NAPL Removal from Fractured Bedrock Using Ivey-Sol®
(SPT®) Non-Ionic Surfactants – Successful Remediation

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Abstract

Ivey-sol® Selective Phase Transfer (SPT®) involves the selective micro-encapsulation of NAPL contaminants at
the molecular level using Patented non-ionic surfactant mixtures. The target NAPL contaminant molecules
undergo a phase transfer, where micelle micro-encapsulated droplets are “dissolved” into water (i.e. smaller
more mobile units) which are stabilized in solution allowing their rapid removal.

In-situ applications achieve contact between the Ivey-sol/SPT mixtures and target NAPL compounds via
injection wells (IW) and/or injection galleries (IG). The IW/IG’s are designed and located to ensure effective
contact between the injected mixtures and the target soil, bedrock and/or groundwater aquifer contaminants.
The ensuing result is a phase transfer (dissolving) of free phase and/or dissolved target NAPL into the
groundwater phase via selective partial-micelle micro-encapsulations. Extraction wells are employed to extract
the dissolved contaminants from the contaminant system, hence reducing the contaminant mass following each
injection event that is monitor via sampling.

The complexity of commercially NAPL compounds led to the development of several Ivey-sol/SPT mixtures
selectively applicable to specific ranges of LNAPL compounds such as; light range gasoline, medium range
diesels, and heavy range bunker-C, and PAH’s and MTBE. DNAPL compounds include; PCE, TCE, TCA,
CTET, phthalates, PCB, some process-wastes and selected pesticides. The Ivey-sol/SPT molecules, in addition
to being environmentally friendly, do not alter their target NAPL compounds as they interact with the surface of
the target molecules only, hence there is no formation of unwanted by-products. Further, they do not persist in
the environment after application as they are used in very low concentration (ppb) and are highly biodegradable
(i.e., 97% in less than 27 days).

Further, Ivey-sol/SPT reduces the NAPL compounds mass that would otherwise be available for release as
vapor phase emissions. Case studies demonstrated that project goals were achieved at 90-95% of the sites
within 18 months¹, and typically within 12
months for most small to medium size sites. Correspondingly, significant cost, time and liability savings have
been realized during the application of Ivey-sol/SPT for soil, groundwater and bed-rock remediation.

1.0 INTRODUCTION

Current site remediation technologies and approaches that have been used to treat Fractured Bedrock
contamination include the use of sub-surface peroxide injections, bio-remediation, conventional pump and
treatment, excavation, vapor extraction, air sparging, oxygen release compounds, natural attenuation and risk
management, to name but a few. Although these techniques are applied, many site-specific conditions (i.e., pH,
DO, COD, BOD, Reduction-Oxidation Potential, moisture, salinity, hardness, temperature, geology factors,
hydraulic conductivity, salinity, Red-ox potential, etc.) must exist for their favorable application. In addition,
each approach may only work for only limited type and or range of contaminants. This can be further
complication by the potential formation of unwanted by-products, some that either unidentified and or
potentially more toxic than the target contamination. Some remediation process(s) used to treat MTBE may
form TBA which has been identified as a by-product of concern.

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Characterization of bedrock aquifers contamination is a more complicated than alluvial soil and groundwater systems when considering methodology, project cost, resource commitment, and interpretation of findings which may require sophisticated three-dimensional computer modeling. Even with considerable effort to characterize a fractured bedrock system, several assumptions are often required lending to some level of uncertainty.

Remediation is often a lengthy and costly process to implement and may introduce some undesirable project risks. Ivey-sol SPT is easily implemented for most in-situ and ex-situ applications. It’s applicable for a wide range of LNAPL and DNAPL contaminants, it does not alter the chemical structure of the target contaminant (i.e., No By-Products), and is not significantly affected by site-specific conditions. The Ivey-sol mixture can increase the wetting property of water, this promotes increased contact with NAPL compounds located in narrow to microscopic fractures that would otherwise remain within the fractured bedrock matrix and potentially contribute to contamination rebound.

The objectives of this paper are four fold. First introduce the reader to the field of non-ionic surface active agents (SAA), secondly to illustrate their application for LNAPL’s and DNAPL’s within fractured bedrock media. The third objective is to present a recently patented remediation technology known by the registered trade marks names, Selective Phase Transfer Technology (SPTT®) and Ivey-sol®. The fourth is to present the project cost and liability benefits associated with this new technology. The terms Ivey-sol and SPTT are interchangeable in this paper.

