Biostimulants for Soil and Groundwater Bioremediation

ECOCYCLE CORPORATION Japan

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Company Business

- Made of engineers and scientists and concentrates on developing technologies for environmental market.
- Business: Environmental remediation, Bioinoculants for agriculture, recycling of industrial effluents, and EHS consultant.
- Some of the clients are manufacturers of automobile, electronic equipment, electrical apparatus, chemical industries, metal industries, semiconductor industries, and government bodies.
- Technological partnership with more than 30 Japanese engineering companies, and GZA Geoenvironmental, USA.

Potential of EcoCycle

- Technical expertise in site investigation and remediation of various sites (large-small, running facilities, different hydrogeology, contamination levels, etc.)
- Pioneers in bioremediation of chlorinated solvents, hexavalent chromium, cyanide, petroleum hydrocarbons, etc. applied over 170 sites in Japan, the US, India, and Taiwan
- Good knowledge in other remedial technologies
- Partnership with engineering companies and net work of research institutes world-wide
- Holds several Japanese and international patents

Field Experience

Chlorinated Solvents | Hexavalent Chromium

- **Contaminations: PCE, TCE, DCE, TCA, DCA, CT, DCM, Cyanide, Benzene, Cr (VI), etc.**
- **Japan, Thailand, the US, Taiwan, India……..**
- **High concentration: 750mg/L**
- **Low K hydrogeology: ~ 10^{-6}cm/sec**
- **Largest site: 7 million m^3**

Japan EPA Funded Site (Demonstration of low cost, environmentally friendly technology)

Comparison of Different Leading Remediation Technologies

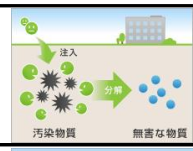
Technology	Remediation Cost (per 1m³)	Time span	Active Facilities	Low K Soil	High Concentration	Vadose Zone	Groun dwater	Limitations
EcoClean	5~15K円	3 ~ 12months	○	○	○: ~ 150mg/L ▲: 150mg/L	▲	○	Concentrations above 500mg/L and extreme pH
Dig and Dispose	40 ~ 60K円	Weeks	×	○	○	○	×	High cost
Pump and Treat	(NA)	Tens of years	○	×	○	Excavat -ion	○	Very long time
Fe(0)	30K円	Months	×	○	▲	○	○	Not for active facility/Affect hydrogeology
Oxidants	5~20K円	Few months ~ years	○	×	▲	▲	○	Cr(VI) may release/Not good under high OC/Kill useful organisms
Hot soil	15 ~ 40K円	Weeks ~ months	×	○	○	○	×	High cost/Not for active facility
Venting	5~15K円	Months ~ few years	○	×	○	○	×	Not for groundwater

Choose the technology based on site conditions, budget and time available for remediation

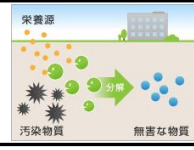
Bioremediation

Exploiting ability of microorganisms to degrade/detoxify contaminants

Bioaugmentation
Introducing microbes in the contaminated media



Biostimulation (Our strength)
Stimulating native microbes



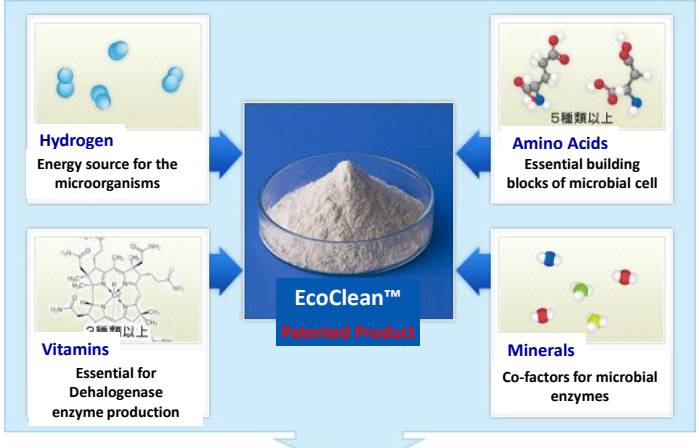
Aerobic degradation
Stimulating microbes that use oxygen for respiration

Facultative anaerobic microbes
Stimulating microbes that live in presence or absence of oxygen
(EcoClean-M mediated Cr(VI) remediation)

Biostimulation
Stimulating microbes that live only when oxygen is absent
(EcoClean mediated chlorinated solvent remediation)

EcoClean Based Bioremediation is for……

EcoClean the Wholesome Food for Dehalogenating Microbial Population



A group of effective microbial consortium capable of respiring chlorinated compounds is stimulated resulting in faster and complete degradation of contaminants.

