LIFE sedremed
ENHANCED BIOREMEDIATION OF CONTAMINATED MARINE SEDIMENTS

LIFE20 ENV/IT/000572

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START DATE OF THE PROJECT: 1 October 2021

DURATION OF THE PROJECT: 42 months

DELIVERABLE B2.1

Detailed work plan of the activities to be implemented

DUE DATE OF DELIVERABLE: 04/2023

ACTUAL SUBMISSION DATE: 10/2024

BENEFICIARY LEADING THIS DELIVERABLE: **EKOGRID**

CONTRIBUTING BENEFICIARY: **SZN, IDRABEL, INV**

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Reason for late submission

The action B2, and the consequent deliverable, were delayed for the following reasons:

- The study of the mesocosms (action B1), necessary to define an in-situ implementation plan of the technologies, has suffered a significant delay, consequently causing a delay in action B2
- The installation of the EKO unit by INV required a mechanical excavation work allow underground passage of the electrical cables up to reach the EKO Unit in the container. This work has suffered a significant delay in bureaucratic procedures for awarding the activity and supplying materials.
- Adverse weather conditions in Autumn caused the installation date to be postponed by several weeks, due also to the availability of the contractors.

Executive summary

Action B2 was meant to apply in-situ of the methodology designed and optimized during action B1. Unfortunately, the work done with small-scale mesocosms in IDRA laboratory provided limited information that could be transferred for the practical in-situ trials. IDRA, and EKO therefore decided to synergistically implement their technologies in the selected areas. Logistic support was provided by SZN and INV.

Originally the remediation strategy should have covered an area of 2 ha and remediated a volume of circa 40,000 m3. Since the technologies still required to be evaluated in situ, it was decided to reduce the pilot area to 100 m2, equal to 200 m3. In that area, we were able to install accessories to be used for periodic monitoring analysis (Action B3).

This test area for the in-situ installation consists of 9 vertical steel electrodes disposed to form a square with a side of 10 m, placed 5 m apart from each other. The electrodes were 1.5 m long, while the active, uninsulated surface was 0.3 m. The electrodes thus formed four squares (A1-A4) of 5x5x2m volumes of sediment (see Paragraph 4.4) that will provide many answers needed to upscale the treatment. IDRA tubes, containing Idrabel product, were installed in two squares (A1-A2) as shown in Paragraphs 3.4 and 4.4. In all four areas were installed BACTRAPS for the monitoring (see Deliverable 3.1).

This study is expected to provide answers to the following questions:

- Can EKOGRID electrokinetic field work in these high salinity, volcanic sand conditions, normally?
    - To produce free radicals and oxygen, both are required for the expected remedial processes – electrochemical oxidation and enhanced bioremediation.
    - Not losing energy allowing the current to flow through the sediment layer instead of using high saline sea water as a path.
- Can EKOGRID reactions improve the effects of IDRA products with the remedial tasks.
- Can we make the IDRA microbes grow faster (better metabolism)?
    - What can the role of Zeolite be?
    - Are the planned monitoring actions (B3) providing sufficient information to analyse the performance of the installation?

1. Introduction

The B2 action aims to the installation of an electro-kinetic system to improve bioremediation capacity and to provide oxygen through water electrolysis (EKO) for oxygenation of biofixed microorganisms (IDRA). For this purpose, 9 electrodes have been installed vertically inside the sediments, and positioned 5 m apart. The electrodes are tubes having holes or slots in the depth of approx. -1 m (inside the sediment). The technology utilizes low-voltage DC pulses, which are led into the treatable sediments matrix. IDRA material has been injected into the sediments through tubes, called “socks”. The degradation processes through the IDRA biomaterial represent an ecofriendly solution to remove pollutants, avoiding/minimizing the risk of non-controlled reactions as in the case of using chemical compounds (e.g., oxidants). Also mechanical dredging is an option to remove polluted sediment, but this technology severally impacts benthic assemblages and determines sediment resuspension thus releasing contaminants in the water column and their ecotoxicological risk. IDRA solution avoids these risks. The IDRA strategy increases the stiffness of the sediment surface to avoid the remobilization of remaining contaminants. Eco-barrier aims are 3: perform bio-dredging on the top of the treated sediment layer; capture and stabilize mobilized heavy metals; create a stable microbiologic biotope to allow the introduction of very specific bacteria.

