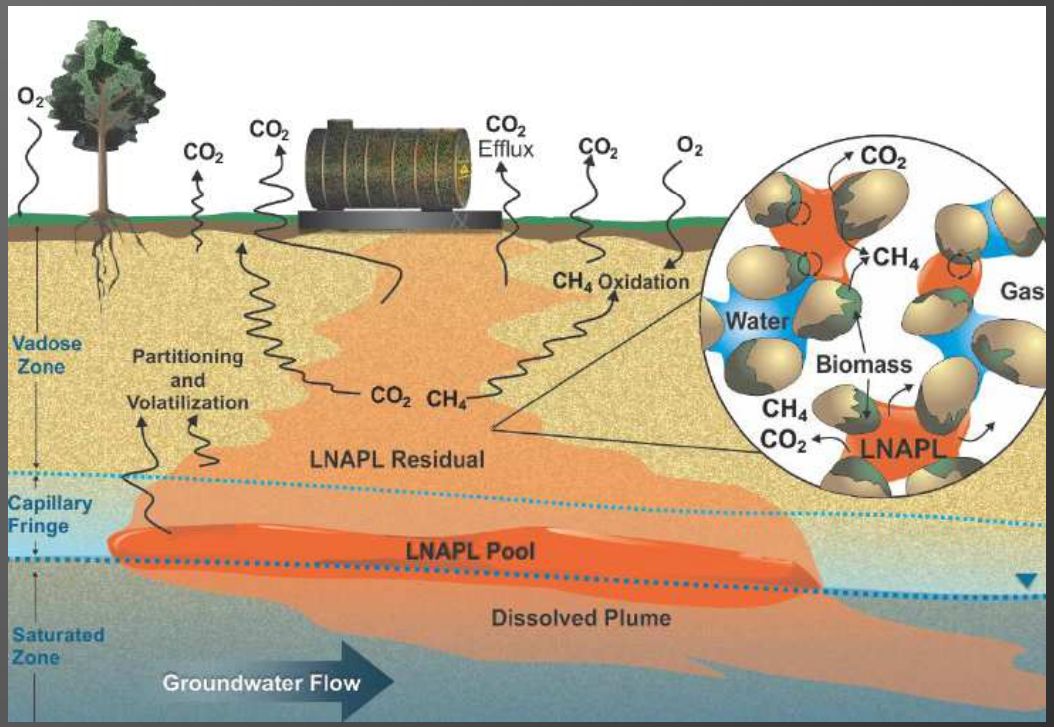
QUANTIFICATION OF VAPOR-PHASE RECOVERY



A presentation for

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by

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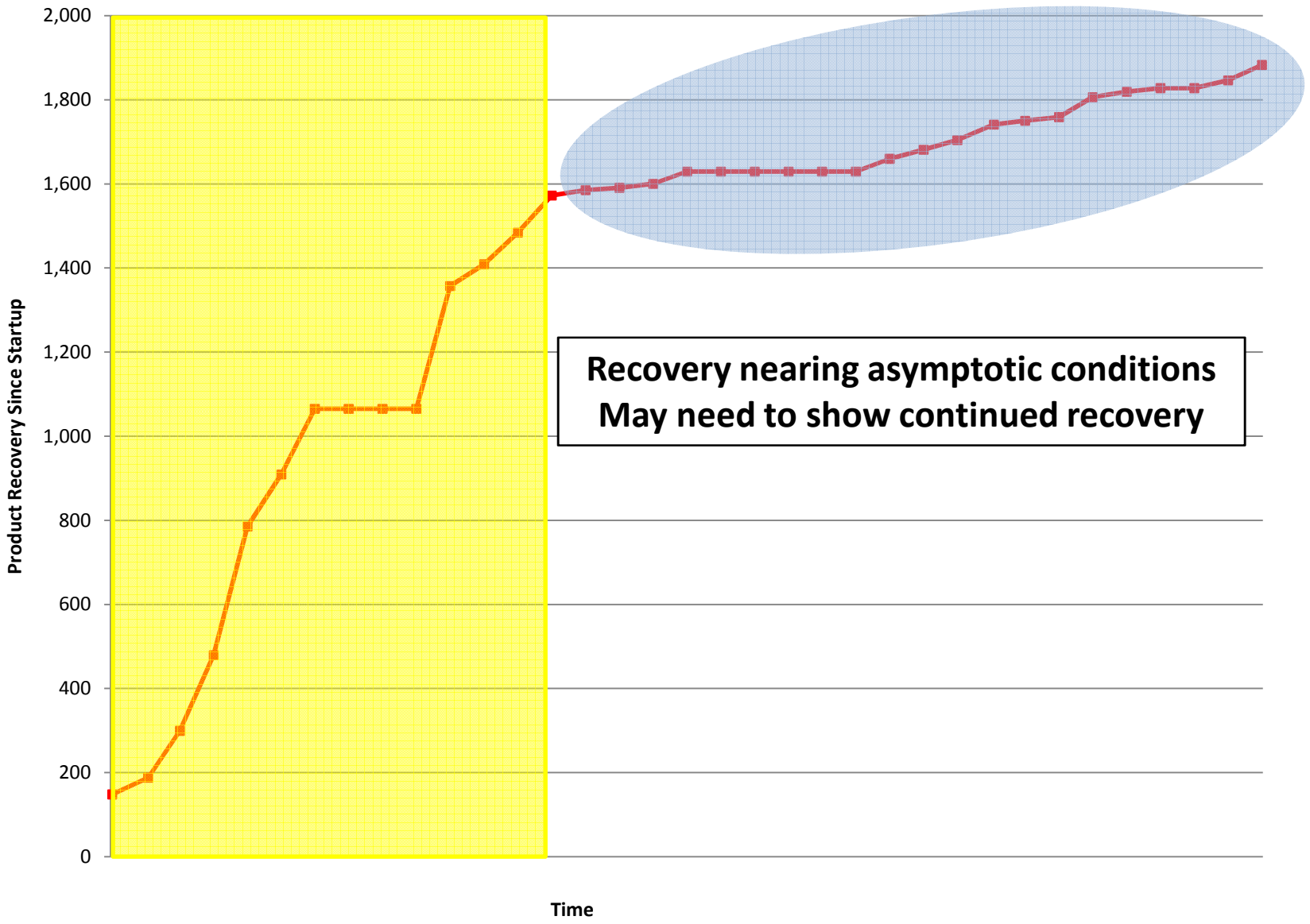
OUTLINE

- Why quantify vapor recovery?
- General methodology for estimating equivalent free-product recovery
- Evaluation of methods for estimating thermal energy content of process stream

Purpose for Quantification

- Demonstrate that LNAPL plume volume is being reduced by more than just liquid-phase extraction
- Show remedial progress when liquid-phase extraction begins to diminish
- Provide option for reaching remedial endpoints

Cumulative Product Recovery Over Time



General Method

"Equivalent Free-Product" Definition:

Volume of free-product that would need to be burned as fuel to produce the same amount of energy that is released by the combustion of the volatile gases within a given volume of soil vapor extracted by the system

- Conversion of gaseous SVE process air to flow rate in equivalent liquid free-product
- Relates the energy content of the vapor and liquid phases

Steps in Calculation

- Field measurements / samples
- Energy content measured and/or estimated from the influent SVE process air
- Vapor phase energy content converted to equivalent liquid phase energy content
- Liquid phase energy content converted to an equivalent free-product recovery volumetric flow rate
  - Based on measured unit weight of the free-product

Assumptions

- The energy in the vapor phase is proportional to the energy in the liquid phase
- The heating value of the SVE stream is not influenced by any external source
  - Leaking natural gas
  - Biodegradation of non-petroleum organic matter
- The contribution of carbon dioxide to the overall energy content of the SVE stream can be neglected

