Education Pack

In situ bioremediation

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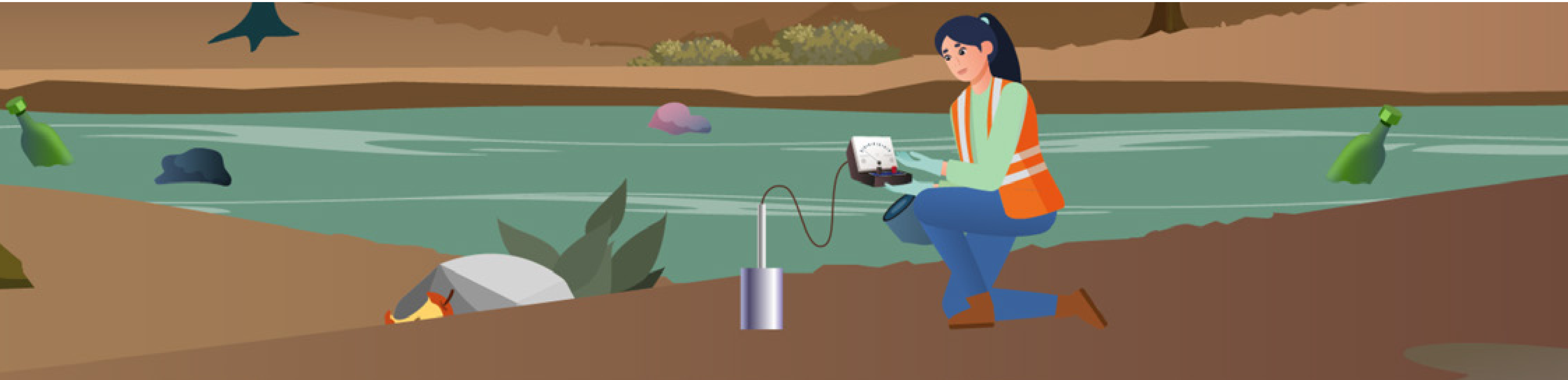
EiCLaR
Enhanced Bioremediation



Introduction and contents

With industrial activity and pollution of the environment being widespread, EiCLaR is developing four bioremediation technologies which use the physical, chemical and electrical processes of biological systems (such as plants, fungi and microbes) to break down contaminants and remove pollution from the environment.

Learn more about these novel technologies that aim to make the clean up of contaminated environments more cost effective and efficient.

Click links below to go to different pages:

Where do the pollutants in soil and groundwater come from?

Pollutants can be natural or man-made and can affect air, water, and soil. They may be from historical pollution incidents such as accidents and spills, contamination from historical industrial land use, contaminant migration overland or by infiltration into the ground, high levels of naturally occurring substances and historical waste deposits such as former landfills. Some common types of chemical pollutants includes substances like industrial chemicals, hydrocarbons, pesticides and metals. Other pollutants include biological, physical and radiological substances.

What is remediation?

Remediation is the process of cleaning up and restoring sites that have been contaminated by pollutants. These pollutants can contaminate the soil and water on and beneath the site and cause harm to people, the environment or both. Remediation typically uses one or more of the following processes to treat the pollutants: biological, physical, chemical or thermal.

What is bioremediation?

Bioremediation uses biological systems including plants, fungi, and microbes to break down contaminants and remove pollution from the environment. Microbes are very small organisms, such as bacteria, that live naturally in the environment. Bioremediation stimulates the growth of certain microbes that use contaminants as a source of food and energy.

Find out more about bioremediation >

A Citizen's Guide to Bioremediation

EPA

What Is Bioremediation?

Bioremediation is the use of microbes to clean up contaminated soil and groundwater. Microbes are very small organisms, such as bacteria, that live naturally in the environment. Bioremediation stimulates the growth of certain microbes that use contaminants as a source of food and energy. Contaminants treated using bioremediation include oil and other petroleum products, solvents, and pesticides.

How Does It Work?

Some types of microbes eat and digest contaminants, usually changing them into small amounts of water and harmless gases like carbon dioxide and ethene. If soil and groundwater do not have enough of the right microbes, they can be added in a process called "bioaugmentation."

For bioremediation to be effective, the right temperature, nutrients, and food also must be present. Proper conditions allow the right microbes to grow and multiply—and eat more contaminants. If conditions are not right, microbes grow too slowly or die, and contaminants are not cleaned up. Conditions may be improved by adding "amendments." Amendments range from household items like molasses and vegetable oil, to air and chemicals that produce oxygen. Amendments are often pumped underground through wells to treat soil and groundwater in situ (in place).

