



# Sustainable Soil Upgrading by Developing Cost Effective, Biogeochemical Remediation Approaches

FP7 Collaborative Project  
Grant Agreement No.: 226956

## NEWSLETTER: DECEMBER 2011



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Deltares/TNO, The Netherlands  
Wageningen University, The Netherlands  
The Institute for Ecology of Industrial Areas,  
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INCD ECOIND, Romania  
The Swedish Geotechnical Institute, Sweden  
ENACON s.r.o. , The Czech Republic  
ECOREM-Baltic, Lithuania  
DEKONTA, Czech Republic  
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### UPSIL's SECOND YEAR: MOVING FROM THE LAB TO THE FIELD

From the first moment the Upsoil project was conceived, the need for field implementation of newly developed technologies became more than evident. Indeed, the first and most obvious advantage of field testing is the improvement of the technology itself, which is then adapted to a heterogeneous and changing natural environment. Additionally other more practical information concerning time, cost and energy consumption of the technology is obtained.

Thus, the Upsoil project aims at improving new technologies by testing them in a variety of field demonstration sites, under different geological, chemical and climatic conditions: preliminary tests have already been done in Belgium, Poland, and Austria, whereas Spain is being currently considered for further tests.

As a result of this, it was decided to normalize all results arising from the different field tests so that newly developed technologies can be easily transferred to other real case scenarios in a satisfactory manner. Consequently, all the results are optimised and validated and written protocols are defined for each novel technology.

Other advantages of technologies field implementation include the involvement of geographically distributed SMEs in the project and the link between fundamental and applied research. Out from the 15 members of the UPSIL Consortium, 7 are SMEs (plus 1 contractor), playing fundamental roles in the various field tests.

Finally, technologies field testing promotes stakeholders participation, such as problem owners, ensuring the focus of the project on actual and most urgent issues in cost-effective sustainable remediation of soils, and setting realistic boundary conditions for cost optimization and acceptable remediation times.

*Nerea Otaegi Ariztimuno*  
Project coordinator

### New developments

In March 2011 successful field testing of a new system for injecting a remediation agent was carried out at the Flanders site to treat BTEX and chlororganic compounds contamination. An on-line monitoring of the key parameters of remediation performance was carried out before, during and after the injection and post treatment results were evaluated. To determine the potential of bio and chemical treatment coupling, batch experiments for both: chemical and biological degradation were carried out between September 2010 and October 2011. The tests were made for soil and groundwater samples taken at the sites in Flanders, Belgium, Węglińiec, Poland and Bruckl, Austria.

The obtained results provided a stimulus to design field experiments for testing, in site conditions, the biostimulation potential in the remediation of soil contaminated with mineral oil and chlorinated hydrocarbons. Preparatory tasks aimed at transforming the lab tests results into field experiments were also performed in the scope of the selective oxidant packing. The laboratory tests focused on the use of the zero valent iron and coated persulfate.



## Technology development:

### Research Line 'a'

*Smart coupling: smart coupling of existing chemical and biological techniques.*

The research goal in this line is to optimize chemical oxidation and enhanced biological technologies as soil cleanup techniques for removal of total petroleum hydrocarbons and chlorinated aromatic hydrocarbons, taking into account the geohydrology, geochemistry of the site as well as contaminants distribution, and soil type(s).

### New developments:

In 2010 and in early 2011 soil samples were collected from three sites: Węglińiec, Poland (petroleum hydrocarbons contamination), Brückl, Austria (contaminated with chlorinated aliphatic hydrocarbons) and a site in Flanders, Belgium (mixed pollution) analysed for chemical reactivity in lab-scale batch tests and microbial activity.

The chemical tests of the Węglińiec samples showed high consumption of the oxidant but at the same time differences in the impact of the chemical remediation process on the soil matrix. These results indicate that the planning activities of the remediation process should also take into account the heterogeneity of the soil with respect to the content of both: the natural organic matter as well as the contaminant.

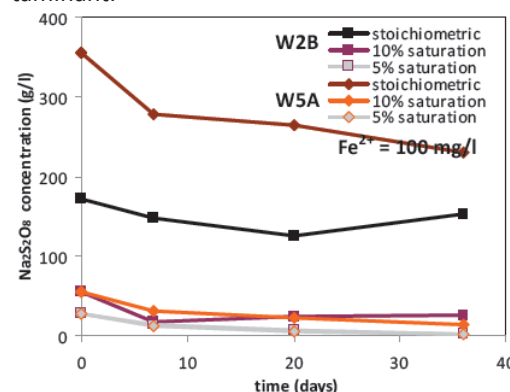


Figure 1 Decrease of persulphate concentration in time (activated treatment) in some of the Węglińiec experiments (Deltares)

The laboratory tests aimed at determining the effectiveness of the biological remediation processes after application of an in-situ chemical oxidation (ISCO) showed that there are some constraints which may affect the effectiveness of the biostimulation. Their main reasons are the changes of the soil conditions. However, in order to determine how to enhance the benefits of using chemical oxidation

and which auxiliary factors continue to impede the biodegradation additional tests are required. For that purpose further pilot field and column tests were planned in late 2011 and early 2012 at the the Węglińiec and Brückl sites to test chemical treatment application together with biostimulation.

