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Biodegradability Testing Explained

Current constraints and future prospects

Whitepaper

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Introduction

The demand for biodegradable products from consumers has become increasingly prevalent in recent years, correlating with a general drive towards sustainability and corporate social responsibility. With more people focusing on the end-of-life (EOL) cycle of their products, it has become imperative to have an accurate system in place not only to validate degradability claims, but to assess toxicity of those degradation products and provide alternative solutions in cases where biodegradation isn't favourable.

Defining biodegradability can be complex, as the term is frequently misused and overly employed. The positive implications of the term often lead individuals to believe it is an eco-friendly process, which is not always the case. This fosters a misguided sense of security, leading people to believe they can dispose of items carelessly. Littering increases as a result, as individuals incorrectly assume that biodegradable items will break down quickly even in inappropriate environments.

French legislation under the AGEC (Anti-Waste for a Circular Economy) law forbids the use of the term 'biodegradable' as a promotional term for plastics to prevent misunderstanding and reduce greenwashing [1]. Likewise, the European Commission has proposed that products prone to littering (including those subject to the Single-Use Plastics Directive) should not claim or be labelled as biodegradable [2].

In some cases it may be better to consider the durability and recyclability of materials, which are two of the main goals set by AGEC [3]. Creating durable materials that can be repaired or recycled is important for the promotion of a circular economy that reduces waste and preserves natural resources. For instance, the production of polyethylene terephthalate (PET) plastic bottles from recycled materials reduces greenhouse gas (GHG) emissions by 70% compared to the use of virgin raw materials [1].

However, where an efficient system is not in place to support circular economy, it is preferable that materials are designed to be biodegradable [4]. This is embodied in the 10th principle of the American Chemical Society's 12 Principles of Green Chemistry titled "Design for Degradation":

"Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment [5]"

If a material cannot be recycled or reused, then it should be degradable and compostable to reduce waste and prevent the accumulation of harmful substances in our environment. This is where accurate and wide-ranging testing is required in order to assess the degradability, disintegration, and toxicological impact of materials. Various tests, as detailed below, measure different parameters associated with degradation to suit the needs of the client, the claim being validated, and the environment in which the material is likely to degrade.

Definitions

Biodegradation is the breakdown of matter into smaller parts and eventual conversion into substances that are reused in biological cycles or accumulate in the environment [6]. In the presence of oxygen, microorganisms break down materials into carbon dioxide, water, mineral salts, and carbon-rich biomass. In anaerobic conditions, they convert materials into carbon dioxide, mineral salts, biomass, and methane [6]. For a material to fully decompose, both disintegration and biodegradation take place.

Disintegration is the physical breakdown of a material into smaller constituent parts, for example by weathering or UV radiation.

When materials fully biodegrade under controlled conditions within a defined timeframe, into constituent parts that are suitable for organic recycling, they are known as **compostable** [7].

It is important to note that materials that are biodegradable are not always compostable and testing can help us determine if a product meets these definitions.

Overview of biodegradability

There are many benefits to biodegradation. It is a process that removes waste, increases landfill diversion, and returns substances to the environment to be reused. Materials capable of completely breaking down into their base components without generating harmful residues are preferable over those which only partially degrade, or release harmful contaminants like pollutants and microplastics.

The development and use of biodegradable products can also help to promote more sustainable practices, including the use of renewable resources, the reduction of harmful waste, and the promotion of circular economy models.

While an important aspect of environmental sustainability, biodegradation is not without limitations. Under aerobic conditions, carbon dioxide (CO_2) is released into the atmosphere, contributing to GHG emissions. Likewise, uncontrolled anaerobic biodegradation releases methane; a GHG twenty-times more damaging than CO_2 [8]. If the process is not managed correctly, it could contribute to climate change.

Even when products are made from biodegradable materials, they might not break down as expected if the correct waste management infrastructure is not in place. For example, many regions do not have the industrial composting facilities necessary to break down certain types of biodegradable waste.

In some cases, so-called biodegradable materials only partially degrade, leaving behind microplastics or toxins. This is a significant issue with some types of biodegradable plastics. Organic pollutants such as polychlorinated biphenyls (PCBs) and bisphenol A (BPA) can be released, which accumulate in the environment [9]. Oxo-degradable plastic products are banned under the Single-Use Plastics Directive (EU 2019/904), as degradation of these plastics through oxidation can lead to the formation of microplastics [10].