EcoClean-E the Slow Hydrogen Releasing Biostimulant

Effective in low K soil, to degrade DNAPL and for coastal area groundwater with high salt concentration.

Target Contaminants

- Halogenated/Chlorinated Aliphatic Hydrocarbons (CAHs): Perchloroethylene (PCE), Trichloroethylene (TCE), Trichloroethane (TCA), Dichloromethane (DCM) which were being used as solvents and de-greasers in the industries like automobile, hardware, electronic equipments, etc.

- And their daughter products like Dichloroethylene (DCE), Dichloroethane (DCA), Vinyl chloride (VC) in Chemical and plastic raw material manufacturers.

What is Special in EcoClean Based Bioremediation

① Short time: Complete remediation within 3～12 months

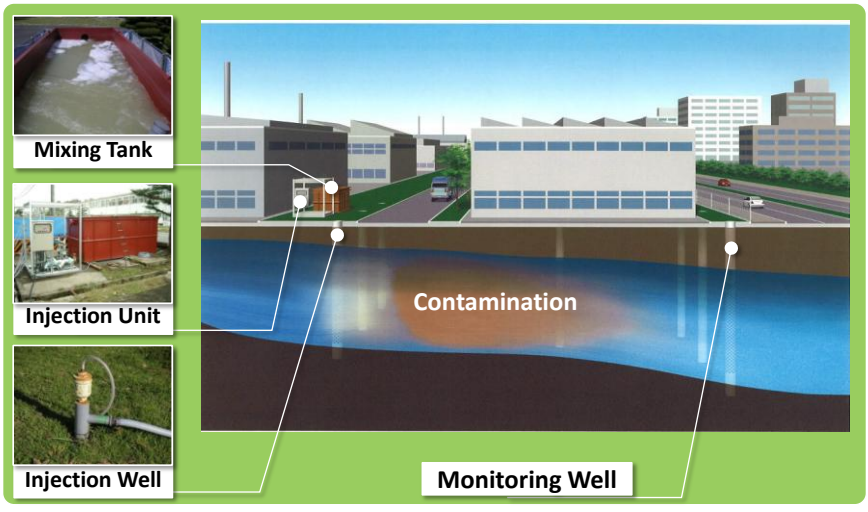
② Remediation of high concentration VOCs contamination (our experience: 380mg/ℓ)

③ High priority of safety issue: EcoClean is completely biodegradable into carbon dioxide and water

④ Low cost technology: 1/3 to 1/5 of conventional methods

⑤ Easy to apply on the site and under the running facilities/factories

EcoClean Gravity Injection



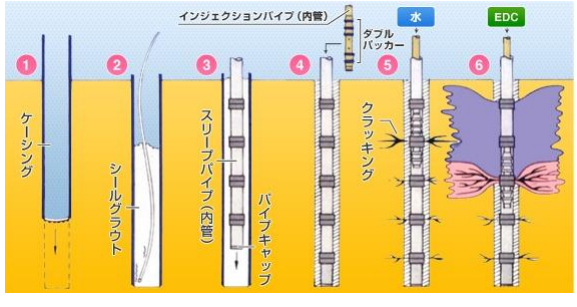
Injection with Direct Push Technology

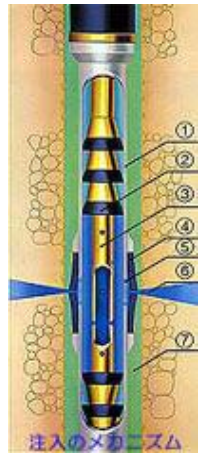
Sturm Ruger,
NH, USA

Wyman-Gordon
Grafton, Massachusetts, USA

GeoProbe 6610-DT track rig
2.3 GPM capacity pump, with pressures up to ~1,000 PSI