Separately, laboratory tests were performed to determine environmental risks associated with the side effects of the oxidation treatment application such as changes in the natural soil composition and mobilization of heavy metals. Tests of soil samples with high heavy metals content performed at TECNALIA showed a high release of the metals from the oxidized soil. Also the toxicity tests performed by ENACON showed a distinct impact of the oxidation process on the microbial population and a rise of the overall toxicity caused by the change of soil pH as well as other changes in the concentrations of chemical components. From the viewpoint of human health, the data obtained from the tests has no indication of a high potential for a negative environmental impact.

### Research Line 'b'

*System driven injection: improved injection system for a more efficient delivery of the reactant.*

The aim of this research line is to optimize the injection of the remediation agent through combining it with a monitoring system. The project site in Flanders contaminated with BTEX and chlororganic compounds was selected for testing the new injection system designed by Ejlskov A/S.

### New developments:

In autumn 2010 preparations for the pilot test were performed under the supervision of SGI with ENACON with the support of ECOREM, VITO, DECONTA. They included measurements, characterisation, slug tests and screening of the physico-chemical parameters of the groundwater. Once the site characterisation was completed with a detailed plan of the experiment, full scale test of the injection system was performed by the UPSOIL members at the Flanders site in February 2011. Sodium permanganate ( $\text{NaMnO}_4$ ) was used as reactant to oxidise the chlorinated hydrocarbons and BTEX present at the site. A total of 335 kg of  $\text{NaMnO}_4$  as 8 % solution were injected in three different injection spots with injection levels varying between 2-7 m below the ground level.

Before, during and after the injection critical parameters such as pH, electric conductivity,

redox potential, soluble oxygen, and temperature of soil matrix were continuously monitored by the installed automatic on-line loggers supervised by Tecnalia. The on-line monitoring was additionally accompanied by periodical manual sampling and chemical analyses performed by VITO, SGI, ECOREM and DECONTA. The effects of the treatment have been monitored for 3 months.

The results obtained from the field test in Flanders allowed to evaluate the effectiveness of the chemical remediation process as well as assess the environmental risks and cost – efficiency aspects. For example temporary metal (especially chromium) release was detected during the oxidation of soil matrix. Investigations related to that issue are ongoing. Further interpretation of the results will allow establishing the operational requirements for the technique.



Figure 2 On-line monitoring installation at the Flanders site

### Research Line 'c'

*Specific targeting: injection of specifically developed chemical oxidants to target them to the right place*

Specific targeting is a new, unique approach in which the oxidant is packed in a mineral or organic protecting layer to avoid reaction with the soil matrix components. The aim of the research is to develop efficient remedial reactants to achieve optimal contaminant degradation of combined biological and chemical in-situ remediation systems. In 2010 the most promising approaches to reactant packing were selected for batch tests in laboratory at VITO, Ecoind, Deltares, Tecnalia.

### New developments:

The collaboration between a number of partners (VITO, Ecoind, Tecnalia) resulted in the development of new reactive particles. These newly developed micro-scale particles were tested in laboratory experiments for their reactivity, stability and fate. Tests with injectable



emulsified zerovalent iron were continued to check the destruction of the chlorinated compounds such as PCE, TCE chlorinated ethenes, chlorinated ethanes.

The preliminary laboratory results delivered promising results of the new selective oxidation/reduction techniques. Pilot testing in real field conditions is considered for spring 2012 at the site in Spain contaminated with chlorinated hydrocarbons. The tests will be carried out by GEOCISA. Samples taken from Spanish sites were analysed to characterize the reaction (VITO). Extensive set of laboratory experiments for different materials is further carried out.

### MONITORING AND CONTROL SCHEME OF REMEDIATION TECHNOLOGIES

The aim of this research line is to optimize the soil and groundwater remediation process performance by a feed-back driven approach. This can be achieved by linking the application of remote sensors with simple but reliable modeling schemes to provide an on-line and real time control of the remediation process. The modeling combines the flow simulation with geochemical modeling program as a baseline reference for assessing the reaction performance.