In brief, Ivey-sol/SPT technology involves the micro-encapsulation of NAPL compounds making them more soluble and mobile in water. The NAPL molecules undergo a phase transfer and are encapsulated as partial-micelles at a molecular level. The micelle-encapsulated molecules are dissolved into the water as small very microscopic mobile units (Figure 1-1). Once dissolved, they are more easily transported and removed from the contaminant system. The Patented SPT/ Ivey-sol Technology is discussed in detail in the following sections through a description of laboratory and field application results, range of commercial applications, and case studies.
2.0 BACKGROUND INFORMATION

SAA (Surface Active Agents) are also known as Phase Transfer Molecules and Surfactant can dissolve in both water and organic solvents. Their chemical ability is largely a function of their physical and chemical characteristics (Figure 2-1). Their molecular structure consists of hydrophilic (water-loving/miscible) and hydrophobic (water-fearing/immiscible) groupings. For Ivey-sol/SPTT, the hydrophilic groupings are also known as oleophobic (oil-fearing/immiscible), and hydrophobic groupings are also known as oleophilic (oil-liking/miscible). The chemical characteristics and behavior of SAA’s are controlled by the functional groups on each molecule. Hence, a broad spectrum of chemical behavior and utility can be observed.

![Figure 2-1 Surface Active Agent (SAA) Hydrophilic (water loving) and Hydrophobic (oil-liking) Groupings Shown.](image)

A significant characteristic of SAA is their ability to greatly reduce the surface or interfacial tension between two liquids or a liquid and a solid. This ability extends to very low concentrations of the SAA. Surface tension is the force acting on the surface of a liquid, tending to bring the contained volume into a form having the least superficial area. Quantitatively, it is the force that appears to act across a line of a unit length on the surface (Figure 2-1). This is also known as interfacial force, interfacial tension or surface tension. In the case of water, the water molecules are strongly associated due to their polarity; the oxygen end of the molecule is more negative than the hydrogen end (Figure 2-2). This results in a special attractive force called hydrogen-bonding between the oxygen and hydrogen atoms of neighboring water molecules. Consequently, a significant amount of energy would be required to overcome the surface tension caused by the hydrogen bonding, and or break apart or separate water molecule into the gaseous state.

The surface tension of water is 72-dyne/cm. SAAs can reduce this value to 30 dynes/cm or lower. Under such conditions, SAA molecules overcome the liquid surface tension forces and demonstrate an ability to dissolve compounds that would otherwise not dissolved in a liquid such as water. With the reduction in water tension the water is described to have better “wetting” properties. This is due to the reduced interaction between neighboring water molecules which reduces a behavior described as “clustering” (i.e. bunching of water molecules together) that is a function of hydrogen-bonding. As a consequence, the interacting clusters of water are much smaller and can flow through media more rapidly (i.e., increased K – conductivity).

![Figure 2-2 Water Molecule with Hydrogen Bonds](image)
There are four main types or classes of SAA, which are primarily based on their hydrophilic groupings present. These include:

- **Anionic**: They have one or more negatively charged groupings. They have very good detergent ability and are commonly used as laundry detergent.
- **Cationic**: They have one or more positively charged groupings. They typically have poor detergency, but are well suited for use as germicides, fabric softeners, and emulsifiers.
- **Non-ionic**: As their name implies, they have no ionic constituents or groupings. They are the largest single group of SAA and have a correspondingly wide range of chemical characteristics and application. SPTT mixtures, which have the unique ability to selectively dissolve LNAPL, DNAPL, polycyclic aromatic hydrocarbons (PAH’s), trichloroethane (TCE), perchloroethylene (PCE) and other similar petroleum products.
- **Amphoteric**: They contain both anionic and cationic groupings and have the characteristics of both anionic and cationic SAA. They work well at neutral pH and are found in products such as hair shampoo, skin cleaners, and carpet shampoo.

