

**Questionnaire**

**Biopile**

**IMPEL Project “Water and Land Remediation 2022-24”**

***Delivering time 1 January 2024 – 28 February 2024***

TABLE OF CONTENTS

[Context 3](#_Toc154742333)

[Introduction 4](#_Toc154742334)

[1. Your contact details 8](#_Toc154742335)

[2. Site background 9](#_Toc154742336)

[3. Pilot-scale 13](#_Toc154742337)

[4. Full-scale application 20](#_Toc154742338)

[5. Results 26](#_Toc154742339)

[6. Post treatment and/or Long Term Monitoring 27](#_Toc154742340)

[7. Additional information 28](#_Toc154742341)

Context

The contaminated sites management is a process that proceeds at different speeds in Member States. This is due partly to difference in legislation that would mean different definitions - some examples being “potentially contaminated sites”, “contaminated sites”, “remediated sites”.

The contaminated sites management is a process that has different speeds in Members States. This project aims to speed up the process, focusing to the remediation phase that is often the bottleneck, with monitoring parameters specific for each remediation technology, that may show clearly the progress of activities towards the target.

Then, the project has also the objective to promote in situ technologies with a clear scheme for their monitoring over time. These documents will contribute to reduce the use of more impacting remediation technologies like Dig&Dump and Pump&Treat.

The main outcome is to Support/exchange technical experience required in Europe in monitoring in situ/on site technologies order to enable those MS in which no monitoring procedure is currently taking place to have one reference they may use completely or partially.

Introduction

This questionnaire looks at the input of case studies where Biopiles were applied in a contaminated site.

The questionnaire will remain active in the period comprehended between **1 January 2024 to 28 February 2024** for the collection of case study. Late submission could be evaluated by the project team.

Each case study may have details of the **site location**, details of the **author(s)** and their **affiliation** and **companies** involved. Those information would help in understanding more about the site but are **not mandatory**.

At least one contact point is mandatory, for resolving any potential problem related to the publication.

It is allowed to make reference to registered products and/or patent but it is necessary to make reference to active species present and eventually by-products or side effects (e.g. pH increase).

**Please note:** data on the costs, on environmental net benefit as well as the sustainability aspects are not included in the objective of this study.

The purpose of this Questionnaire is to collect specific information on cases of remediation technology. To do so, you are kindly requested to **submit one or more case studies each with a different file**.

In case you cannot fill the questionnaire please answer to the last question in order address the project team your possible remarks, concerns, requests, suggestions.

As previously mentioned, the responses of the filled Questionnaires will be analysed in order to identify criteria for the evaluation of the performance of the remediation. The experiences collected may be useful to prepare the monitoring plan of different remediation phases for similar cases.

You can both fill the Questionnaire in Annex I and upload documents in English.

Please copy-paste, in the Questionnaire answers, any images, photos, maps, graphs, flowcharts and diagrams that can be useful for a better understanding.

Please send the Questionnaire to [marco.falconi@impel.eu](mailto:marco.falconi@impel.eu).

In case the file of the filled Questionnaire and/or of any useful document attached is too large, please send it/them to via We Transfer (<https://wetransfer.com/>) or Share File (<https://www.sharefile.com/>) or any other preferred internet tool.

**Final note:** The Questionnaire should not be completed only with successful cases of remediation technology application but also with unsuccessful assessment cases; in fact, for those unsuccessful cases, shortcomings and improvement actions will be identified and analysed.

Moreover, feel free to share this questionnaire to inspectors, a public officers or any other stakeholders. Participation or consultancy, site owners, environmental service companies are welcomed.

Thank you very much for your collaboration from all the WLR project team.

If you need assistance or clarifications, you may contact:

Mr. Marco Falconi

Email: marco.falconi@impel.eu

Mobile Phone: +39 3471204170

**DISCLAIMER:**

The questionnaire is subject to the Directive 2003/4/EC of the European Parliament and of the Council of 28 January 2003 on public access to environmental information.

As a consequence, the information contained in the filled Questionnaire will not be confidential, not only for the information of the intended recipient and may be used, published or redistributed by IMPEL without the prior written consent of the compiler.