#### New developments:

The developed basic structure of the monitoring and control scheme was adapted for Flanders site application in 2010 and the monitoring system was installed by Tecnalia in 2011. The design of the sensor network included placement of sensors, preparation of sensors/nodes architecture and building of the wireless systems. In autumn 2010 6 sensors were installed at the Flanders site for measuring key parameters such as pH, dissolved oxygen, temperature and ox/redox potential. The performance of the monitoring system was evaluated from the viewpoint of its reliability, sensitivity and resistance to disturbances.

Oxidant movement in the soil and groundwater was spatially and timely traced by real time measuring loggers. Additional laboratory analyses and alternative loggers might be needed to complement existing sensors in order to improve the interpretation.

The system combining sensors installed in the field with a modeling capacity for a long term and a short term control was completed. A computational model for assessing the progress of the remediation process was calibrated using the on-line monitoring data. The results of the monitoring were applied to evaluate the overall control scheme. The data

were analysed to determine the key relations between the control and monitoring parameters for the purpose of providing the operators with a reliable interpretation of the data.

Based on the results of the mathematical modeling carried out by IETU prediction of pH, oxygen, ox/redox potential can be carried out together with defining the critical levels of the parameters affecting soil functions and properties. Moreover, the modeling results give an outlook of the evolution of soil/groundwater parameters. Simple one dimensional model helps finding how the different soil properties (pyrite, organic matter and PCE content) may influence the effectiveness of the remediation while a two dimensional model enables considering different layers (vertical profile) to check if a multilayer injection well can increase the efficiency of ISCO remediation.

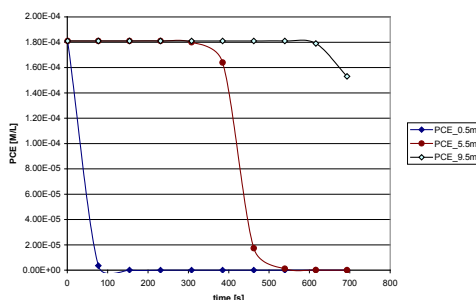


Figure 3 Changes of PCE concentrations simulated using PhreeqC code and Excel input data

On the basis of the mathematical modeling the feedback driven response program can be prepared as an output unit (injections, alarming). The needs for an operational optimisation of the injection campaign were studied to establish the feed back requirements.

It should be stressed that the anticipated benefits of the on-line monitoring supported by modeling can be achieved only when an optimal design and control of the injections, control of the injected volume and a better control of the remediation conditions are ensured. The results of the on-line monitoring applied at the Flanders site, provide an universal basis for designing the control system. The model can be extended with an easy interface for the operator.

#### Stakeholder interaction

The UPSOIL Stakeholder Panel consists of the members representing industry, problem owners and authorities including financial supporters of large redevelopment projects.

#### 2<sup>nd</sup> Stakeholder Panel meeting and workshops



The Second Joint Stakeholder Meeting and Workshop were held in Antwerp, Belgium on 25 March 2011.

The event was aimed at presenting and discussing the overall idea behind the UPSOIL project. Special attention was given to the new reagent delivery system that was demonstrated at a site in Flanders, Belgium. Over 40 people representing consultants and engineers in the field of remediation took part in the meeting.

The main conclusions from the meeting were as follows:

- the UPSOIL approach proved to fit well into the revitalization schemes aimed at a short-term release of the site with an outlook for a full soil recovery,
- the reliability of the UPSOIL approaches needs to be tested in full scale including their cost-efficiency and benefits for the stakeholders,
- it is difficult to provide a definite proof of the UPSOIL approaches performance but in general the technologies have many advantages to be considered in practice,
- the risk that the proposed technologies may fail can be tackled reliably to some extent by e.g. coupling of different methods and through appropriate design of the monitoring system.

#### 3<sup>rd</sup> Stakeholder Panel meeting and workshops

On October 19th 2011, following the established cooperation (more info on the next page), the EU funded projects CityChlor and UPSOIL in cooperation with the HOMBRE project organized a workshop entitled „Integrating in situ remediation technologies into land use cycles” The focus of the event was laid on the understanding of both: land use cycles in terms of how brownfields evolve and are redeveloped as well as speaking technically on the integration of soil remediation into these cycles.



The event turned into a productive discussion and interaction among the different parties within the soil remediation field, such as academic institutions, local and national government, research institutes, consultancies, and contractors. The chairman of the day, Huub Rijnaarts from Wageningen University mediated and stimulated discussion throughout the workshop.

The key points raised at the meeting were as follows:

- smart remediation approaches can be fully utilised within the concepts based on sustainable approaches focused on a long term improvement of the soil conditions in circular land management.
- the use of the existing practical experiences in ISCO and biological remediation techniques together with their exchange will help building the capacities for sustainable remediation processes and decisions
- the risks associated with the application of the ISCO technology have to be carefully considered and well understood in order to be properly managed during the remediation.

