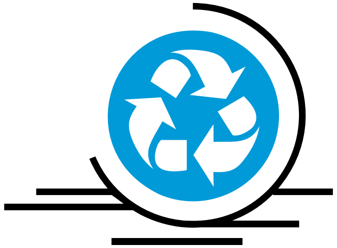
- **Environmental Sustainability**



What is Environmentally Sustainable Remediation?

"That which potentially provides the best outcomes for the economic, social, institutional and environmental aspects of human society in addition to the non-human environments both now and into the indefinite future"



Why Consider Environmentally Sustainable Remediation Alternatives?

- Fortune 500 Client Requests
  - GHG foot printing is a growing concern
  - Limiting long term liability is important
  - Enterprise Risk Management
- LEEDS
- Green buildings

GAC Environmental Impact

- 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

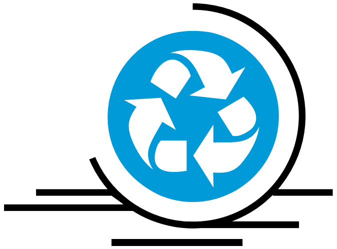
= Large carbon footprint

Thermal Oxidation Env. Impact

- Supplemental fuel usage is most significant carbon footprint lever
- Direct incineration results in CO2 emissions
- Salts collected from acid scrubber
- Moderate carbon footprint can be high

C3 Technology Env. Impact

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



Green House Gases (GHG)

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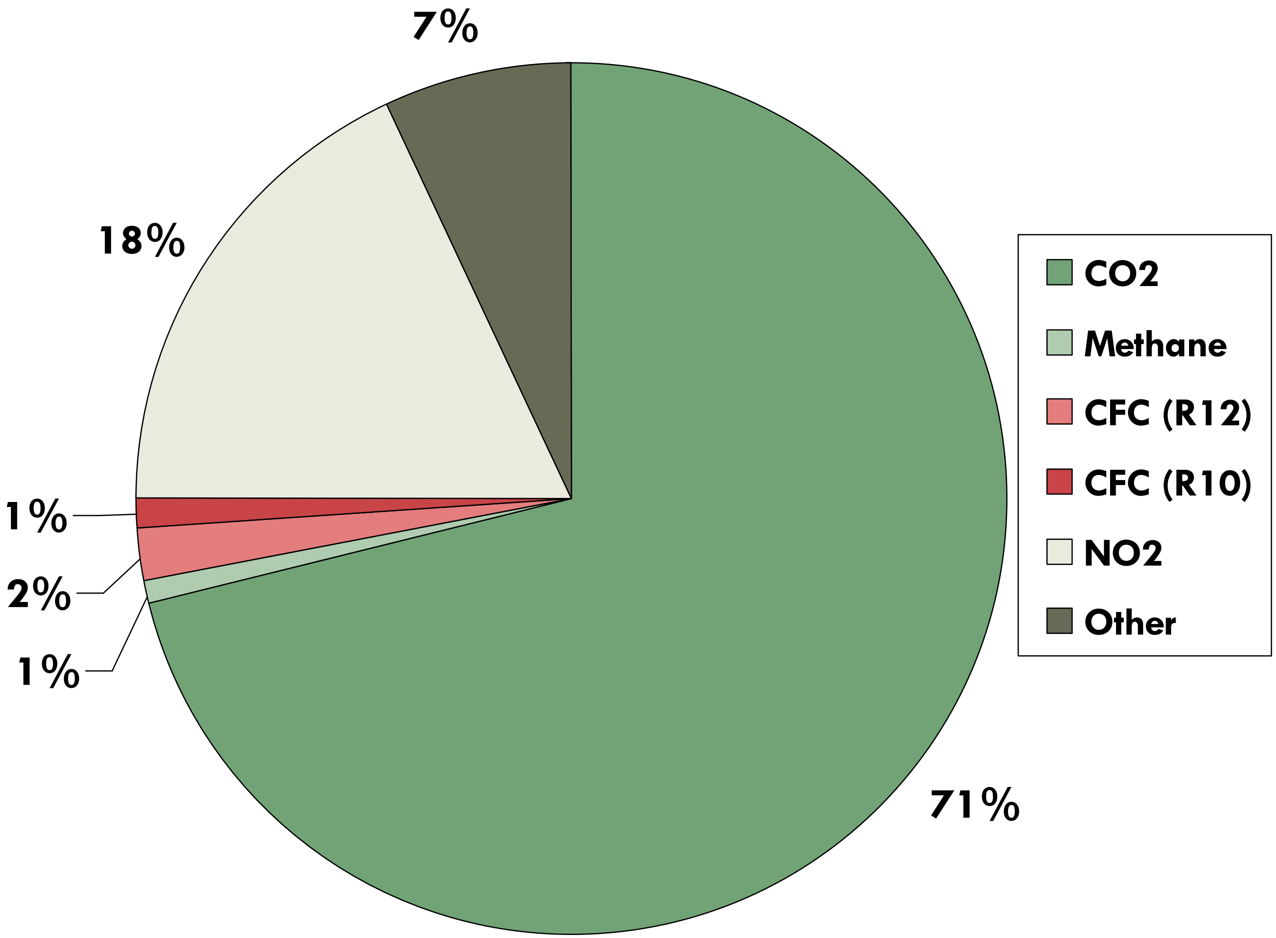