****

**Annex 1**

**Biopiles**

**IMPEL Project “Water and Land Remediation 2022-24”**

***Delivering time 1 January 2024 – 28 February 2024***

1. Your contact details

|  |  |
| --- | --- |
| * 1. ***Name and Surname\**** |  |
| * 1. ***Country/Jurisdiction*** |  |
| * 1. ***Organisation*** |  |
| * 1. ***Position*** |  |
| * 1. ***Duties*** |  |
| * 1. ***Email address*** |  |
| * 1. ***Phone number*** |  |

\* If you do need, you can fill the Questionnaire as anonymous. In this case, we kindly ask you to fill just the box no. 1.6, 1.7, that will be used to contact you for any problems related to the publication.

1. Site background

|  |
| --- |
| **2.1****History of the site** |
| Please describe the history of the site (you may add one or more pictures and cadastral plans that have followed one another over the years)   * *(your answer) …* * *EXAMPLE OF ANSWER*   The subject site is situated near Frankfurt am Main, Germany on the grounds of a former chemical manufacturing facility which produced solvents for metalwork, cleaning chemicals, and specialty oils. Other facilities of environmental concern on the property included a former oils and chemicals storage building, as well as an underground storage tank and pipeline for the storage of industrial solvents.  The plant was in operation from the mid- 1960s until a fire destroyed it, causing the plant to cease operations in 1974. It is suspected that the fire and resulting explosion was a major factor in the release of contaminants to the subsurface environment. The property was subsequently acquired in 1985 by new owners who used the site for manufacture of industrial presses until 2014. Since then, the property is used for general warehouse storage, parking lot, and auto mechanic shop.    Site of former chemical manufacturing facility in Hessen, Germany  Significant challenges to the implementation of remedial measures at the site were the massive impacts of co-mingled contaminants of concern to underlying soils and groundwater including   * Chlorinated aliphatic hydrocarbons, primarily cis-Dichloroethylene (cDCE) * Aromatic petroleum hydrocarbons (BTEX), including trimethybenzene (TMB) * Aliphatic total petroleum hydrocarbons (TPH) * Trace amounts of polycyclic aromatic hydrocarbons (PAHs) * Free- phase oil at one location |

|  |
| --- |
| **2.2****Geological setting** |
| Please describe the geological setting (you may add one or more pictures)   * *(your answer) …* * *EXAMPLE OF ANSWER*   The area of investigation consists of a surface layer of concrete which is underlain by gravel and sand fill to a depth of 1,3 m below the ground surface (bgs). Underlying the fill soils are quarternary deposits of gravel and sand colluvium of variable thickness, interbedded with sand and clay layers. Silty clays are encountered below the colluviums between depths of 3,6 to 8,3 m bgs which forms a hydraulic boundary between the overlying quarternary colluvial aquifer and an underlying tertiary (drinking water) aquifer comprising fine to medium sands. The depth to groundwater ranges from 2 to 3 m bgs. |

|  |
| --- |
| **2.3****Contaminants of concern** |
| Please describe the contaminants of concern (mentioning also if there are contaminants with natural background concentrations)   * *(your answer)* * *EXAMPLE OF ANSWER*   A total of 6 subsurface investigations were conducted between 1999 and 2017 in an effort to delineate and quantify the distribution of contaminants underlying the site.  The results of these investigations determined that petroleum hydrocarbon contamination (TPH and BTEX impacts) were largely confined within soils in the unsaturated zone with contaminant concentrations upwards to 5,000 mg/kg and 344 mg/kg respectively. Dissolved- phase contaminant impacts to groundwater within the quaternary aquifer consisted primarily of total chlorinated aliphatic hydrocarbons (CHCs) of upwards to 44,300 μg/L, followed by TPH (2,000 μg/L) and BTEX (1,800 μg/L).  The major component of CHC contamination was cis-1,2 DCE (54%), followed by tetrachlorethylene (“PCE” 28%), and trichloroethylene (“TCE” 16%). The major component of BTEX contamination was trimethylbenzene (TMB >76%) followed by xylenes.  Free-phase oil product was detected at one monitoring well location with an apparent thickness of a few cm.  Calculations to estimate the mass of contaminants present within the quaternary aquifer indicated a total of approximately 3.7 kg of dissolved phase CHCs and 8.7 kg of sorbed phase CHCs respectively. The estimated total of BTEX and TPH contaminants (dissolved and sorbed) was approximately 2.5 kg. Applicable groundwater regulatory limits for contaminants of concern found in groundwater at the site are summarized here: HCs: 20 μg/L, VC: 0.5 μg/L, BTEX: 20 μg/L TMB: 1 μg/L TPHs: 100 μg/L  The delineation of the various contaminants of concern was achieved using a combination of soil probe borings, drilling and sampling of groundwater monitoring wells, and through the use of innovative Direct Push technologies using Geoprobe® drilling equipment and specialized sampling technology such as Membrane Interface Probe (MIP), Screen Point groundwater sampling, and Electrical Conductivity (EC) downhole tools. |