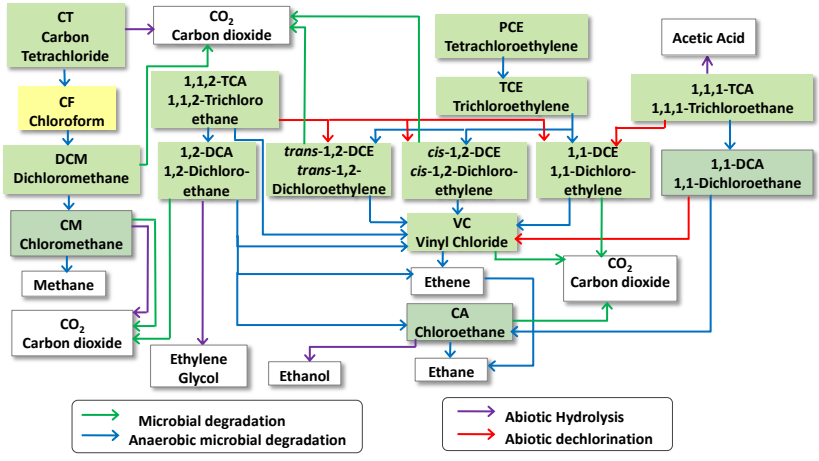
Double Packer Injection





- Injection points are designed based on distribution of contamination
- Injection pressure, dilution, etc. depend on hydrogeology
- Precautions taken to avoid short-circuit

Various Chlorinated Solvents and Their Decomposition Pathways



Chlorinated solvents are degraded by microorganism with EcoClean. The resulted end products of the whole process would be non-toxic ethylene, inorganic chlorides, carbon dioxide and water.

Chlorinated Aliphatic Hydrocarbons Contaminated Site, Near Nagoya

Site Characteristics:

Former Metal Finishing Facility ➡ Golf Driving Range ➡ Planned Residential Area

Plume Size: 6,781m^{2}x12m

Pollutants: TCE, *cis*-1,2-DCE

Hydrogeology: Medium to coarse Sand with some Silty Sand

Hydraulic Conductivity(K): 10^{-2} to 10^{-3}cm/sec.

High Natural Organic Matter

Initial ORP : <-100 mv

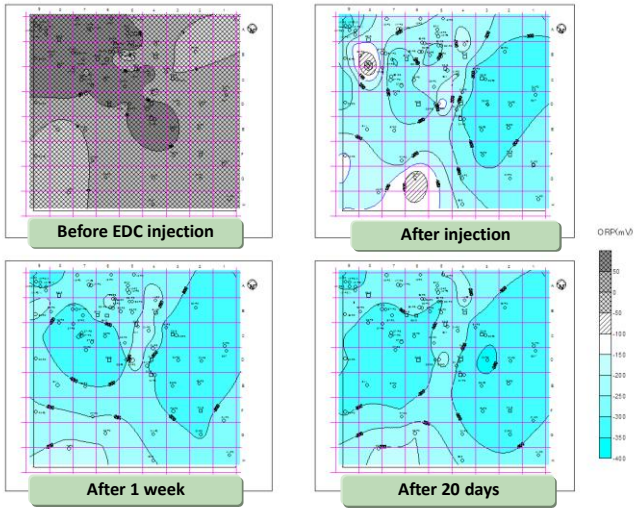
Remedial Approach:

Failed ISCO followed by Enhanced Reductive Dehalogenation

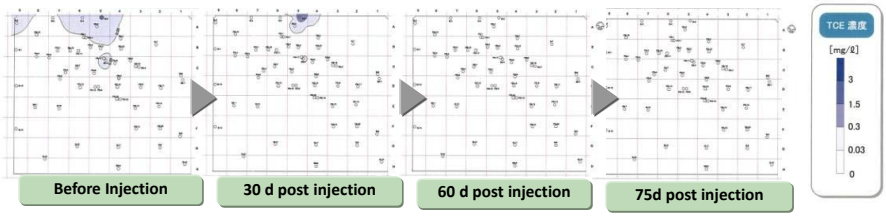
Biostimulant Load: 7,000kgs biostimulant was diluted 100 times in water and injected in existing wells (around 25 wells)