Microbe takes in oil, oxygen, and nutrients and releases gases and water.

The conditions necessary for bioremediation in soil cannot always be achieved in situ, however. At some sites, the climate may be too cold for microbes to be active, or the soil might be too dense to allow amendments to spread evenly underground. At such sites, EPA might dig up the soil to clean it "ex situ" (above ground) on a pad or in tanks. The soil may then be heated, stirred, or mixed with amendments to improve conditions.

Sometimes mixing soil can cause contaminants to evaporate before the microbes can eat them. To prevent the vapors from contaminating the air, the soil can be mixed inside a special tank or building where vapors from chemicals that evaporate may be collected and treated.

Is Oxygen Always Needed?

Some contaminants can only be bioremediated in an aerobic environment—one that contains oxygen. Others can only be bioremediated in an anaerobic environment without oxygen. Anaerobic microbes do not need oxygen to grow.

To clean up contaminated groundwater in situ, wells are drilled to pump some of the groundwater into above ground tanks. Here, the water is mixed with amendments before it is pumped back into the ground. The groundwater enriched with amendments allows microbes to bioremediate the rest of the contaminated groundwater underground. Groundwater also can be pumped into a "bioreactor" for ex situ treatment. Bioreactors are tanks in which groundwater is mixed with microbes and amendments for treatment. Depending on the site, the treated water may be pumped back to the ground or discharged to surface water or to a municipal wastewater system.

How Long Will It Take?

It may take a few months or even several years for microbes to clean up a site, depending on several factors. For example, bioremediation will take longer where:

- Contaminant concentrations are high, or contaminants are trapped in hard-to-reach areas, like rock fractures and dense soil.
- The contaminated area is large or deep.

What does *in situ* mean?

When clean up processes occur at the site of the pollution, in the soil or groundwater, this is known as *in situ* treatment. If these processes are biological, then it is known as *in situ* bioremediation. Conversely, when soil is dug up to clean it above the ground or when groundwater is pumped for treatment above ground it is referred to as *ex situ* treatment.

What is the EiCLaR project?

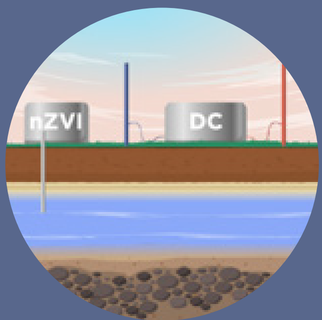
Enhanced and Innovative *In Situ* Biotechnologies for Contaminated Land Remediation (EiCLaR) was a project funded by the EU and China. It ran from January 2021 until the end of 2024 and was composed of 13 EU and 5 Chinese partners.

The project was coordinated by Professor Timothy M. Vogel at the French National Centre for Scientific Research and Professor Xin Song at the Institute of Soil Science, Chinese Academy of Sciences. EiCLaR has developed scientific and technical innovations for *in situ* bioremediation technologies that have been developed into industrial processes for the rapid, efficient, cost-effective treatment of a range of environmental pollutants (solvents, metals, hydrocarbons).

These technologies expand the range of applications to industrial sites that contain complex, high concentration pollutant mixtures:

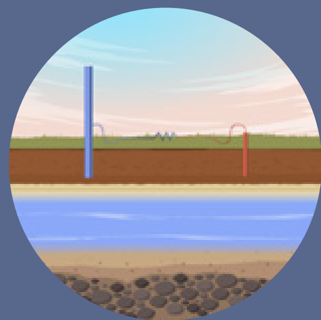
- electro-nanobioremediation
- monitored bioaugmentation
- bioelectrochemical remediation
- enhanced phytoremediation

Types of bioremediation



Electro-nanobioremediation

Monitored bioaugmentation



Bioelectrochemical remediation

Enhanced phytoremediation

Electro-nanobioremediation

Electro-nanobioremediation is an innovative and advanced remediation technology that combines three key approaches to efficiently clean up contaminated environments. It integrates electrokinetics, nanotechnology, and bioremediation techniques to tackle complex and persistent pollutants in soil and groundwater.

In this process, electrodes are installed in the contaminated area, and an electric field is applied to promote the movement of charged contaminants towards the electrodes. Nanoparticles, such as zero-valent iron or other metal-based nanoparticles, are introduced to the environment. These nanoparticles help the breakdown of organic contaminants into less harmful compounds.