### 3.0 MECHANISM

When SAA are dissolved or dispersed in liquids, they are preferentially absorbed at an interface. This unique characteristic gives rise to a variety of physical-chemical properties of particular interest. As indicated above, the SAA molecules have a hydrophilic grouping with an attraction for the polar water surfaces. This grouping will ensure its solubility in water. Once a non-ionic SAA is dissolved, its hydrophilic grouping associates with the water at one or more of the oxygen atoms in the grouping (Figure 3-1). The hydrophobic groups aggregate within each other. When the concentration of the surfactant is raised, micelles will form. This concentration is known as the critical micelle concentration (CMC). Ivey-sol/SPTT is effective well below the CMC. The SAA molecules align themselves with the water surface. The hydrophilic groups align outward, toward the water, and hydrophobic groups are squeezed inward, away from the
water (Figure 3-2). Because of this chemical reorientation at a surface, the SAA aggregates as a function of the concentration, and micelles will form once the CMC is met.

![Figure 3-1 SAA Hydrophilic Interaction With Polar Water Molecule](image1)

![Figure 3-2 Alignment At Surface and Squeezed In Water Solution](image2)

The hydrophobic (water-fearing) groups on SAA may align themselves on non-polar molecular surfaces, such as those commonly found in petroleum products. The SAA will aggregate around the oil molecules and form a micelle, which will dissolve the non-polar oil phase in the polar water phase. This mechanism lifts and removes oils from soil and dissolves free petroleum product into the water phase (Figure 3-3).

This mechanism can be described as follows:

a) When oil / petroleum product is absorbed on a soil grain, water alone will not remove it from the soil. This is a function of the hydrophobic characteristics of the oil, which repels the water at its surface and its inherent low water solubility.

b) With the addition of SAA molecules, the hydrophobic grouping is repelled by the water but attracted to the oil in the soil. At the same time, the hydrophilic grouping is attracted to the water molecules.

c) These opposing forces loosen the oil from the surface of the soil grain and suspend it in the water phase. Once dissolved, the suspended oil is easily removed from the water phase when recovered for treatment.

![Figure 3-3 SAA Interaction With Oil On A Surface With Micelle Encapsulated Of Oil Droplet](image3)

Emulsions can be described as either oil droplets suspended or dissolved in water, or water suspended or dissolved in oil or a mixture of both. It is the selection of the SAA and their order of addition that will dictate the type of emulsion that can be established, the concentration of SAA required, and the range of utility. Solubilization is closely related to emulsification. As the emulsified oil droplets become smaller, a condition is achieved where the droplet and the micelle are similar in size. Once this condition is achieved, the oil droplet can be described as being dissolved or miscible in solution.

To establish a micelle, the CMC of the SAA must be present. However, for certain non-ionic SAA, such as those present in SPTT mixtures, the oil products are dissolved with SPTT mixture at concentrations well below the CMC. This procedure allows the SAA to aggregate around the petroleum molecule and substantially
increase its solubility in water. This unique feature allows for the rapid and cost effective removal of oil products from the environment.

4.0 SELECTIVE PHASE TRANSFER TECHNOLOGY (SPTT™)
Selective Phase Transfer Technology, as outlined in Section 1.0, is a fully patented technology that was developed between 1993 and 1998 through extensive collaboration with local University Research Staff and ongoing field testing. The result of the five-year effort was the development of four patented mixtures introduced through two patented processes, one in-situ and one ex-situ. The SPTT mixtures are composed of highly specific, non-ionic surface-active agents formulated to permit the selective dissolving of a wide range of LNAPL and DNAPL compounds of environmental concern. The results achieved during laboratory research and field-applications confirmed the effectiveness of the SPTT mixtures as a solution for air, soil and groundwater remediation. This section will discuss the technology from an applied perspective, introducing supportive technical reference information where applicable, and address MTBE application.

4.1 TECHNOLOGY GENERAL FACTS
Some general facts regarding the technology are listed below. These facts were derived from field performance results, laboratory findings, client and regulatory feedback and work completed by others.

- Application of Ivey-sol/SPTT for NAPL contamination is 75% faster than pump and treat approaches;
- 90-95% of contaminated site are cleaned-up in less than 18 months;
- Range of application includes: LNAPLs, DNAPLs, Heavy Metals, and Radio-Active Contamination.
- Average clean-up period for most small to medium size sites is 12 to 18 months;
- Reviewed and approved for use in USA and Canada by various state and provincial departments of environmental protection;
- Generally regarded as non-toxic and safe for both land-based (in-situ & ex-situ) and off-shore spills and shore-line clean-up applications;
- Application does not hinder performance of groundwater pump and treat systems.
- Not affected by salinity, hardness, pH, metals, DO, COD, BOD, Red-Ox Potentials, contaminant types or concentrations;
4.2 IN-SITU APPLICATION