Calculating Equivalent Recovery

$$Q_{fp,equiv} = \frac{24\dot{q}_{SVE}}{(H_{c,fp})(\gamma_{fp,v})}$$

- $Q_{fp,equiv}$ = equivalent free-product recovery in gallons per day (gpd)
- q_{SVE} = measured / estimated heating rate of the influent SVE process stream in BTU/hour
- $H_{c,fp}$ = heating value / heat of combustion for the liquid free-product, in BTU/lb
- $\gamma_{fp,v}$ = unit weight of liquid free-product, in lb/gal

Heating Value of Vapor

- Thermal Method
  - Using temperature measurements
- Combustion Energy Method
  - Using lab analysis
  - Using screening equipment

Thermal method

- Temperature set-point in oxidizer maintains chamber temperature by opening or closing valve to control supplemental fuel
- The amount of heat required to maintain set-point temperature is directly proportional to the flow of process air being heated

General Heating Rate Formula

$$\dot{q} = Q\, c_p (T_2 - T_1)$$

- q = heating rate input to the fluid to cause the desired temperature change;
- Q = fluid volumetric flow rate;
- c_p = specific heat of the fluid being heated;
- T_2 = final temperature that the fluid is heated to (setpoint temperature);
- T_1 = initial temperature of the inlet stream.

$$\dot{q}_{tot} = \frac{Q_{tot} \times 1.1 \times (T_2 - T_1)}{AH}$$

- AH = available heat factor

Thermal Energy Balance

- q_{ng} is the heating rate of natural gas fed to the Flame-Ox in BTU/hr.

$$\dot{q}_{tot} = \dot{q}_{ng} + \dot{q}_{SVE}$$

- With known natural gas consumption, heating rate of SVE stream can be determined

Thermal Energy Method

Advantages

- **Inputs are easy to measure**
- **No special samples need to be collected and no special measurements are required beyond the process air flow rate, temperature and natural gas usage**

Disadvantages

- **Significant calibration and performance testing required**
- **Available heat factor not easily measured, variable to operating conditions**
- **Accuracy is limited when energy content of vapor stream is low relative to supplemental fuel**

Combustion Method

- Utilizes the concentrations of the major compounds present in the stream
  - molecular and energy data of these compounds
  - estimate the theoretical amount of energy released during the combustion of those compounds
- The theoretical amount of energy released during the combustion of a flammable compound is equal to the volume of that compound multiplied by the heat of combustion of that compound (typically in BTU/ft^3 for a gas)

Combustion Method Formula

$$\dot{q}_{c,i} = \frac{60 C_i Q_{SVE} H_{c,i}}{1 \times 10^6}$$

- $q_{c,i}$ = heating rate produced from the combustion of a given flow rate of a volatile component, (i);
- C_i = concentration of the compound in the SVE process stream, in ppmv;
- Q_{SVE} = SVE process stream volumetric flowrate in acfm;
- $H_{c,i}$ = heat of combustion of the compound (i), as published in reference literature, in BTU/ft^3;

Combustion of Process Stream

$$\dot{q}_{SVE} = \sum_{i=1}^{n} \dot{q}_{c,i} = \sum_{i=1}^{n} \frac{60 C_i Q_{SVE} H_{c,i}}{1 \times 10^6}$$

- SVE process stream heating factor is equivalent of the sum of all component combustion energies
- Lab analysis for methane and TPH can simplify this summation

Combustion Method

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Advantages

- **Direct measurement of energy content**
- **No factors in the equation that are estimated (such as Available Heat) – leads to greater accuracy**