Quantity and composition of IDRA product were defined in the B1 action (see Deliverable B1.1).

In the following paragraphs, we present a summary of the technologies.

1.1. EKOGRID system

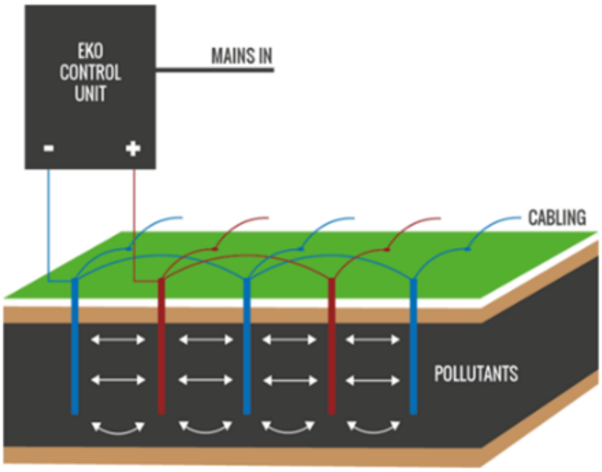

Figure 1 shows the main parts of a typical EKOGRID installation.

EKO Control Unit provides short (20 to 2000 ms) constant voltage pulses through the electrodes to the soil. Every other pulse with reversed polarity.

Electrodes are typically made of steel but can be of MMO coated titanium, also. They are often made of perforated tubes when they can be used for irrigation and/or injection of additives.

Electric cables are required to provide power to each electrode in the grid.

Figure 1. Typical EKOGRID installation

Spacing and orientation: electrodes are typically installed vertically approximately 5 m apart from each other.

Specials: electrodes are typically partly insulated to guide the energy to the depths required (e.g., the depth of plume).

Functioning – remediation of hydrocarbons:

The Electrokinetic pulsepatterns, or rather the reactions generated, are producing e.g., free radicals and oxygen (oxidizing agents) inside the pores of the matrix (sediment). Each of the tiny negatively charged soil particles (or grains) provides an active reaction surface for the phenomena. The polarity of the output (and the electrodes) is constantly reversed after each milliseconds-long pulse.

The radicals formed can directly attack longer hydrocarbon chains, benzene rings and complicated compounds present eg in crude oil, causing a kind of cracking or oxidation effect (**ElectroKinetic Oxidation** = EKO).

Equally important is that Oxygen is formed in the reactions activating the microbiological life in soil and ground water. The activity of the microbes will increase even at great depths, normally suffering from depletion of oxygen. The constantly altering polarity of the pulses are also causing shaking of water and its contents, increasing bioavailability.

Functioning – Ground (Pore) Water Management

Originally this invention was used for humidity control (mainly drying) of concrete, masonry walls, and clayish soil by maximizing the electroosmotic functioning. This can be made by changing the applied pulse pattern to be asymmetric.

This phenomenon is largely used with irrigation periods and to spread additives, such as nutrients around the treatment zone.

The pulse patterns will be altered depending on the task to achieve. During the electrochemical oxidation phase, the positive and negative pulses are equally long (100 ms). To move the pore water and possibly some of the IDRA products, the other pulse is longer (500 ms), forming the asymmetric pulse pattern. During the first months, this asymmetric pulse was used 8 hours per day.

The method has been effective in degrading a wide variety of organic compounds: Aliphatic hydrocarbons, BTEX compounds, PAH compounds, chlorinated HC, and MTBE, even some PCB and dioxins. Some complex mixes such as heavy crude oil and Creosote have been treated successfully. The effects are the results of the decomposition of pollutants due to electrokinetic oxidation or enhanced (activated) bioremediation.

1.2. IDRABEL Product

The IDRABEL (hereafter "IDRA") product includes a mix of zeolites, mineral support, and bacteria to use directly in-situ. IDRA mineral supports hold fixed microorganisms able to fix metals thus reducing their bioavailability and degrade hydrocarbons and other pollutants. The in-situ treatment of surface water bodies and harbour areas with IDRA products will generate the following effects and benefits:

- Degradation of toxic organic compounds (hydrocarbons, PCBs, halogenates, surfactants, etc.)
- Fixation of heavy metals and reduction of their bioavailability and thus their toxicity
- Improvement of the physicochemical and biological quality of water and sediment.

