

aragorn



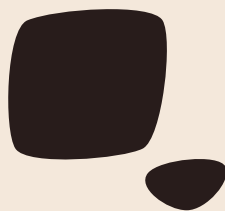
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Factsheets on the four groups
of persistent pollutants:

Metals	OCBs	← PETCO →	PFAS
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Petroleum and coal compounds



This factsheet is designed to help anyone interested in learning about the most persistent pollutants affecting local land and water.

It explains what these contaminants are, why they matter, and how landowners and other stakeholders can learn how to assess and manage them responsibly.



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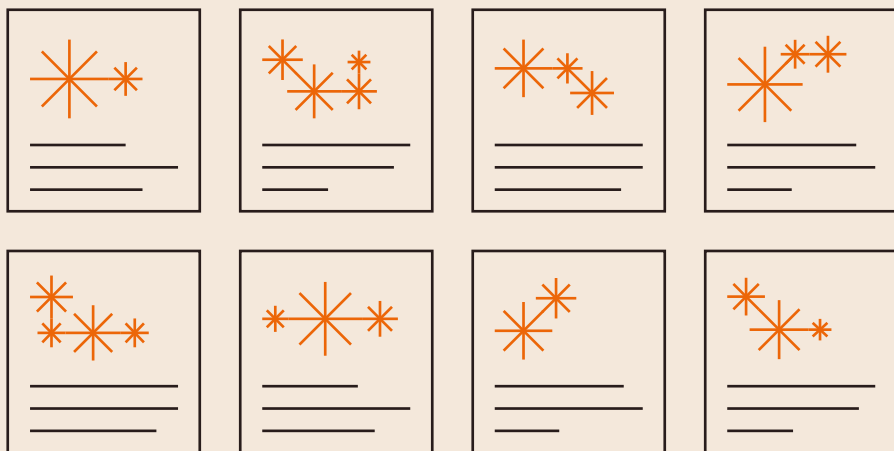
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What are these contaminants and what are they used for?

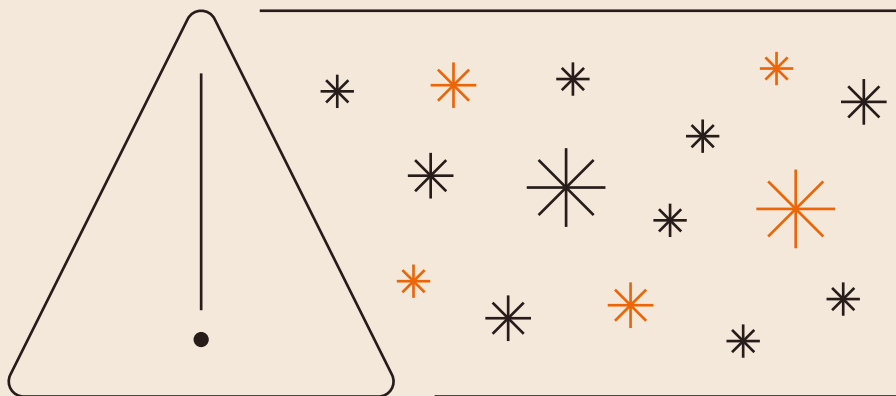
Petrochemical compounds are **chemical substances released from raw oil or directly derived from petroleum or natural gas**. They typically consist of a variety of constituents and their precise composition can be unknown and variable. Together they cover a wide range of petroleum-related chemicals, from simple fuels to complex compounds found in tar and smoke. These materials are also **used to manufacture a wide range of products** including plastics, synthetic fibers, detergents, fertilizers, solvents, rubber, and adhesives. They are important because of their use in industry, and disturbing for their potential to contaminate soil, water, and air.

PETCO can be grouped into three main families. The first family is **aliphatic hydrocarbons**. These are the simplest, made only of carbon and hydrogen in straight chains, branched chains, or simple rings. They are the main ingredients in fuels like gasoline and diesel, and are also used as solvents, lubricants, or raw materials for making other chemicals.

The second family is **monocyclic aromatics**, which are chemicals built around a single benzene ring. Well-known examples are benzene, toluene, ethylbenzene, and xylenes (together called BTEX). These substances are often used in fuels, paints, glues, and as starting materials for plastics and synthetic fibers. The third family is **polycyclic aromatic compounds (PACs)**. These are more complex molecules with two or more benzene rings joined together. A **special group** called **polycyclic aromatic hydrocarbons (PAHs)** includes well-known substances such as naphthalene (found in mothballs) and benzo[a]pyrene (a toxic compound formed during combustion). PAHs are found in coal tar, petroleum, and smoke from burning processes.

