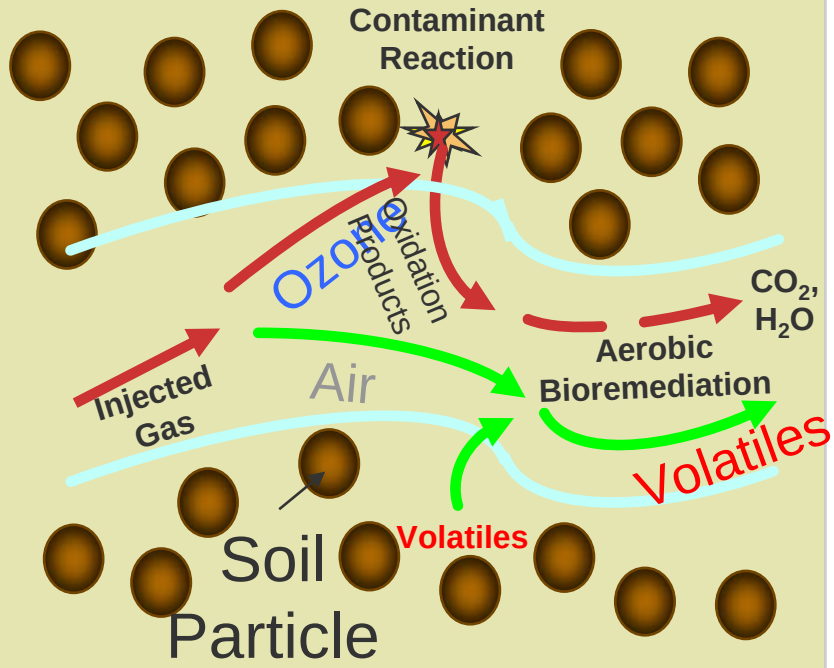
In Situ Ozonation - What

- **Enhancement by injection of ozone for air sparging and soil vapor extraction technologies.**
  - Direct oxidation
  - VOC stripping
  - Aerobic Bioremediation
- **Ozone has one of the highest oxidation potentials (- 2.07V).**
- **Oxidation reaction with ozone is rapid (minutes to days).**



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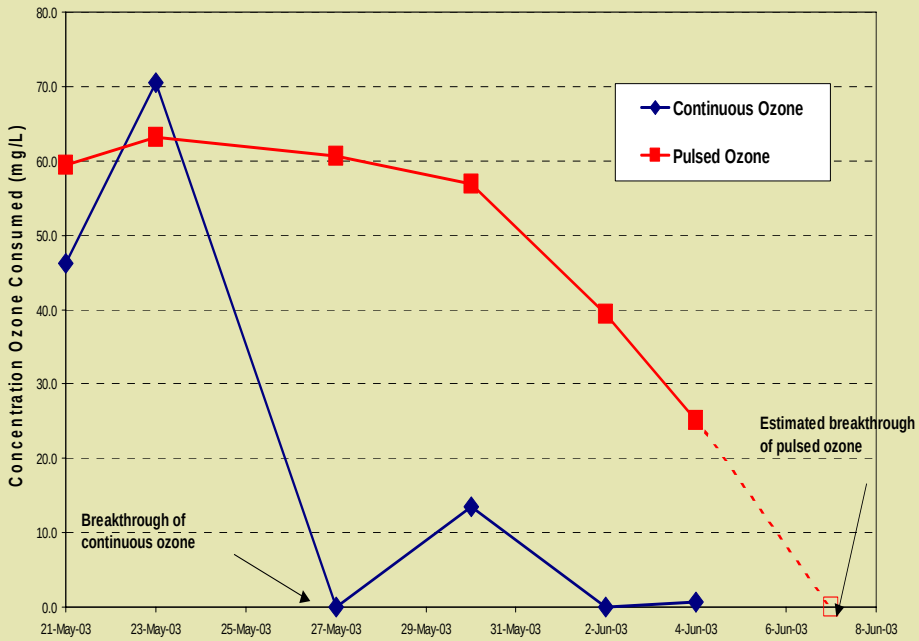
Ex Situ Ozonation - How

- **Pulsed injection**
  - Sequential injection in individual wells or treatment cells
  - PLC and solenoid valve controlled