1.3. Combined IDRA / EKOGRID functioning

With this Bagnoli Bay pilot we are searching for answers to the following questions:

1.3.1. IDRA Bacteria activation

The aerobic microbes require oxygen for effective metabolism. Electrochemical reactions that are triggered by EKOGRID can produce oxygen. The reactions are normally happening in all pores, even outside the IDRA tubes. Increased DO can hopefully help the microbes to grow to wider areas from the tube. The idea is also to allow EKOGRID pulsing (shaking) effect to increase the bioavailability of all components (pollutants, water, nutrients, bacteria, oxygen, etc).

1.3.2. Nutrients

Nutrients (food) is very important for the bacteria. The pulse is changed regularly form EKO pulse (symmetric) to EO (asymmetric). This should make the nutrients to spread over the entire treatment zone.

1.3.3. Zeolite

Zeolite is a very porous material that could tie heavy metals and take them away from the pore water. EKOGRID typically handles the heavy metal problem keeping the conditions neutral (pH, Redox), and most of the metals stay in oxides and neutral. However, it is important to note that positively charged ions will move towards the cathode. Hopefully, we can find out, if they when passing zeolite layer, will stay in there or will they carry on moving towards the cathode.

IDRA design has been validated thanks to B1 action.

The operation of the EKO Control Units can be monitored and controlled remotely. This allows to monitor whether the system is safely turned on, to receive alarms for power failures and/or to understand if there are cable breaks.

2. Installation Report

2.1. Location

Site H (selected for mesocosms studies - **see Deliverable B.1.1**) was used for the installation of the IDRABEL and EKOGRID technologies. The map below (**Figure 2**) shows the location of the EKO Unit and the electrodes. The unit is placed well protected in a container. INV supplied the mains electricity in it, digging into the ground to allow the cable to pass underground avoiding problems related to bad weather and theft. The cable route is marked with red.

Figure 2: Location of the EKO Unit and cable route.

2.2. EKOGRID system layout planning

Nine electrodes (1,5m long) were prefabricated in Finland, fitted with cables (40 m+ long) and heat shrink insulation (1,2 m long). The layout of the electrodes and cables is shown in **Figure 3**. The material of the electrodes is mild steel.

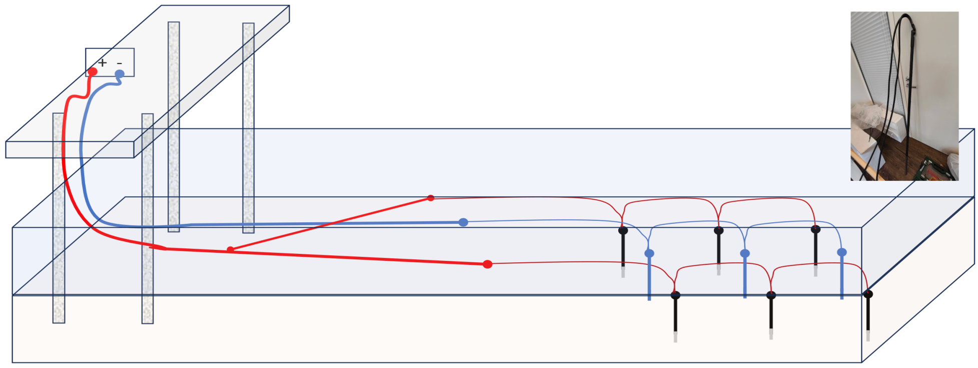

Figure 3: General layout of the EKOGRID system. 9 electrodes, each 1.5 m long fitted with 1.2 m heat shrink.

2.3. IDRABEL installation planning

To insert the IDRA product inside the sediments, a "sock" was developed by IDRABEL to be pushed into the ground. The best material for the production of the sock has proven to be a TENCATE SOLMAX Membrane GT525D, a polymer sheet that offers a water permeability of 300 l/m²s, with micro holes (hole size, 350µ) (**Figure 4**). Therefore, 18 IDRA socks were prepared: 2 m long, 5 cm diameter (3925 cm³), with 7.2 kg of IDRA product per tube. The 2 m socks have been installed in the sediment in a U-shape, by an air-injection system, as shown in **Figure 5**. In this way, the socks will be inserted 1 m deep into the sediment.

Figure 4. GT525D used for the production of the idrabel "sock"

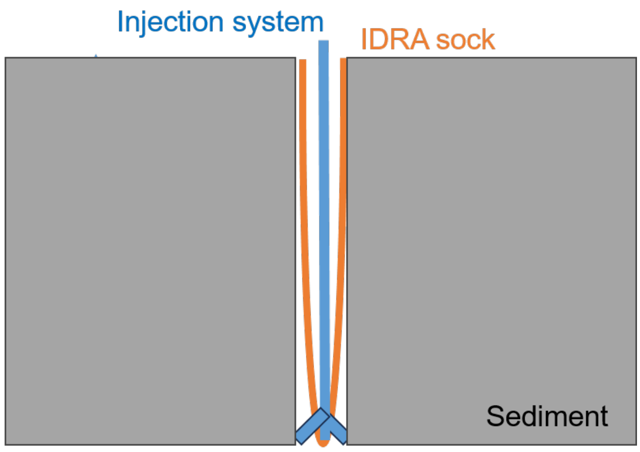

Figure 5. Planned method for installing IDRA socks. In grey: sediment; in blue: the air injection system; in orange: the IDRA sock.

2.4. *In-situ* installation

The *in-situ* installation was carried out on November 22, 2023, thanks to the company Deep Sea Technology.

The installation drawing is shown in the diagram below (**Figure 6**). In detail, 9 EKOGRID electrodes were installed forming a 10 m x 10 m square, including four squares (A1-A4) of 5x5x2m volumes of sediment (at the following link, the video of the electrodes installation: https://doi.org/10.5281/zenodo.13918906). Half of the area treated with the electrodes was also treated with IDRA tubes (squares A1 and A2), to monitor both the electrode technology alone and the combination of the two electrode/IDRA tube technologies (at the following link, the video of the IDRABEL socks installation: https://doi.org/10.5281/zenodo.13918937). In all four areas were installed BACTRAPS for the monitoring (see Deliverable 3.1; at the following link the video of the BACTRAP installation: https://zenodo.org/records/13918891). Moreover, the areas A2 and A4 have been designated for subsequent core sampling, as shown in the Figure 6.