Specially Monitored and Regulated by Nagoya City

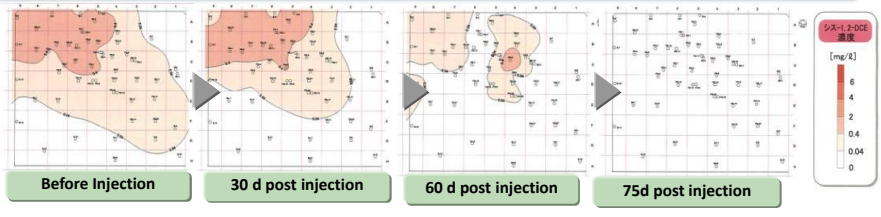
Post-injection Changes in ORP



TCE Degradation

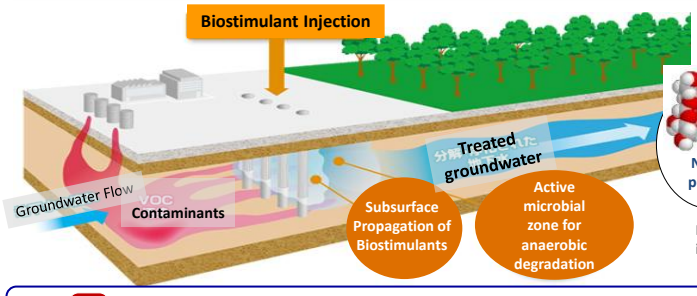


cis-1,2-DCE Degradation

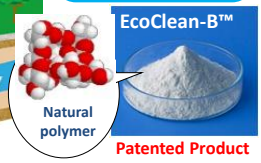


Post remedial monitoring for 2 years (as per Japanese regulations) showed no sign of contamination rebound

Permeable Reactive Bio-barriers



Specially designed for biobarrier



Patented Product

Natural polymer that can stay in subsurface for longer time

? Merits of EcoClean Biobarrier over other Conventional Methods

Comparison of Pump & Treat !

- Running cost (electricity; carbon filters; stripper maintenance etc.) is considerable
- Accelerated groundwater flow due to extraction may result in spread of the contamination from the source

Comparison with Zero-valent Iron barrier !

- Cost: Around 1/3 of ZVI barrier.
- Large augur is used to mix ZVI into the soil that consumes large working space and limits operation in active facilities
- ZVI oxidizes resulting rusty groundwater down gradient to ZVI barrier.

EcoClean biobarrier is low cost, environmental friendly and needs no maintenance.

EcoClean-M for Bioremediation of Hexavalent Chromium

- EcoClean-M is a bioremediation agent for soil and groundwater contaminated with hexavalent chromium (VI).
- It is a mixture of well-balanced nutrients and energy source for microbes capable of respiring Cr(VI).
- In this process the water soluble, highly toxic Cr(VI) is reduced to non-soluble and stable chromium (III).

EcoClean-M™

Patented Product

Advantages of EcoClean-M based Bioremediation

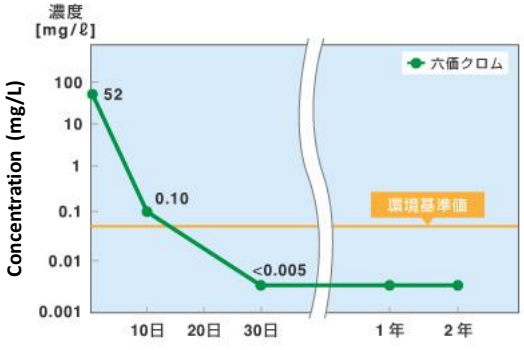
- In-situ technology
- Easy to apply even in running facilities
- less than 1/3 the cost of conventional technologies
- Short remediation time (1-3 months)
- Environmentally green; the product is biodegradable to carbon dioxide and water

Site A: Near Tokyo, Automobile Parts Manufacturer

Site Characteristics:

Area: 10,000 m^2; thickness of overburden aquifer: 5 m from GL

Hydrogeology: Sandy Loam; Gravel; GW level: 2-3 m from the GL



Days after EDC-M injection

Post remedial monitoring for 5 years showed no sign of contamination rebound

Green Clean for High Performance Aerobic Remediation

- **Green Clean biostimulants are optimal nutritional source for aerobic microorganisms capable of biodegradation of petroleum hydrocarbons (BTEX, light oils, etc.) cyanide compounds, and chlorinated hydrocarbons.**
- **Green Clean is dissolved in water containing high concentration of oxygen and injected to subsurface.**
- **Made of food materials and food additives, and safe to use.**