|  |
| --- |
| **2.4****Regulatory framework** |
| Please describe the regulatory framework applicable. This should include target values to be reached, , eventual specific approval needed for application of chemicals in the ground   * *(your answer) …* * *EXAMPLE OF ANSWER*   Based upon the results of subsurface contamination quantified at the site, the regional environmental regulatory authority ordered that soil and groundwater remediation efforts be implemented at the site to mitigate contaminant impacts on potential environmental receptors. The specific goal of the regulatory clean up order was to “prevent the danger of contaminant exposure to receptors and prevent the long term spreading of contaminants”. In order to achieve this goal, the regulation requires that “applicable remedial measures be applied to minimize or remove contaminants (i.e decontamination) and to prevent or minimize the spread of contaminants i.e. (containment)”.  A Remediation Action Plan was subsequently requested by the authority to comply with the above mentioned regulatory requirements. The remedial plan submitted to the authority proposed remediation of the heavily impacted unsatured zone soils by excavation and disposal, resulting in the removal of approximately 300 m3 of contaminated soil to a depth of 2 m to 3m bgs. This remedial measure was implemented concurrently with the decommissioning and removal of the existing oil and chemical storage building on the property. There were no specific contaminant clean up criteria for soil quality required for the excavation of impacted surface soils.  For the remediation of dissolved phase contaminants in the unsaturated zone, a feasibility study for the implementation of in situ chemical oxidation (ISCO) and in situ bioremediation (ISBR) was proposed as possible cost-effective and sustainable remediation alternatives to conventional excavation/disposal and large diameter soil replacement borings that were being considered. The results of the study determined that ISCO was a viable approach, although its effectiveness for practical purposes could be severely limited based upon the low hydraulic conductivity of the saturated zone sediments.  Risk-based remediation criteria were developed for CHC contaminants at the site whereby a reduction of total CHC concentrations (i.e for PCE, TCE, DCE and VC) of 95% over 3 consecutive monitoring events in source area monitoring wells was required. |

1. Pilot-scale

|  |
| --- |
| **3.1****Laboratory Study** |
| Please describe the laboratory studies that have been performed   * *Application of a small part of contaminated soil to a biopile* * *Analysis of present bacteria or DNA sequencing analysis* * *Bench-scale laboratory equipment that simulates full-scale unit operations* * *(your answer) …* * *EXAMPLE OF ANSWER*   *Small amount of contaminated material (110 lb) was processed in bench-scale laboratory equipment that simulates full-scale unit operations. Two steps of the process, thermal desorption followed by treatment and handling of the process off-gas were modeled separately.*  *Appropriate biopiles equipment dimensions, process flowrates, and mass and energy balances for the key components were established as well as presence of right type of bacteria.* |

|  |
| --- |
| **3.2****Treatment unit comprehending site preparation and base preparation (pilot scale)** |
| Please describe the characteristic and parameters used for implementing the biopile at pilot scale   * *EXAMPLE OF ANSWER*   *The pilot-scale unit were built in direct proportion to an existing or planned full-scale system. Because this testing involves larger equipment than used in the second tier, and the processing of up to several tons of actual material, it was carried out at the project site mantaining a temperature lower than 500°C that allows to have soil that may be reused and not ashes. The objects of this tier of testing were to predict to the extent possible, how an existing or planned thermal desorption system would perform on actual site material and to reveal potential problems. Alternatively, it could serve to demonstrate operational parameters and cost that were estimated from the two previous tiers of testing. In view of the time required and the cost associated with this third tier of testing (perhaps several hundred thousand dollars), it would be undertaken only for complex or unusual sites, if at all.* |