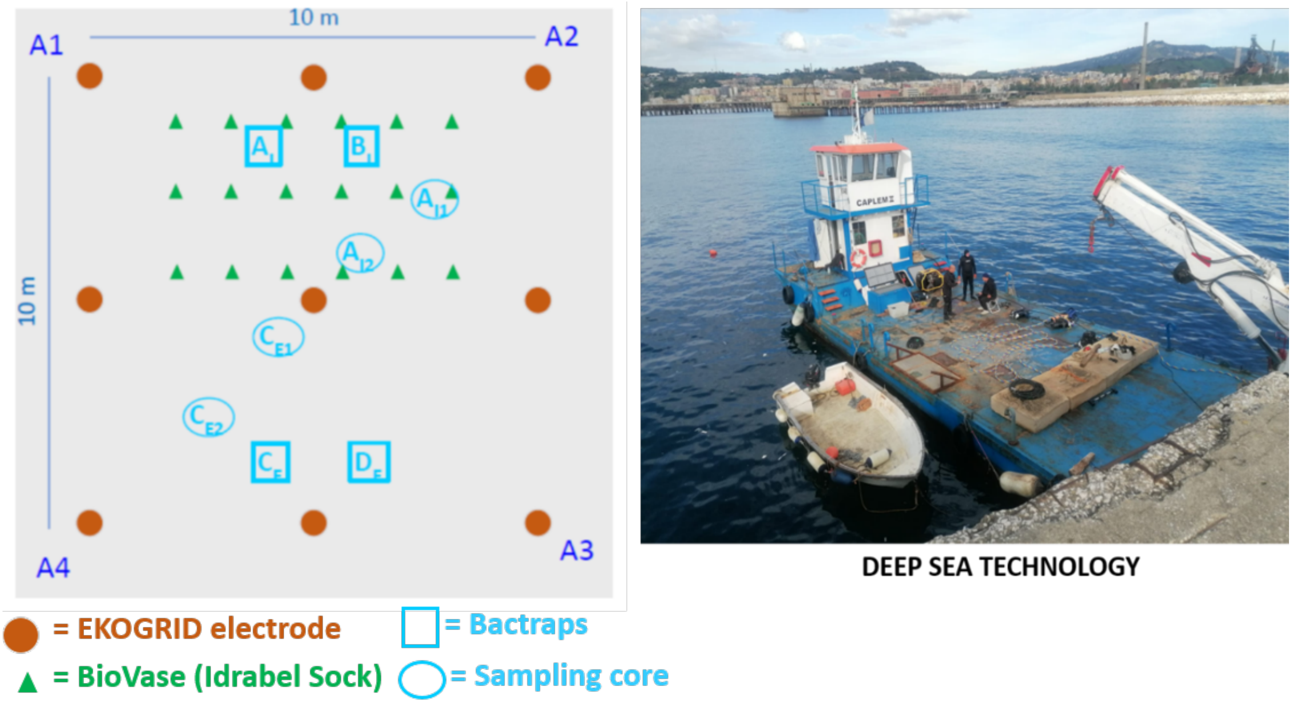

Figure 6. Left: The installation drawing. In red: the EKOGRID electrodes; in green: the IDRABEL socks. Right: Installation performed by the Deep Sea Technology.

The *in-situ* experiment started on December 1, 2023, when the electrical cables attached to the electrodes were connected to the EKO Unit, and the electricity was turned on. In the photo below (**Figure 7**), the EKO Unit is placed in a container, a safe and dry place, and some details of the interior of the EKO Unit. This photo was taken during the commissioning, therefore it's possible to see some extra cables connected to the measuring instruments. Furthermore, some holes in the wall of the container were necessary to allow (i) the underwater cables to enter the container and reach the EKO Unit, and (ii) the antenna cable to be placed outside the road container; the antenna is essential to make the remote connection for monitoring and control of the Unit.

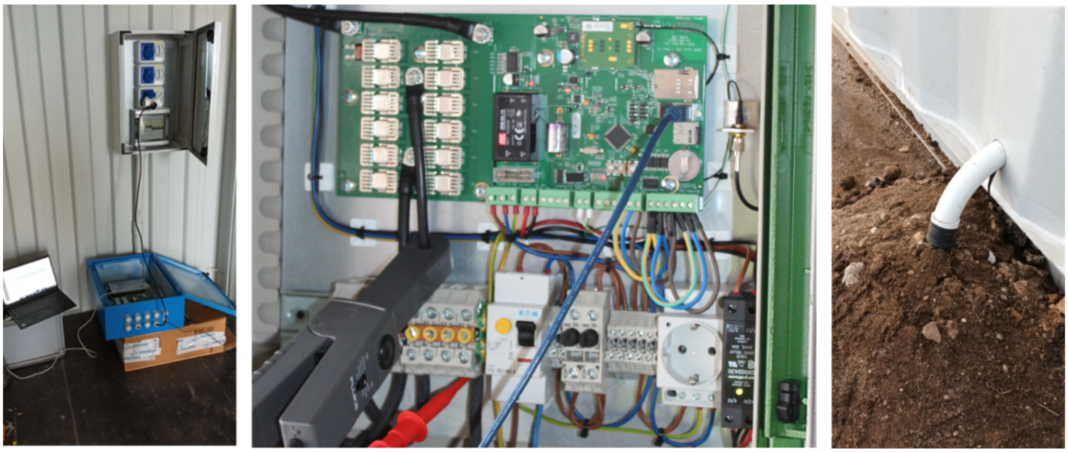

Figure 7. Left: the EKOGRID Unit in the container; Center: the interior of the EKO Unit; Right: a hole in the wall of the container for electric power cable and the antenna

3. Preliminary info from the EKO Unit and Conclusions

The graph below (**Figure 8**) shows the voltage and current outputs during one pulsation cycle, indicating that the installation was a technical success. The system does not lose energy to the seawater but retains sediment with a nice pulsation pattern.

Moreover, **Figure 9** shows that the system worked as planned during the first weeks after the installation.