In-situ application of the technology are applicable to air, soil and groundwater LNAPL and DNAPL contamination. Once the site has been investigated and site conditions (i.e., hydrogeology, contaminant plume delineation, geology) are known, an application approach for Ivey-sol / SPT can be developed (Figure 4-1). Typically, injection galleries (IG) and or injection wells (IW) are installed across the site to permit the introduction of the Ivey-sol / SPT mixtures. The shallow IGs or IWs are used for shallow overburden contamination, while IWs are the preferred approach for fractured bedrock injection and remediation using the subject technology. Once the mixtures are introduced they are flushed with a pre-set volume of water to drive the mixture through the matrix making “effective contact” with the target contaminants. Once contacted, the contaminants are micro-encapsulated and liberated from the matrix and dissolved into the groundwater table. Once dissolved, they are in a mobile form and can be rapidly recovered for treatment at one of more extraction wells on-site.

A special application for this technology has been to clean up contamination located under building foundations. Typically, most efforts to clean up contamination under a foundation are overshadowed by potential structural failure (Figure 4-1). Ivey-sol / SPT has proven to be a useful alternative to soil excavation in this case. The drilling of IWs through the basement floor and injection of SPT mixtures at these points has proven to be a successful alternative to excavation.

During SPTT treatment, any organic vapors emitting from the sub-surface typically diminish rapidly. Upon injection, the SPT mixtures interact and encapsulate the target NAPLs and mildly altering their effective vapor pressure minimizing their likelihood and or ability to become a gas.

SPT mixtures are not negatively affected by metals, hardness, salinity, pH, DO, COD, BOD, Reduction/Oxidation Potentials, contaminant concentration, and/or type of organic contamination. The range of soil types that have been successfully treated have included, silty sands to permeable tills (K =1x10^{-5} cm/sec) to sand and gravel (K = 1 x 10^{-3} cm/sec).

Figure 4-1  In-situ SPTT Injection, Contaminant Encapsulation, Solubilization and Removal At Recover Well On-site.

4.3 RESPONSE PROFILE
During in-situ treatment, the dissolved contaminant concentrations will increase in response to each Ivey-sol / SPT injection. The term for this response, both in time and concentration over the life of the project, is referred to as the “Response Profile”. All sites exhibit this response profile phenomenon. The peaks and valleys in contaminant concentration are observed in direct response to a series of injections over time. The response profiles, although similar for every site, vary both in time, concentration and amplitude. Following each injection event a spike in contaminant concentration is observed at MWs and or the extraction wells location on-site. The concentration of each subsequent spike tends to decay as the original contaminant mass is sequentially removed as site reclamation is being realized (Figure 4-2). The observed variations from site to site are a function of numerous variables that include: soil and bedrock geology, hydrogeology, contaminant type and concentration, number and location of IGs and IWs, and pump and treat system related specifications.

Injections undertaken during the first three months use volumes and concentrations slightly lower than site conditions information would suggest. This approach, termed the “Initial Conservative Approach”, which has proven an effective method for interpretation of site conditions in response to Ivey-sol / SPT applications. This interpretive period allows for verification of adequate containment and control, and permit minor modification of the managed application of the technology. This, in turn, leads to expedited treatment in a timely and cost effective manner. This Initial Conservative Approach is well embraced by project stakeholders understanding the future benefits that this will generate to the project. Injections are typically undertaken once per month until an appreciable portion of the original contaminant mass has been removed from the site, after which more frequent injections can be undertaken.

![Figure 4-2](image)

**Figure 4-2** Concentration Response Profile At Recovery Wells Following SPTT Injections Over Time

### 4.4 ENCAPSULATION EFFECTS

Most SAAs must be present at a critical concentration in solution before they can form stable micelles, known as the critical micelle concentration (CMC). The molecules in the SPTT mixture are unique in that they can aggregate to organic molecules (i.e., partially encapsulate) and still render them soluble in water at concentrations well below the CMC (Figure 4-3). This is a function of the chemical characteristics of each SAA molecule in the Ivey-sol / SPT mixtures. During site remediation, partial encapsulation of organic contaminants is dominant.\(^6\)
Figure 4-3  SPTT Aggregation On Oil Droplet Well Below The Critical Micelle Concentration Dissolving The Contaminant.

The Ivey-sol / SPT concentrations used during site clean up result in a very low concentration in the influent water entering the groundwater treatment system on site. This further guards against negative effects on the performance and operation of the treatment systems, including exceeding the treatment capacity that could be experienced with other SAA that require CMC to be effected. This has been verified during field applications.
4.5 SELECTIVITY AND RANGE OF APPLICATION

Selective micelle encapsulation is a unique quality of Ivey-sol / SPT. This is a function of the hydrophobic (oil liking) groupings on each SAA molecule that are attracted to organic molecules. As the functional hydrophobic groupings are changed, the type and/or class of organic molecules each SAA will have an affinity for will correspondingly change.

Hence, selectivity was achieved with Ivey-sol / SPT through formulating mixtures of SAAs that have a desired affinity for the class or type organic compounds of interest. With selectivity, formulations of SAAs were developed that had application for specific type of organic contaminants such as gasoline, fuel-oil, diesel, motor oil, bunker-C, MTBE, PAHs, TCE, PCE, PCB and CTET (Figure 4-4).

![Selective Micelle Encapsulation of Contamination](image)

**Figure 4-4** SPTT Selective Micelle Encapsulation A Function of Hydrophobic Groupings.

The four primary Ivey-sol / SPT mixtures were formulated to remediate specific types and classes of LNAPL and DNAPL organic contamination. The original research focused on LNAPLs but was expanded to include PAHs and select priority DNAPL compounds. A partial summary of the selectivity achieved for the primary SPT mixtures are detailed in Table 4-1. In addition, this table also lists some of the dissolved concentrations achieved for selected organic contaminants in water $^{6,7,13,14}$.

Co-SAA effects were realized during the testing and development of the Ivey-sol / SPT mixtures. That is to say, in the presence of certain organic contaminants, the total contaminant-encapsulation capacity of the mixtures were greater than a sum of the contaminant-encapsulation capacities of the first, second, third and additional SAA components alone in the aqueous carrier. Co-SAA effects have lead to the development of selective Ivey-sol / SPT mixture for the three main petroleum hydrocarbon ranges. Specifically; low range $C_6$-C$_{11}$ (i.e., gasoline), medium range C$_{11}$ –C$_{21}$ (i.e., fuel oil and diesel), and heavy range C$_{21+}$ range (i.e., bunker-C).
Ivey-sol /SPT mixtures have a wide range of commercial applications based on the laboratory and field results gathered to date\textsuperscript{26}. This includes, but is not limited to: LNAPL and DNAPL air, soil and groundwater remediation, degreaser, oil tank cleaning, enhanced oil recovery (oil-sand/oil-shale), off-shore oil spill dispersant, shoreline spill clean-up, medical applications, mineral floatation, industrial chemistry, odor removal/control, and stain removal.

<table>
<thead>
<tr>
<th>Organic Contaminant</th>
<th>SPTT 101</th>
<th>SPTT 102</th>
<th>SPTT 103</th>
<th>SPTT 104</th>
<th>Concentration Dissolved In Water (ppb / ug/l - ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_6 ) (- ) ( C_{11} )</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td>&gt; 700,000</td>
</tr>
<tr>
<td>( C_{11} ) (- ) ( C_{21} )</td>
<td></td>
<td>●</td>
<td></td>
<td></td>
<td>&gt; 3,000,000</td>
</tr>
<tr>
<td>( C_{21} ) (- ) ( C_{35}^+ )</td>
<td></td>
<td></td>
<td>●</td>
<td></td>
<td>&gt; 30,000,000</td>
</tr>
<tr>
<td>PAHs</td>
<td></td>
<td></td>
<td>●</td>
<td></td>
<td>350,000</td>
</tr>
<tr>
<td>TCE</td>
<td></td>
<td></td>
<td>●</td>
<td>25+Fold Increase</td>
<td></td>
</tr>
<tr>
<td>PCE</td>
<td></td>
<td></td>
<td>●</td>
<td>25+Fold Increase</td>
<td></td>
</tr>
<tr>
<td>MTBE</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td>&gt; 740% Increase</td>
</tr>
<tr>
<td>CTET</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td>25+Fold Increase</td>
</tr>
<tr>
<td>Aromatic: BTEX</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td>46,300-50,500</td>
</tr>
<tr>
<td>Aliphatic</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
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<td>Gasoline</td>
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<td>12,050,000</td>
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<td></td>
<td></td>
<td>3,020,000</td>
</tr>
<tr>
<td>Bunker C</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td>31,150,000</td>
</tr>
</tbody>
</table>

Note: These Values Represent The Maximum NAPL Concentrations Achieved Under Controlled Laboratory Conditions.