Electro-nanobioremediation pilot tests

Glycerol-based substrate at the pilot site

Soil extraction from boxes for electro-nanobioremediation column experiments

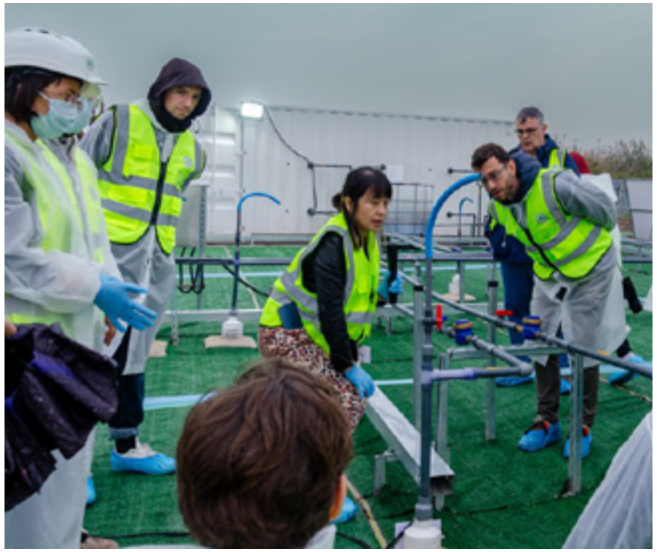
Electro-nanobioremediation (continued)

Bioremediation comes into play as naturally occurring microorganisms or specifically introduced bacteria take advantage of the enhanced conditions created by the electric field and nanoparticles. These microorganisms can effectively break down a wide range of pollutants, including hydrocarbons, into harmless byproducts, such as water and carbon dioxide.

The combined use of electrokinetics, nanotechnology, and bioremediation in electro-nanobioremediation provides a collaborative effect, leading to faster and more efficient cleanup of contaminated sites. This technology shows great promise in addressing environmental pollution challenges while minimizing the need for disruptive excavation or costly conventional remediation methods.

Substrate dosing unit

Preparation of a new set of power electrodes for regular replacement



Technology demonstration of electro-nanobioremediation at a site in China

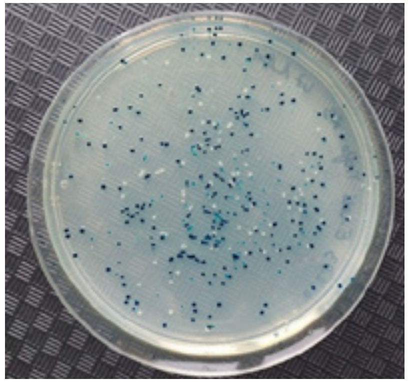
Monitored bioaugmentation

Monitored bioaugmentation uses microorganisms injected into contaminated soil and wastewater to speed up the breakdown of solvents (e.g. chloroethenes) using the natural biological process of aerobic degradation.

Chloroethenes are used as a cleaning agent in industrial processes and due to improper handling and storage, these chemicals can be released into the environment, where they will sink into the soil and groundwater.

Aerobic metabolic degradation represents a new and promising concept to remove chloroethenes from the subsurface environment. The key benefit of the metabolic aerobic process is there is no risk of formation of hazardous intermediate products and auxiliary substrates are not required and, therefore, with a limited amount of oxygen approximately 100 times more pollutants can be removed as compared to cometabolic degradation.

Implementing monitored bioaugmentation technology at a site in Belgium. Injection rig for adding oxygen to ground is shown

