BIOSYSMO

OCT. 2026

PRESS RELEASE



ADVANCING SUSTAINABLE BIOREMEDIATION IN EUROPE

Key findings and policy recommendations from the BIOSYSMO project

Horizon Europe
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BIOSYSMO — Bioremediation systems exploiting synergies for improved removal of mixed pollutants — was a European research and innovation project coordinated by IDENER. AI and funded by the European Union under Horizon Europe (Grant Agreement No. 101060211).

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EXECUTIVE SUMMARY

Environmental contamination remains a major challenge across Europe, particularly at sites affected by complex mixtures of legacy and emergent contaminants, such as metals, petroleum hydrocarbons, pesticides, pharmaceuticals and other persistent pollutants. Addressing these challenges requires remediation strategies that are effective under site specific conditions while minimising secondary environmental impacts and supporting long term ecosystem recovery.

Over four years, BIOSYSMO investigated the combination of microorganisms, plants and bioelectrochemical systems to develop more effective and sustainable approaches for remediating contaminated soils, sediments and groundwater. These technologies were supported by advanced environmental characterisation, predictive modelling, environmental risk assessment and life cycle sustainability assessment.

Through five complementary case studies involving contaminated sites across Europe, BIOSYSMO demonstrated high removal efficiencies for selected contaminants, validated several technologies at TRL 4 and advanced two of the approaches to TRL 5 under real contaminated site conditions.

Beyond technological performance, the project generated important evidence on the opportunities for field implementation, strategies to address residual environmental risks and ways to optimise the balance between treatment efficiency and environmental sustainability.

The main policy lesson is that sustainable remediation requires integrated, site specific decisions based on contaminant removal, alongside environmental risk reduction, long term performance and sustainability scores.

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1. THE CHALLENGE

Contaminated soils, sediments and groundwater frequently contain mixtures of pollutants with different chemical properties, environmental behaviours and associated risks. These conditions are challenging for remediation, as technologies effective against individual contaminants may not perform equally well when applied to mixed contamination.

Conventional approaches, including excavation, soil replacement and intensive physicochemical treatment, may involve substantial resource consumption, secondary waste generation or disruption of affected ecosystems.

Bioremediation offers alternative or complementary solutions by exploiting the capacity of microorganisms, plants and their interactions to degrade, transform, immobilise or remove contaminants. However, its effectiveness depends strongly on environmental conditions, contaminant characteristics and bioavailability, microbial activity and the stability of biological processes over time.

These challenges are particularly relevant to the European Union's Zero Pollution Action Plan, the EU Soil Strategy for 2030 and the Soil Monitoring Law, which reinforce the importance of contamination prevention, environmental monitoring and appropriate management of contaminated sites.

BIOSYSMO addressed these challenges by investigating complementary biological and bioelectrochemical mechanisms, supported by computational tools and integrated environmental holistic assessments.

2. KEY FINDINGS FROM BIOSYSMO: ACHIEVEMENTS AND LESSONS LEARNED

Integrated bioremediation technologies demonstrated strong potential, paving the way for wider implementation.

BIOSYSMO demonstrated the potential of integrating microbial, plant based and bioelectrochemical processes to address complex mixtures of environmental pollutants. Removal efficiencies exceeded 90% for selected hydrocarbons, pharmaceuticals and metals under specific experimental and pilot conditions, with two technologies advancing to TRL 5 through validation under real contaminated site conditions. Further research and development will focus on assessing long term operational stability, environmental impacts, economic viability and social implications, as well as evaluating the transferability and scalability of these solutions across diverse contaminated environments.

Field demonstrations confirmed technological feasibility and provided valuable insights to support the transition from laboratory to field applications.

In France, poplar based phytoremediation was successfully established under real contaminated site conditions. However, the improvements associated with microbial inoculation observed in controlled experiments were not fully reproduced in the field. These findings provided valuable insights into the challenges of translating laboratory optimised solutions into field applications and underscored the

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importance of stepwise validation and long term monitoring, particularly to account for environmental heterogeneity, microbial persistence and site specific conditions that may influence treatment performance.

High contaminant removal should go along with equivalent reductions in environmental risk.

BIOSYSMO demonstrated effective removal of several pollutants, alongside immobilisation and redistribution mechanisms for metals and efficient degradation of organic contaminants. These achievements also highlighted opportunities to further strengthen environmental risk reduction assessments, particularly where contaminants retained in sediments, soils or plant compartments may continue to pose environmental risks depending on their stability and bioavailability. Combining chemical, ecological and ecotoxicological assessments with contaminant removal efficiencies will support a more comprehensive evaluation of remediation outcomes.

Integrated sustainability assessments identified opportunities to optimise remediation performance and environmental impacts.

The integrated sustainability assessments of biological remediation technologies identified opportunities to reduce soil disturbance and resource intensive treatment operations. However, higher treatment efficiencies did not consistently correspond to lower environmental impacts. Electricity consumption in bioelectrochemical systems, infrastructure requirements and microbial inoculum production emerged as relevant environmental hotspots. These findings provided valuable guidance for optimising technology configurations and improving their environmental performance during future scale up.

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Predictive modelling and integrated data resources can improve remediation design, with experimental validation remaining essential.

BIOSYSMOdb integrated information on more than 19,000 compounds, 3,800 reactions, approximately 1,000 metabolic pathways and 7,000 organisms. Together with genomic analyses and computational models, this resource supports the identification of microbial degradation capabilities and the investigation of complementary biological processes. While translating predicted microbial functions into stable remediation performance remains challenging, particularly under heterogeneous environmental conditions, the results established a valuable foundation for further integration of modelling with experimental monitoring and uncertainty assessment.

Bioremediation can contribute to ecosystem restoration and resource recovery, while managing secondary risks.

Plant based remediation demonstrated potential benefits for vegetation establishment, soil stabilisation, carbon sequestration and biomass production, along with contaminant removal. At the French industrial phytoremediation demonstration, estimated carbon sequestration reached 16.5 tonnes CO_2 eq ha^{-1} $year^{-1}$. Opportunities to valorise contaminated biomass and recover metals from remediation residues can also be explored. However, the potential accumulation of contaminants in biomass, the potential remobilisation of immobilised pollutants and the environmental impacts of subsequent treatment or valorisation require careful assessment to ensure that remediation does not transfer contamination between environmental compartments.

3. EVIDENCE FROM SELECTED DEMONSTRATION SITES

BIOSYSMO investigated complementary remediation technologies across different environmental matrices and contamination profiles. The following examples illustrate the diversity of applications, the main results achieved and the remaining challenges for implementation.

Industrial site, NE Spain (exact location confidential) | Bioelectrochemical groundwater treatment | TRL 5

A pilot scale bioelectrochemical system treated groundwater contaminated with petroleum hydrocarbons on site, achieving more than 92% total petroleum hydrocarbon (TPH) removal during nine treatment cycles using 110 L batches (aprox 7 days duration). The demonstration confirmed the potential of electrochemical

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stimulation to enhance microbial metabolism and improve treatment removal efficiency and kinetics. However, operational energy demand, infrastructure requirements and long term system stability remain important considerations for future scale up.



Vieux Charmont, France | Poplar based phytoremediation | TRL 5

Poplar based phytoremediation was demonstrated under field conditions at an industrial area affected by metal and organic contamination. Following planting in May 2025, monitoring continued until July 2026, assessing plant establishment, contaminant behaviour and microbial responses. Field establishment was successful. Improvements associated with microbial inoculation observed in controlled laboratory experiments were not reproduced under field conditions, providing valuable insights into the importance of long term biological stability and site specific adaptation for future optimisation.

Industrial site, Flanders, Belgium (exact location confidential) | Hybrid phytoremediation and bioelectrochemical treatment | TRL 4

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A hybrid treatment system targeting metal(loid) contaminated groundwater achieved 85-90% removal in initial phytoremediation mesocosms. During subsequent continuous operation, the integrated phyto bioelectrochemical system increased groundwater pH from approximately 1.8 to 7.34, promoted metal immobilisation and substantially reduced groundwater toxicity. These results highlighted the environmental benefits of combining phytoremediation and bioelectrochemical processes, particularly their potential to improve groundwater quality and reduce associated ecological risks under challenging contamination conditions. Future work will focus on field scale validation, long term operational stability and economic feasibility to support further technological development and deployment.



Douro and Lima estuaries, Portugal | Plant-microbe remediation | TRL 4

Plant-microbe systems were investigated for remediation of estuarine sediments contaminated with both pharmaceuticals and metals. Mesocosm experiments achieved more than 99% ketoprofen removal in the Douro system and approximately 90% venlafaxine removal in the Lima system. The experiments demonstrated organic contaminants degradation and metal retention and immobilisation within the system. These promising results provided a foundation for further development, although long term stability of accumulated contaminants, microbial persistence and the influence of natural tidal and seasonal variability remain important considerations for future implementation.

Île de France, France, and Sabiñánigo, Spain | Microbial remediation of persistent pesticides | TRL 4

Microbial bioaugmentation strategies were investigated for legacy pesticide contamination, including atrazine in France and lindane in Spain. Engineered microbial systems achieved complete atrazine depletion after 30 days under selected experimental conditions, although complete pathway functionality was not consistently demonstrated. Naturally enriched microbial communities achieved 75% lindane depletion after 30 days in contaminated soil microcosms. These results illustrate the potential of targeted microbial approaches while highlighting the need for further validation, improved process robustness and consideration of regulatory constraints.

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4. POLICY RECOMMENDATIONS

01

Support integrated biological and hybrid remediation strategies

European and national authorities should encourage the assessment of biological and hybrid remediation technologies as alternatives or complements to conventional treatments, particularly for sites affected by mixed pollutants.

Technology selection should consider site characteristics, pollutant behaviour, treatment performance and potential secondary environmental impacts.

02

Strengthen risk based assessment of remediation effectiveness

Remediation evaluation should move beyond contaminant concentration measurements and incorporate chemical, ecological and ecotoxicological assessments where relevant, evaluating risk reduction along with contaminant removal efficiency.

This is particularly important for technologies based on contaminant immobilisation or redistribution, where reductions in dissolved pollutant concentrations may not correspond to equivalent reductions in overall environmental risk.

03

Facilitate long term field validation and monitoring

Future European and national research and innovation programmes should support longer demonstration periods, representative field conditions and harmonised performance monitoring.

Particular attention should be given to microbial persistence, seasonal variability, operational stability and the environmental behaviour of contaminants during and following treatment.

04

Integrate life cycle sustainability assessment into remediation decisions

Remediation strategies should be evaluated using environmental, economic and social criteria alongside contaminant removal efficiency.

Life cycle assessment, life cycle costing and complementary sustainability indicators can help identify trade offs related to energy consumption, infrastructure, microbial inoculum production, contaminated biomass management and resource recovery.

05

Promote data driven remediation and knowledge transfer

European environmental authorities, research organisations and remediation practitioners should support interoperable environmental datasets, accessible computational tools and the transfer of validated research outcomes into practical remediation guidance.

Predictive tools should complement, rather than replace, experimental characterisation and site specific environmental assessment.

06

Strengthen the transition from research to market deployment

European and national innovation frameworks should strengthen the pathways connecting publicly funded research with industrial uptake and commercial deployment. This requires not only continued support for technology demonstration, but also greater involvement of private investors, remediation companies and end users in defining viable exploitation pathways.

Public and private partnerships, targeted follow on funding and effective technology and knowledge transfer mechanisms could help build on Horizon Europe investments, reduce barriers to adoption and accelerate the translation of promising bioremediation technologies into practical solutions for contaminated site management.

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CLOSING REMARKS

BIOSYSMO has demonstrated the considerable potential of integrated bioremediation approaches for addressing complex environmental contamination, while also identifying the technical and environmental challenges that must be addressed to support their wider implementation. Its findings reinforce a central message for European environmental policy: effective remediation should be measured not only by pollutant removal, but also by lasting risk reduction, environmental sustainability, economic viability, social implications and long term performance under real world conditions. These principles provide a foundation for more informed and responsible remediation decisions across Europe.



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UNIVERSIDAD DE BURGOS | ICCRAM

Institut "Jožef Stefan" Ljubljana, Slovenija

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