The rate at which a material biodegrades depends on several conditions:

- Material structure
- Environmental endpoint (i.e. soil, compost, landfill, or water)
- Temperature
- Level of microorganisms
- Chemical alteration

The structure of a material can influence degradation. For instance, untreated natural fabrics such as cotton will typically degrade faster than synthetic materials [11]. On a structural level, there is research that suggests aliphatic compounds are more susceptible to biodegradation than aromatic compounds [12]. Other research suggests that halogens and branched chains might hinder biodegradation [5].

The environment where waste is disposed of also impacts its breakdown. Conditions such as temperature, oxygen and nutrient levels, pH, and the presence and diversity of microorganisms vary across different matrices, leading to distinct rates of degradation.

Higher temperatures can speed up degradation by increasing the activity and growth of microorganisms. Additionally, the rate of degradation can be altered if chemistry is used to change the composition of the material during its product lifecycle. An example of this is the chemical cross-linking of collagen during the production of leather.

We can use the conditions of degradation, as well as its products, to measure and assess biodegradability and compostability via testing. This helps validate materials which are safely biodegradable, and flag materials which are not.

Current biodegradability & disintegration testing

Biodegradability, disintegration, and compost tests are carried out in order to study the environmental and toxicological impact of materials. There are various standards and test methods which focus on this, **Table 1** summarises the main services offered by Eurofins globally.

Over time, an established framework for assessing biodegradability has been created, primarily supported by the Organisation for Economic Co-operation and Development (OECD) and International Organization for Standardisation (ISO).
These standardised biodegradation tests can estimate the biodegradability of pure chemicals or individual components within materials.

The assessments are conducted in settings designed to a certain extent, to mirror natural environments. There exists a range of methods, which primarily estimate the likelihood of a material to biodegrade but can also assess the rate of biodegradation, disintegration, and ecological impact [13].

There are similarities between OECD and ISO standardised tests. The OECD has instituted three tiers of testing: ready biodegradability, inherent biodegradability, and simulation testing [13].

Ready biodegradability tests

Ready biodegradability tests (RBTs) classify substances as readily biodegradable if they meet thresholds set by the standard. For example, during OECD 301 testing the following pass levels must be achieved after 28 days (within a 10-day window):

- Production of at least 60% Theoretical Carbon Dioxide ($ThCO_2$)
- Consumption of at least 60% Theoretical Oxygen Demand (ThOD)
- Removal of at least 70% Dissolved Organic Carbon (DOC) [14]

RBTs are important as they form the basis of many regulatory measures and have been incorporated into European legislation under REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) [13]. However, there are limitations to the methodologies. The test conditions are quite strict, for instance, duration is limited to 28 days and a pre-adapted inoculum cannot be used [13]. RBTs are often low-throughput, highly variable and lack replication, resulting in false negatives amongst the reported fails [15]. Enhanced RBTs have been developed due to these criticisms, including increasing the duration of tests up to 60 days and using larger test vessels, which aim to provide more realistic test conditions and therefore more accurate biodegradability predictions [13].

Summary of services offered by Eurofins	
Standards organisation	**Types of testing offered**
American Society for Testing and Materials (ASTM)	• Biodegradation tests for plastics
Coordinating European Council (CEC)	• Biodegradation tests for lubricating oils and formulations
Deutsches Institut für Normung (DIN)	• Biodegradability of water, wastewater, sludge
International Organization for Standardization (ISO)	• Ultimate aerobic and anaerobic biodegradability tests • Ultimate biodegradability in aqueous mediums • Biodegradability and compostability tests for packaging • Aerobic biodegradability of plastic and leather materials • Disintegration tests for plastic, leather, and textile materials
Organisation for Economic Co-operation and Development (OECD)	• Ready biodegradability tests • Inherent biodegradability tests • Aerobic and anaerobic biodegradation tests • Biodegradability in seawater • Biodegradation tests for insoluble, water-soluble, volatile, and non-volatile materials
Office of Prevention, Pesticides and Toxic Substances (OPPTS)	• Ready biodegradability tests

Table 1: A summary of the key biodegradability, disintegration, and composting services offered by Eurofins globally according to their standards.Inherent biodegradability tests

Inherent biodegradation tests are less stringent and have a higher probability of complete biodegradation, therefore face less criticism than RBTs. Chemicals that are biodegradable in inherent tests are considered to be biodegradable under various natural and technical conditions, such as wastewater treatment plants. If further criteria are met, materials can be classified as non-persistent. This is the case for materials with a lag phase under 3 days during OECD 302B testing [13].