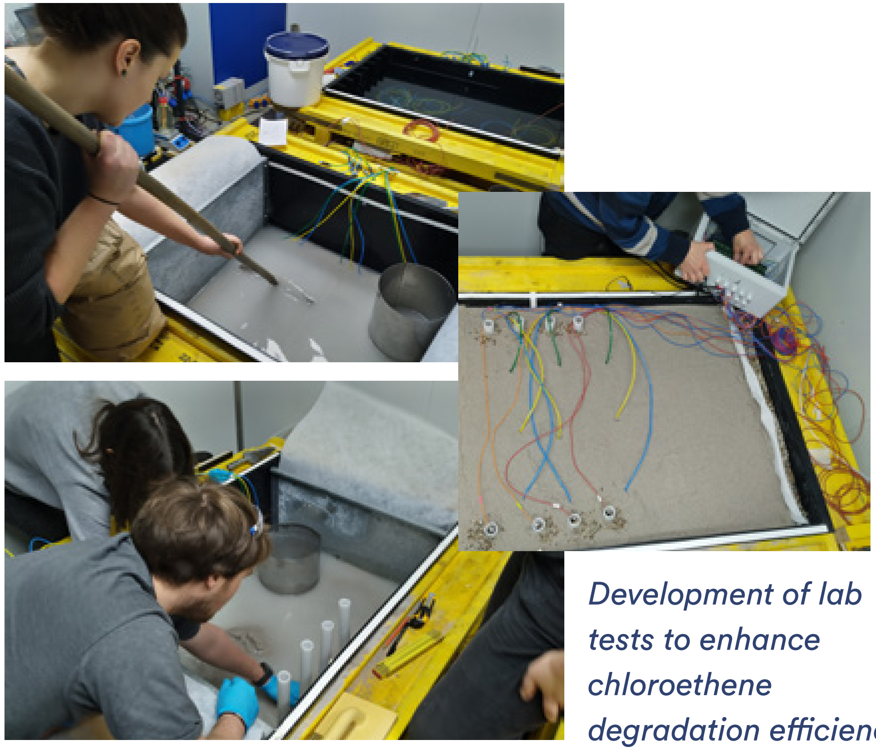


Isolation of bacteria with target genes

If the required microorganisms are not present at a specific site, enriched cultures can be added to the field site (bioaugmentation). Therefore, bioaugmentation in combination with biochar injection and enhanced electrokinetic distribution represents a highly innovative and promising approach developed in EiCLaR. Aerobic chloroethene biodegradation can occur under natural conditions or after addition of oxygen in engineered approaches on-site.

Types of bioremediation

Monitored bioaugmentation (continued)



Development of lab tests to enhance chloroethene degradation efficiency

Laboratory setup to determine the soil oxygen demand at the test site in Belgium

Cultivation of the aerobic chloroethene-degrading microorganisms

Bioelectrochemical remediation

In simple terms, bioelectrochemical remediation converts chemical energy into electrical energy by adding an electrode with electroactive bacteria to soil or water to convert pollutants into less harmful substances. Bioelectrochemical remediation technology shares its origins with microbial fuel cells.

The bioelectrochemical remediation system developed within the EiCLaR project leverages bacteria capable of anaerobic hydrocarbon degradation and electron exchange to surfaces or shuttles outside the cell. This well-coordinated biological process converts the chemical energy stored in hydrocarbons directly into electricity. The process involves a series of redox reactions: organic degraders transform complex hydrocarbons into simpler molecules, which are then oxidized by electroactive bacteria in the anaerobic anode. Electrons are transported through conductive materials to a cathode exposed to air, where oxygen is reduced to water.

Bioelectrochemical remediation can simultaneously remove pollutants and recover energy from the substrate. Both electricity generation at the anode and microbial electrolysis, which uses a small amount of energy to drive chosen reactions at the cathode, are utilized.


Large-scale microbial fuel cells experiment. Hydraulic set up (left) and top view of the microbial fuel cell (right)

Microbial fuel cell experiments at the University of Stuttgart

Installing bioelectrochemical remediation technology on a site in the UK

Enhanced phytoremediation

Phytoremediation is a remediation technique that utilizes plants to immobilize, uptake, stabilize, or degrade contaminants. Enhanced phytoremediation refers to the use of methods and techniques which improve the efficiency of phytoremediation processes (e.g. use of additives, application of electric current).

