INTRODUCTION

In Situ Chemical Oxidation (ISCO) is a remedial technique that introduces a chemical oxidant into the subsurface to oxidize contaminants as a method of converting them to innocuous byproducts such as carbon dioxide, chloride, or water. In situ processes involve placement of oxidants in direct contact with the contaminated soil and groundwater and can be applied in the saturated or unsaturated portion of the subsurface.

The most common oxidants used for ISCO are permanganate (MnO_4^-), persulfate ($S_2O_8^{2-}$), hydrogen peroxide (H_2O_2), and ozone (O_3). A detailed summary of the oxidation chemistry and applicability to classes of contaminants can be found in the *Technical and Regulatory Guidance for In Situ Chemical Oxidation of Contaminated Soil and Groundwater – Second Edition (Link to Guidance)* published by the Interstate Technology and Regulatory Council (ITRC).

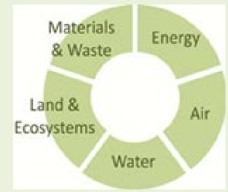
The most common delivery methods used to introduce oxidants to the subsurface include:

- **Injection through dedicated injection wells or temporary direct push injection points**
  The use of temporary direct push injection wells versus dedicated injection wells will vary based on the site geology/hydrogeology, site access, the ability to install and maintain permanent infrastructure on the site, and the anticipated number of injection events needed to meet the remedial objectives.
- **Recirculation that includes coupled injection and extraction wells**
  This delivery method would be used to expedite pore volume flushes across a source area or when surface obstructions do not provide access for complete coverage of the target treatment area.
- **Soil mixing by blending an oxidant into the soil matrix using specialized mixing tools from the ground surface**
  This application is typical in shallow source zones, low permeability material that makes injection difficult, or source areas with significant heterogeneity.

The following sections provide key considerations and Best Management Practices (BMPs) that can be considered throughout design, construction, operation, and monitoring phases of any ISCO project.

Core Elements of Green Remediation

- *Reducing total energy use and increasing renewable energy use*
- *Reducing air pollutants and greenhouse gas emissions*
- *Reducing water use and negative impacts on water resources*
- *Improving materials management and waste reduction efforts, and*
- *Enhancing land management and ecosystem protection*



DESIGNING AN ISCO REMEDIATION SYSTEM

Planning during the design phase provides an opportunity to identify BMPs that can be used throughout the ISCO project.

The design of an ISCO system begins with a robust conceptual site model (CSM) to assure a thorough understanding of the contaminant source area(s) and plumes. To move forward in an ISCO system design it is necessary to understand the factors influencing groundwater flow and contaminant migration, including aquifer heterogeneity, hydraulic conductivity, and identification of obstructions or preferential pathways in the subsurface. Additionally, data needed to determine oxidant loading include groundwater geochemistry, soil heterogeneity, and the chemical oxidant demand of the soil and groundwater at the site.

In addition to a robust CSM, bench or pilot scale treatability testing should be completed during system design. A well-designed bench or pilot scale testing program will:

- Determine the treatment capacity of a range of oxidants and potential activators;
- Determine the loading of the oxidant necessary for successful application and an understanding of the non-target demand;
- Evaluate the post-amendment chemistry to ensure the ISCO amendment does not generate any negative byproducts;
- Determine if any supplemental technologies are needed to destroy contaminants in hot spots or areas where nonaqueous phase liquid (NAPL) may be present;
- Provide data to develop preliminary costs estimates, including an estimated number of

applications to address the total oxidant demand; and

- Understand fate and transport of the injectant and potential for impacts on proximate non-target receptors.

In addition to remedial objectives to protect human health and the environment, it is the policy of NYSDEC to approach remediation projects in a way that minimizes the environmental footprint of a clean-up action. This concept, outlined in DEC Program Policy 31, is referred to as "Green Remediation". Additionally, Commissioner's Policy CP-75 – DEC Sustainability, seeks to have NYSDEC continue its "lead by example" approach to accelerate and guide the transition to the low-carbon sustainable economy of the future.

A well-understood CSM allows the designer to optimize the placement of injection points as well as the volume and types of oxidants.

With a robust CSM and the results of a well-designed treatability study, the designer will be able to complete a system design that will focus on getting the oxidant to the areas where treatment is needed in a way that minimizes resource use. BMPs to be used during the construction phase should be identified in the design phase and included in the final design. It should be noted that the primary goal in remediation is to protect human health and the environment; the "greening" of a remedial technology should not reduce its effectiveness.