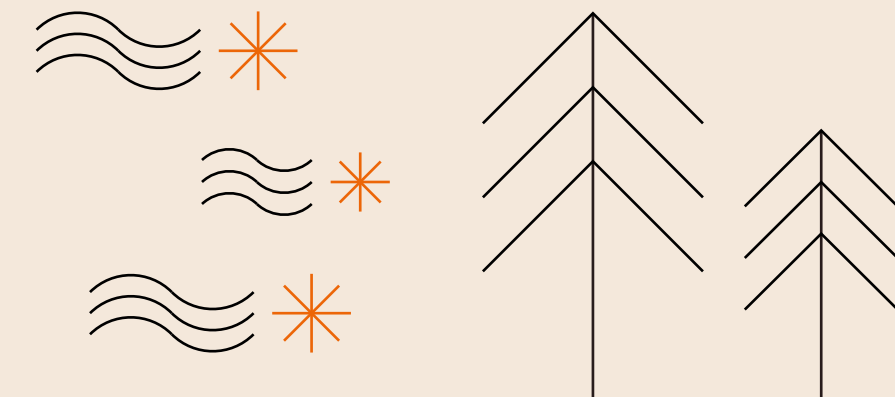
Modified forms of PAHs also exist:

- ☀ **Alkylated PAHs**, which are common in crude oil and used to identify petroleum pollution.
- ☀ **Oxy-PAHs**, which form when PAHs react with oxygen in the environment.
- ☀ **NSO-PACs**, which contain nitrogen, sulfur, or oxygen in their rings and occur naturally in fossil fuels or are used to make products like dyes, medicines, and agricultural chemicals.



Why are we concerned?

PETCO substances, including various hydrocarbons and their derivatives, are among the most common and major environmental contaminants worldwide. **They pose significant environmental and health risk due to their widespread use, persistence, and toxicity.** They enter the environment through accidental spills, industrial activities, improper use, or disposal. Contaminated sites often require long-term monitoring and technically complex remediation strategies, as **the chemical nature of PETCO individuals is diverse, complicating the treatment and risk assessment.** Many PETCO substances (e.g. benzene, PAHs) are toxic to humans and animals. Some are classified as carcinogenic, mutagenic, or endocrine-disruptive even at low concentrations. Some of the PETCO substances (e.g. PAHs) can persist in soils and groundwater for decades, others (e.g. BTEX) are mobile in the environment, easily spreading through air and water, potentially reaching the drinking water sources. **Certain PAHs and their derivatives can accumulate in living organisms,** affecting the food chain and modifying the ecosystems.



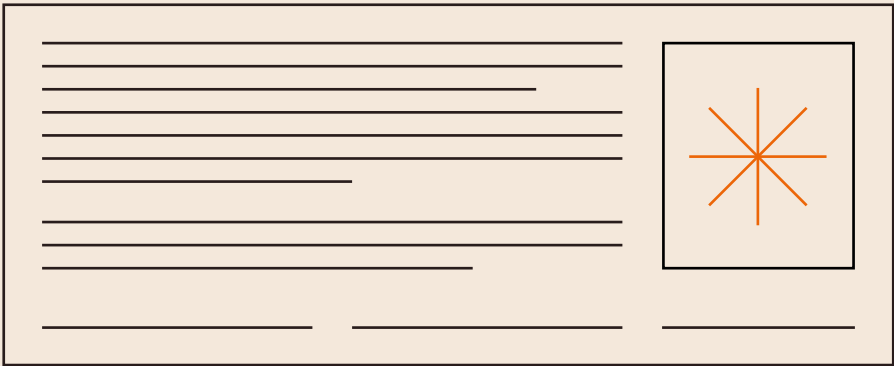
Environmental fate, transport, effects

The behavior of PETCO substances in the environment depends on their chemical structure, volatility, solubility, and tendency to bind to soil particles. Once present in the environment, they can migrate, degrade, or persist:

- ☀ **Volatile compounds** (e.g. BTEX, short-chain aliphatics) may rapidly evaporate from the soil surface into the air. Air migration occurs via vapor intrusion, potentially affecting indoor air quality in building above contaminated zones.
- ☀ **Soluble compounds** (e.g. BTEX, some oxy-PAHs, short-chain aliphatics) can leach down through the soil profile, eventually reaching groundwater. Leaching occurs primarily in sandy, permeable soils. These compounds usually cause groundwater contamination.
- ☀ **Hydrophobic compounds** (e.g. PAHs, long-chain aliphatics) can bind to humic acid or clayey soil components, resulting in limited mobility and prolonged contamination.

Abiotic and biotic breakdown, mediated by oxidation, photolysis, and microorganisms, is possible for many aliphatic and some aromatic compounds. Light aliphatics may degrade within weeks, while some PAHs may persist for decades. The stability and persistence of aromatics increase with an increasing number of aromatic rings in the conjugated system. **Food chain accumulation may occur through uptake by plants, ingestion by soil organisms, or bioaccumulation in aquatic species.** Long-chain PAHs and some NSO-compounds are particularly prone to bioaccumulation.

Key human exposure routes include inhalation of contaminated air, ingestion of contaminated water or food, as well as dermal contact with contaminated soil, water or materials. Chronic exposure to PETCO compounds as benzene, benzo[a]pyrene was **linked to cancer, reproductive toxicity, neurological effects, and immune system injury.**



Regulation and guidelines

European framework for soil legislation

The European Union introduced legislation on soil health in the **Soil Monitoring and Resilience Directive (SMRD)** that mandates the monitoring and assessment of soil quality. However, most threshold limit values and procedural rules are set and enforced by Member States and often at regional/local level. EU sets frameworks, principles and reporting/monitoring obligations, and **Member States translate these into national laws** (setting site-identification, screening values, risk assessment methods and mandatory remediation duties); local authorities typically implement, inspect and require remediation on the ground.

There are two common approaches used by Member States:

- ☀ **Generic screening/threshold values** (soil screening values, intervention values) that trigger further action when exceeded.
- ☀ **Risk-based site assessment** where exposure pathways and site-specific conditions determine whether remediation is required and what measures are appropriate.

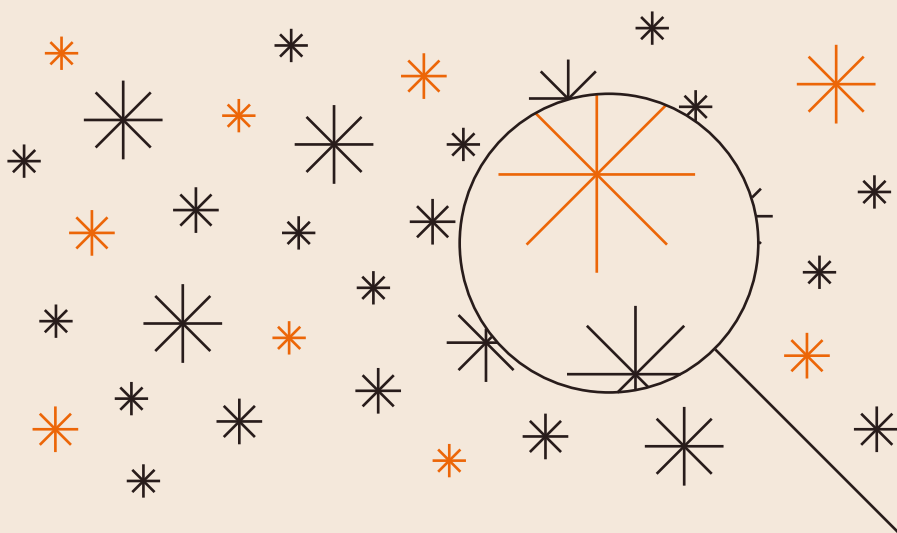
For specific Member States approaches, the specific **Member State's environment ministry** or **national environmental agency** (e.g., UK: Environment Agency; Germany: Länder Umweltämter; Sweden: Naturvårdsverket) may contain information on national soil law, contaminated-land guidance, national screening values or risk assessment protocols.

Links to other European regulations

Soil rules may be affected and can affect other EU rules such as groundwater/surface-water protection under the Water Framework Directive and dangerous substances rules, waste and landfill legislation (affecting historical waste-derived contamination), and permitting under the Industrial Emissions Directive. These links mean that **EU law can impose soil-protective outcomes** through water protection, waste rules or pollution permitting.

International frameworks and conventions

While EU and national laws provide binding rules within specific jurisdictions, **international treaties and organizations provide global standards**, obligations, and guidance that influence national regulations, enable cross-border cooperation, and address chemicals that persist and move beyond one country's borders. Examples are the Stockholm Convention on Persistent Organic Pollutants (POPs), Minamata Convention on Mercury, and the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes (including contaminated soils).



Soil testing and analysis

When investigating contaminated land or groundwater, the way samples are taken is just as important as the laboratory analysis. To get reliable results, samples need to be collected carefully, preserved immediately, and transported under controlled conditions. There are standardized methods for environmental characterization of soil and related matrices, for example the European Committee for Standardization CEN/TC 444, with the goal of **harmonizing how environmental data are collected and reported across Europe**.

Also, national or regional guidance might specify how and when soil or groundwater should be tested, and what analytical standards to use. Sampling protocols therefore often need to be conducted or supervised by accredited laboratories.

PETCO is sensitive to sampling errors. Some of these compounds are volatile and can evaporate or break down if handled incorrectly, while others are sticky and tend to cling to soil particles or containers.

Volatile substances like BTEX and short-chain aliphatics can be lost if the soil is exposed to the air for too long. To avoid this, small amounts of soil are usually transferred directly into airtight containers, often prefilled with preservatives or stabilizing liquids that stop the compounds from escaping.

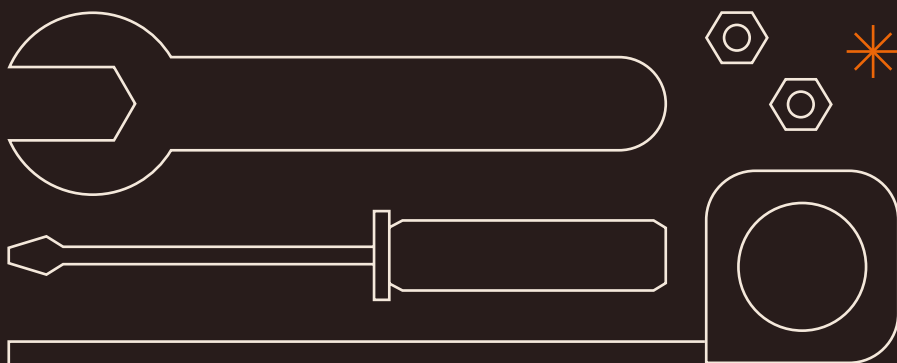
For less volatile but more persistent pollutants such as PAHs and long-chain aliphatics, **the main challenge is preventing cross-contamination and ensuring the sample stays intact**. Clean tools should be used, gloves should be changed between samples, and the soil should be placed in inert glass containers rather than plastic, which can sometimes absorb organic compounds.

Hydrocarbons such as BTEX, short-chain aliphatics, PAHs, oxy-PAHs, **and long-chain aliphatics each behave differently**, so laboratories use a mix of methods suited to their volatility and solubility. For the lighter, more volatile compounds like BTEX and short-chain aliphatics, the priority is to prevent losses during preparation. In water, these substances can be extracted directly from the liquid by purging the sample with an inert gas (such as helium). This is called purge-and-trap analysis. In soil, similar results are achieved by sealing a portion of the sample in a vial and gently heating or agitating it, allowing the volatile compounds to move into the air space above the sample, called headspace.

For the heavier, less volatile pollutants such as PAHs, oxy-PAHs, **and long-chain aliphatics, the process is different**. These compounds are tightly bound to soil particles or dissolved only weakly in water, so they must first be extracted using solvents.

In soil, the sample is mixed with organic solvents (such as hexane, dichloromethane, or acetone mixtures) that dissolve the hydrocarbons. Modern techniques often use automated extraction systems like accelerated solvent extraction (ASE), that ensure thorough contact between soil and solvent. For water, solid-phase extraction (SPE) is commonly used.

Once extracted, the analysis itself relies on highly sensitive instruments, usually gas chromatography (GC) coupled with different detectors. For volatile compounds like BTEX, flame ionization detectors (FID) or mass spectrometers (MS) are commonly used. Advanced automatic BTX monitors are commonly used today for continuous monitoring of these compounds. For PAHs and oxy-PAHs, gas chromatography coupled with mass spectrometry (GC-MS) provides both separation and precise identification, even at very low concentrations. PAHs and transformation products can be quantified with high performance liquid chromatography fluorescence detector (HPLC-FLD), GC-FID, GC-MS. Long-chain aliphatics, which can include unresolved mixtures of hydrocarbons, are often quantified as broad ranges (e.g. C10–C40 fractions) rather than as single compounds.



Remediation options

If your land is contaminated, **remediation means cleaning it up or managing the pollution**, to sufficiently reduce the risk to people, water, or the ecosystem animals and plants. Remediation does not always mean physically removing all the contaminated soil, it can also involve isolating the pollution or treating it on site. **Costs can vary widely depending on the contamination and chosen method.** The table below provides an overview of the different remediation principles together with specific methods and their advantages and limitations.





Physical removal or isolation of contaminants

Excavation:

Remove contaminated soil or sediment; which is subsequently treated off-site (by soil washing, biodegradation, e.g.)

Soil vapor extraction:

Suction of the contaminated vapors, which are passing through the filter. Suitable for: volatile short chain aliphatics, monoaromatics, light PAHs

Thermal volatilisation:

Remove volatile contaminants. Suitable for: BTEX, phenol, cresol, mid-weight PAHs, short- medium chain aliphatics

Advantages:

Immediate removal
Suitable for many contaminants types and high concentrations (source)
Scalable and controllable

Limitations:

High costs & high energy input
Invasive & destructive
Volatility dependent
(not suitable for heavy PAHs)



Chemical agents transform contaminants into less harmful substances

In-situ Chemical Oxidation:

Inject oxidizers like permanganate or persulfate.
Suitable for: volatile short chain aliphatics, monoaromatics, light PAHs; mixed contamination

In-situ Chemical Reduction:

Inject reducing agents (e.g., zero-valent iron)

Advantages:

- Treats contaminants on site
- Potential for full contaminant destruction
- Fast reaction time

Limitations:

- High reagent demand
- Costly if multiple injection and monitoring is required
- Selectivity & potential hazardous by-products
- Inaccessible contamination



Biological processes remove, degrade, or contain contaminants

Bioremediation:

Use or stimulate microorganisms. Suitable for: short chain aliphatics, monoaromatics, light PAHs

Phytoremediation:

Use plants to absorb and/or degrade contaminants. Suitable for: short chain aliphatics, monoaromatics, light PAHs

Bioventing:

injection of air into the unsaturated soil stimulates the indigenous microorganisms to degradation. Suitable for: short chain aliphatics, monoaromatics, light PAHs

Monitored natural attenuation:

non-intervention, monitoring of the contamination content and spreading. Suitable for: short chain aliphatics, monoaromatics, light PAHs

Composting:

Mixing of contaminated soil with organic material (compost, wood chips, straw) which lead to increased temperature and microbial activity suitable for: less volatile compounds, heavier PAHs, longer-chain aliphatics

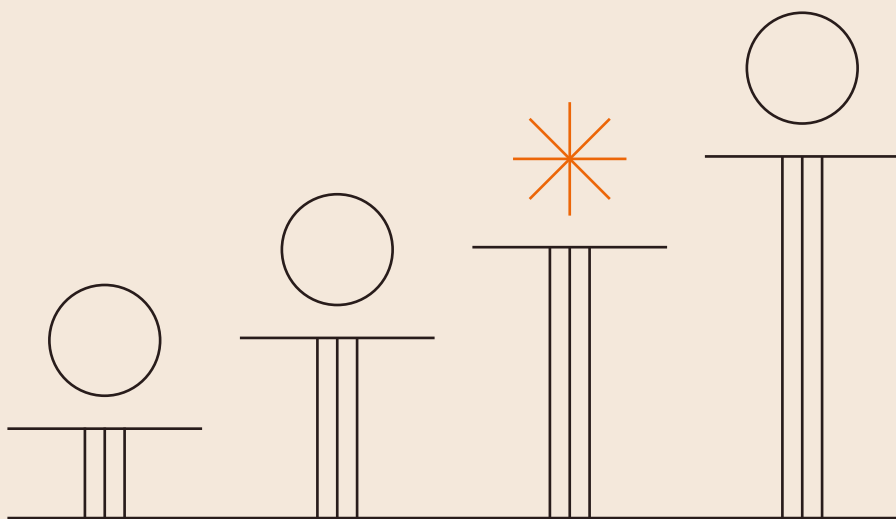
Advantages:

Low-cost, sustainable, and non-invasive
Suitable for low concentrations
Environmentally friendly
Relatively easy to perform

Limitations:

Slow degradation/uptake thus long treatment time
Less effective for more complex contamination
Strongly dependent on soil conditions
Potential secondary contamination of air





Initial steps to assess a potentially contaminated site

Gather information about the site

Before any work or decisions can begin it's important to build a complete picture of the site. This means gathering different kinds of information about the land itself, its history, and its surroundings. Each piece helps us understand how pollution might spread and who or what could be affected.

- ☀ **Collect site history**, such as uses, know sources of pollution, old maps, news on special events, environmental permits, as past uses often helps explain what types of pollution might be present.
- ☀ **Topographical data**, including shape of the land and location of buildings, helps predict pathways of pollution via water and air including spreading of dust.

- ☀ **Geological data** on type of soil or rock and how deep the layers are, matters since some solids trap pollution while others let it spread quickly.
- ☀ **Hydrogeology**, such as depth of water and direction of groundwater flow is important since contamination can move with groundwater and reach wells, rivers, or lakes, creating health and environmental risks.
- ☀ **Meteorological data** (climate and weather) can wash pollutants deeper into the soil or spread them to water bodies. Wind can carry dust or vapours to nearby areas.
- ☀ **Contamination data** (what is in the soil and water) show how serious the problem is and whether it poses a direct risk.
- ☀ **Surrounding exposure pathways** (how people or nature could come into contact) determines the risks. Even if pollution is present, it only becomes dangerous if it has a “pathway” to reach people, animals, or ecosystems.

Gathering of the background information should be followed by field verification – sampling of soil, groundwater, surface water, as well as on-site screening using portable instruments. This data will be the basis for the risk assessment.

Assess the economic and logistic factors



Budget:

Cost of treatment, monitoring, and long-term management.



Infrastructure:

Availability of equipment and skilled personnel.



Timeframe:

Urgency of remediation (e.g., emergency vs. long-term project).

Set the remediation goals



Containment vs. destruction:

Whether the goal is to immobilize or eliminate the contamination.



Reuse potential:

Whether the soil needs to be reused (e.g., agriculture, construction).



Risk reduction:

Immediate vs. long-term health and environmental risk mitigation.

Understand the rules and responsibilities

It is of importance to clarify **who is legally responsible for the contamination** (landowner, business provider, etc.), **who caused the contamination** and **when it may create different obligations**. Check whether the site or soil use falls under any EU directive obligations (water, industrial emissions, waste), as these also can bring binding obligations.

Most often it is the Member State's contaminated-land regime: national law, agency guidance, and any regional technical guidance on soil use and contamination, that are the most important rules to be aware of.

Some regions or municipalities have additional rules for construction, excavation, or soil movement even if national or EU rules do not explicitly require action. Certain contamination incidents may require **mandatory reporting to environmental authorities and potential restrictions on land use**.

Consult experts and find information

Remediation and restoration depend on the risk level and intended use of the land. Therefore, it is advisable to consult experts to perform risk assessments and recommend actions in line with the current legislation. Seeking expert advice early can also be cost saving, as early misguided actions can become expensive over time. Environmental consultants can help with performing basic screening for initial assessment, doing legal compliance check, and develop remediation plans. They should also be very familiar with local and national regulations and able to translate them into practical guidance for landowners.

There are many useful resources for anyone seeking more information on pollutants and soil remediation. Because knowledge in this field is constantly evolving, it is recommended to consult both national and regional knowledge hubs as well as European sources. For example, the **Common Forum** (commonforum.eu) brings together expertise and facilitates information exchange on contaminated land and groundwater management. The **EU Soil Observatory (EUSO)** (joint-research-centre.ec.europa.eu) provides soil data, supports research and innovation, and raises awareness of the importance of soils. The **European Food Safety Authority (EFSA)** (efsa.europa.eu) offers scientific advice to risk managers, especially on risks linked to the food chain.

The **European Chemical Agency (ECHA)** manages the implementation of the EU's chemicals legislation and promotes the safe use of chemicals to protect human health and the environment (echa.europa.eu).



ACHIEVING REMEDIATION AND GOVERNING RESTORATION OF CONTAMINATED SOILS NOW



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