### 4.6 MTBE APPLICATION

MTBE was introduced as an octane replacement for tetraethyl lead in the 1970s, used as an oxygenating agent added to ~30% of U.S. gasoline supply to reduce carbon monoxide emissions of automobiles and meet air quality standards. Almost the entire production of MTBE (9.1 billion pounds in 1992 by 27 companies in the United States) is used as a gasoline additive.

![Chemical structure of MTBE](image)

**Figure 4-5** Common name: Methyl Tertiary Butyl Ether (MTBE). Chemical name: 2-Methoxy-2-methyl-propane. Molecular Formula: C5H12O. Solubility (In water): 51.26 g/L @ 25°C

In 1999, it was estimated that between 5 and 10% of community drinking water supplies in high MTBE use areas had detectable MTBE levels; as many as 9000 community water supply wells in 31 states many be affected. MTBE is considered a potential human carcinogen (Ref. USEPA)
Applied research conducted with Dr. David Craft with the University of Alberta resulted in a special Ivey-sol / SPT mixture formulation that could selectively increase the controlled solubility and increased rate of MTBE recovery by > 740% (Table 4.1). Given that > 9% of community drinking water supplies from Maine to California are impacted with MTBE.

4.6 EX-SITU APPLICATION
The Ex-situ applications were developed and use one of two processes describer below. Details relating to the ex-situ methods will be limited in the scope for this paper. An ex-situ STPP methodology was developed and patented for the treatment of excavated contaminated soils\textsuperscript{,}\textsuperscript{4,15}. The process uses a patented roll off de-watering unit (Figure 4-6). These are termed Ex-situ Treatment Units (ETUs). Each unit can treat approximately 2 cycles of 30 cubic yards of contaminated soil per day. This translates to between 95 and 115 tons per day per unit. Advantages of this approach are that it is scalable to the quantity of contaminated soil to be treated, and soil can be treated on-site at the source, and is often cheaper than off-site transportation and disposal. This process is effective for a wide range of soil types with permeability between $K = 1\times10^{-3}$ and $1\times10^{-5}$ cm/sec. Silts and clays ($K = 1\times10^{-7}$ cm/sec) can also be treated but would require the addition of chemical polymer additives, similar to the types used in commercial sludge dewatering.

The second ex-situ methodology, developed in 2004, uses a soils/solid waste 20 m$^3$ mechanical mixing unit. The contaminated soil/solids are placed in the treatment unit and then flooded with the Ivey-sol/water mixture at predetermined concentration. The Ivey-sol water solids are circulated and mixed through the continue-flow treatment unit resulting in rapid treatment of the solids. The process water can also be treated to release the hydrocarbon contaminants for recovery and re-processing by a refinery. Case studies demonstrate this innovative process to be a portable, scaleable, economic non-thermal soil treatment method which approaches a zero-waste treatment technology.

![Ex-situ Soil Treatment Unit](image)

Figure 4-6   Ex-situ Soil Treatment Unit

4.7 COST AND RISK BENEFIT
A wide range of remedial technologies, including both in-situ and ex-situ approaches, are available for soil and groundwater remediation, as shown in Table 4-1\textsuperscript{16}. Many factors drive the choice of the appropriate remedial method on a site-specific basis, with project duration, cost and associated risk among the most important.

| Table 4-1: Examples of Remedial Action Treatment Technologies By Media and Method Categories |
|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| Soil In Situ                                  | Soil Ex Situ                                  | Groundwater In-Situ                           | Groundwater Ex-Situ                           |

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The cost benefits of Ivey-sol / SPT, in comparison to other remedial technologies, is best measured in terms of reduced project duration, reduced project cost factors over time, and project risk factors, as follows:

- **Reduced Time / Project Duration.** With 90-95% of small to medium size sites are experiencing Ivey-sol/SPT cleaned up in less than 18 months. Shorter project duration results in lower overall project costs. If a given project were to take 5 to 7 years (i.e., 60 to 84 months) to reach closure using traditional remedial technologies, the addition Ivey-sol / SPT could, by comparison, save 40 plus months on the total project duration and cost. The improvement in hydrocarbon recovery rates observed during combined Ivey-sol / SPT groundwater recovery/treatment has been noted in the range of 400 - 500% plus, thereby accelerating the site remediation process.

- **Reduced Project Costs.** Ease of implementation, reduced monitoring and maintenance requirements, reduced contracting and consulting fees, and lower risk of project cost overruns have all been shown to result from Ivey-sol / SPT implementation. The reduced project durations witnessed during application and the corresponding project cost savings over time are scalable. Ivey-sol / SPT client feedback has consistently shown clients claiming 20% or more reduced project costs and liabilities compared to alternative remedial technologies that were considered.

Various chemical effects to recovered groundwater with SPTT/NAPL mixtures have also been noted to reduce system repair and maintenance costs. In particular, the oxidation of metals, specifically iron, in recovered groundwater was observed during Ivey-sol / SPT application. This metal oxide reduction resulted in fewer expendable filter media replacements and fewer repairs to various system components.

- **Reduced Project Risks.** Chemical oxidation and/or some forms of bioremediation can form unwanted or unknown chemical by-products during their application. A well documented example in the late 1980’s was the biodegradation of CET forming vinyl-chloride which was reportedly 10-15 plus times more toxic than the CET. Another relevant example of potentially harmful by-products resulting from chemical oxidation is the eventual degradation of MTBE into acetone or TBA. Given that no chemical reaction is 100% all NAPL remediation technologies involving chemical oxidation and/or chemical reduction may have a risk of forming unwanted chemical remediation by-products that are not commonly tracked during most remediation projects and may pose future risk to applicable stakeholders.

Ivey-sol / SPT by comparison, does alter the chemical structure of the LNAPL, DNAPL, or as the focus of this paper MTBE. Hence this allows for their unaltered recovery and removal from soil and/or groundwater contaminant system. Thereby reducing and/or eliminating the project risks that some remedial technologies may unknowingly introduce to the practitioners. Given the current climate of awareness and concern over the formation of by-products, various regulatory agencies, environmental consultants and clients may be held liable for the negative effects to human health and the environment that some of these by-products may cause.
In addition to the benefit of reduced by-product production during Ivey-sol/SPT implementation, the mixtures themselves are also non-reactive and non-toxic, posing little or no danger to human health and the environment. SPTT mixtures are also biodegradable at a rate of 97% within 27 days of mixture injection.

5.0 CONCLUSION
Ivey-sol/SPT Technology has a very wide range of application for LNAPL and DNAPL organic contaminants. With in-situ and ex-situ remediation alternatives, this technology can often prove more suitable than traditional technologies for a given site and contamination. It has a decisive advantage in that it is not significantly affected by environmental factors that negatively affect other technologies (i.e., pH change, high salinity, DO, COD, BOD, water hardness, temperature variation, dissolves metals, reduction-oxidation potentials, geology, multiple contaminants and high contamination levels).

Applied research concluded with Dr. David Craft, with the University of Alberta in May 2003, determined that Ivey-sol/SPT could selectively micro-encapsulate MTBE making it more soluble in water. The net increase solubility and controlled rate of recovery was determined to be on the order of 740%. Hence, this finding confirms Ivey-sol/SPT as a viable and innovative method for the elimination of MTBE from ground water aquifers.

Favourable environmental and human health testing results make this one or the most environmental friendly technologies available. This, coupled performance data showing greater than 90-95% of small to medium size sites being cleaned up in less than 18 months, with many small sites completed in less than 12 months, make this a versatile, rapid and cost saving alternative for soil and groundwater NAPL remediation.

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**Biographical Sketch**

George A. Ivey, B.Sc., CES, CESA is a Senior Remediation Specialist with Ivey International Inc. He has been working in the environmental field for over seventeen years working on more than 1500 environmental projects internationally. His educational background includes Organic Chemistry, Geological Engineering and a Master’s in Project Management, provided him a multi-disciplinary foundation for interpreting many of today’s environmental challenges and a decisive advantage when working multi-disciplinary project teams and stakeholders.

He was responsible for the development of four patents, most notably, the developments of the technology know by the trade names Ivey-sol and Selective Phase Transfer (SPT) Technology. This is a non-ionic surfactant mixture that can treat a broad range of petroleum hydrocarbons, chlorinated solvents and heavy metal contaminants in soil and groundwater.