

gPRO Comparisons to Other Technologies

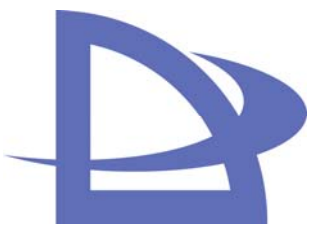
The gPRO is a versatile tool for groundwater treatment that provides high rate gas inFusion into groundwater pumped through microporous hollow fiber cross-current flow modules. The gPRO compliments the capabilities of iSOC and HiSOC systems for gas inFusion applications and extends gas inFusion to new market areas. gPRO systems are targeted on groundwater treatment using primarily biological but also chemical and physical processes depending on the gas infused and the remediation approach. Current applications envisioned for the gPRO include:

- Biological treatment
 - Aerobic oxidation (oxygen)
 - Cometabolic oxidation (oxygen and alkane gas)
 - Cosubstrate oxidation (oxygen and ethene or other co-substrates)
 - Anaerobic reductive dechlorination (hydrogen)
- Chemical treatment
 - pH adjustment (sulfur dioxide, carbon dioxide, ammonia)
 - Geochemical fixation of metals (hydrogen and sulfur dioxide)
 - Oxidation of metals (oxygen)
- Physical treatment
 - LNAPL and DNAPL recovery enhancement (carbon dioxide)
 - Specific gas inFusion applications for bioremediation are listed in the following table.

Table 1: Gas inFusion Bioremediation Applications

| Contaminant | Gas Delivered | Electron Donor | Carbon Source | Process |
|----------------------|---|--|--|--|
| Hydrocarbons | O ₂ | Contaminant | Contaminant | Aerobic Degradation |
| | O ₂ + Alkane | Alkane + Contaminant | Alkane + Contaminant | Aerobic Degradation |
| MTBE MTBE | O ₂ | Contaminant | Contaminant | Aerobic Degradation |
| | O ₂ + Alkane | Alkane + Contaminant | Alkane + Contaminant | Aerobic Cometabolism |
| CAH* (PCE, TCE, DCE) | H ₂ | H ₂ | In-Situ Organics | Anaerobic Degradation |
| | H ₂ | H ₂ + Organic Electron Donor | Added Organic | Anaerobic Degradation |
| | Alkane | Alkane | Alkane | Anaerobic Degradation |
| CAH (TCE, DCE, VC) | O ₂ + Alkane | Alkane | Alkane | Aerobic Cometabolism |
| | O ₂ | Alkane | In-Situ Organics (natural methane) | Aerobic Cometabolism |
| CAH (Vinyl Chloride) | O ₂ | Contaminant | Contaminant | Aerobic Degradation |
| | O ₂ + Ethene (Co-Substrate) | Ethene + Contaminant | Ethene + Contaminant | Aerobic Degradation |
| Ammonia | O ₂ | Ammonia | In-Situ Organics or CO ₂ | Nitrification (Aerobic) |
| Nitrate | H ₂ +/- CO ₂ | H ₂ | In-Situ Organics or CO ₂ | Denitrification (Anaerobic) |
| Perchlorate | H ₂ +/- CO ₂ | H ₂ Organic or CO ₂ | In-Situ or Added Organic or CO ₂ | Dissimilatory Reduction (Anaerobic) |
| 1-4, Dioxane | O ₂ + Propane | Propane | In-Situ or Added Organics | Aerobic Cometabolism |

* CAH – Chlorinated Aliphatic Hydrocarbons



gPRO[®] Technology Comparison

Various competing technologies exist for certain applications of the gPRO system. Primary competitors for aerobic biological treatment are air/biosparging and oxygen sparging. Ozone sparging is a physical alternative technology targeted at similar groundwater contamination problems. Each of these methods requires significant electrical power consumed by compressors to inject gas substrates. Chemical oxidation with liquid injections, groundwater pump and treat, and dual phase extraction are technologies that compete with gPRO for groundwater treatment applications but may also be applied in concert with gPRO applications.

