NEWSLETTER

SPRING 2023

Enhanced and Innovative *In Situ* Biotechnologies for Contaminated Land Remediation

Introduction to EiCLaR

Enhanced and Innovative *In Situ* Biotechnologies for Contaminated Land Remediation (EiCLaR) is a four year project funded by the EU and China. It was launched on 1 January 2021 and is composed of thirteen European and five Chinese partners.

The project is being coordinated by Professor Timothy Vogel at École Centrale de Lyon and Professor Xin Song at the Institute of Soil Science, Chinese Academy of Sciences.

Professor Vogel and Professor Song set out the context for the project below and explain why the EU / China collaboration is so important for its success.

Background

Bioremediation of contaminated sites has grown rapidly since the early 1990s, but the applications of different biotechnologies have levelled off in part because of their inability to deal with complex environments in a rapid and competitive manner. The broad goal of EiCLaR is to lift biotechnologies to new performance levels through fusion of different *in situ* bioremediation (ISBR) technologies with non-biological processes.

The potential environmental and commercial targets for these technologies can be found among the wide range of problematic sites in Europe and China. The number of contaminated sites is enormous with estimates for Europe (EU-28) alone (excluding many diffuse land contamination problems) of about 2.8 million sites[1], while in China there are at least 200,000 official contaminated sites[2]. The goal of the integrated technologies in this project is to provide permanent and more cost-effective and sustainable resolutions for >50% of these sites by expanding the range of *in situ* biologically treatable land contamination problems.

Global efforts in environmental remediation represent significant economic activity. In 2017 it was estimated that managing contaminated land in Europe alone costs an estimated €6.5 billion per year[3]. For China, the central government alone allocates more than 10 billion RMB (>€1 billion) per year for soil remediation and risk management. A 2020 estimate[4] for the "global soil treatment market" valued it at US $36.5 billion in 2018 with an estimated annual growth of 6.2% over 2020-2025. These markets are a major opportunity for innovation and entrepreneurship in the EU and China, which underpins the interest of the small and medium-sized enterprise (SME) partners in EiCLaR.

Of all remediation technologies ISBR has greatest potential in sustainable and risk-based land management (SRBLM). SRBLM is increasingly a part of European and Member State policy and regulation, and also in China, including the 2018 law on soil pollution which sets the goal of a risk-based approach.

Most practitioners recognise ISBR as a long established remediation technique. It is widely and successfully used in land contamination remediation mainly for managing primarily biodegradable or respirable organic contaminants, but also for modifying some trace element species, e.g. Cr (VI) to Cr (III). A large number of sites have been treated and there are many commercial solution technologies for these applications in many countries around the world.

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Bottlenecks to overcome

However, there are key limitations for currently available ISBR:

- Applications are mostly pathway management; they tend to have limited effectiveness with high contaminant concentrations found in primary or secondary source zones (in particular when the contaminant exists as a nonaqueous phase liquid).
- Not all contaminants are biolabile or biodegradable.
- Biological treatments may be, or may be perceived to be, slower than other available remediation options and of limited effectiveness for mixed contamination problems (e.g. metals and organics).

The EiCLaR project

The hypothesis underlying the research in EiCLaR is that integration with specific physical, electrical and chemical processes will provide a clear value-added component to modern environmental biotechnologies. These

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°965945.

enhanced and innovative biological remediation systems will achieve a step change in performance over existing ISBR solutions and increase the range of biologically treatable problems in terms of contamination types, concentrations (e.g., source treatment), and complexity (e.g., mixtures).

This goal will be supported by including cross-cutting decision support that links to demonstrable risk management and sustainability performance, and in-depth engagement with remediation practitioners and markets in the EU and China.

The diagram below shows the relationship between the EU and Chinese parts of the project.

The EU part of EiCLaR consists of three technology development work packages:

i) electro-nanobioremediation with novel catalyst and electro-chemical enhancements,

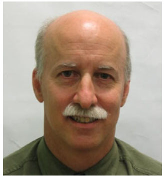
ii) monitored bioaugmentation and bioelectrochemical remediation, and

iii) enhanced phytoremediation via plant growth improvements with fungal and biochar additions combined with electrokinetic or electrochemical treatment of soil.

There are also work packages which address cross-cutting technical decision support, stakeholder dialogue and dissemination and an overarching management one.

These will be explored in more detail later in the newsletter.

Some comments from the coordinators



Professor Vogel explains the thinking behind the project and what he hopes it can achieve:

"The EiCLaR project drives novel ISBR technologies targeting complex contaminated sites in Europe and China through the developed synergy among our European and Chinese partners whose expertise spans from fundamental environmental and microbiological sciences to practical site clean-up and sustainable solutions. All the partners rely on the established excellent reputation of the participating scientists, engineers and communication specialists to push these technologies through to their timely implementation."

Tim Vogel

Professor Song gives her thoughts on how the project is working towards its goals through active collaboration:

"As Margaret Mead once said, 'Never doubt that a small group of thoughtful, committed people can change the world'. Here at EiCLaR, we, a small group of scientists from China and Europe, are committed to active collaborations to develop green and sustainable remedial biotechnologies to address the challenges of bioremediation applications for mixed contaminants in soil and groundwater."

Xin Song

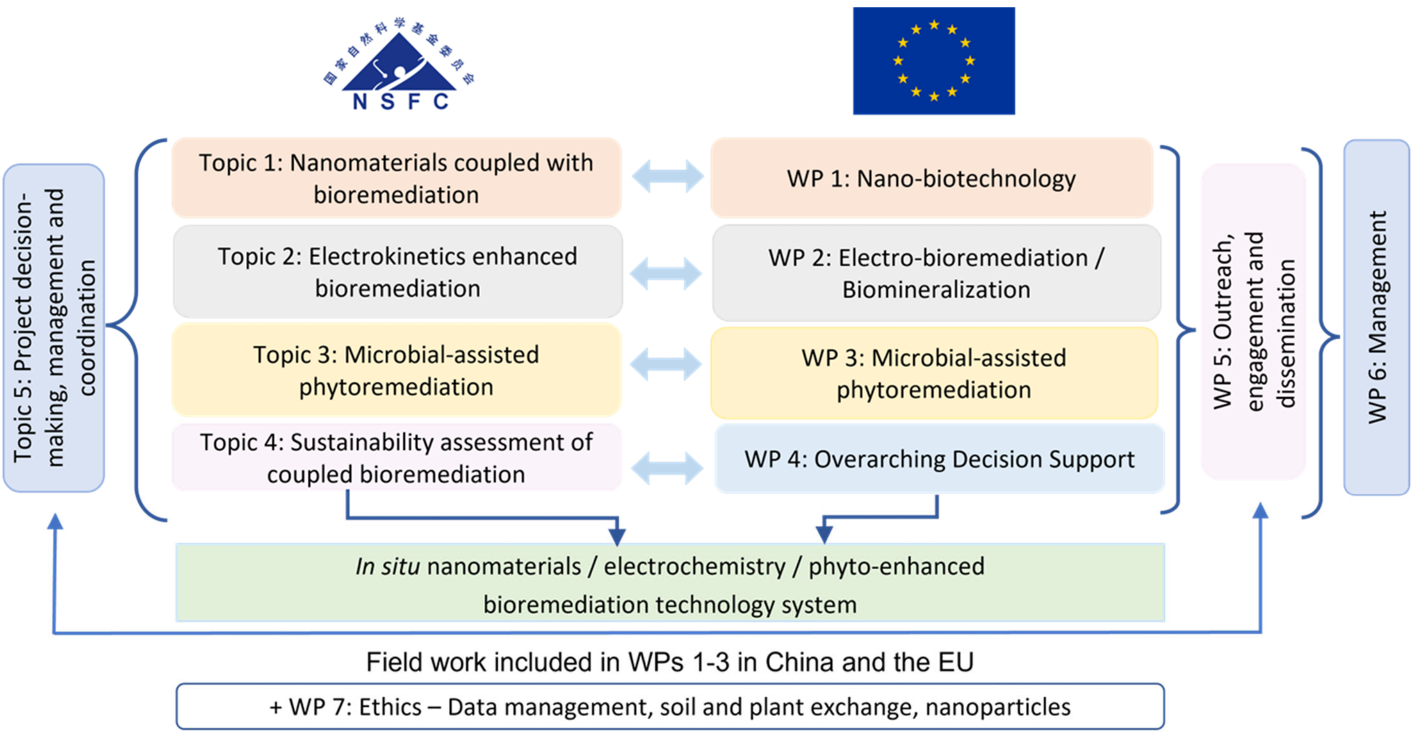
References

[1] European Commission, Joint Research Centre, Payá Pérez, A., Rodríguez Eugenio, N., Status of local soil contamination in Europe : revision of the indicator 'Progress in the management contaminated sites in Europe', Publications Office, 2018, https://data.europa.eu/doi/10.2760/093804

[2] Zhang and Li. (2016) [J]. Front. Environ. Sci. Eng. 10(4): 19

[3] Global Markets for Environmental Remediation Technologies 2017 https://www.reportlinker.com/p02584389/Global-Markets-for-Environmental-Remediation-Technologies.html and Ernst and Young (2013) Evaluation of expenditure and jobs for addressing soil contamination in Member States for DG Environment, ENV.B.1/ETU/2011/0012;

[4] https://www.reportlinker.com/p05865950/Soil-Treatment-Market-Growth-Trends-and-Forecast.html



EiCLaR work plan.

Project Partners

The EiCLaR project has thirteen European and five Chinese partners (listed below, with their shortened names, to help with the technology descriptions on p4-6).

The European partners represent leading research institutions, consulting companies, outreach experts and remediation companies from eight countries (France, Germany, Czech Republic, Sweden, Belgium, The Netherlands, Finland and the UK). The Chinese partners all represent leading academic institutions in China.

Although the project started in January 2021 during the Covid-19 pandemic and early meetings were held online, in 2022 two face-to-face meetings took place in Lyon, France and Reading, UK, when partners took the opportunity to discuss the project and exchange ideas in person. It is anticipated that the European partners will visit their Chinese counterparts in China later in 2023 to further these exchanges.

Fortunately, the pandemic taught us all how to work effectively online and so the progress of the project has not been impacted. However, it has been very rewarding to get together once again and have these interactions in the same room (or over dinner).

Kick-off meeting for the EiCLaR project, 6 April 2021, Nanjing, China.

EiCLaR seminar organised and attended by Chinese project partners in Hangzhou (August 2022).

EiCLaR European project partners at annual meeting in Reading (October 2022).

ECL	École Centrale de Lyon, France
R3	r3 Environmental Technology Ltd, UK
DVGW	DVGW-Technologiezentrum Wasser, Germany
USTUTT	VEGAS: Research Facility for Subsurface Remediation, University of Stuttgart, Germany
PWT	Photon Water Technology s. r. o., Czech Republic
LTU	Luleå University of Technology, Sweden
TUL	Technical University of Liberec, Czech Republic
SPAQUE	SPAQUE, Belgium
CL:AIRE	CL:AIRE, UK
DSBP	Dutch Sino Business Promotions, The Netherlands
BOSS	BoSS Consult GmbH, Germany
SERPOL	SERPOL, France
EKO	EKOGRID Oy, Finland
ISSAS	Institute of Soil Science, Chinese Academy of Sciences, P. R. China
SJTU	Shanghai Jiao Tong University, P. R. China
ZJU	Zhejiang University, P. R. China
CUG	China University of Geosciences, P. R. China
GIG	Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, P. R. China

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Electro-nanobioremediation (ENB)

USTUTT and ISSAS are leading the work on electro-nanobioremediation (ENB) with involvement from TUL, PWT, DVGW, R3, EKO, DSBP and SJTU.

Introduction

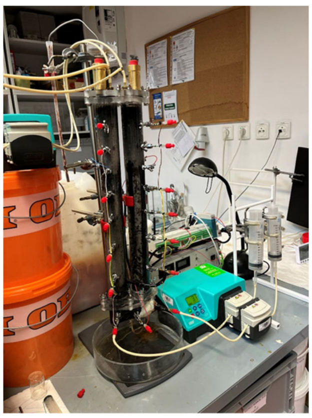
Nanoremediation is the use of nanomaterials, often iron nanoparticles, for contaminated site remediation. It has received significant attention recently with a substantial number of field demonstrations in North America and Europe. However, it has failed to make a market breakthrough, largely on cost grounds, but also because of regulatory concerns in some jurisdictions and several specific technical problems. Nanoscale zero-valent iron (nZVI) particles possess several limitations, such as short-term reactivity and also rapid aggregation, that negatively affects their lifetime, reactivity and mobility.

To overcome this, different surface modifications and methods of application of nZVI particles may be used to accelerate their migration in groundwater and increase their contact with contaminants. A recent innovation by EiCLaR partners TUL and PWT has been the combination of nano-scale and/or micro-scale ZVI with applied electrokinetic treatment for extended lifetimes and microbial degradation for synergistic effects.

The electrokinetic remediation process involves applying low-voltage direct current across a section of contaminated aquifer material. This physical-chemical technique has been brought to market in Europe, China and Australia by PWT as it is not only improves technical performance, but also makes nanoremediation price competitive. Yet, it could be enhanced further by microbially-driven contaminant degradation, which often has limited effectiveness at sites with high initial pollutant concentrations as this can inhibit bacterial growth and require relatively long treatment times. The integration of nanomaterials and bioremediation has great potential to be effective, efficient and sustainable.

Work progress

Column experiments show that an increase in the current intensity also leads to a pH increase which in turn increases the stability and longevity of the nZVI particles (shown to right at TUL).



ISSAS is undertaking a field test at the Suzhou Chemical Plant for the removal of TCE using nZVI coupled microbial technology (shown to left).

Bioelectrochemical Remediation (BER)

ECL, DVGW, ZJU and CUG are leading the work on bioelectrochemical remediation (BER) with support from USTUTT, BOSS, EKO, R3 and DSBP.

Introduction

Microbial bioelectrochemical systems are electrochemical devices and/or applications in which an anode and a cathode favour redox-reactions that are catalysed by microorganisms. The biocatalytic principle of a bioelectrochemical system contributes to enhance thermodynamically favourable or drive thermodynamically unfavourable reactions and can thus be an alternative electron acceptor for improving hydrocarbon removal or an electron donor for reductive dechlorination and metal reduction.

In recent years, studies conclusively demonstrated the success of an *in situ* bio-electrochemical technology for total petroleum hydrocarbons and diesel as well as recalcitrant compounds such as polycyclic aromatic hydrocarbons, in contaminated soil, sediment and liquid media.

The suitability of BER to improve microbial pollutant degradation has been demonstrated in general, but there is a lack of understanding with respect to operating parameters, microbial community selection and complex composition of field samples. Furthermore, scale up experiments from proof of concept tests to field tests under real boundary conditions are missing.

In the EiCLaR project, the optimisation and validation of BER for aromatic hydrocarbon mixtures, hexavalent chromium and chlorinated solvents in soil and groundwater will be conducted to develop the key operating parameters for field applications.

Work progress

Lab-scale experiments have already been conducted to investigate the development of electroactive microorganisms after placing electrodes in microbial fuel cells containing hydrocarbons present in polluted soils (see below at ECL). This bioelectrochemical system (BES) is a low-input bioremediation approach. A range of operational parameters is under study for their effect(s) on hydrocarbon degradation.

The recent progress from CUG has been to gain insights into the effects of different environmental factors (electrode products, redox conditions & water chemistry) on bio-stimulation of chlorinated solvents by indigenous soil microbes.

EiCLaR Technologies

Monitored Bioaugmentation (MBR)

DVGW is leading the work on monitored bioaugmentation (MBR) in collaboration with ECL, BOSS, USTUTT, EKO, R3, DSBP and ZJU.

Introduction

A new, efficient aerobic chloroethene biodegradation process has been studied in recent years. *Aerobic metabolic degradation* represents a new and promising concept for removing contaminants from the subsurface environment for improving groundwater quality. The metabolic aerobic process is favourable because there is no risk of formation of hazardous metabolites 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.

Aerobic chloroethene biodegradation can occur under natural conditions or after addition of oxygen both *in situ* or in *ex situ* engineered approaches (e.g. in bioreactors or biological activated carbon). If the required microorganisms are not present at a specific site, enriched cultures can be added to the field site (bioaugmentation). Bioaugmentation, however, has proven contentious, and field based evidence of success has been variable. Effective proof of concept therefore demands that field tests for bioaugmentation methods must be optimised and validated.