According to ECHA guidelines, biodegradation under 20% in inherent testing may be considered as evidence of a persistent substance. Biodegradation above 20% but below the pass rate of 70%, suggests primary biodegradability in which stable degradation products are likely to be formed [13].

Simulated biodegradability tests

Simulated tests are very close to environmental conditions meaning they have the highest predictive power. Environments such as freshwater bodies and sediment can be evaluated, as detailed in OECD 308 and 309, as well as anaerobic conditions. The caveat to this increased accuracy is the tests are costly, time-consuming, and difficult to automate [13]. The main advantages and disadvantages of this tiered testing system are summarised in **Table 2**.

Comparative table of OECD biodegradability testing	
Ready biodegradability tests	
Advantages	**Disadvantages**
• Cost-effective • Relatively quick results (within 28 days) • Simple set-up • Serves as a good screening tool	• Limited precision • Stringent test conditions • Some compounds may fail if they degrade slightly slower than test criteria, but would pass inherent tests
Inherent biodegradability tests	
Advantages	**Disadvantages**
• Probability of complete biodegradation higher than RBTs • Less stringent test conditions • Higher credibility of results	• Longer timeframe for results • Less standardised than RBTs • Potential for overestimation of biodegradability
Simulated biodegradability tests	
Advantages	**Disadvantages**
• Highest predictive power • Much closer to environmental conditions • More comprehensive than other tests	• Costly • Resource-intensive • Results can be challenging to interpret due to complexity of simulated environment

Table 2: A summary of the advantages and disadvantages of the OECD tiered system of biodegradability testing.

Measured parameters

Biodegradability tests often measure CO_2 output or oxygen (O_2) demand. For example, the test method set out by ISO 20136 determines the degradability of leather by exposing grindings to an inoculum in an aqueous medium and measuring CO_2 production. The amount of CO_2 evolved is then used to calculate the rate of aerobic biodegradation [16].

Parameters such as change in mass, odour, appearance, and chemical analysis can also be measured, which is covered in ISO 20200 methodology [17]. This is a standard for disintegration testing which is used to determine the percentage of disintegration of plastics.

There are tests to suit nearly all types of environments and test substances, and where methods are not in place they can often be modified. Such is the case for ISO 20200, which can be modified for leather and textiles [18].

To ensure the products of degradation and disintegration are not harmful, toxicity tests are carried out to test how compostable a material is and to flag possible contaminants. To give an example, supplementary tests are available after completion of ISO 20200 testing, which analyse compost nutrition and toxicology. These include ecotoxicity, plant response and weed tests.

Ecotoxicity tests evaluate the end compost after degradability or disintegration tests. Over 200 components are quantitatively measured such as phenols, pesticides, and metals [17]. Plant response and weed tests evaluate the effect of the substrate on the growth of plants (crop and non-crop), as well as weed propagulation.

The bio-enriching or bio-suppressive properties of the degradation products produced are measured by these tests and can be used to give information about the nutrition of the soil/compost that the test material has degraded in [18].

Globally, there are other important standards such as those set by the American Society for Testing and Materials (ASTM). These standards were developed to establish degradability and biodegradability and assess the impact of degraded plastics [19].
Additionally in the US, the Office of Prevention, Pesticides and Toxic Substances (OPPTS), developed a series of biodegradability test guidelines. One such test is OPPTS 835.3140, which is a ready biodegradability test based on OECD 310 [20].

Limitations of biodegradability testing

One of the biggest limitations of current biodegradation and compost tests is time.

Methods can take many months to complete and are typically designed to examine one sample at a time. Additionally, a number of tests use preferable lab conditions that do not accurately mimic those found in the environment. Tests that simulate environmental conditions more authentically are often more expensive.