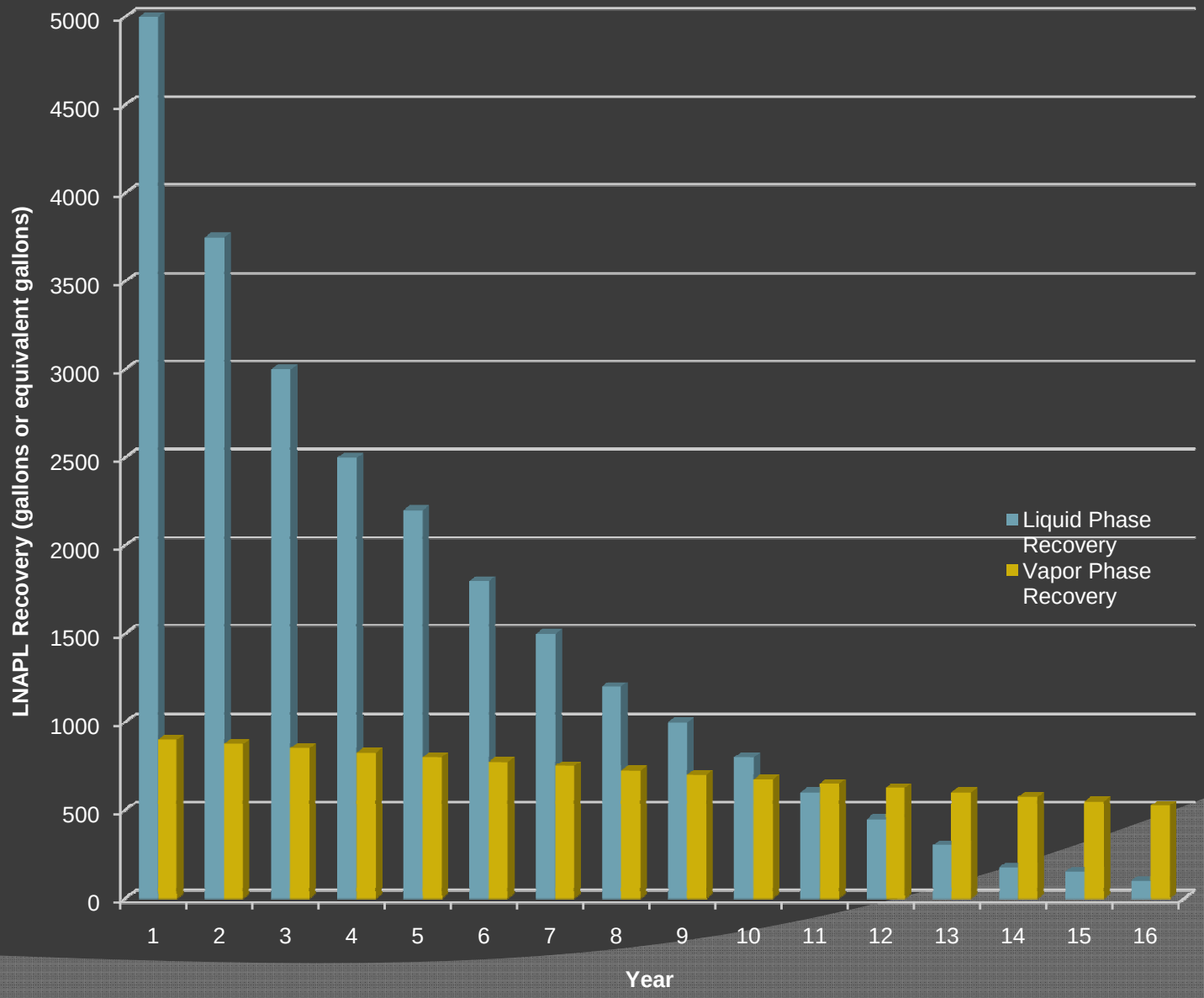
Disadvantages

- **Frequent data required – samples or screening**

Use screening equipment such as Hydrocarbon Flame Ionization Detector instead of lab analysis

- **Real-time data without need for frequent lab analysis**

Comparison to Liquid Phase



Summary

- SVE systems are removing LNAPL mass in the vapor-phase
- Quantifying this rate of degradation is valuable
  - Vapor phase will eventually become primary removal mechanism
- There are different methods of calculating
  - We have found Combustion Method to yield most consistent results

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QUESTIONS?

Thank you for your time!

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