|  |
| --- |
| **3.3****Pre Treatment (pilot scale)** |
| Please describe if and which pretreatment was installed in the pilot scale application in field   * Shredding * Screening * Dewatering * *EXAMPLE OF ANSWER*   *The dewatering was performed by an inflatable bladder dam that restricts water from reentering during site remediation. It consists of an industrial-grade vinyl-coated polyester, making it sturdier and more durable. In addition 4 pumps were used for 3 days to remove the remaining GW .* |

|  |
| --- |
| **3.4****Aeration and post treatment for air effluent (pilot scale)** |
| Please describe if and which post treatment was installed for the effluent in the full scale application in field   * Air scrubber * Granulated activated carbon * *Indicate what path the material that comes out as dust from flue gas filtration (if possible, indicate with what percentage it can be recovered in the soil circuit. Typically we are talking about max 500 kg/hour on a 10 ton/h treated flows)* * *EXAMPLE OF ANSWER*   *Off-gasses from the soil were carried from the biopile by induced air flow through the surface. Air flow was induced through the cylinder at a rate of 0.25 to 0.30 cubic feet per minute (cfm). The amount of air flow per mass of soil in the was much smaller than in the full-scale unit. Because of the relatively !esser amount of particulates produced, a baghouse was not induded in the design of the bench-scale unit.*  *The off-gasses from the bench-scale unit were first vented through a series of water cooled condensers, which simulate the Venturi scrubber in the full-scale system.* |

|  |
| --- |
| **3.5****Moisture addition, leachate collection and post treatment for water (pilot scale)** |
| Please describe if and which post treatment was installed for water in the pilot scale application in field   * *EXAMPLE OF ANSWER*   *The effluent goes to an existing wastewater treatment plant.*  *This waste sludge or water gets treated in a Waste Water Treatment Plant & sludge dewatering. The WWTP is fully automatic in operation by using Thickeners & Filter Press.*  Sludge treatment from C &amp; D Waste Recycling &amp; Soil Washing – COGEDE |

|  |
| --- |
| **3.6****Nutrient addition and microbial amendment (pilot scale)** |
| Please describe if and which post treatment was installed for the effluent in the full scale application in field   * Air scrubber * Granulated activated carbon * *Indicate what path the material that comes out as dust from flue gas filtration (if possible, indicate with what percentage it can be recovered in the soil circuit. Typically we are talking about max 500 kg/hour on a 10 ton/h treated flows)* * *EXAMPLE OF ANSWER*   *Off-gasses from the soil were carried from the biopile by induced air flow through the surface. Air flow was induced through the cylinder at a rate of 0.25 to 0.30 cubic feet per minute (cfm). The amount of air flow per mass of soil in the was much smaller than in the full-scale unit. Because of the relatively !esser amount of particulates produced, a baghouse was not induded in the design of the bench-scale unit.*  *The off-gasses from the bench-scale unit were first vented through a series of water cooled condensers, which simulate the Venturi scrubber in the full-scale system.* |

|  |
| --- |
| **3.7****Control parameters (pilot scale)** |
| Please make a list of control parameters for the pilot scale application in field that are helpful for the feasibility full scale.  Field monitoring and sampling program that will adequately monitor the effectiveness of the treatment in three dimensions.   * *(your answer) …* * *EXAMPLE OF ANSWER*   *To assess the removal efficiency, the contaminants of concern and potential byproducts are measured at the air treatment plant, water treatment plant and there are also 12 soil gas survey probes and 5 ambient air devices installed in the area* |

1. Full-scale application

|  |
| --- |
| **4.1****Main treatment unit** |
| *Please describe the number and characteristic of Biopile system in the full scale application*   * *General layout* * *Air addition* * *Other info*   *(your answer) …*  *EXAMPLE OF ANSWER*  *Select biopile configurations are presented in Figures below. Adding or eliminating system options may be appropriate for specific contaminates and soils. General construction rules thumb are summarized below:*  *• Pile height - 4 to 10 ft*  *• 10 ft space between piles if equipment access is required, no equipment movement on piles*  *• 1% slope of pile base for leachate drainage*  *• Less than 45% slope of pile sides*  *• Membrane under and/or over pile*  *• Aeration – mechanical mixing or pressurized or vacuum aeration*  *• Catalyst and water addition – soaker hoses, surface spray or vacuum communication through piles. Add catalyst during initial mixing operation*  *• Leachate Collection – gravity or vacuum extraction*  *• Leachate Treatment – recirculation or treatment*  *• Off gas treatment required for volatile petroleum compounds like gasoline, generally not required for diesel* |