Vegetable oil, sugar and carbohydrate injection and hydrogen sparging technologies compete with direct hydrogen inFusion for reductive dechlorination of chlorinated compounds and anaerobic bioremediation and geochemical fixation of other contaminants including nitrate, perchlorate, and metals such as hexavalent chromium. In certain situations these technologies may be applied with a more beneficial effect by combination with direct hydrogen gas inFusion and therefore may be used in concert with gPRO.

Treatments targeted on unsaturated zone soil contamination such as SVE and excavation for off site disposal do not compete with gPRO which is targeted on saturated zone contamination problems. The following table compares gPRO to competing technologies.

Table 2: gPRO Comparison with Competing Technologies:

| Technology | Treatment Process | Equipment | Applicable Lithology | Limitations | gPRO [®] Advantages |
|-------------------|--|--|--|--|---|
| gPRO [®] | Active gas inFusion into water forming groundwater in situ treatment areas for biological, chemical & physical treatment | gPRO [®] unit, groundwater pumps, pretreatment systems, manifold to injection wells | Permeable soil with layered or uniform stratigraphy, high or low heterogeneity and unlimited by well depth | gPRO [®] is not subject to many limitations of competing technologies - only requires sufficient permeability to extract and/or inject sufficient water to deliver substrates to the treatment area | N/A |
| Air sparging | High flow compressed gas injection designed to physically strip volatile contaminants from groundwater | Compressor, sparge wells, timer, conduit | Permeable soil with uniform stratigraphy generally limited to saturated thickness > 5 ft but < 50 ft | Depth limitations and requirement for SVE. Uneven distribution of gas due to channeling & possible unwanted migration due to water table mounding. Possible vapor intrusion. | gPRO [®] delivery wells can be used to target substrate delivery where needed with hydraulic control and without mobilizing contaminants to the unsaturated zone |
| Bio-sparging | Low flow compressed gas injection designed to increase biological degradation | Compressor, sparge wells, timer, conduit | Permeable soil with uniform stratigraphy generally limited to saturated thickness > 5 ft but < 50 ft | Depth limitations and possible requirement for SVE, uneven distribution of gas. Possible vapor intrusion. | gPRO [®] delivery wells can be used to target substrate delivery where needed and provide larger mass of substrate |



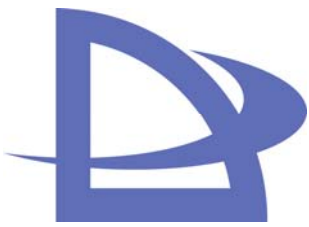
gPRO[®] Technology Comparison

| | | | | | |
|--|---|---|---|---|--|
| Oxygen sparging | Low flow compressed gas injection designed to increase biological degradation | Oxygen source, oxygen pump, sparge wells, timer, conduit | Permeable soil with uniform stratigraphy generally limited to saturated thickness > 5 ft but < 100 ft | Depth limitations and possible requirement for SVE, uneven distribution of gas. Possible vapor intrusion. | gPRO [®] delivery wells can be used to target substrate delivery where needed with out moving oxygen to the unsaturated zone |
| Ozone sparging | Low flow compressed gas injection designed to chemically oxidize contaminants | Oxygen generator, ozone generator, compressor, sparge wells, timer, | Permeable soil with uniform stratigraphy generally limited to saturated thickness > 5 ft but < 100 ft below water table | Depth limitations and possible requirement for SVE, uneven distribution of gas. Possible dangerous effects on subsurface infrastructure. Possible vapor intrusion. | gPRO [®] delivery wells can be used to target substrate delivery where needed with out moving oxygen to the unsaturated zone |
| Chemical oxidation | Liquid injection designed to chemically oxidize contaminants | Injection wells, pumps, direct push | Relatively permeable soil and limited competing demand from natural organic compounds | Requires direct contact with contaminant, oxidant rapidly degrades, generally not suited for large area treatment | gPRO [®] delivery wells can be used to target substrate delivery where needed for biological treatment |
| Dual phase extraction | Vacuum extraction from multi-phase wells, ex situ treatment | Vacuum blowers, separation and treatment systems | Permeable soil with uniform stratigraphy generally applied to surface of water table | Limited to shallow depths and limitations of NAPL movement under hydrostatic conditions | gPRO [®] NAPL recovery technology works in conjunction with DPE to mobilize NAPL for removal and bioremediation. |
| Pump & treat | Groundwater extraction from pumping wells | Pumping and above ground treatment systems | Permeable soil with layered or uniform stratigraphy with low heterogeneity | Ex situ treatment results in long tailing of contaminant concentrations due to poor mass removal. | gPRO [®] in situ treatment degrades contaminant mass in formation |
| Hydrogen sparging | Compressed gas injection | Compressed gas supply, injection wells | Permeable soil with uniform stratigraphy generally limited to saturated thickness > 5 ft but < 50 ft | Depth limitations and possible concerns over hydrogen reaching unsaturated zone, vapor intrusion and reaching locations where the lowered explosivity limit may be exceeded.. | gPRO [®] delivery wells can be used to target substrate delivery where needed with hydraulic control without mobilizing contaminants or substrate to the unsaturated zone |
| Carbon based electron donor Reductive dechlorination | Active or passive injection systems | Pumping systems and/or injection wells | Relatively permeable soil | Viscous liquids and excess biomass required for fermentation reactions reduce formation permeability and result in secondary water quality impacts | gPRO [®] hydrogen delivery provides electron donor directly without need for fermentation reactions |

Application of gPRO at Specific Sites

The selection of a gas inFusion system for a particular site depends on the:

- Hydrogeologic conditions
- Groundwater flow conditions
- Nature of the contaminant



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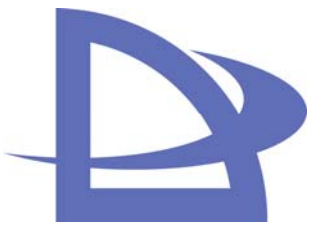
Technology selection should also consider:

- Treatment objectives
- Geochemical conditions

The selection will also have to be made in consideration of other treatment technologies in operation or under consideration for combination at the site. In general the gPRO systems require hydrogeologic conditions suitable for extraction and reinjection of groundwater or the ability to inject large volumes of water from an alternative water supply. Sites where hydrogeologic conditions are suitable for pump and treat system operation are ideal however gPRO applications are not strictly limited to these conditions. Both iSOC and gPRO[®] may be applicable for different applications at the same site (e.g. gPRO for source area treatment and iSOC for downgradient biobarrier).

Table 3: Site Criteria for Selection of gPRO Technology

| Site Criteria | Degree Applicable (least) + → (most)+++++ | | |
|---|---|---|------------------------------|
| Hydrogeologic Conditions | | | |
| Stratigraphy | Simple | → | Complex |
| gPRO [®] | +++++ | | +++++ |
| Aquifer material | Course Grained | → | Fine Grained |
| gPRO [®] | +++++ | | +++ |
| Degree of heterogeneity | Low | → | High |
| gPRO [®] | +++++ | | ++ |
| Groundwater Flow Parameters | | | |
| Hydraulic conductivity (k) | High (> 0.01 cm/s) | → | Low (<0.0001 cm/s) |
| gPRO [®] | +++++ | | ++ |
| Hydraulic gradient (i) | Low | → | High |
| gPRO [®] | +++++ | | +++++ |
| Temporal variation in gradient | Little | → | High |
| gPRO [®] | +++++ | | +++ |
| Horizontal flow velocity | Slow (<0.5 ft/day) | → | Fast (>1.5ft/day) |
| gPRO [®] | +++++ | | +++ |
| Vertical flow | Little | → | High downward |
| gPRO [®] | +++ | | ++ |
| Mass of contaminant (and competing donors/acceptors) | Low | → | High |
| gPRO [®] | +++++ | | +++++ |
| Volume of contaminated material | Low | → | High |
| gPRO [®] | +++++ | | +++++ |



| Bioavailability | Low | → | High |
|--------------------------------|------------|----------|-------------|
| gPRO [®] | + | | +++++ |
| Solubility (s) | Low | → | High |
| gPRO [®] | +++ | | +++++ |
| Sorption potential (kd) | Low | → | High |
| gPRO [®] | +++++ | | +++ |