Work progress

Collaborative lab-tests involving USTUTT and DVGW have been undertaken to enhance chloroethene degradation efficiency (see below). Different boundary conditions will be used to validate MBR as a promising approach for metabolic aerobic chloroethene degradation. This innovative method will be benchmarked against anaerobic and chemical treatment.

ZJU has focused its research on the effects of heavy metals such as As/Cr on TCE reductive dichlorination (Microbial Response and Resistance).

Ongoing work is being done to understand the microbial interspecific interactions in the presence of TCE-heavy metal pollution.

Enhanced Phytoremediation (EPR)

LTU and GIG are leading the work on enhanced phytoremediation (EPR) with support from SERPOL, ECL, EKO, R3, DSBP and ISSAS.

Introduction

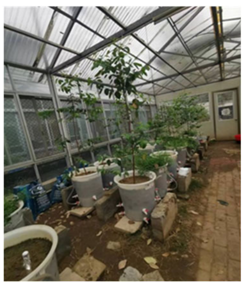
Over the past three decades, phytoremediation has been considered as a less expensive and environmental-friendly remediation technology compared to traditional physicochemical methods. Although early estimates of the worldwide market of phytoremediation were large, the technology has not achieved its predicted potential as a broad range commercial technology due to a number of limitations. Focus was often put on phytoextraction of metals, which is relatively slow and incomplete and generates a problematic biomass in many regulatory jurisdictions. A more successful approach has been by exploiting the synergistic interactions between plants, microorganisms and/or mycorrhizae to completely degrade or immobilise contaminants *in situ*. The range of contaminating substances targeted by such phytostabilisation/degradation has grown ever since.

Nevertheless, soil toxicity to plants has been another important limitation. Plant establishment and microbial/fungal activity are often limited on barren contaminated sites due to the soil toxicity and nutrient deficiency. Research efforts have continued to overcome those limitations and arbuscular mycorrhizal fungi (AMF) has been shown to promote plant performances (growth, survival, tolerance), take part in soil structuration and increase the phytoremediation efficiency of organic as well as inorganic pollution. Furthermore, the distribution of nutrients, amendments and AMF will be optimised by applying the dispersive force of electrical fields.

Work progress

Experiments have already been set up at LTU using soil samples from a historically contaminated site in Sweden containing a mixture of organic and inorganic contaminants (see below).

GIG has been using Alfalfa and Eucalyptus plants for TCE and PAHs co-contamination remediation experiments (see below).



Supporting the Technologies

The four technologies in EiCLaR are supported by three cross-cutting work packages involving all project partners, described below.

R3 leads the work on providing case study-based decision support guidance. This will use the "operating windows" concept to facilitate the inclusion of EiCLaR technologies in contaminated site remedy selection and identify viable opportunities for scale-up / enhancement of EiCLaR technologies.

This work package will develop targeted briefings (White Papers) for different practitioner audiences which may be influential in technology uptake (site managers, service providers, regulators, procurement professionals).

This work package will also ensure practical and market relevance of the technologies, including development of a road-map to show their route to implementation, determine their environmental burdens and their potential for delivering sustainability and value gains.

SPAQUE is leading the project's work package on outreach, engagement and dissemination. This work will support engagement with the EU and China remediation market and support the scale up, market awareness and business planning activities across the rest of the project. It will provide outreach to the wider public (e.g. via project brochures - see below) and offer meaningful technical and scientific dissemination to interested user groups such as regulators, contaminated land managers, industry, service providers and researchers.

Introductory project brochure.

Technical Advisory Board

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Within this work package exists a further key support mechanism for the EiCLaR project - engagement with its two advisory panels: a Technical Advisory Board to channel external expertise to the project and a Stakeholder's Board to develop a constituency of support for onward technology development / marketing. Members of each Board are listed in the tables above.

As well as its involvement in the technical work packages, ECL is also responsible for the overall management of the project.

Keeping Informed

The next EiCLaR Newsletter will be published in Autumn 2023 and will provide further updates on the EiCLaR technologies and the wider project work.

In the meantime, to keep informed about EiCLaR progress, activities and events please visit our website at www.EiCLaR.org or via LinkedIn or WeChat (available in China).

Alternatively, contact Timothy M. Vogel or Maria Tovilla Coutino at École Centrale de Lyon via email: vogel@univ-lyon1.fr or maria.tovilla-coutino@ec-lyon.fr