While some tests implement defined thresholds and pass criteria, others yield results that are open to interpretation. This lack of clarity can lead to inconclusive findings and the need for additional testing.

Despite limitations, these tests are undeniably important not only when considering the environmental footprint of products, but for compliance with relevant regulations, legislation, and claims validation.

Guidelines and regulations

There are important regulatory frameworks in place to ensure materials are assessed for potentially hazardous properties.

EU

Under REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) regulation in the EU, all organic chemicals manufactured or imported for more than one ton per year must be evaluated for their ready biodegradability. A series of RBTs, such as OECD 301 are recommended for evaluation.

Degradation tests are used to fulfil regulatory needs such as:

- Identifying PBT (Persistent, Bioaccumulative and Toxic) or vPvB (very Persistent and very Bioaccumulative) properties
- Determining the potential to cause long-term adverse effects (environmental hazard classification)
- Determining Predicted Environment Concentration (PEC) for risk characterisation [14]

Though there is currently no EU law in place relating to biobased, biodegradable, and compostable plastics, the European Commission has drafted a forthcoming framework which aims to improve understanding of biobased and biodegradable plastics [21].

In agriculture, the EU Fertilising Products Regulation has established guidelines for biodegradation. These must be substantiated through rigorous testing methods that measure ready biodegradation, inherent biodegradation, or simulation studies [22].

Compostable packaging is regulated in the current draft of the Packaging and Packaging Waste Directive (PPWD). The PPWD aims to reduce packaging waste and promote its reuse or recovery [23]. Packaging items such as tea bags, sticky labels, and lightweight plastic bags must be compostable in industrially controlled environments. In certain conditions, Member States can mandate that lightweight plastic bags be made from industrially compostable biodegradable polymers [23].

In France, AGEC law also outlines rules for biodegradation. Aside from prohibiting the word on products and packaging, the legislation also bans the use of non-biodegradable plastic in products such as tea bags, and the distribution of unsolicited printed matter containing ink from non-biodegradable sources [1].

It is likely that biodegradability will be further regulated in the EU with the introduction of the Digital Product Passport (DPP). The DPP will facilitate the exchange of key product-related information essential for sustainability and circularity, including those specified in Annex III of the Ecodesign for Sustainable Products Regulation (ESPR) Proposal. Information such as biodegradability, recyclability, durability, and traceability will be made available digitally for consumers to easily access [24].

China

Whilst there are currently no mandatory standards in China, there are several voluntary standards relating to the biodegradability of plastics. GB/T 41010 standard specifies the degradability and identification requirements of biodegradable plastics and products. One requirement is that biodegradable plastics and products must have a relative degree of biodegradation of at least 90%. The standard also outlines pass rates for ecotoxicity evaluation such as phytotoxicity and earthworm tests on degradation products [25]. Other relevant voluntary standards include GB/T 38082-2019 relating to biodegradable plastic shopping bags, and GB/T 41008-2021 for biodegradable drinking straws [25].

In 2020 Jilin, Hainan, and Guangdong provinces released their local plastic bags banning policy and in 2022 aimed to reduce consumption of single-use plastic products and promote alternatives. Similar plastic-banning policies were released to all provinces upon the adoption of the “Opinions on further strengthening the control of plastic pollution” policy [26].

There are three main aims at a national level, which local provinces are intending to follow:

- **2020**; the banning and restriction of the production, sale, and use of selected plastic products in certain regions/fields.
- **2022**; the reduction in consumption of disposable plastic products, the promotion of alternative products, and an increase in plastic waste resources and energy utilisation. Green logistics models have also been formed in areas with prominent plastic pollution.
- **2025**; the establishment of a management system for the production, circulation, consumption, recycling, and disposal of plastic products. Improvements in alternative product development and application have also been proposed along with the reduction of plastic waste landfill in key cities [26].

The Chinese government are also set to ban plastic bags in postal and express delivery outlets in 2025 [27]. This has driven the production of biodegradable plastics in China [28] as well as the development of biodegradability and disintegration testing capabilities.

US

The primary guideline in the US is the Federal Trade Commission’s Green Guides which aim to reduce deceptive environmental marketing claims [29].
In California, there are multiple laws protecting consumers from misleading environmental marketing claims in product sale and promotion [30]. There are several other states which have introduced restrictions relating to marketing claims, particularly for single-use plastic bags. These are detailed further in the following section.

Validating claims

Regulating biodegradability claims is vital for protecting the environment from products that are not truly biodegradable which can accumulate and cause harm. It also safeguards the trust and transparency expected by consumers. Composting claims are equally significant. If a product is labelled as biodegradable and ends up in a composting facility, but it doesn’t break down properly, it can contaminate the compost. This underlines the importance of regulation and accurate labelling. Claims on biodegradability should be transparent, verifiable, and supported by relevant standards and testing methodologies.

EU & UK

The labelling of materials as biodegradable or compostable is regulated so that claims made on packaging must be validated.
The European Green Deal has proposed that plastic products and packaging that can only be composted in industrial facilities cannot bear the “compostable” label. Additionally products and packaging made of compostable plastic materials in domestic or industrial composting must include ‘Do not dispose in nature’ in their labelling.
It is also forbidden to include the words “biodegradable”, “environmentally friendly” or equivalent statements on products or packaging. The Green Deal approaches biodegradable plastics with caution. They must be labelled to show the timespan in which they will biodegrade, under which circumstances and which environment [2].

For composting claims, it should be made clear whether the conditions relate to industrial or home composting. The main specification standard for industrial composting in Europe is EN 13432 which outlines criteria for packaging that can be recovered through biodegradation. From this, several certification programs have been developed, some of which comply with the EU Packaging Directive (94/62/EEC) [31].

There are currently no standardised conditions for home composting, however there is an OK Compost HOME certification program which has been the basis for the development of several standards such as prEN 17427 in Europe, NF T 51800 in France, and AS 5810 in Australia. PrEN 17427 will set a maximum duration of 26 weeks for 90% disintegration to be reached, compared to EN 13432 which is 12 weeks [31].

Biodegradation and ecotoxicity testing can help to meet the demands of EN 13432, particularly the following:

- **Biodegradation**; at least 90% of materials have to be broken down by biological action within 6 months to CO_2
- **Disintegration**; at least 90% of the product must be able to pass through a 2 x 2 mm mesh after 12 weeks
- **Quality of the final compost and ecotoxicity**; the quality of soil should not decline as a result of the added packaging material

In the UK and EU, the Green Claims Directive has been proposed, which will provide further guidance on biodegradability claims and definitions. The current draft of the EU Green Claims Directive includes requirements for substantiation of green claims such as “biodegradable” and “compostable”. This will increase the necessity for biodegradability and compost tests.

The EU Ecolabel managed by the European Commission is another scheme which promotes the use of goods and services using sustainable ingredients. For instance, the importance of lubricants being biodegradable in water has been acknowledged due to significant quantities of these substances ending up in the environment during typical use. There are limits on the total weight percentage for ingredients in these lubricants based on their biodegradability potential [32]. There are similar conditions amongst other categories of the EU Ecolabel including detergents and textile products [33].

US

In the US, the FTC has addressed the use of environmental claims through the Green Guides. These guides aim to reduce deceptive environmental marketing claims. In terms of degradability, the following is outlined [29].

- Marketers asserting a product’s degradability must possess credible scientific proof that the item will fully decompose and revert to nature swiftly after standard disposal.
- Making unqualified degradability assertions for items that don’t fully decompose within a year of standard disposal in the solid waste stream is misleading. Such claims are deceptive for items ending up in landfills, incinerators, or recycling facilities, as these places don’t offer conditions for complete decomposition within a year.

- Claims about degradability should be transparently specified to prevent misleading impressions about the product or packaging's ability to decompose in its typical disposal environment, along with its degradation speed and extent [29].

In California, consumer products must meet specific legal requirements in order to be labelled as compostable. Compostable plastic products must meet the standards of ASTM D6400, which establishes requirements for labelling as compostable in aerobic industrial and municipal conditions [34]. Compostable plastic bags must be labelled with a certification logo indicating compliance with ASTM D6400, amongst other requirements [35].

Similarly in Maryland, House Bill 1349 details prohibitions on the selling of certain plastic products labelled as biodegradable, degradable, or decomposable, unless the product meets specific standards. Plastic products labelled as compostable must meet ASTM D6400 or ASTM D6868 standard specifications [36].