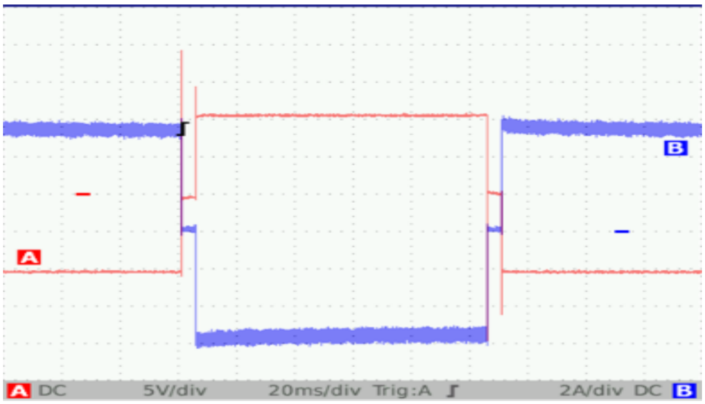

Figure 8. Signal recorded by EKO Unit. The red curve shows the shape of the voltage output. Please note the 5 ms long "rest period" (no voltage output) before changing the polarity. The blue curve shows the current output generated. Regarding the system efficiency, it's important and positive to see the elliptic decline of the current after the initialization. This means that the system was successfully using the sediment (instead of seawater) for the current path.

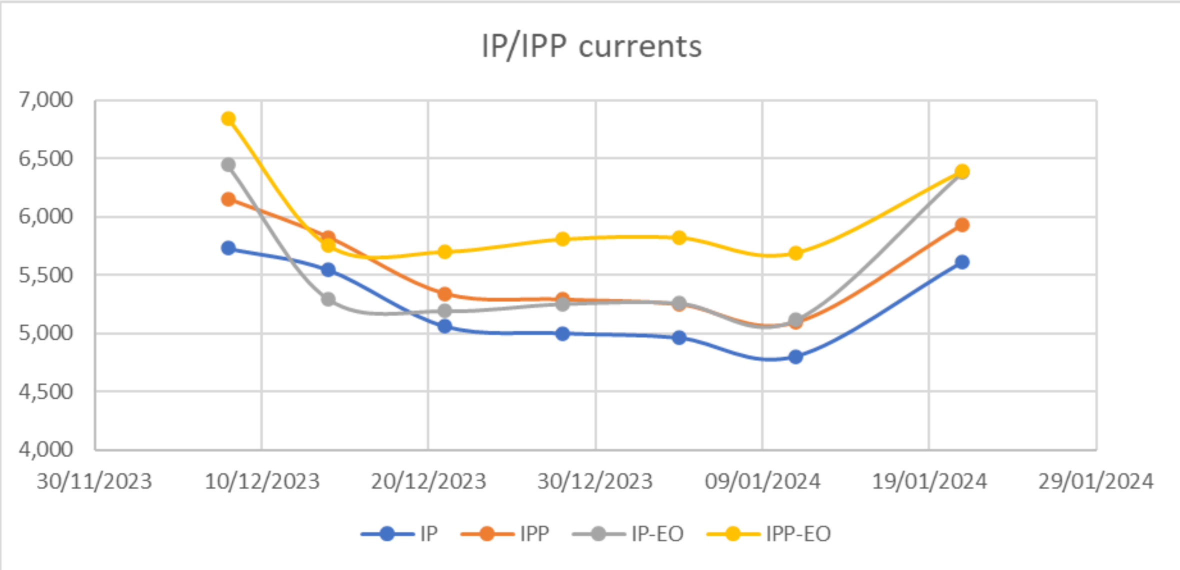

Figure 9. Current output values from the remote control system, during different phases. EO means values that are taken during the EO or transportation pulse. It is worth saying that during the time period shown here, the system was mechanically okay. Later, due to the harsh conditions, the installation (cables, electrodes, and even the EKO Unit) suffered mechanical damage. Those happening raised the question of the need to have another pilot with better mechanical realisation.

In conclusion, the EKOGRID and IDRABEL technologies have been successfully installed in Bagnoli, thanks to the support of the Deep Sea Technology Company. The subsequent monitoring activity will allow us to verify the functioning of these technologies in seawater.