Each BMP must be evaluated on a site-specific basis. A significant portion of the environmental footprint left by construction of an ISCO system involves the installation and testing of wells used to deliver the selected reagents and monitor performance. Recommended BMPs to include:

BMPs related to the design of injection points:

- Using direct-push technology for constructing temporary or permanent wells rather than typical rotary methods, wherever feasible, to eliminate the need for disposal of cuttings and improve efficiency of substrate delivery into discrete vertical intervals;
- Maximizing reuse of existing or new wells and boreholes for injections to avoid a range of wasted resources;
- Use gravity-fed injection if geologically feasible; and
- Using groundwater recirculation processes allowing multiple passes of groundwater through fewer wells.

BMPs related to continued monitoring programs:

- Use an optimized sampling schedule to minimize the number of samples and accounts for adjustments as treatment progresses and the plume size decreases;
- Consider using passive sampling devices during monitoring for less energy usage and further waste reduction; and
- Develop a flexible injection program that evaluates adjustments in delivery for follow-up injections. This BMP provides the ability to focus on a recalcitrant area with targeted injections and limits additional injections in areas that are either performing well or have limited effectiveness.

Consider the carbon footprint of oxidants during the selection process in cases where oxidants can be equally effective.	
CARBON FOOTPRINT	
Oxidant	**CO_2 per Ton**
Hydrogen Peroxide	1.2
Sodium Persulfate	1.25
Permanganate	4.0

BMPs for sourcing chemical oxidants can focus on reduction of greenhouse gas (GHG) emissions through the sourcing and handling of the oxidants. BMPs include:

- Once the type of oxidant has been selected, evaluate the vendors and base selection on proximity to the site to reduced emissions associated with delivery;
- Stage the oxidant onsite at the time of delivery in a location with secondary containment that is convenient to the injection well network and injection equipment. This will limit the need for heavy equipment onsite to continuously move the oxidant throughout the injection; and
- Request the oxidant in packaging that does not require specialized or heavy equipment to move while onsite.

REMEDIAL CONSTRUCTION CONSIDERATIONS

While implementing an ISCO remedial program, some additional BMPs may be considered based on CSM elements, design constraints, and site or public conditions. Additional BMPs could include:

- *Energy Consumption*
  Energy consumption focuses on the need to conserve energy supply and reduce emissions of GHG. On site, this typically includes electrical use, fuel consumption from on-site equipment and transportation, and other energy usages associated with the remedy.
- *Greenhouse Gas (GHG) Emissions*
  GHG emissions are directly related to climate change and have adverse effects on human health and the environment. As such, emissions of GHGs should be reduced wherever possible. On-site, GHG emissions are typically from the oxidant selected (see details on GHG emissions for common oxidants), equipment usage, transportation, and materials.
- *Criteria Air Pollutant Emissions*
  Air pollutants are regulated by the Clean Air Act of 1970 and are known contributors to various health effects such as asthma, lung cancer, and eye irritation. Criteria pollutants include sulfur oxides (SOx), particulate matter (PM), and other substances and are typically contributed to transportation, electrical usage, and heavy machinery used on-site.
- *Water Impacts*
  Optimized water consumption and minimal impacts to water resources is desirable on site. Water usage is dependent on site characteristics and should be evaluated extensively during remedial activities.
- *Ecological Impacts*
  The positive and negative effects of remedial activity on the surrounding ecosystems should be evaluated.
- *Resource Consumption*
  This metric includes resources that are not accounted for in other metrics, such as landfill space or imported materials.
- *Worker Safety*
  Worker safety is generally more at risk during remedial activities due to the presence and usage of equipment and heavy machinery.
- *Community Impacts*
  Due to the scale of remedial activities, disturbances can sometimes extend to the surrounding community. The health and safety issues caused by these disturbances should be mitigated and monitored closely.

For a comprehensive sustainable ISCO design, green remediation practices, objectives, and technologies should be considered for the entire life cycle of the project. Reducing the environmental footprint of such projects begins with adequate site characterization, well-defined target zones, and complete knowledge of Green and Sustainable Remediation metrics. These metrics are met by incorporating environmental footprint reduction tactics throughout the remedial design and carefully planning the operation and management of the site.

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