|  |
| --- |
| **4.2****Pre Treatment** |
| Please describe if and which pretreatment was installed in the full scale application in field   * Shredding * Screening * Dewatering * *EXAMPLE OF ANSWER*   *The dewatering was performed by an inflatable bladder dam that restricts water from reentering the job site during site remediation. It consists of an industrial-grade vinyl-coated polyester, making it sturdier and more durable. In addition 4 pumps were used for 3 days to remove the remaining GW .* |

|  |
| --- |
| **4.3****Post Treatment for effluent** |
| Please describe if and which post treatment was installed for the effluent in the full scale application   * Post combustion * Air scrubber * Granulated activated carbon * *Indicate what path the material that comes out as dust from flue gas filtration (if possible, indicate with what percentage it can be recovered in the soil circuit. Typically we are talking about max 500 kg/hour on a 10 ton/h treated flows)* * *EXAMPLE OF ANSWER*   *Off-gasses from the soil were carried from the dryer by induced air flow through the rotating cylinder. Air flow was induced through the cylinder at a rate of 0.25 to 0.30 cubic feet per minute (cfm). The amount of air flow per mass of soil in the dryer was much smaller than in the full-scale unit. Because of the relatively !esser amount of particulates produced, a baghouse was not induded in the design of the bench-scale unit.*  *The off-gasses from the bench-scale unit were first vented through a series of water cooled condensers, which simulateci the Venturi scrubber in the full-scale system. This unit condensed water vapor and some volatile and semivolatile organics, induding MBOCA. For the fifth and sixth run, the condenser off-gas was vented through Tenax or polyurethane foam (PUF) tubes, respectively, to sample for volatile or semivolatile compounds which remained in the off-gas. This measured the amount of volatiles and semivolatiles which would enter the vapor phase carbon unit in* |

|  |
| --- |
| **4.4****Post Treatment for water (pilot scale)** |
| Please describe if and which post treatment was installed for water in the full scale application in field   * *EXAMPLE OF ANSWER*   *The effluent goes to an existing wastewater treatment plant.*  *This waste sludge or water gets treated in a Waste Water Treatment Plant & sludge dewatering. The WWTP is fully automatic in operation by using Thickeners & Filter Press.*  Sludge treatment from C &amp; D Waste Recycling &amp; Soil Washing – COGEDE |

|  |
| --- |
| **4.5****Control parameters (pilot scale)** |
| Please make a list of control parameters for the full scale application in field that are helpful for control the full scale plant  Field monitoring and sampling program that will adequately monitor the effectiveness of the treatment in three dimensions.   * *(your answer) …* * *EXAMPLE OF ANSWER*   *Total heterotrophic plate counts (HPC) - Standard Methods 9215*  *• Gasoline Recoverable Organics - EPA Modified Method 8015D*  *• Diesel Recoverable Organics - EPA Modified Method 8015D*  *• Oil and Grease - Method 1664B*  *• Hydrocarbons - EPA method 8010, EPA Method 5030, EPA Method 9071*  *• EPA TCLP Metals - Method 1311*  *• PAHs - SW 846 Test Method 8100, 8270D*  *• Water quality of leachates - pH, DO, specific conductance, temp, BOD, COD, total petroleum*  *hydrocarbons, BOD - SM 5210 B, COD - Hach Method 8000*  *• Soil gas piezometers - CO2, O2, CH4, VOCs and sVOCs*  *• Dynamax PR2 Multi Depth Soil Moisture Probe*  *• Lantec GA5000 Gas Extraction Monitor - CH4, CO2, O2, H2S*  *• QRAE 3, RAE Systems (Honeywell), 4 gas pump monitor - LEL, CH4, CO, H2S*  *• MultiRAE, RAE Systems (Honeywell), Model PGM6228 pump monitor - NH3, O2, CH4, VOC*  *• Hand auger*  *• Whirl-Pak sampling bag*  *• Sampling port, pump or bailer to collect leachate samples*  *• Fluke Model 52 K/J Thermometer, John Fluke Manufacturing Co., Inc. Everett, WA*  *• Soil temperature J Type or K Type thermocouples placed within the biopile*  *• Radius of influence testing of air injection or extraction - magnehelic gages* |