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In Situ Ozonation - How

- **Ozone gas (O_3) injection**
  - Vadose zone direct contact
  - Sparging in saturated zone
  - Treatment cells
- **Uses on-site ozone gas generation (3 TO 5% conc.)**
- **Ozone degrades to oxygen for secondary aerobic biodegradation**

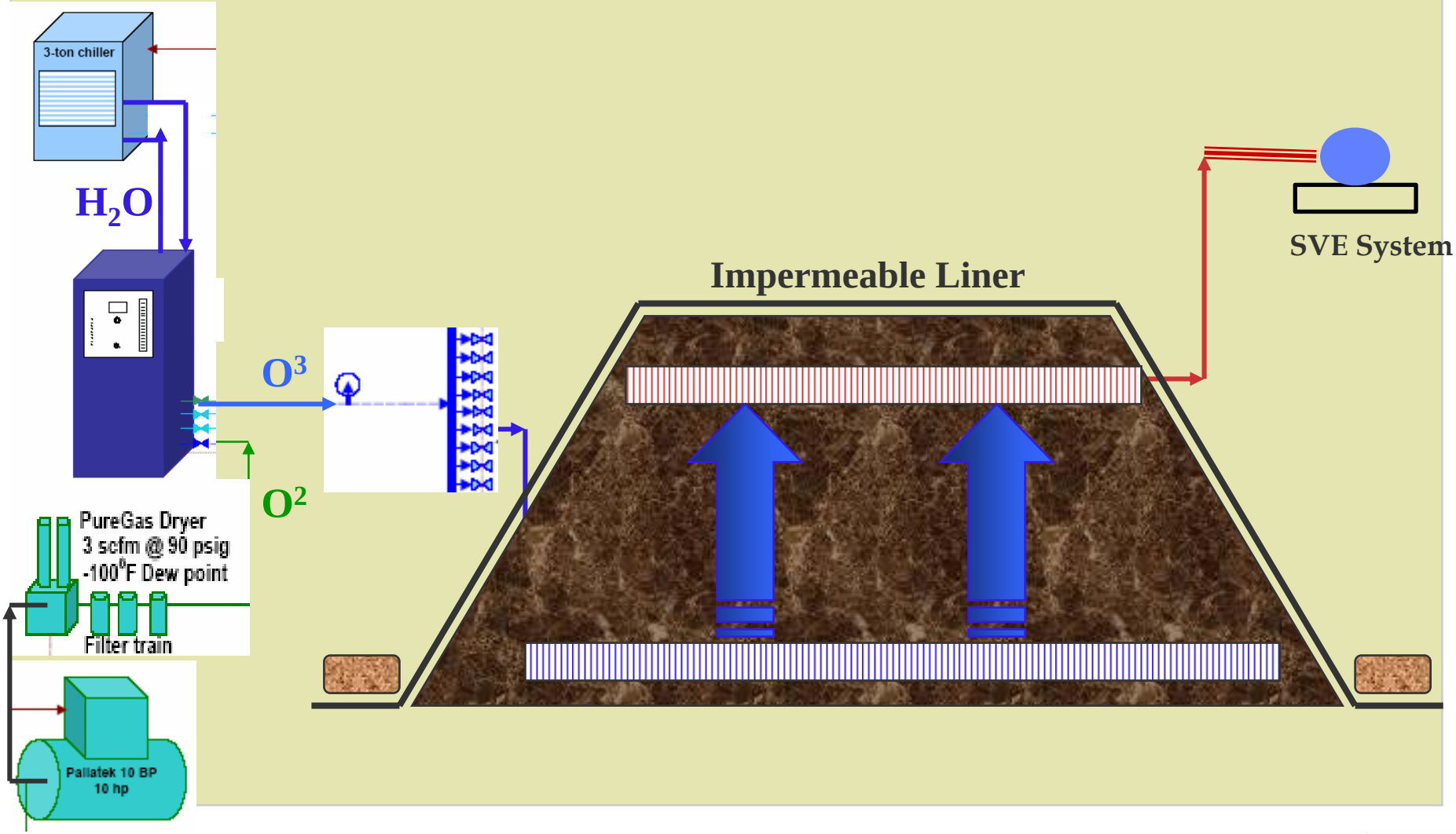
Ozonation - Where

- **Vadose zone**
  - Coarse-grained, air permeable lithology – unrestricted
  - Fine-grained clays and silts – fracturing required
- **Saturated zone**
  - Coarse-grained, permeable lithology
    - Enhanced air sparging
    - Sparge/ozone barriers
- **Ex situ – modified bio-piles (“burritos”)**