GHG Footprint Case Studies

	Case Study 1	Case Study 2	Case Study 3
GAC	400	1,300	1,800
TO	200	300	800
C3	150	300	600
	➢ ***C3 has lowest footprint*** ➢ Equivalent size systems	➢ ***C3 and TO have equivalent footprint*** ➢ Equivalent size systems	➢ ***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

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- ☐ **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

[illegible]

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

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- Technical Feasibility
  - Refrigeration reveals significant opportunity
- Cost Analysis
  - Refrigeration offers cost savings
  - Time of remediation may be reduced $$
- Environmental Sustainability
  - No emissions on site
  - Chemical recovery = resource conservation
  - Cost recovery by sale/reuse of chemical

Questions

Thank you!

References

- AFCEE, 1996. *A General Evaluation of Bioventing for Removal Actions at Air Force / Department of Defense Installations Worldwide: General Engineering Evaluation / Cost Analysis (EE/CA).* June.
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- EPA.GOV, Climate Leaders Reporting- Inventory Management Plan Checklist. Version 03/10/2005

Feasibility Analysis

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The precise cost-effective transition point depends on site-specific technical and economic conditions, including:

- Contaminant Properties
  - Henry’s Law
  - vapor pressure
  - boiling point
  - molecular weight
  - LEL
- Concentration level
- Cost of utilities (i.e., electricity, supplemental fuel)
- Disposal/recycling costs
- Transportation/location of site
- Regulatory requirements/permitting

Cost Comparison Assumptions

- Capital (equipment procurement and setup costs)
  - Motors, blowers, compressors, thermal units, etc.
  - Piping
  - Installation
  - Instrumentation
  - Delivery
- Operation and maintenance costs
  - Expendables
  - Reporting
  - Site visit activities
  - Field staff transportation
  - Waste transportation and disposal
  - Laboratory
  - Electricity ($0.12 per kwh) / energy/
  - Supplemental Fuel costs (Natural Gas at $0.015 per cubic foot)
  - Field equipment
  - Equipment maintenance or replacement
  - Subcontractor or subconsultant markup (15%)