In 2021, Washington State introduced a statewide ban on single-use plastic bags. The new law also prohibits the words biodegradable, degradable, or decomposable on produce bags and thick re-usable bags, with fines being imposed for repeated violations. Additionally, these bags cannot be tinted green or brown unless they are certified as compostable [37].

There are also standards in Minnesota for the labelling of plastic bags. Under Section 325E.046 of the 2022 Minnesota Statutes, plastic bags must not be labelled as biodegradable or degradable unless a scientifically based standard is developed for biodegradability which the products are certified to meet [38]. Similarly to the restrictions in other states, plastic bags must not be labelled as compostable unless they meet ASTM D6400 standards. Manufacturers, distributors, or wholesalers who violate these restrictions may be fined [38].

China

As outlined in the Chinese standard GB/T 41010, plastics and products which claim to be subject to industrial composting, high-solids anaerobic digestion or home composting must have a disintegration rate of at least 90% [25].

In conclusion, having robust standards for evaluating degradability, compostability, and ecotoxicity is vital to meet regulations and substantiate claims. It's equally crucial to back these claims with adequate data to reduce greenwashing and miscommunication.

Future of biodegradability testing

As discussed, though current testing methods are valuable, they come with several limitations. Just as with enhanced RBTs, could it be feasible to refine current tests by adapting existing techniques, or even developing new ones?

Potential may lie in high-throughput rapid assessments of biodegradability and disintegration, allowing simultaneous testing of multiple samples [15]. Likewise, the automation of already available tests, such as RBTs, could be another way to increase the productivity of biodegradability testing. With additional research, high-throughput techniques could become valuable tools for biodegradability prediction; overcoming the limitations of existing low-throughput methods.

Another area of interest is predictive modelling, such as quantitative structure-activity relationship (QSAR) studies which are encouraged under REACH [39]. With enough experimental data, in silico models could be produced which provide preliminary insights on biodegradability based on a material's structure. This again reduces the time, costs, and labour associated with current testing methods.

Summary

When biodegradation is the desirable or preferred outcome, the testing methods detailed in this report are crucial for confirming degradation and evaluating the toxicity of the resultant products, as well as substantiating claims and adhering to relevant regulations. Ensuring the EOL cycle of a product is safe, environmentally friendly, non-toxic, and non-damaging is imperative. Where degradability cannot or should not be achieved, the recyclability and re-usability of a material should be the next consideration.

With continued research, it is hopeful that we will not only develop tests that are faster, cheaper, and more accurate, but also design products that degrade more efficiently. There are plenty of exciting opportunities to explore, and given the momentum towards sustainability driven by consumers and regulatory frameworks, it is likely we will see advancements in testing and predicting biodegradability in the near future.

If you would like more information on biodegradability services offered by Eurofins, or our durability and recyclability assessments, please visit sustainabilityservices.eurofins.com, or e-mail us on SustainabilityServices@cpt.eurofinseu.com.

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Table of Abbreviations

Abbreviation	Meaning
AGEC	Anti-Waste for a Circular Economy
ASTM	American Society for Testing and Materials
BPA	Bisphenol A
CO_2	Carbon Dioxide
DOC	Dissolved Organic Carbon
DPP	Digital Product Passport
EOL	End-of-life
ESPR	Ecodesign for Sustainable Products Regulation
FTC	Federal Trade Commission
GHG	Greenhouse Gas
HT-BST	High-Throughput Biodegradation-Screening Tests
ISO	International Organization for Standardization
O_2	Oxygen
OECD	Organisation for Economic Co-operation and Development
OPPTS	Office of Prevention, Pesticides and Toxic Substances
PBT	Persistent, Bioaccumulative and Toxic
PCBs	Polychlorinated Biphenyls
PEC	Predicted Environment Concentration
PET	Polyethylene terephthalate
POPs	Persistent Organic Pollutants
PPWD	Packaging and Packaging Waste Directive
QSAR	Quantitative Structure-Activity Relationship
RBT	Ready Biodegradability Test
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
$ThCO_2$	Theoretical Carbon Dioxide
ThOD	Theoretical Oxygen Demand
VPvB	Very Persistent and Very Bioaccumulative

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