Project Profile: Ex Situ Ozonation at Former Flare Pit Site

Site Conditions	Former flare pit site in northern Alberta. Impacts to soil by F2 to F3 petroleum hydrocarbons (PHC).
Regulatory	Alberta Energy and Utilities Board (EUB).
Soils	Soils used to construct the treatment cells were comprised of clayey soils with relatively high moisture content that were very heterogeneous.
Pilot Test Strategy	Constructed three treatment cells to evaluate ozone, oxygen and air injection over a three month test period.

Ex-Situ Ozonation - How



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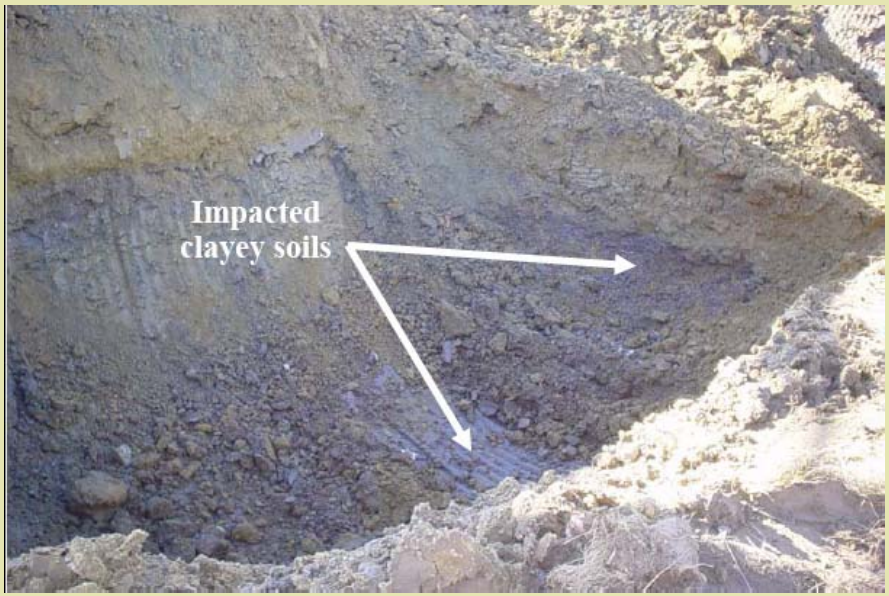
Impacted Soil Excavation



Impacted wet and clayey soils in floor and sidewalls of excavation

Treatment cell soils excavated and mixed to reduce heterogeneities and moisture content.

Treatment Cell Construction

Excavated soil stockpiled for cell construction

Excavated, impacted soils placed in cell liners

Injection Piping Construction

Injection well layout at bottom of cell

Injection well screen -Sch 80 PVC material

Injection Piping Construction , Cont.

Filter sand backfill around injection points

Extraction Piping System

2-inch dia. Sch 80 PVC installed at top of cell

Extraction piping manifold

Treatment Cell Construction

Completed treatment cells with straw insulating layers in place.

Injection and SVE connector piping construction

Ozone and Oxygen Generation Equipment

Containerized oxygen and ozone generation equipment.

Oxygen generation, injection manifold and PLC control equipment

Pilot Test Conclusions

- An area of highly discolored, bleached soil was observed around each of the eight ozone injection points in treatment cell P-3.
- Highly oxidized (white/chalky) wood debris found throughout soil treatment pile.
- F3 and F4 concentrations in discolored soils near an injection point were reduced between 84 and 93 percent.

Pilot Test Conclusions

- **Soil heterogeneity & moisture content were the dominant factors in the pilot test.**
- **The ozone system operated continuously through the winter and was essentially unaffected by weather conditions.**
- **Final F2, F3, and F4 concentrations decreased from baseline conditions in both the oxygen and ozone cells.**
- **The ozone cell concentrations decreased roughly twice as much as the oxygen cell concentrations.**
- **F2 to F4 PHC concentrations can be reduced to below 100 mg/kg.**