C3-Technology Process Flow Diagram

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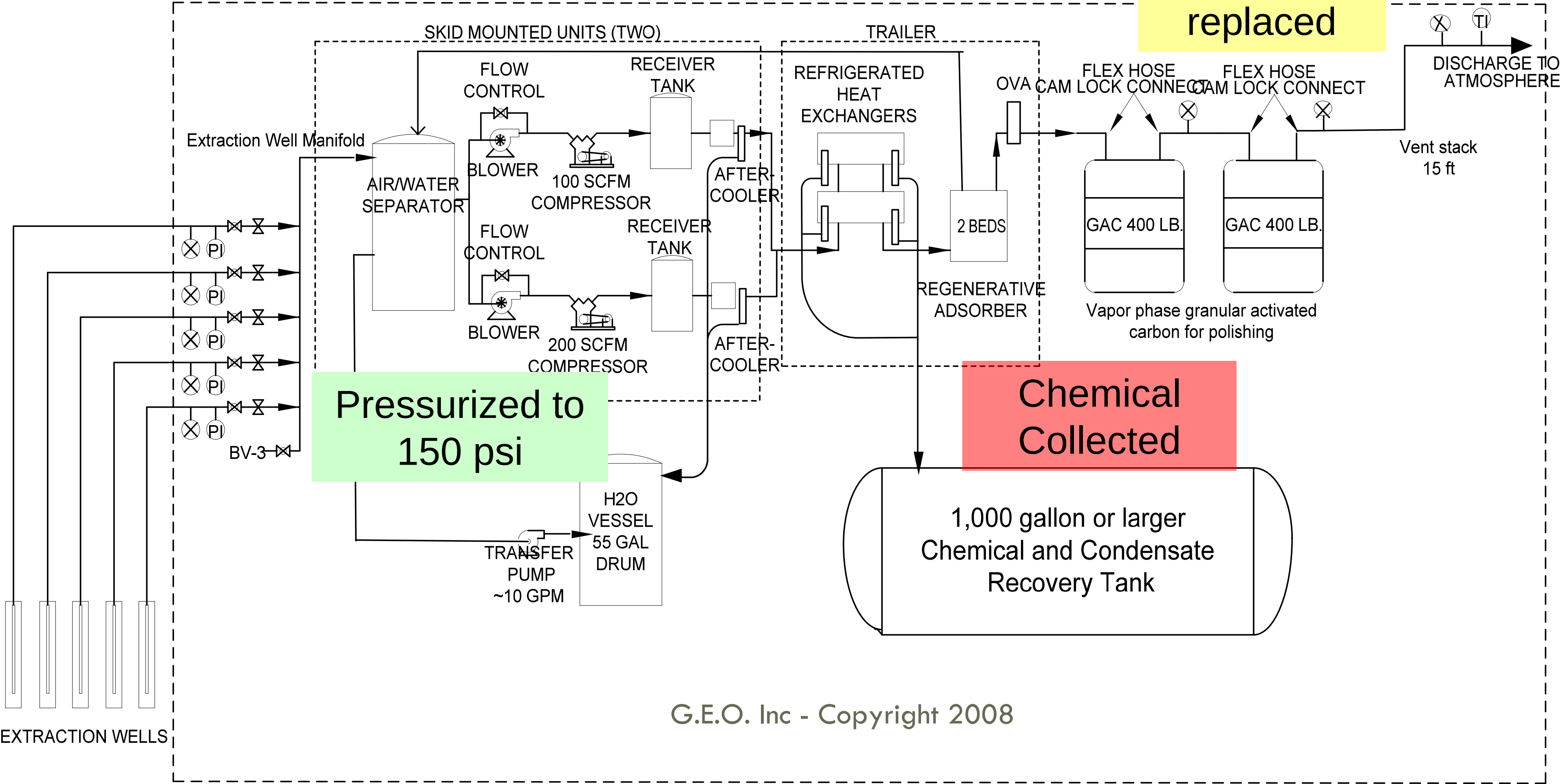
300 SCFM System



Cooled to -40 Degrees F

Adsorbents seldom replaced

Pressurized to 150 psi

Chemical Collected

Carbon Footprint Model Assumptions

- Calculations derived from published protocols
- Focus on the 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*