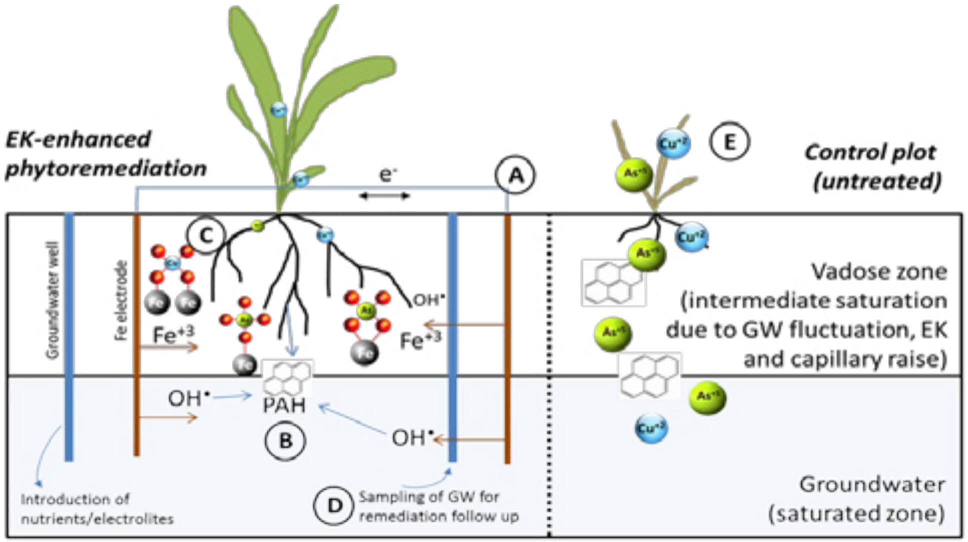
The EiCLaR project went one stage further and developed a novel soil remediation technology to immobilize arsenic and simultaneously degrade hydrocarbons *in situ*. The technology synergistically combines three individual techniques: phytoremediation, chemical immobilization, and electrochemical oxidation. Individually, each method serves a specific purpose, but together they leverage their strengths to effectively address complex soil contamination: phytoremediation utilizes plants to stabilize and degrade contaminants, chemical immobilization binds arsenic to reduce its mobility, and electrochemical oxidation breaks down hydrocarbon.

Additionally, the technology enhances soil health and promotes microbial activity, providing an integrated electrochemical-biological solution for complex soil contamination.

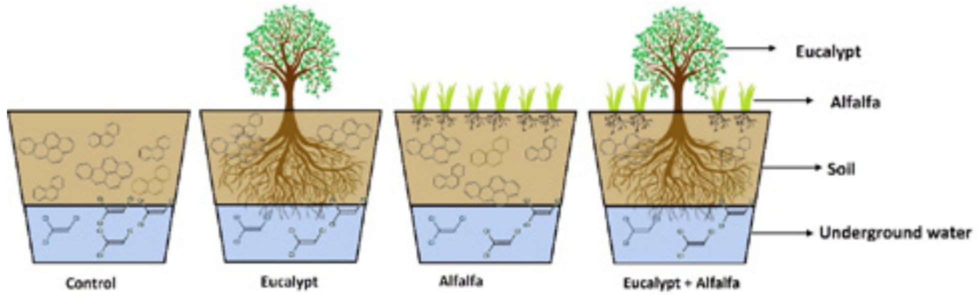
Separate research within EiCLaR has demonstrated that alfalfa and eucalyptus have potential for treating co-contamination by hydrocarbons and chloroethenes.

Assessing the potential of alfalfa and eucalyptus for phytoremediation

Enhanced phytoremediation (continued)



Principles of the enhanced phytoremediation approach applied in the EiCLaR project (A) Electrodes are inserted through the vadose zone into the groundwater layer. (B) Organic contaminants will get degraded due to the reactive oxygen species formed by electricity and through excretion of fatty acids (e.g. linoleic acid) by plant roots. Reduced soil toxicity would stimulate indigenous microbial population, which will further contribute to contaminant degradation and promotion of plant colonization. (C) Mobile and bioavailable fractions of metal(loid)s will come in contact with iron oxides originating from corroding electrodes leading to reduced soil toxicity. (D) Groundwater quality will be monitored and soil remediation success evaluated. Untreated site (E) is used as a control for comparison of the remediation success. GW – groundwater; EK- electrokinetics.



Schematic of alfalfa and eucalyptus phytoremediation experiments

More information

For more information about the EiCLaR project visit **eiclar.eu** where you can find the following additional resources:

- **Introductory video** (EiCLaR in a nutshell) – a short video explaining the project **eiclar.eu/category/videos/**

- **Animated explainer video** – an animation aimed at a general audience to provide a broad understanding of the technologies within the EiCLaR project **eiclar.eu/category/videos/**

- **Technical bulletins** – a series of short documents describing the EiCLaR outputs and signposting to more detailed information **eiclar.eu/library/**

- **Podcasts** – interviews with some of the main people working on the EiCLaR project to find out a bit more about their backgrounds, how they got to their current positions and their role and activities within the project **eiclar.eu/category/videos/**

- **List of journal papers published in peer-reviewed scientific journals** – these outputs capture the most technical aspects of the research and are fundamental to demonstrate the quality of research being undertaken **eiclar.eu/library/**

- **White papers** – a technical briefing note for each of the EiCLaR technologies, targeted to different practitioner audiences: for site owners/managers (including real estate developers), for regulators, for service providers and for environmental service procurement personnel **eiclar.eu/library/**

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