## UPSOIL papers and presentations

Optimization of Coupled ISCO and Bioremediation at a Diesel Contaminated Railway Site Nora B. Sutton ([Nora.Sutton@wur.nl](mailto:Nora.Sutton@wur.nl)), Tim Grotenhuis and Huub Rijnaarts (Wageningen University, Wageningen, The Netherlands)

Presentation: Soils and Sustainability, European perspectives on soil management. Pauline van Gaans (on behalf of Upsoil, SoilTrEC and Hombre partners) BodemBreed November 30, 2010.

Publication: Looking down, Finding out about the soil beneath our feet. Deltares VIEWS n° 4, December 2010.

## Cooperation with other activities

UPSOIL builds synergies with other soil remediation and land management efforts financed by the EC including such projects as AQUAREHAB – “Development of rehabilitation

technologies and approaches for multipres-sured degraded water resources and the integration of their impact in river basin management -([www.aquarehab.com](http://www.aquarehab.com)) and Soil tech initiative of EU 7th FP funded projects cluster lead by Helmholtz Institute in Lipsk Cluster website: [www.soiltechnologyresearch.eu](http://www.soiltechnologyresearch.eu).

Recently, a new cooperation with the project “Tackling urban soil and groundwater contamination caused by chlorinated solvents” (acronym: CityChlor) was established. CityChlor is a project funded by INTERREG IVB North-West Europe (NWE). More information on this initiative is available on the web site : [www.citychlor.eu](http://www.citychlor.eu) The 3rd Workshop and UPSOIL Stakeholder Panel Meeting organized in Utrecht jointly with CityChlor project and another land management related initiative – the HOMBRE project: “HOListic Management of Brownfield Regeneration” which is funded by EC 7th Framework Program FP7 (website: <http://www.zerobrownfields.eu>). Final UPSOIL conference is to be organised together with the AQUAREHAB project conference in Barcelona in September 2012.

Further cooperation will be sought with another FP7 funded project TIMBRE: – Tailored Improvement of Brownfield Regeneration in Europe <http://www.timbre-project.eu/>.

UPSOIL events in the period 10.2010-10.2011

- Third General Assembly meeting Vienna 20- 21 September 2010– site visit in Bruckl
- Fourth GA meeting Antwerp 23 –25 of March 2011, with a visit at Flanders site
- Fifth GA meeting in Utrecht on 17-18 October 2011

## Events:

Stakeholder Panel meeting and workshop The 3rd Stakeholders Panel meeting and workshop organized in Utrecht on 19 of October 2011 Sustainable Soil Upgrading by Developing Cost effective, Biogeochemical Remediation Approaches UPSOIL organised together with City Chlor project.

Events planned in 2012

Two workshops are scheduled:

- “Data requirements and process control techniques” in March 2012 in the Czech Republic
- “Advances in soil remediation techniques” in September 2012, in Romania.

The final conference of the UPSOIL project and Stakeholder Panel meeting are scheduled for in September 2012. For detailed informa-

tion of the events please consult UPSOIL web page [www.upsoil.eu](http://www.upsoil.eu).

## UPSOIL at a glance

UPSOIL is Collaborative Project funded under the SEVENTH FRAMEWORK PROGRAMME of the EU under THEME 6 ENVIRONMENT (INCLUDING CLIMATE CHANGE)”

The project’s objective is to make the required breakthrough in in-situ (bio)chemical remediation for organic contaminants, by developing robust in-situ (bio)chemical technologies for fast, cost-effective, integrated source zone and plume treatment. Work comprises laboratory and field testing, new tools development and modeling.

The Aim of the UPSOIL project is to develop robust technologies for fast, cost-effective, integrated source zone and plume treatment that result in both allowable risk levels and maximal use of the natural soil rehabilitation potential at a longer term.

UPSOIL research topics include:

- ✦ Integration of source and plume treatment via smart coupling of chemical Biological technologies
- ✦ improving injection of the remediation agent
- ✦ New, improved reactive materials targeted in more precise way to the contamination plume

Feed-back-driven remediation (in-situ monitoring tools).

The consortium lead by Technalia includes 6 scientific institutions and 7 SMEs specialized in soil remediation. Four testing sites have been selected (Poland, Spain, Austria and Belgium) for testing the new approaches and technologies.

The technical work is matched with the dissemination activities aimed at spreading the knowledge and rising the interest among the stakeholders concerning the application of the innovative technologies for a sustainable use of soil resources in Europe.



Project web page : [www.upsoil.eu](http://www.upsoil.eu)

Grant Agreement No.: 226956

Start date: 1 October 2009

End date: 31 September 2012