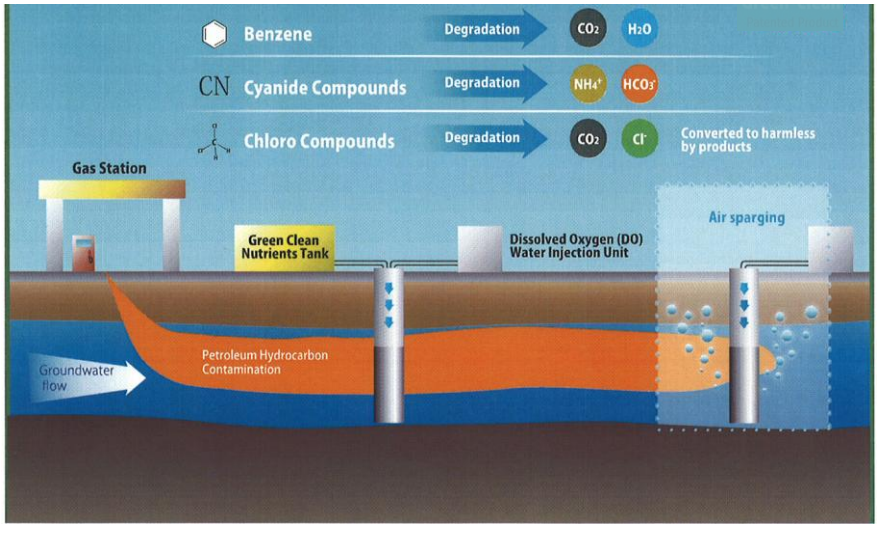
Green Clean™

Patented Product

Green Clean Bioremediation Applicable to

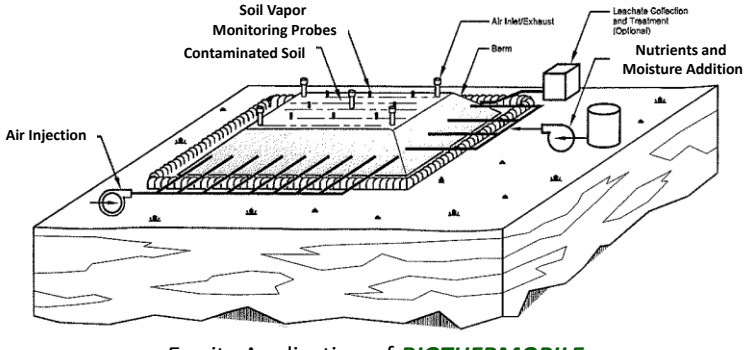
- **Gasoline Stands, Refineries**
  - **Petroleum Hydrocarbons Contamination (BTEX, gasoline, diesel, kerosene, light oil, etc.)**
  - **dicyclopentadiene, PAHs, etc.**
- **Chemical manufacturers & users**
  - **Ethylene dichloride, Dichloromethane, Vinyl Chloride, etc.**
- **Gas Manufacture, Electroplating Industries**
  - **Cyanides and cyanide metal complexes**
  - **Polyaromatic hydrocarbons (PAHs ,naphthalene, benzopyrene, etc.)**

In-situ Application of Green Clean



Green Clean-BP for Remediation of Soil Contaminated with Petroleum Hydrocarbons

- ***BIOTHERMOPILE*** **is useful for treating aerobically degradable contaminants, on-site or off-site.**
- **Green Clean-BP is efficient to degrade various petroleum hydrocarbons of high concentrations in short times.**
- **Soil contaminated with petroleum hydrocarbons is made into a pile & Green Clean-BP is mixed to stimulate natural microorganisms that degrade contaminants.**
- **Low cost, easy to apply and there is no environmental burden.**



Ex-situ Application of ***BIOTHERMOPILE***

Custom-made Nutrients for the Contaminants of Concern

We also manufacture custom-made bioremediation nutrients for a wide range of contaminants. Please contact EcoCycle Corporation for further information.

An Example of Contamination Concern	Custom-made Nutrients
Chlorobenzenes (dichlorobenzene, etc.), hexachlorobutadiene Chlorophenols (pentachlorophenol's, etc.), BCEE, Toxaphene Trinitrotoluene, Trinitrobenzene, perchlorate, chlorinated agricultural chemicals & pesticides.	**EcoClean-X**
Polyaromatic hydrocarbons (PAHs, naphthalene, benzopyrene, etc.) Dioxanes, MTBE, methyl ethyl ketone, dicyclopentadiene, etc. Agricultural Chemicals (Simazine, Thiobencarb, Thiram, etc.)	**Green Clean-X**
Heavy metals of lead, arsenic, cadmium, selenium, copper, cobalt, zinc, & nickel ※ Water soluble contaminants are biologically stabilized	**EcoClean-MX**

***Please contact EcoCycle if the contaminants and/or groups are multiple.**
Combination of nutrients are applied and/or new nutrients are designed & manufactured.

Summary

- Bioremediation: Environmental friendly green technology
- Bioremediation: *in-situ application; v*arious contaminants are targets.
- Bioremediation: High concentration of contaminants can be degraded; shorter time; cheaper to many existing technologies.
- Bioremediation: Good for running facilities, almost no noise, simple equipment are needed.
- Very good inter-disciplinary knowledge is needed to succeed.