1. Results

|  |
| --- |
| **5.1** **Removal rate** |
| Please briefly describe the efficiency of the treatment *(your answer) …*  *EXAMPLE OF ANSWER*    *As shown in Table above the SoilTech ATP system achieved the cleanup goal of 97% removal by mass of PCBs in soil and sediment, achieving an average PCB removal efficiency of 99.98%. Treated soil PCB concentrations ranged from 0.4 to 8.9 mgtkg. The PCB DRE requirement was achieved for stack gas emissions after the process modifications described above were made in early May 1992.*    *As shown in Table above, the concentration of tota! dioxins and furans in the stack gas was less than the stack gas emission requirement of 30 nanograms per dry standard cubie meter (ng/dscm) in 3 of the 10 stack gas tests conducted prior to completing the process modifications described above. The concentrations of tota! dioxins and furans measured near the conclusion of the modifications period (4/10/92) was 24. 7 ng/dscm. Tota! dioxins and furans were not analyzed in subsequent stack gas tests. The concentration of tota! dioxins and furans in the stack gas during the three test runs conducted during the SITE Demonstration on June 16, 1992 was 0.0787 ng/dscm.* |

1. Post treatment and/or Long Term Monitoring

|  |
| --- |
| **6.1** **Post treatment and/or Long Term Monitoring** |
| Please describe the monitoring parameters for post treatment and long term monitoring *(your answer) …*  *EXAMPLE OF ANSWER*  *There were test on the release at long term that resulted in materials that does not leach significant amount of contaminants.* |

1. Additional information

|  |
| --- |
| **7.1****Lesson learnt** |
| Please describe Key findings and lessons learned about this site. Difficulties and weaknesses, successes and strengths, keystones, shortcomings and rooms for improvement. Please give your opinions as regard to 1) methodology and procedures, 2) technical aspects 3) legislative, organizational aspects.  (your answer) …  *EXAMPLE OF ANSWER*  The ATP system achieved an average mass removal effìciency of 99. 98 percent for PCBs during the full-scale cleanup; this was much higher than the PCB soil/sediment cleanup goal of 97 percent removal. Treated soil PCB concentrations ranged from 0.4 to 8.9 mg/kg.  • The PCB DRE and tota! dioxin and furan stack gas emission requirements ~tDs1;4,.. of 99.9999% DRE and 30 ngldscm, respectively, were met after making severa! modifìcations to the flue gas treatment system.  • The majorìty of PCBs accumulateci in the vapor scrubber oils. Approximately 50,000 gallons of oil were generateci during full-scale cleanup and were disposed off site. |

|  |
| --- |
| **7.2****Additional information** |
| Given the clues and the evidence found in the specific case, can you suggest criteria for the determination of clues and evidence referable to the success of remediation?  *(your answer) …*  *EXAMPLE OF ANSWER*  *Bench-scale treatability study results were an accurate predictor of fullscale PCB removal and indicated that a thermal treatment system removed more than 99% of a PCB congener from the soil/sediment at OMC.*  *• Pilot study testing of effluent was limited to PCBs and total suspended solids (TSS). Discharged water was subject to a limit of 1 part-per-billion (ppb) tor PCBs. Effluent testing tollowing mobilization of the ATP unit to the site identified the presence of contaminants including phenols and acetone. The wastewater system was modified to reduce phenol and acetone levels to acceptable levels tor discharge to a POTW. PCB levels were less than the 1 ppb limit.* |

|  |
| --- |
| **7.3****Training need** |
| Please give your opinion as regard to the training needs from the technical, procedural, organizational point of view and which training tool you think is effective (workshops, training on-the job, webinars, e-learning, etc.). *(your answer) …* |

|  |
| --- |
| **7.4** **Additional remarks** |
| Please feel free to give any additional information, remarks, concerns, requests, suggestions *(your answer) …* |

Glossary of Terms A glossary will help a you to maintain the level of precision necessary for key terms and maintain consistency across the text. We found out that sometimes terms that sounds similar like “contaminated” and “polluted” are used in the same way as synonyms in some country, while in other they have different meanings (due to legislation or for other reasons). So fill in this glossary for your key elements and of course for acronyms.

|  |  |
| --- | --- |
| **Term (alphabetical order)** | **Definition** |
| VOC | Volatile organic compounds (VOCs) are organic chemicals that have a high vapor pressure at ordinary room temperature |
| .... | ..... |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |