INFORMATION
REPORT

JULY 2019

BIODEGRADABLE AND COMPOSTABLE BIOPLASTICS

SITUATIONAL ANALYSIS

REPORT
INFORMATION

ZOOM ON…

FOREWORD

A lot of scientific research is being carried out today into “bioplastics“, not only in France and Europe but also in other countries across the globe like China or the United States. Since 20 years, a number of interesting innovations have appeared on the market and have been developped on a large scale. In many cities of Europe and certain French urban areas, biodegradable and compostable bioplastic bags are now being used to collect organic household waste.

When they are both “biosourced“, meaning manufactured from mostly plant-based organic resources, and biodegradable, meaning totally decomposed and assimilated by micro-organisms under given conditions, bioplastics help to considerably limit this material’s impact on our environment. They do so by preserving the natural ecosystems, reducing greenhouse gas emissions, and preserving fossil resources. They are in full sync with the roadmaps of the circular economy deployed by the French government and the European Union.

As bioplastics evolve through breakthroughs in research and innovation, the subject tends to introduce relatively complex notions that can sometimes cause confusion. They are also a subject that gives rise to preconceived notions, received ideas or opinions that are more or less well-grounded.

Having set the context, the objective of this information report is to draw up a situational analysis of scientific knowledge around biosourced, biodegradable and compostable bioplastics, and to explain how these new materials constitute an attractive solution - among others - to improve the way we manage waste.

To help us in this work, we have relied on the expertise and pedagogical skills of three researchers who are well acquainted with the subject and who agreed to answer our questions: Nathalie Gontard, Research Director at INRA, Stéphane Bruzaud, Research Professor at the University of Bretagne Sud and Jean-François Ghiglione, Research Director at CNRS. We also drew heavily on their scientific publications or public lectures.

They enlighten us throughout this information report, even though, of course, they are committed only by the words explicitly attributed to them.

Stéphane Bruzaud sums it up well: “*the idea is to manufacture plastics with a resource other than oil... plants for example... which at the end of their life will be able to decompose naturally without littering the environment for years or decades.*“

“*Today, research is working on polymers that already exist in a natural state, synthesized either by plants (starch, cellulose, etc.) or by micro-organisms (PHA), and which biodegrade rapidly under natural conditions,*“ adds Nathalie Gontard. “*They can be manufactured using residues from agriculture or agricultural foods so as not to compete with farmland intended to grow food for humans and animals.*“

Jean-François Ghiglione adds “*bioplastics must meet both the rational use of biological resources, guarantee complete biodegradation under environmental conditions or by recycling processes such as composting, and not be toxic to natural species. Science today brings several innovations of the future in this field of sustainable ecodesign, which is part of the circular economy*“.

Obviously, biosourced and biodegradable plastics are not going to solve all the issues linked to the negative external effects of plastics in one magic swoop. Neither will they replace all the polymers we use today. Likewise, they are not a single solution that would rule out all others. But it would be a pity to step away, for all the wrong reasons, from an attractive solution of organic recycling complementary to the recycling of materials, which makes a lot of sense when it comes to recovering bio-waste, a sector whose development is key and now a matter of urgency.

In initiating this information report, SPHERE Group, an independent French family group and European leader in household packaging, and KANEKA, a Japanese group specializing in chemistry, wish to provide all the necessary details on the issue of bio-based, biodegradable and compostable bioplastics, so that citizens and politicians are able to make informed decisions based on the current state of scientific knowledge.

EXPERT OPINIONS

Nathalie Gontard is Director of INRA Research at the "Engineering of Agropolymers and Emerging Technologies" unit in Montpellier. She is also a specialist in food and packaging sciences.

She was awarded the European Stars Trophy in the "Environment, Climate Change" category in 2015 and received the 2017 INRA Scientific Challenge Prize for her work on the manufacture of bio-degradable food packaging from the by-products of agricultural food industries.

She is currently coordinating the European project "No Agro-Waste" (NOAW 2020), "zero waste in agriculture", a project supported by the European Union and involving 32 countries, including China, which aims to redevelop agro-waste into bioenergy, biofertilizers and biodegradable bioplastics (PHA).

Stéphane Bruzaud is a professor at the University of Bretagne Sud (South Brittany) and a researcher at the Institut de Recherche Dupuy de Lôme (IRDL), specializing in materials engineering. Based in Lorient, he coordinates research into biopolymer engineering and the manufacture of bioplastics from biotechnological processes.

He also develops research on the assessment of environmental pollution by plastics and has participated in the scientific study of Tara Méditerranée, aimed at better understanding the impacts of plastics on the Mediterranean ecosystem.

He is also leading the BlueEcoPHA project, supported by the ADEME and involving industrialists from the West of France, which aims to produce a bio-based and biodegradable bioplastic (PHA) on a local scale using co-products from the agricultural food industries and marine bacteria.

Jean-François Ghiglione is CNRS Research Director at the Banyuls Oceanological Observatory. He coordinates the Ecotoxicology and Marine Microbial Metabolic Engineering team in the Microbial Oceanography Laboratory (LOMIC, UMR 7621).

He is a member of the Executive Committee of GDR Polymers and Oceans and co-founder of Plastic@Sea.

He is also the coordinator of several scientific programmes on the fate, biodegradation and toxicity of plastics in the marine environment and is the scientific head of the 2019 Tara Microplastics mission.

INTRODUCTION, CHALLENGES AND OUTLOOK

CHALLENGES

PLASTIC, AN ESSENTIAL MATERIAL IN TODAY'S ECONOMY

The word "plastic" comes from the Latin "plasticus", itself borrowed from the Greek "plastikós" meaning "relative to modeling". It is indeed this tremendous "plasticity", with no limits to the shape it can be given, combined with its low cost, that explains how this material has become an essential part of today's modern economy. All the more so in that combines other precious qualities including low density and a high resistance-to-weight ratio, hydrophobicity, biological inertia, deformability and mechanical resistance.

Evidently, the word plastic makes no reference to the material's origins (plant, fossil, etc.) nor to its capacity for biodegradation.

Today, plastics are a key component in a wide range of sectors, from packaging to construction, from transport to health to electronics. For example, they account for around 15% of the total weight of a car and around 50% of a Boeing Dreamliner(1).

Over the last half century, the world production of plastics has risen 20-fold, soaring from 15 million tonnes in 1964 to 311 million in 2014. According to the Ellen MacArthur Foundation, it should double again over the next twenty years and almost quadruple by the year 2050(1). It hit 320 million tonnes in 2015, 335 million in 2016 and 348 million in 2017.

Plastic has become a source of wealth (contributing 27.5 billion euros to public finances in European countries), and of employment (over 1.5 million jobs in Europe)(2).

As the primary application, plastic packaging represents 26% of the total volume of plastic products(1). Inexpensive, light and doing its job very well, "*plastic packaging can, what is more, have a positive effect on the environment: its light weight effectively helps to reduce the consumption of fuel needed for transportation and its protective properties give better protection for food, thereby cutting food wastage,*" emphasized the Ellen MacArthur Foundation, which works on the self-assigned mission of speeding up the transition towards the circular economy.

"*Plastic packaging is a key element for preventing exterior contamination (chemical or microbial), for preserving the quality and traceability of products, and for reducing loss and wastage by protecting food,*" noted Nathalie Gontard, Director of Research at INRA(2).

The upshot is that plastics are increasingly replacing other packaging materials. Between 2000 and 2015, their share of the total volume of packaging rose from 17% to 25% owing to the strong growth of 5% p.a. in the world market for plastic packaging.
In 2013, the industry placed 78 million tonnes of plastic packaging on the market, a volume that should continue to grow strongly, according to the Ellen MacArthur Foundation, doubling over the next 15 years and quadrupling by the year 2050 to top 318 million tonnes a year.
This is more than the whole plastics industry today(1).

BUT ONE PRODUCING NEGATIVE EXTERNAL EFFECTS

Although it offers any number of advantages, the current economy for plastics is grounded essentially in a linear value chain, based on the "extract-manufacture-dump" triptych, which presents a number of major economic and environmental drawbacks.

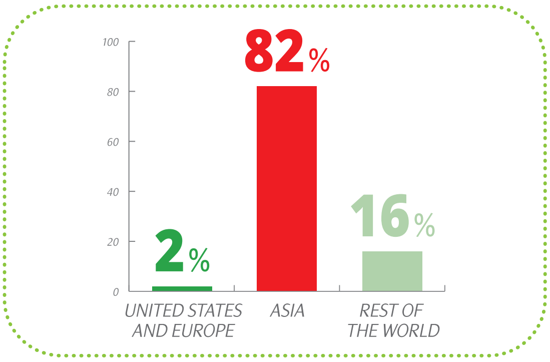
Worldwide, only 14% of plastic packaging is collected for recycling, the majority of which, however, is transformed into applications of lower value that are not recyclable after use. All in all, if we factor in the losses that occur during sorting and reprocessing, only 5% of the value of materials is retained for subsequent use(1).

After an initial short-term cycle of use, 95% of the value of plastic packaging is thus lost each year, representing between 80 and 120 billion US dollars, according to the Ellen MacArthur Foundation.
Additionally, according to the UN Programme for the Environment, plastic packaging produces significant negative external effects estimated at 40 billion US dollars a year, a sum that is higher than the profits of the plastic packaging industry

as a whole. These negative impacts on the environment concern primarily the degradation of natural systems linked to spillages of plastic packaging, particularly into the oceans, and the emissions of greenhouse gases arising from the production of plastics and the incineration of waste.

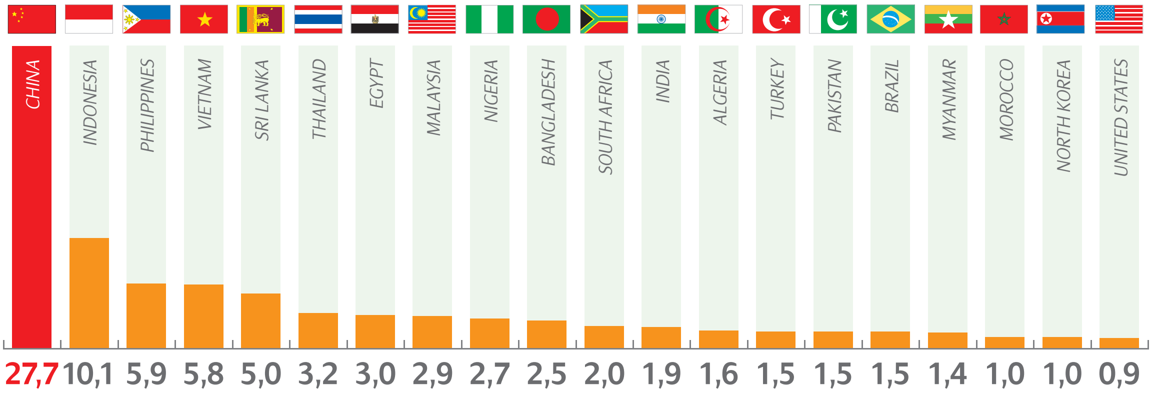
This spillage concerns packaging that never enters the collection cycle, simply because it is not collected, or, when it does get collected it is either dumped illegally or badly handled. Globally, in 2013, the Ellen MacArthur Foundation reckoned that spillage concerned 32% of all plastic products on the market (14% collected for recycling, 14% incinerated or redeveloped for energy purposes, and 40% dumped).

Geographic split of plastic spilling into the oceans



Source: Ellen MacArthur Foundation
For a new economy of plastics, 2017

The main countries spilling plastic waste into the oceans



(in % share of world spillage into the ocean measured in millions of tonnes of plastic waste per year)

Source: J. R. Jambeck et al, *Plastic waste inputs from land into the ocean*, Science, 2015

THE USE OF FOSSIL RESOURCES AND GREENHOUSE GAS EMISSIONS

Plastics production is based on a limited stock of fossil raw materials (oil and gas), which together constitute more than 90% of feed-stock. According to the Ellen MacArthur Foundation, about 6% (between 4% and 8% according to estimates) of world oil consumption is dedicated to plastic production, the equivalent of global consumption in the aviation sector. About half of these fossil resources are used as raw material for manufacturing, and the other half as fuel in the production process.

CO_2 emissions from plastics are estimated to have reached about 390 million tonnes in 2012, according to the MainStream Project's calculation based on data from the International Energy Agency(1). This represents about 1% of total CO_2 emissions. The production phase produces most of these emissions, with the rest of the carbon being released as greenhouse gases depending on the product's end-of-life treatment.

Even if plastics make it possible to achieve efficiency gains in terms of resource utilisation during their useful life (due to their light weight compared to other materials), their carbon impact is therefore rather considerable and could rise significantly with increases in production.

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THE DEGRADATION OF NATURAL SYSTEMS LINKED TO SPILLAGE, PARTICULARLY INTO THE OCEANS

Every year, at least 8 million tonnes of plastic make their way into marine ecosystems around the world - the equivalent to unloading the contents of a garbage truck at sea every minute. If nothing is done, this number will rise to two per minute by the year 2030, and to four per minute by 2050, according to calculations by the Ellen MacArthur Foundation(1).

Plastic packaging accounts for most of these spillages. It is effectively the main application of plastics and because of its small size, very short useful life and low residual value, it is particularly likely to be lost to the environment. Plastic packaging represents more than 62% of all waste collected during international coastal cleaning operations(1).

According to currently available research, the oceans now contain more than 150 million tonnes of plastic waste(1). And stocks are forecast at 250 million tonnes by 2025. According to the Stemming the Tide report, published in 2015 by Ocean Conservancy, there could be one tonne of plastic for every three tonnes of fish in the oceans by 2025... And even as much plastic as fish (in weight) by 2050, according to projections from the Ellen MacArthur Foundation, which expect the annual flow of plastic waste to grow in pace with plastic packaging.

As the Stemming the Tide report points out, even if concerted efforts were made to reduce the flow of plastics into the oceans, the volume of waste reaching the seas would level out, without decreasing, resulting in a continued increase in the volume of plastics dumped into the oceans.

The plastics found in the oceans have a significant impact on our natural maritime heritage. According to Valuing Plastic (United Nations Environment Programme), the damage to marine ecosystems amounts to at least 13 billion US dollars per year.

FOCUS ON THE PLASTIC POLLUTION OF OCEANS

“THE 7TH CONTINENT“

EIn 1997, Charles Moore discovered what is now known as the “7th Plastic Continent“: a vortex of plastic waste in the North Pacific Ocean, which covers an area of 3.5 million square kilometres (six times the size of France) and is 30 metres deep(3). This is an accumulation zone created by marine currents called oceanic gyres.

Unfortunately, this is not an isolated case: there are four other accumulation zones identified in four other gyres (South Pacific, North Atlantic, South Atlantic and the Indian Ocean). In these wormholes, concentrations of 5 kg of plastic per square kilometre have been recorded(4).

When reduced to the surface of a football pitch (about 7,000m²), this concentration equates to about 35 grams of plastic, the weight of an empty plastic bottle of one and a half litres.

The Mediterranean, a semi-enclosed sea whose waters are renewed only every 90 years, is not spared. The Tara Méditerranée expedition (2014) and Expédition Med (every year since 2010) have recorded concentrations of micro-plastics (particles of 0.3 to 5 mm) as high as in the North Pacific gyre(4). The plastic debris floating on the surface of the water is dominated by particles smaller than 5 mm, commonly known as micro-plastic and resulting from the fragmentation of plastic materials.

“*Whatever the sampling point in the Mediterranean, the same types of plastics are found in more or less the same proportions: 70 to 75% polyethylene (PE), used to manufacture all flexible* *packaging such as plastic bags, cups and various disposable objects, and which, because of its density, tends to float, and 20 to 25% polypropylene (PP),*“ explains Stéphane Bruzaud, Professor and Researcher at the University of Bretagne Sud. “*There are also significant proportions of polyamide (PA) or polystyrene (PS) near areas of intense human activity (tourists, harbours, fishing ports), for example off Marseille, Toulon and in the bay of Saint-Tropez - Fréjus - Saint-Raphaël*“(3).

With a density of less than 1 and inert in water, plastics initially float on the surface of the oceans, explains the scientist. They are then colonized by microorganisms and become heavier and heavier. When their density exceeds one, they start to sink. We consider that 70% of plastics are immersed at the bottom of the oceans.... And when they reach the ocean bed, where the temperature is 4°C and where there is little life (conditions that inhibit biodegradation), they will take decades, even centuries, to degrade.

The “surface estimates“ of the mass of plastic waste in the oceans represent only “*1% of the continent’s spillage“ (8 million tonnes spilled per year). This is only “*the tip of the iceberg,*“* says Jean-François Ghiglione, CNRS Research Director and Deputy Director of the Banyuls-sur-Mer Oceanological Observatory. The remaining 99% is considered to be submerged below the surface, and will then be *“either ingested by fish or lodged in sediments on the ocean floor*“(4).

“*Globally, of the 78 million tonnes of plastic packaging produced annually (2013 figures), 32% is randomly dispersed in our environment and 40% is stored in landfills, meaning that 72% is not recovered and has every chance of one day ending up spilled on our land or in our oceans,*“ explains Nathalie Gontard(5).

According to Jean-François Ghiglione, it is estimated that 10% of the plastics produced will end up at sea, that 80% of the plastic that reaches the sea comes from the continent, and that 30% of the waste comes from consumers(4, 6).

WHAT ARE THE CONSEQUENCES FOR MARINE ECOSYSTEMS?

Plastics slowly break down into micro-particles and when they reach the size of plankton, the animals that feed on them - especially fish - will absorb them. “*Plankton being the fundamental link in the marine food chain, plastics infiltrate all levels of the ocean food chain,*“ says Stéphane Bruzaud(3).

In accumulation areas, the observed concentration of micro-plastics is even comparable to that of zooplankton that feed fish that will end up on our plates.

“*In addition, plastic waste causes the death of hundreds of thousands of marine mammals and seabirds every year, through suffocation, strangulation or exhaustion*“, adds Stéphane Bruzaud.

“*The disastrous effects of ingesting plastic debris confused with prey are well documented*“, according to Jean-François Ghiglione. “*The sea turtle, for example, does not know the difference between a plastic bag and a jellyfish, an animal on which it feeds daily. IFREMER in Corsica is thus recovering more and more dead turtles full of plastic*“(4, 6).

The first danger to these animals is the obstruction of the airways, i.e. choking. According to Jean-François Ghiglione, 1.4 million birds are found dead each year, filled with plastic, and 14,000 marine mammals (turtles, etc.) are killed each year by plastic. The second danger is strangulation, particularly because of “ghost nets“ lost at sea by fishermen, which represent 10% of plastic waste in the oceans(4).

“*Plastics are equally vectors for the dispersion of toxic compounds that can also accumulate in food chains*“, says Jean-François Ghiglione. These compounds can be directly present in the composition of plastics (phthalate or biphenyl additives that serves as plasticizers, stabilizers, flame retardants, etc.) or adsorb to their surface (hydrocarbons, pesticides, etc.). «*Some of these pollutants are endocrine disrupters that deregulate the growth, development, blood pressure, blood sugar levels and reproduction of the animals that ingest them. The effects are observed at all levels of the food chain,*» he emphasises.

Micro-plastics can also serve as vectors for pathogenic microorganism that cause disease in marine animals. They are also colonized by larvae of invasive species, which are likely to invade new ecosystem miles from the pollution source and displace the species present (4,6).

LITTLE KNOWN EFFECTS ON HUMAN HEALTH

Massively synthesized over the past 50 years, plastics will take decades, even centuries to degrade into micro-plastics and then into plastic nanoparticles, explains Nathalie Gontard(5), who evokes a real “time bomb“(2). “*Once this nanometric size is reached, approximately by the end of the 21st century, accumulated plastics will then have every facility to spread very widely and rapidly not only in our environment but also in all living organisms, including ours, with potentially frightening effects that are currently very poorly assessed*“(5).

“*Plastic is now so widespread in all geological layers and compartments that it is now being studied as a stratigraphic marker of the Anthropocene, the post-18th century geological era characterized by the interference of human activity with natural cycles,*“ the scientist points out(2).
“*Plastic nanoparticles are now found in oysters, beer, honey, salt or water, because nanoplastics are so volatile that they manage to interfere with all resources,*“ says Stéphane Bruzaud. “*To date, little is known about the impacts on human health*“(3).

“*If fish are eaten without their stomachs where microplastics accumulate, a Ghent University study on North Sea mussels showed that the consumer ingests 300 plastic microparticles for every portion of mussels* (3). *A recent American study also showed that the bottled waters of 11 brands were 93% polluted with more than 300 particles and up to 10,000 microplastic particles per litre, which is much higher than what can be found in tap water.*“, says Jean-François Ghiglione.

WHAT ARE THE SOLUTIONS?

CLEAN UP THE SEAS AND OCEANS? AN ILLUSION!

The project was named “*The Ocean Cleanup*“: *Boyan Slat, a 22-year-old Dutchman, set out in the summer of 2018, after raising 20 million euros, to clean up the North Pacific gyre* (“the 7th continent“) *with a 120-metre long floating dam that recovers waste... And then on to tackle other identified accumulation areas in the oceans.*

“I*t's like raking an area that is six times the size of France with a 120-metre rake,*“ says Jean-François Ghiglione. “*When the expedition returns in 2025, the oceans will have accumulated 400 times more plastic than what will be collected. What's more, this projet only collects macro-surface waste, which represents just 1% of the total plastic present at sea*“.

Other similar initiatives have also been launched, such as the Manta project (“*The Sea Cleaner*“) by the Franco-Swiss navigator Yvan Bourgnon, which, with an ecological boat 49 metres wide and 70 metres long, aims to collect plastic from the oceans to recycle it or transform it into fuel. Project cost: €30 million. He is due to set sail in 2022.

The “Plastic Odyssey“ project, led by young Frenchmen Simon Bernard and Alexandre Dechelotte, relies on an ecological catamaran that transforms plastic into fuel using a pyrolyzer and is powered with plastic waste. The boat can produce 3 litres of fuel in one hour from 5 kilos of waste.

All these projects have the merit of raising world awareness to the problem of ocean plastic pollution and the need for action. They also highlight interesting technological innovations.... But they will not “clean up the oceans“.

“*There is not a single plastic continent that can be cleaned with a large net,*“ says Alexandre Dechelotte, co-founder of Plastic Odyssey at Le Monde. “*We will not be able to clean our oceans of the plastic waste from the last fifty years. However, we do have a collective responsibility to stem the flow and initiate transition. The surface area is too large to cover for these projects not to be ‘illusory on an ocean-wide scale*“, says Stéphane Bruzaud. Especially since they raise two awkward questions: “*What do we do with the recovered waste?*“ and “*Who pays the very high cost of cleaning up in international waters?*“ *The solution is therefore not at sea. And it is not a question of* “solving the problem“, rather of ensuring that “it does not get even worse“(3).

GOING WITHOUT PLASTIC? IMPOSSIBLE, TOO MANY DISADVANTAGE!

Is a world without plastic possible today? “No,“ replies Stéphane Bruzaud. “*These materials are often criticized but they remain essential because they have genuine qualities (resistance, lightness, price, etc.). Today, we cannot do without plastic because it is a material that remains indispensable for many industrial sectors such as the biomedical, automotive, aeronautics or construction industries*“(3).

“*Today, imagining a world without plastics is nigh on impossible. Plastics are increasingly being used throughout the economy and are a key element in sectors as diverse as packaging, construction, transportation, health and electronics,*“ says the Ellen MacArthur Foundation(1).

In the field of packaging, it is not easy to replace this material because alternatives to plastic have a considerable number of drawbacks. Paper bags, for example, cannot be compacted like plastic bags. It is estimated that for the same number of packages, it takes about five times as many trucks to transport paper packages as plastic ones. Paper bags also offer significantly lower capacities in terms of strength and volumes transported. Not to mention their sensitivity to humidity, rain, and any liquid that may leak inside the packaging, nor their ecological footprint, which is less flattering than many people may think.

USE LESS OF IT, ESPECIALLY FOR DISPOSABLE PLASTIC BAGS

The reduction at source of the use of single-use plastic packaging is one of the objectives of several recent pieces of legislation and in particular the law governing energy transition for green growth *(see p. 30-31)*.

Today, single-use plastic bags distributed at supermarket check-outs are banned. For other bags distributed at sales outlets (in the fruit and vegetables department, in cheese or butcher's shops, for example), only bags that are biosourced (with a minimum plant matter content of 40% in 2018-2019, 50% in 2020 and 60% in 2025) and compostable at home are still authorized. Disposable plastic tableware (cups, glasses, etc.) will be subject to the same conditions from 2020 onwards
Also prohibited by the Biodiversity Reclamation Act are exfoliating scrubs containing plastic micro-beads (since 2018) and plastic cotton buds (from 2020). The list of banned plastic utensils (from 2020) is also extended with the EGAlim Act and the Pacte legislation to cover straws, disposable plates, cutlery, mixing sticks for drinks, meal trays, ice cream tubs, steak picks, disposable glass covers... While the European Single-Use Plastics (SUP) directive bans eight single-use products for which alternatives exist: cotton sticks, cutlery, plates, straws, EPS food containers and cups, plastic spoons and balloon sticks.

Secondary packaging, or "overwrap", often used for marketing reasons, can also be reduced. In its plea for a "New Economy of Plastics", the Ellen MacArthur Foundation also advocates, among other things, "strengthening the adoption of reusable packaging, as a priority in professional applications, but also in certain targeted applications for consumers such as plastic bags", considering that "reuse is an attractive economic opportunity for at least 20% of plastic packaging" (1).

RECYCLING: ADVANTAGES BUT ALSO LIMITS

"*100% of plastics recycled by 2025*": this is the ambitious objective set by France when it presented its climate plan in July 2017. From a circular economy perspective, it is generally considered that, where possible, material recycling is preferable to organic recycling (composting or methanization), because the former keeps materials in the economy, while with the latter, plastic breaks down into lower value elements such as water and CO_2 .

Easy in theory, but not so simple in practice. According to the Ellen MacArthur Foundation, today, worldwide, only 14% of plastic packaging is recycled and only 2% is recycled in a closed circuit, i.e. for a similar use ("bottle to bottle", for example). Indeed, 8% is recycled in an open circuit, i.e. for different applications (to make a sweater, for example)... And 4% is lost during the recycling process(1).

The recycling rate for plastics in the broad sense of the term is even lower than that for plastic packaging and well below the global recycling rates for paper (58%), iron (70%) or steel (90%). Plastics pay the price for their lightness, the main factor restricting the recycling rate.

However, the Ellen MacArthur Foundation believes that "with concerted efforts on design and post-use treatment systems, recycling would be of economic interest for 50% of non-reusable plastic packaging" - i.e. 40% of the plastic packaging currently in use. A recent study also showed that in Europe, 53% of plastic packaging could be effectively recycled with positive economic and environmental benefits(1).

But recycling also has its limits. In the case of the open circuit (or cascade recycling), for example to make a sweater, "*given that the fibres of the used sweater are charged with numerous additives, dyes, contaminants, etc., the degradation of the polymer makes them unsuitable for recycling for a similar use,*" explains Nathalie Gontard. This is more about "decycling" than "recycling"(2).

Additionally, in the case of the closed circuit, "*thermo-mechanical recycling as currently applied in bottle-to-bottle technologies involves a deterioration of the material's properties. This occurs by damaging or shortening the polymer chains of PET and by the presence of contaminants and impurities from pre-use, and the degradation of monomers and additives,* *resulting in a reduction in the material cycle. The safety of recycled plastics for food contact, by nature, requires the recovery of virgin materials that could not be achieved at a low environmental cost using current methodologies. Recycling is not the only solution to solving the problem of the plastic economy. Alternative packaging solutions must be deployed*“(7).

“*In addition, closed-circuit recycling means collecting, sorting, decontaminating and re-polymerizing a plastic that degrades during the recycling process. The logistical constraints of collection are significant, the energy consumption of the multiple stages is debatable, and the likelihood of dangerous contamination is high. Also, the maximum number of decontamination cycles is limited and the recycled plastic must be mixed with virgin material*“(2).

As a result, only PET bottle plastics - which represent less than 10% of the plastics consumed - can comply with the constraints of closed-circuit recycling and be regenerated for exactly the same use. Moreover, today in Europe, only half of PET is collected for recycling, and only 7% is recycled from bottle to bottle(7).

“*For reasons of consumer safety (risk of contamination) and for technological reasons (different properties of the virgin polymer), the closed-circuit recycling rate is extremely low; it can theoretically reach a maximum of 5% of used plastics*“, explains Nathalie Gontard.

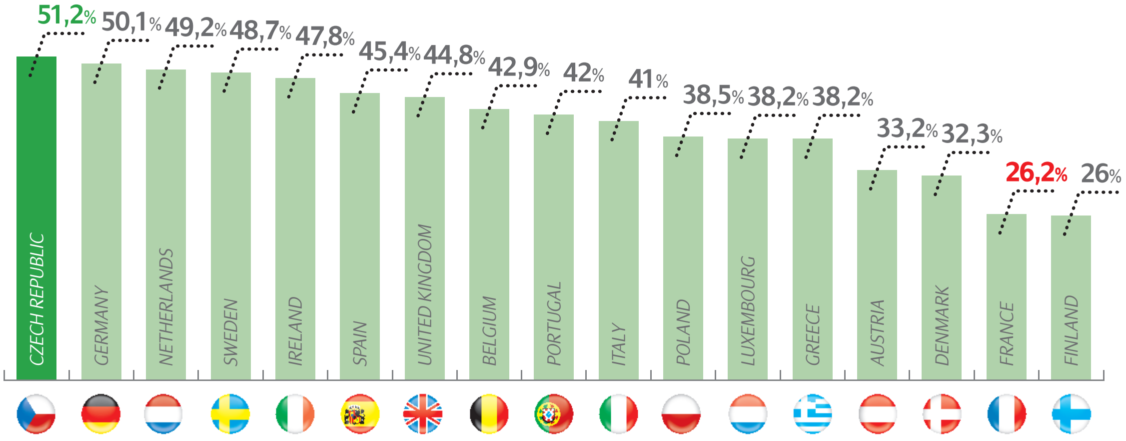
“*It should be noted here that the recycling of a material embraces the principle of a circular economy only if the circuit can be reproduced ad infinitum, which is nearly the case for glass or metal. Biodegradable materials are naturally located in the biological cycle of organic matter, which ensures their unlimited renewal (provided however that the speed of consumption remains compatible with that of production).*
Plastic recycling is therefore not a magic bullet sparing our terrestrial ecosystem from the potential damage of the waste we produce, even if it can help to slow it down in its own modest way. We should not be blinded by the mirage of 100%-recycling, which alone cannot solve the major issue of post-use management of plastic waste“(2).

RECYCLING OF PLASTIC PACKAGING IN EUROPE AND IN FRANCE

In Europe, the recycling rate for plastic packaging reached 40.8% in 2016 according to Plastics Europe's annual report, in which bottom-of-the-class France ranks 29th out of 30 countries with a recycling rate of 26.2%. The Czech Republic (51.2%) and Germany (50.1%) are the highest ranked, followed by the Netherlands (49.2%), Sweden (48.7%), Ireland (47.8%), Spain (45.4%) and the United Kingdom (44.8%). Then come, among others, Belgium (42.9%), Norway (42.4%), Italy (41.0%) or Denmark (32.3%); Finland (26.0%) is the back-marker just behind France.

In France, only plastic bottles and vials (PET and HDPE) have been recyclable to date. In 2016, the French recycling rate was 26% for all plastic packaging, reaching 55% for bottles, but only 1% for jars and trays or for films, according to figures from the Technical Committee for the Recycling of Plastic Packaging (Cotrep). The collection agency Citeo has planned to gradually extend sorting to all plastic packaging, including pots, trays and plastic films, by 2022. At the end of 2016, a quarter of French people were able to recycle all plastics, i.e. more than 15 million people compared to 3.7 million in 2014, according to Cotrep.

Levels of recycling for plastic packaging in 2016



Source: Plastic Europe

BIOSOURCED AND BIODEGRADABLE BIOPLASTICS

Despite all the actions taken to improve collection and processing infrastructure, plastic packaging spilling into the environment cannot be completely eliminated - and even with a spill rate of only 1%, about one million tonnes of plastic packaging would leave the collection system and be released into the environment each year. This is why it is essential to reduce the negative environmental impact of plastic packaging that eludes collection and treatment systems (lack of sorting or spillage in the environment)... And consequently to invest in the creation of new packaging that is environmentally friendly. Plastics that would ideally be biodegradable under natural conditions in soils and aquatic environments (seas and rivers).

“*The idea is to manufacture plastics with a resource other than oil, such as vegetable coproducts, which, at the end of their life are biodegradable, i.e. capable of decomposing naturally, without persisting for years and decades in the environment,*“ explains Stéphane Bruzaud(3). In other words, plastics that are both “biosourced“ and “biodegradable“.

In addition, using renewable raw materials helps to both preserve fossil resources and reduce carbon emissions during the life-span phase and also during the production phase. Today, the law set the minimum biosourced content for single-use plastic bags at 30% from January 1st 2017, 40% from January 1st, 2018, 50% from January 1st 2020 and 60% from January 1st 2025. However, the goal is to elaborate 100% biosoured bioplastics.

Biosourced and biodegradable bioplastics are the subject of much research and are now finding industrial applications. In particular, they represent an attractive solution for the organic recycling of bio-waste. This is the subject of the second part of this information report.

THE IMPORTANCE OF CONSUMER BEHAVIOUR AND INFORMATION

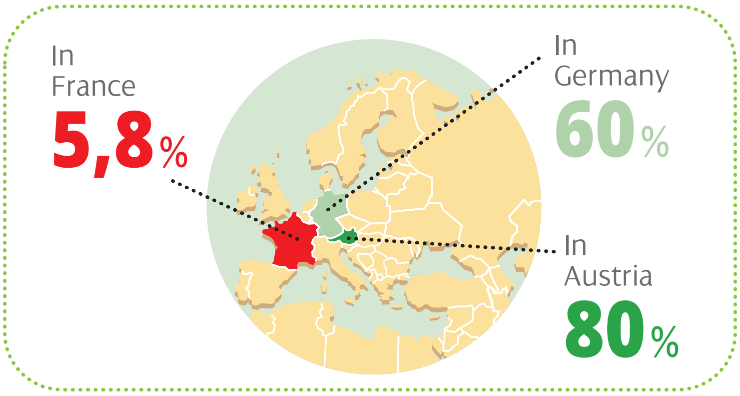
Do not throw away, always reduce, re-use, recycle, compost... As with other materials, all solutions to reduce plastic pollution are also based on the adoption of virtuous behaviours. Public awareness, education and information are therefore at the heart of all policies to better manage the end of life of plastics, and in particular to optimise at source separation and packaging collection.

This is a key element, particularly for the development of biosourced and biodegradable “bioplastics“, the most relevant end-of-life of which is domestic or industrial composting. The subject involves complex concepts, which can lead to confusion. This is a point to which we will also return in the second part.

THE NECESSITY TO ORGANIZE THE SORTING, COLLECTING AND RECOVERY PROCESSES, ESPECIALLY FOR BIO-WASTE

The success of recovery strategies, whether material (recycling), organic (composting with or without methanization), or energy-based (incineration with energy production), depends primarily on the quality of sorting and collection. Citizens must be able to have effective processes readily available.
This is particularly the case for bio-waste, which can be collected together with their biodegradable packaging, as is the case in many European cities and in some French urban areas, which unfortunately, to date, are too few in number. This will be the subject of the last chapter of this document.

Levels of bio-waste collection in France, Germany and Austria



Source: ADEME, 2013

LEVELS OF SEPARATED COLLECTION OF BIO-WASTE IN EUROPE

Country/Region	Levels of separated collection of bio-waste
FRANCE	5,8%
GERMANY	60%
AUSTRIA	80%
ITALY	41%
BELGIUM	
→ *Flanders*	67%
→ *Walloon*	50%
SPAIN	
→ *Catalonia*	50%
UNITED KINGDOM	
→ *England*	53%

Source: ADEME, 2013

BIOSOURCED AND BIODEGRADABLE BIOPLASTICS

WHAT ARE “BIOPLASTICS“? BIOPLASTICS ARE BIOSOURCED AND/OR BIODEGRADABLE

The widely used term “bioplastic“ can be confusing because it refers to materials of a different nature and different properties. The prefix “bio“ can effectively refer to either the biological origin of the plastic (“biosourced“) or its end of life (“biodegradable“) - and even sometimes to its use in the medical field (“biomedical“, “biocompatible”).

However, some bio-sourced plastics, i.e. plastics made from renewable biological resources - most often vegetable - are not biodegradable, i.e. they are not assimilable by micro-organisms (see *examples in the table below*). And conversely, some plastics from petrochemicals (and therefore not biosourced) are biodegradable.

Finally, a third category of plastics combines the two properties and are both biosourced and biodegradable, such as starch- or cellulose-based polymers, PLA (polylactic acid), PHA (polyhydroxy-alkanoates) or bio-PBS (polybutylene succinate). These are of course the most interesting products. Moreover, the French definition, published in the Official Journal of December 22, 2016, reserves the term “bioplastic“ for these materials, which are both biosourced and biodegradable.

“Bioplastics“ therefore encompass a large number of materials that are either biosourced or biodegradable, or both. This is why the term “bioplastic“ cannot stand alone and why we need to specify a plastic’s origin (biosourced or not) and end-of-life (biodegradable or not) each time the word is used.

According to Nathalie Gontard, “t*his confusion, by creating suspicion, has been prejudicial to bioplastics since the outset, especially since some manufacturers take advantage of this confusion to green wash certain materials without the environmental benefits ever being clear. A bio-PE or bio-PET, which is not biodegradable, is for example of no interest from the point of view of the plastic waste problem. If we want to decipher the real potential benefits of the many initiatives that exist in this field, we must firstly clarify the definition of the term “bio/organic“. We cannot just make do with the word “bioplastic“ otherwise we risk going off on the wrong trail*“(8).

EXAMPLES OF DIFFERENT TYPES OF PLASTIC LISTED ACCORDING TO ORIGIN (BIOSOURCED OR NOT) AND END-OF-LIFE (BIODEGRADABLE OR NOT)

Origin/End of life	Taken from biomass (biosourced)	From petrochemicals (not biosourced)
Biodegradable (in conditions of industrial compost, as a minimum)	- Starch- or cellulose-based polymers - PHA (polyhydroxy-alcanoates) - PLA (polylactic acid) - bio-PBS (polybutylene succinate)	- PCL (polycaprolactone) - PBAT (polybutylene adipate-co-terephtalate) - PBS (polybutylene succinate) - copolyesters
Non biodegradable	- bio-PE (bio-polyethylene) - bio-PET (ethylene bioterephtalate) - bio-PTT (trimethylene bio-polyterephtalate) - biosourced polyamides (PA) & polyurethanes (PUR)	- PE (polyethylene) - PET (ethylene terephtalate) - PS (polystyrene) - PP (polypropylene) - PVC (polyvinyl polychloride - PA (polyamides) and PUR (polyurethanes)

“OXO-DEGRADABLE“ OR “FRAGMENTABLE“ PLASTICS ARE NOT BIOPLASTICS AND ARE NOT BIODEGRADABLE

In recent years, plastics described as “oxo-degradable“, “fragmentable“, “oxo-fragmentable“, or even “bio-fragmentable“ or “oxo-biodegradable“ have appeared on the market. They are not “bioplastics“ because they are neither biosourced nor biodegradable.

They are actually polymers of petrochemical origin containing mineral oxidizing additives that promote their degradation into small pieces (until they become invisible to the naked eye). These plastics can effectively fragment, under certain conditions of light and heat, etc., but they are not biodegradable according to applicable standards (EN 13432 or NF T51-800). In addition, these additives might contain heavy metals whose environmental effects are currently unknown.

These plastics have, what is more, been banned by the Law on Energy Transition for Green Growth for Packaging and Bag Applications (Article 75, II): “*The production, distribution, sale, availability and use of packaging or bags made, in whole or in part, from oxo-fragmentable plastic is prohibited.*“ An oxo-fragmentable plastic is degradable but not assimilable by micro-organisms and not compostable pursuant to applicable standards for the organic recovery of plastics. For other applications, such as agricultural mulching, these fragmentable plastics are still allowed. But this should not be for long, because the new European Single-Use Plastics (SUP) directive, approved by the European Parliament on March 27, 2019, provides for a ban on oxo-degradable plastics for all uses, including agricultural mulching.

1. BIOSOURCED PLASTICS

WHAT DO WE CALL “BIOSOURCED“ PLASTICS? PLASTICS PRODUCED FROM RENEWABLE BIOLOGICAL RESOURCES

Biosourced bioplastics are manufactured, in part or in whole, from renewable biological resources, most often vegetable.

The sources of raw materials vary considerably. “*We find everything related to biomass, organic matter, particularly starches, sugars and vegetable oils*“, says Stéphane Bruzaud(9).
Starch and sugars are extracted from potatoes, sugar cane, beet, corn, wheat, rice, etc. Vegetable oils can come from sunflower, flax, soya, palm or olive trees, for example.

Natural fibres, such as cotton, jute, hemp and wood, can also be used to make bio-based plastics, as well as proteins and fats from the animal world, such as casein, whey, fat or gelatin. Plastics are manufactured from vegetable raw materials using either chemical processes (hydrolysis, dehydration, etc.) or biotechnological processes (fermentation, extraction, etc.). Some polymers, such as PHAs, are produced from plant resources by bacteria.

Some bio-based polymers have a structure identical to that of fossil-based polymers (such as PE and PET from sugar cane for example), while others have an innovative structure different to that of existing petrochemical polymers (such as PLA from starch)(10).

“*We know how to make plastics using vegetable resources,*“ says Stéphane Bruzaud. *“Today, all major forms of plastic can be reproduced with plant matter, at least at the research and development stage*“(3).

WHAT DO THE STATUTE BOOKS SAY? A MINIMUM OF 40% OF BIOSOURCED MATERIAL

The decree implementing the Energy Transition for Green Growth Act for single-use plastic bags defines “biosourced material“ as “*any material of biological origin excluding materials integrated into geological or fossilized formations*“. As for “biosourced content“, it is the “*percentage, expressed as a fraction of total carbon, of biosourced materials contained in the bag, determined according to the calculation method specified by the applicable international standard for ascertaining the biosourced carbon content of plastics*“ (ISO 16620-2 and CEN/TS 16640 standards).

The law set the minimum biosourced content for single-use plastic bags at 30% from January 1st 2017, 40% from January 1st, 2018, 50% from January 1st 2020 and 60% from January 1st 2025.

WHAT IS THE BENEFIT OF BIOSOURCED PLASTICS? REDUCED USE OF FOSSIL RESOURCES

As we have seen in the first part of this document *(see p. 6)*, even though plastics help achieve efficiency gains in terms of resource use during their use lifespan (on account of their light weight compared to other materials), their carbon footprint is quite considerable.

“*It is crucial to address the impact of greenhouse gases in production and post-use treatment,*“ says the Foundation Ellen MacArthur. Hence the interest in “*de-connecting the production of plastics from the use of fossil raw materials*“. “*The use of renewable raw materials would enable the plastic packaging sector to reduce its carbon emissions both during the lifespan phase and the production phase - thus contributing effectively to a carbon-free world,*“ stressed the foundation(1).

The use of renewable raw materials in the manufacture of plastics is therefore a solution to reduce the use of fossil fuels.

The production of biosourced plastics also offers opportunities for the recovery and development of biomass (agricultural and agricultural food co-products, waste, ligno-cellulose, etc.)(10).

HOW MUCH PRESSURE ON AGRICULTURAL LAND AND HOW MUCH COMPETITION WITH FOOD RESOURCES? VERY LITTLE COMPETITION WITH AGRICULTURAL LAND, AND ANTICIPATORY LEADS IN RESEARCH

Given that most bio-sourced plastics currently on the market use plant raw materials grown on agricultural land, there are concerns about the risk of future competition over the use of food resources.

However, these legitimate concerns about food security and pressure on agricultural land should not be overstated. This is because the production of biosourced polymers, the volumes of which are still low, currently requires very few agricultural resources.

According to data published by *European Bioplastics*, the global bioplastics production capacity was 2.11 million tonnes in 2018, representing the use of 0.81 million hectares of land(11). This represents less than 0.02% of the world’s agricultural land area (4.9 billion hectares). This 0.02% share of agricultural land used is not expected to be reached until 2023 with a projected increase in global production of bio-based plastics of 2.6 million tonnes.

A study conducted in 2010 by OWS, a Belgian laboratory specializing in the assessment of biodegradability and compostability, also concluded that if 10% of the plastics on the market were biosourced plastics, this would only engage 0.54% of Europe’s useful agricultural area. Today, however, plastics of biological origin account for only 1% of plastics.

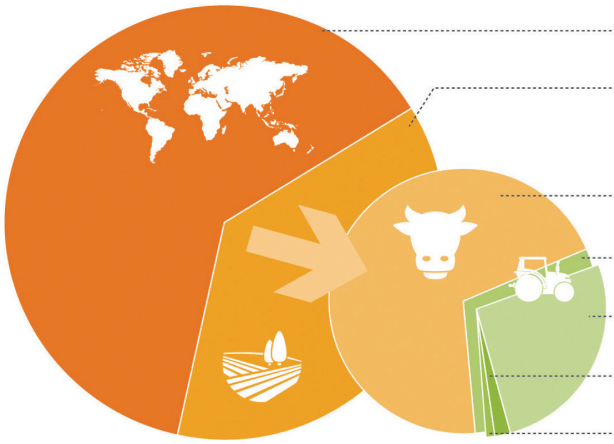
But to prevent this question from truly raising its head in the long term, research is now focusing on the production of biopolymers from diversified resources that do not compete with food crops. This includes organic waste: crop residues, agricultural food by-products, etc.

“*In our research, we are trying to make bioplastics from non-food resources and attempting to promote bio-waste,*“ explains Stéphane Bruzaud. “*These vegetable co-products will then be able to enter a new cycle of industrial production according to the famous concept of a circular economy*“(9).

“*We must be realistic: if we want to use these biosourced materials on a massive scale, we need available resources,*“ says Nathalie Gontard. “*Currently, however, food resources, or at least plants grown on agricultural land, are being used. In anticipation, research is now turning to biological resources that are not likely to pose a problem for food security, i.e. residues that are not used for either human or animal food.*“(8).

“*Diverting food resources that consume large amounts of pesticides and contribute to soil depletion would have negative effects on environmental and human health*“, says Jean-François Ghiglione. “*Eco-design must be considered taking into account the entire life cycle of products, from production to end of life, with obviously a follow-up of their environmental impact. Recycling organic waste into bio-based plastics is, in my opinion, the way forward*“.

Estimated use of land for bioplastics in 2018 and 2023



Total surface area of land
13 billion ha = 100%

Total surface area of farm land
4.9 billion ha = 38%

TOTAL SURFACE AREA OF FARM LAND

Pasture land
3.3 billion ha = 67%*

Arable land**
1.4 billion ha = 29%*

Human and animal foods*
1.24 billion = 25%*

Utilisation for the production of matter*
106 millions ha = 2%*

Bio-fuels
53 millions ha = 1%*

Bioplastics
2018:
0,81 million ha ≈ 0,016 %*
2023:
1,02 million ha ≈ 0,020 %*

*compared to the total surface area of agricultural land
** including land lying fallow (approx. 1%)

Sources: European Bioplastics (2018), FAO Stats (2014, Nova-Institute (2018), and Institute for Bioplastics and Biocomposites (2016)

2. BIODEGRADABLE AND COMPOSTABLE PLASTICS

WHAT IS BIODEGRADABILITY? A CONSENSUAL DEFINITION

As we are reminded by the ADEME (Agence de l'environnement et de la maîtrise de l'énergie), a material is said to be "biodegradable" if it can be decomposed under the action of micro-organisms (bacteria, fungi, algae, earthworms, etc.). The result is the formation of water (H_2O), carbon dioxide (CO_2) and/or methane (CH_4), and by-products (residues, new biomass) that are not toxic for the environment(12).

This consensual definition is used in at least five applicable standards (ISO, CEN), including the European and French standard NF EN 13432 as to requirements for "packaging recoverable by composting and biodegradation".

It follows from this definition that "*biodegradability is the intrinsic capacity of a material to be degraded by microbial attack, to gradually simplify its structure and eventually convert easily into water, CO_2 and/or CH_4 and a new biomass*" (12).

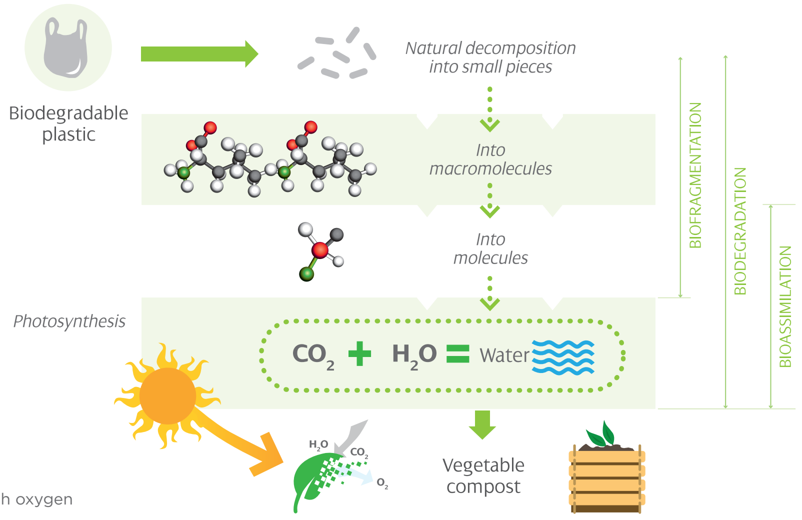
WHY IT IS NOT THAT SIMPLE? BIODEGRADATION DEPENDS ON CONDITIONS OF THE ENVIRONMENT

Biodegradation is influenced by certain parameters for the environment in which it takes place: physico-chemical (temperature, humidity, pH) and micro-biological (quantity and nature of microorganisms).

"*To have real meaning, the term "bio-degradable" must be clarified and linked not only to a duration, compatible with our human scale, but also to the conditions of biodegradation,*" emphasizes Stéphane Bruzaud. "*This is what creates the ambiguity of this term and renders the whole notion so complex… Because taking it to extremes, a plastic of non-biodegradable petrochemical origin, such as polyethylene or polystyrene, will certainly biodegrade after four centuries. Likewise, a biodegradable polymer placed at the North Pole, at -20°C and in the absence of bacteria, will biodegrade much more slowly than if it were put in industrial compost, with numerous micro-organisms, at 50 or 60°C and in the presence of humidity*"(9).

The Aerobic* Biodegradation Process

In a temperate humid environment with the presence of micro-organisms



*with oxygen

Biodegradation is in fact a succession of several phenomena, which partially overlap. First of all, they will be more physical in origin: the material will fragment, crack, particularly under the effect of shocks and sunlight. When the particle size becomes smaller, chemical phenomena will appear: for example in the case of polyesters, water will hydrolyze the ester function and cut the polymer chain at different places. Finally, when the chain sizes become even smaller (reduced molecular weight and high oxidation degree), biological degradation will come into play: microorganisms (mainly bacteria and fungi) will metabolize these chains through their enzymes, the final result being a microbial biomass production and mineralization which corresponds to the production of a mixture of water (H_2O) and carbon dioxide (CO_2) and/or methane (CH_4) (4).

«*Heat, humidity and the presence of nutrients and numerous micro-organisms promote this biodegradation process. A biodegradable plastic will always degrade much faster than a plastic that is not, but the biodegradation process will be slowed down in the environment if the right conditions of biodegradation are not met.*» emphasise Jean-François Ghiglione

This is why biodegradable plastic bags should never be left in the wild. It is also why biodegradable bioplastics are truly relevant in an end-of-life scenario through composting (domestic or industrial) or methanization.

WHAT IS COMPOSTING? OPTIMIZING AND CONTROLLING THE NATURAL BIODEGRADATION PROCESS

According to the ADEME definition, composting is an aerobic transformation process (i.e. in the presence of oxygen, unlike methanization, which is an anaerobic reaction, i.e. without oxygen) of fermentable materials under controlled conditions.

It helps obtain a stabilized fertilizing material, rich in humic compounds, called compost. It is accompanied by the release of heat and carbon dioxide(13).

It is a process widely used, especially in agricultural environments, because compost helps to improve soil quality by enhancing its structure and fertility.

Waste that can be composted is green waste, livestock manure, agricultural waste, agri-food waste, organic waste (bio-waste) from large producers and households, sewage sludge.... And biodegradable and compostable bioplastics, which can be collected and treated with bio-waste.

Composting is easily implemented, allowing local administration to minimize waste transport. According to the ADEME, local composting is therefore a simple solution to implement, being at once efficient, inexpensive and with low CO_2 emissions (no transporting of material)(13).

There are two types of composting: individual (domestic) composting, which can be carried out by individuals, and industrial composting, which is most often carried out by local authorities as part of the organic recovery of the fermentable fraction of municipal waste. In industrial composting facilities, the amount of air, humidity and temperature can be controlled, reducing composting times. And above all, the mass effect obtained under industrial composting conditions helps to naturally raise the temperature to 50 or 60°C owing to the fact that fermentation releases heat.

“*It is currently accepted that there is little point in transferring end-of-life biodegradable plastics to landfill, incineration and sorting-recovery facilities, because their specificity, namely biodegradation, would not be exploited,*“ according to the ADEME. “*This biodegradability could be advantageously exploited in the composting or methanization sectors in cases of food packaging associated with bio-waste or biodegradable bags used as containers for the selective collection of fermentable waste*“(14).

“*When integrated into an organic treatment process, biodegradable plastic waste can improve the recovery of this waste (compost quality or increased biogas production in a methanization plant),*“ the ADEME also points out. “*In particular when the biodegradable plastic waste is made up of biosourced plastics, it can improve the yield and quality of compost by degrading (improvement of the ratio of carbon-to-nitrogen content)*“(15).

COMPOSTING... A PRACTICE ON THE UP AND UP

While 25% of households reported composting their organic waste in 2008, this figure rose to 47% in 2013 according to a study by ADEME.

According to an IFOP survey carried out for the ADEME in 2015(16), a little more than half of the French population sorts its kitchen waste (leftovers from meals, vegetable peel, etc.), either by giving it to animals (17%) or by composting (39%); 44% say they put it in the same bin as other household waste, often for practical reasons (inhabitants of urban areas, in apartments, a one-person home, etc.).

We should also remember that according to INSEE, 68% of French people live in individual houses and therefore have the possibility of composting at home.

The implementation of a system for sorting bio-waste at source should be widespread in France by 2025 under the law on energy transition for green growth, and even by December 31, 2023 under the European directive 2018/851.

HOW TO TELL WHETHER PACKAGING IS BIODEGRADABLE UNDER COMPOSTING CONDITION?

BIODEGRADATION GOVERNED BY STANDARDS

According to the definition adopted by the French authorities (*Official Journal* of December 22, 2017), the adjective “biodegradable“ is defined as *“a substance or material that decomposes into various elements under the action of living organisms“*. With this precision: “the biodegradability of a substance or material is assessed, in environmental terms, according to the degree of decomposition, the time needed for this decomposition, and the effect the obtained elements have on the environment“.

Today in France, two standards govern the designation “biodegradable“ under composting condition for packaging: NF EN 13432 for biodegradability under industrial composting conditions, and NF T51-800 for biodegradability under domestic composting conditions.

Plastic packaging that complies with these standards is therefore biodegradable and can be recovered organically either by industrial composting (NF EN 13432) or domestic composting (NF T51-800), in the same way as organic waste (food waste, green waste, etc.).

For the reasons explained above, bioplastics that decompose in industrial composting plants, at a temperature of 50 to 60°C, do not necessarily decompose in garden compost.

The European and French standard NF EN 13432, relating to “packaging recoverable by composting and biodegradation“, sets out four acceptance criteria, all of which must be met for the material to be declared suitable for industrial composting.
- **Composition:** the standard establishes a maximum level of acceptable volatile solids, heavy metals and fluorine in the initial material.
- **Disintegration:** this is the ability of the product to break up under the effect of composting. The rejection threshold is 10% of the initial mass over a 2 mm sieve after 12 weeks of testing.
- **Biodegradability:** the acceptable threshold for bio-assimilation is at least 90% in total (or 90% of the maximum degradation of a reference substance) within 6 months.
- **Final compost quality and ecotoxicity:** it must not be modified by the packaging materials added to the compost and must not be dangerous for the environment. The standard requires ecotoxicological tests to be carried out on the final compost and requires performance that is 90% higher than that of the corresponding model compost.

The NF T51-800 standard, which governs suitability for domestic composting, includes the same requirements as the NF EN 13432 standard with regard to the composition of the initial material (maximum rate of volatile solids, heavy metals and fluorine), the quality of the final compost and ecotoxicity. But it adjusts the thresholds for biodegradability (more than 90% in less than 12 months) and disintegration (less than 10% over a 2 mm sieve in less than 6 months) because composting cycles are longer, particularly because of a lower temperature of biodegradation (around 25°C).

These biodegradable plastics can also be recycled in industrial environments when collection systems are in place, or in individual composters otherwise, thus offering the possibility of systematic organic recycling of plastics that comply with the NF T51-800 standard, says the ADEME(15).

HOW DO WE RECOGNIZE COMPOSTABLE PACKAGING? LABELS BASED ON STANDARDS

There are also specific labels for biodegradable materials that guarantee their biodegradability or compostability properties. Issued by certification bodies such as TÜV AUSTRIA, these conformity tags are based on existing standards, in particular NF EN 13432 and NF T51-800, and form a direct continuum.

The certification body thus delivers an independent guarantee of compliance with the standard, not only when registering the product but also as to the duration, by way of continuous controls.

For instance, the "OK compost INDUSTRIAL" label certifies the conformity of bioplastics with the European standard EN 13432 and therefore their biodegradability under industrial composting conditions. Similarly, the "OK compost HOME" label certifies the conformity of bioplastics with the French standard NF T51-800 and consequently their biodegradability under domestic composting conditions.

Three other labels, issued by the same organization, also adapt the biodegradability and disintegration criteria to different end-of-life environments for biodegradable bioplastics (soil, water, seawater): "OK biodegradable SOIL", "OK biodegradable WATER", "OK biodegradable MARINE" *(see table below)*.

The labels "compostable seedling" and "DIN-Geprüft Industrial Compostable" are present on some bioplastic products. They are equivalent to the OK compost label and certify the conformity of bioplastics with the European standard EN 13432, which certifies that products are 90% biodegradable in 6 months under industrial composting conditions.

TWO EXAMPLES OF LOGOS CERTIFYING THE COMPOSTABILITY OF A PACKAGING

ADAPTATION OF CRITERIA FOR BIODEGRADATION AND DISINTEGRATION TO CONDITIONS OF BIODEGRADATION

Condition of biodegradation	Temperature	Biodegradation (over 90 %)	Disintegration (less than 10% over 2 mm sieve)
Industrial composting	50 - 70°C	Within 6 months	Within 12 weeks
Home composting	20 - 30°C	Within 12 months	Within 6 months
Biodegradation in soil	20 - 25°C	Within 24 months	No requirement
Biodegradation in water	20 - 25°C	Within 56 days	No requirement
Marine biodegradation	20 - 25°C	Within 6 months	Within 12 months

BIODEGRADATION DEPENDS ON THE MATERIAL AND ITS MANUFACTURING PROCESS

In addition to the physico-chemical (temperature, humidity, pH) and microbiological (quantity and quality of microorganisms) parameters of the degradation medium, the biodegradation of materials is also influenced by the molecular structure and properties of the polymers that go to make up the material.

As pointed out by Jean-François Ghiglione in particular, “*it is commonly accepted that a low molecular weight of the polymer and a high oxydation degree facilitates biodegradation, by the action of enzymes. Other factors include the hydrophilic or hydrophobic nature of the material and their crystallinity that can influence the diversity of species that settle on plastic, or porosity, which can also play a role in the formation of the microbial biofilm and the diffusion of enzymes through the polymer*“.

The material’s manufacturing process (extrusion, injection, thermoforming, etc.), as well as the conditions of shaping (temperature, pressure, use of plasticizers, additives) also have an influence on biodegradation. This is because these factors will produce materials with very different characteristics in terms of both crystallinity and composition, or regarding reaction in water, resulting in different forms of biodegradation as the ADEME stresses it(12).

The thickness of the material obtained also affects the rate of biodegradation. In general, the thicker the material, the slower the degradation, especially if we consider that the degradation mechanism is all about surface erosion.

“*Additives can inhibit microbial growth even at low doses if they contain toxic elements,*“ the ADEME also reports. “*Finally, the incorporation of biodegradable fillers of low molecular weight can promote the overall biodegradation of the material, leaving the other inert components to an uncertain fate. This is the case for starch/polyethylene mixtures where the removal of the starch is at best only accompanied by a fragmentation of the remaining polyethylene*“(12).

HOW DO WE MEASURE BIODEGRADABILITY?

STUDY TESTS ON THE BIODEGRADABILITY OF POLYMERS

Methods for the measurement of biodegradability are varied and difficult to implement. They can be carried out according to two categories of tests:
- **laboratory tests (in vitro),** based on the measurement of CO_2 and/or CH_4 production, oxygen consumption or enzymatic tests, when the material is exposed to a source of microorganisms;
- **field tests (in situ)** in soils and composts. Samples are buried following a specific protocol. After a specified exposure time, visual and mass changes are recorded for each sample. In soils, conditions are often known but not controlled. In composting stations, conditions can be briefly controlled (temperature, aeration, humidity, grain size, etc.)(12).

Work conducted by the CEMAGREF has shown that in vitro degradation rates and the physico-chemical characteristics of materials are significant for predicting the fate of a given material in its environment, provided that at least one of the characteristics of climate (temperature histogram), soil (soil grain size) and duration of exposure is added(12).

WHAT ARE THE BIODEGRADABLE POLYMERS?

THE DIFFERENT TYPES OF BIODEGRADABLE PLASTICS

1. Natural polymers of vegetable or animal origin

Biodegradable plastics include first of all those derived from polymers naturally synthesized by plants, in particular polysaccharides (starch, cellulose, lignin, etc.) and oils (rape-seed, soya, sunflower, etc.), but also proteins (gluten). Some of these polymers are found in wood, paper, viscose, cellophane and all textile fibres (cotton, linen, hemp, etc.). But biopolymers are also found in animal products (collagen, gelatin, casein), which can also be used to make plastics. However, it should be remembered that some polymers of biological origin are not biodegradable, the best-known example being natural rubber..

2. Natural polymers of bacterial origins

Other polymers, such as PHAs, are produced by microorganisms through fermentation. They accumulate in the cytoplasm of certain bacteria placed in conditions of fermentation. The fermentable raw materials used are mainly sugars and starch. PHAs include several polymers, including PHB (polyhydroxybutyrate), PHBH (poly 3-hydroxybutyrate-co-3-hydroxyhexanoate) and PHBV (polyhydroxybutyratevalerate).

“*These polymers, synthesized by plants or micro-organisms, which already exist in their natural state, are biodegradable under natural conditions,*“ says Nathalie Gontard(8).

3. Biosourced synthetic polymers

These synthetic polymers are manufactured through the polycondensation (heating) of natural monomers. The best known is PLA (polylactic acid), resulting from the polymerization of lactic acid molecules. This monomer, necessary for the synthesis of PLA, is obtained by bacterial fermentation (biotechnologies) from renewable resources.

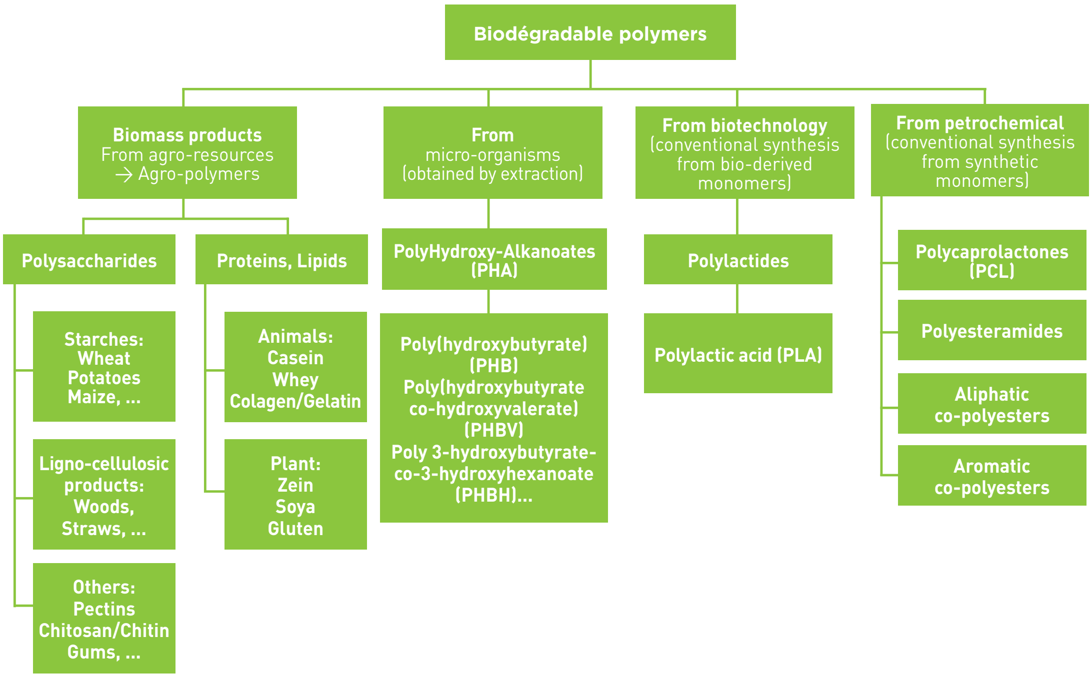
“*PLA, which is a synthetic material, is biodegradable only under industrial compost conditions. The temperature of these materials must be increased to pass through their glass transition so that biodegradation can begin,*“ stressed Nathalie Gontard(8).

4. Polymers produced from petrochemicals

There are also materials obtained from biodegradable synthetic polymers, in particular aliphatic polymers, such as PCL (polycaprolactone), PBS (polybutylene succinate), PBAT (polybutylene adipate-co-terephthalate), PGA (polyglycolic acid) or PVOH (polyvinyl acid).

Biodegradable plastics on the market can also be composite. It is therefore possible, for example, to mix starch with PCLs (not biosourced) to obtain substances with mechanical performance comparable to traditional plastics.

CLASSIFICATION OF MAIN BIODEGRADABLE PLASTICS



According to Luc Avérous, 2008

WHAT DOES SCIENCE HAVE TO SAY? WHEN RESEARCH CLOSELY STUDIES THE BIODEGRADATION OF BIOPLASTICS

Study of the biodegradation of PHAs

Stéphane Bruzaud completed one of his two theses on the biodegradation of PHAs by recreating marine environments in a laboratory (at 25°C). "*Biodegradation is quite spectacular,*" he explains, *"because after 220 days, we achieve 90% biodegradation.*" By way of comparison, under the same conditions and after the same period of time, cellulose is only 50% biodegraded and PLA only 20%(3).

"Of course, these are results obtained at 25°C in a laboratory," says Stéphane Bruzaud. At 15°C, it will of course take longer.... And if PHA is lying on the ocean bed, at 4°C, it will take even longer. But nevertheless, it gives us some idea. We are on a time scale of a few months, even a few years, and in every case an incomparable period of time compared to the time it would take for a conventional petrochemical plastic such as polyethylene or polystyrene to degrade"(9).

"For the latter, we are talking about very long periods of time, at least decades," says the scientist. "Some people talk about 100 or 200 years, or even 400 or more years, it's a bit like an auction sale!.... But we lack the perspective to really know the state of degradation of plastics after 50 years or 100 years. Because these materials were invented in the 1960s and began to be used on a massive scale only in the 1970s and 1980s. All the pollution observed today is therefore only 30 to 40 years old at most"(9).

Jean-François Ghiglione is currently leading several research programs on the biodegradability of plastics at sea. *"The marine environment is somewhat the poor relation of scientific studies on the biodegradation of plastics, certainly because biodegradation times are slower than in soils or under compost conditions. Nevertheless, the Ocean is the final receptacle for all waste and more resources must be devoted to it in order to predict its future. Today, the biodegradation times of plastics at sea are very little known, due to a lack of studies in the field. Our work has shown that biosourced plastics such as PHAs are the fastest degrading ones."*

Study of the biodegradation of PLA

*"PLA is generally classified as "*biodegradable*" plastic, but from my point of view, we should tone this down slightly and say that it is rather "biocompostable" under industrial compost conditions,"* comments Stéphane Bruzaud. *"Because it requires a sufficiently high temperature to initiate and catalyse the degradation process"(9).*

"In a study commissioned by the Ministry of Ecological Transition and Solidarity , we tested the biodegradability of PLA compared to other bio-based or conventional polymers," says Jean-François Ghiglione. *" While the biodegradation of PLA has already been demonstrated under composting conditions, we have not observed a similar phenomenon at sea, where the temperatures and diversity of bacterial species are much lower than under industrial composting conditions."*

DEGRADATION TIMES FOR PLA AS A FUNCTION OF ENVIRONMENTAL CONDITIONS

Temperature	Humidity	Time until the beginning of fermentation (in months)	Time for total degradation (in months)
4°	100 %	64	122
25°	20 %	30	58
25°	80 %	24	37
40°	80 %	5,1	10
60°	20 %	1,0	2,5
60°	80 %	0,5	2,0

Source: Stéphane Bruzaud

“PLASTISPHERE“: BACTERIA THAT DEGRADE PLASTICS

“Plastics are a new medium that is colonized by a wide variety of microorganisms,» explains Jean-François Ghiglione, CNRS Research Director, in a videoconference (4). *“The species that grow there are really specific to plastic, since they are only present in minute quantities in the water. These include cyanobacteria which, like plants, store* CO_2 *and will produce oxygen and organic matter. But there are also heterotrophic bacteria that will produce* CO_2 *and consume oxygen. The carbon footprint on these plastics distributed in all oceans remains to be determined. Finally, there are also many bacteria that specialize in oil degradation, called “hydrocarbonoclast bacteria“. They are therefore likely to degrade plastics, which are mainly composed of petroleum. But direct proof has not yet been provided.* An intense microbial life that Jean-François Ghiglione likes to call the *“*plastisphere*“.*

“It was observed by electron microscopy that these very abundant and diverse bacteria were able to make “holes“, and therefore to participate to its fragmentation (bio-deterioration),“ continues the researcher. *“When these bacteria are isolated in laboratory, we can sequence their DNA and better understand processes involved in biodegradation. Bacteria send enzymes outside their cells to attack the plastic, which is a polymer and break it into pieces (bio-fragmentation). As a result, they transform the polymer, into oligomers, then into monomers, which they will then be able to assimilate (assimilation). There are several demonstrations under laboratory conditions that show that these bacteria go so far as to completely mineralize the plastic and transform it completely into* CO_2 *(mineralization)“.*

“But we have to distinguish between biodegradation under laboratory conditions and biodegradation in the natural environment, which is slower“ Jean-François Ghiglione also points out. *“We are now trying to demonstrate this biodegradability in the natural environment (this is the subject of a thesis in our laboratory) and it is really anything but simple because they are often very long time kinetics“.*

THE ADEME HAS TESTED COMPOSTABLE BAGS AT HOME

The ADEME has conducted a study to appraise the possibility of home composting for “fruit and vegetable“ bags made from 40% bio-sourced material and labelled “compostable“ under domestic conditions. Findings should be published very soon, but the first elements were revealed at the 2018 edition of Pollutec according to the Actu-Environnement publication. The main conclusion: “*it is possible, provided that it is very thorough and that composting instructions are strictly adhered to*“(17).

According to Actu-Environnement, about ten different protocols were used: empty bags or bags filled with fermentable waste, single-layer bags or lined bags, compost regularly stirred or simply in piles, etc.(17). At the end of the experiment, a visual inspection and a count of the plastic fragments where carried out according to size.

“*The first visual inspection confirms that in some cases, the composting of the bags seems complete,*“ says Actu-Environnement. “*This is the case for composts made in twelve months and stirred regularly, in accordance with the official standard. In practice, the best way to ensure the decomposition of the bags is to put them open into the composter after filling them with bio-waste. In this case, the checks found only three plastic fragments from 0 to 1 mm. The results are still good with lined bags, but larger plastic fragments remain (thirteen pieces larger than 20 mm and 5 from 0 to 1 mm)*“(17).

On the other hand, as soon as composting strays from the ideal method, performance declines. Thus, composting empty bags is the first factor in lower performance. But it is primarily the lack of stirring that causes the problem. “*The study thus helps establish good practices to ensure the complete degradation of compostable plastic bags: it is, then, necessary to fill the bags with biodegradable waste and stir the compost*“.

WHAT ARE THE BENEFITS OF BIODEGRADABLE BIOPLASTICS?

ONE SOLUTION AMONG OTHERS TO LIMIT FUTURE PLASTIC POLLUTION

The primary benefit of biodegradable bioplastics is to limit the ecological footprint of materials. This is particularly relevant for single-use objects, which have a very short useful life (sometimes just a few minutes), but a very long life before biodegradation (at least several decades, even centuries). These are objects that are also among those most likely to end up in the oceans and have harmful effects on the environment. Packaging and plastic bags are consequently very much in the front line.

Whatever measures are introduced to limit "spillage" outside the sorting and collection system, these spills cannot be completely eliminated from the surface of the planet. And even with a spillage rate of only 1%, about one million tonnes of plastic packaging would be released into the environment each year, according to the Ellen MacArthur Foundation(1). Developing plastic packaging that is harmless to the environment and whose negative impacts are considerably reduced in the event of a spillage is therefore clearly a considerable step forward.

"*The challenge is to eliminate what nature takes decades or centuries to eliminate,*" says Stéphane Bruzaud. "*It is a question, in a way, of taking advantage of the famous concept of programmed obsolescence to design plastics whose decomposition time can be predicted*"(3).

"*Biodegradable materials are opening up new end-of-life options such as biodegradability, compostability or anaerobic digestion (methanization),*" adds Nathalie Gontard. "*Biosourced and biodegradable polymers under natural conditions (starch, PHA, etc.) are materials that guarantee, from the moment they are designed (eco-design) that they will be biodegraded as organic matter*" (8).

"*Bio-based, biodegradable and recyclable plastics are one of the solutions to fight plastic pollution,*" adds Jean-François Ghiglione. "*To this must also be added «non-toxic to the environment» as provided for by the European Chemicals Agency (ECHA). This is called eco-design, i.e. products that are designed from the outset not only for their main use but also for their reuse and their future in the environment*".

The organic recovery of bio-based and biodegradable bioplastics is therefore a solution that can be perfectly integrated, alongside recycling and reuse, into the new end-of-life plastics economy that the Ellen MacArthur Foundation, for example, is calling for.

"*But this does not mean that we have to be naive or say that biodegradable bioplastics will solve the problem of ocean pollution by plastics,*" says Stéphane Bruzaud. "*Because this is due above all to a lack of decent citizenship. First of all, it is a problem of behaviour and waste collection. And quite clearly, biodegradable bioplastics will not solve what is a behavioural problem*"(9).

"*In particular, we will need to lift the confusion in the minds of many consumers, who may be saying to themselves: 'It is a biodegradable plastic, so I can get rid of it without worrying about sorting'. Because if left in the wild, even a biodegradable bag, whose degradation time is drastically shortened compared to that of a traditional plastic bag, will not biodegrade instantly and will have ample time to produce harmful effects on the environment, in particular on birds and marine life*"(9).

TESTING THE INDUSTRIAL COMPOSTING OF PLA IN PARIS

Since September 2018, Citeo and Les Alchimistes, a Paris-based bio-waste recovery company, have been experimenting with the industrial composting of PLA (polylactic acid) in Paris using an innovative electromechanical process(18). It is an experiment aimed at testing responsible composting processes and collection methods. The objective of these tests is twofold: to certify that industrial composting meets compost quality standards, and to find a suitable collection method for this type of packaging close to the consumption basin. The project is expected to deliver its first findings in May 2019.

As a polymer produced from plant resources, PLA is biodegradable under industrial composting conditions - but not domestic composting. In addition, it is considered a “disrupter“ in PET sorting - earning it a 100% malus from Citeo for bottle applications. Hence the need to find new ways of recovery.

The electromechanical composting tested consists of three stages:
1) pre-treatment: a preliminary stage which sorts received packaging, crushes it into fine-grained plastic flakes and stirs it for three days in the composter with bio-waste to start the composting process;
2) composting: maturation in a closed container allows rapid degradation (in 6 weeks) thanks in particular to regular stirring of the compost and an aeration system allowing complete oxygenation. This type of composter can treat up to 120 kilos of food waste each day, or 25 to 35 tonnes a year depending on the frequency of filling;
3) post-composting operations: these help test and analyse the compost in its maturation phases. The objective is to label the compost (NFU 44 051 standard) in order to distribute the first compost “made in Paris“ from compostable packaging and bio-waste.

A REVIEW OF LEGISLATION GOVERNING SINGLE-USE PLASTIC PRODUCTS AND PACKAGING

▶ Energy Transition for Green Growth legislation (the LTECV Act of 2015)

> Ban on single-use checkout bags (2016)

The LTECV Act (Energy Transition for Green Growth) introduced a ban on single-use plastic bags handed out at check-outs in food and non-food shops. Since July 1, 2016, only reusable plastic bags, more than 50 microns thick, or made of materials other than plastic (paper, fabric, etc.) may be distributed at check-out, either free of charge or charged extra.

> Ban on other single-use bags (2017)

Since January 1st, 2017, this ban has also applied to other bags distributed at sales outlets (e.g. bags provided at fruit and vegetable departments, cheese shops or butcher shops). For the latter, only home-compostable biosourced bags with a minimum required plant material content that gradually increases over time (40% in 2018, 50% in 2020 and 60% in 2025), are still authorized.

The decree implementing article 75 of the LTECV Act sets out the information that must appear on these biodegradable disposable plastic bags to inform the consumer of their end-of-life management. A marking has to be affixed to these plastic bags indicating:

- that they can be used for domestic composting, detailing the references of the corresponding standard or indicating that it offers equivalent guarantees;

- that they can be sorted in a separate collection of bio-waste and should not be abandoned in the wild.

> Ban on routing films (2017)

Since January 1st, 2017, non-biodegradable and non-compostable plastic packaging, that is not home-compostable, used for sending addressed or unaddressed print media and advertising, is also prohibited.

> Ban on disposable plastic tableware (2020)

The same law also confirmed the outlawing, from 2020 onwards, of the provision of disposable plastic cups, glasses and plates for the kitchen and eating. Here again, only items that are home compostable and that consist, in whole or in part, of biosourced materials may continue to be distributed, either free or charged extra. .

▶ Law for the Reclamation of Biodiversity (2016)

> Ban on exfoliating plastic micro-beads (2018) and cotton swabs (2020)

The Biodiversity Reclamation Act prohibits the marketing of exfoliating scrubs containing plastic micro-beads (from January 1st, 2018), and plastic cotton buds (from January 1st, 2020).

▶ EGAlim Law (2018)

> Outlawing of straws, cutlery, meal trays, etc.

Act N° 2018-938 of October 30, 2018 for the balance of trade relations in the agricultural sector and healthy, sustainable and accessible food for all, known as the EGAlim Act, extends the list of prohibited plastic products (from January 1st, 2020): straws, cutlery, mixing sticks for drinks, meal trays, ice-cream tubs, salad bowls, boxes, steak picks, disposable glass covers...

The EGAlim law also prohibits the use of cooking trays and plastic water bottles in school catering. The current exceptions, namely a minimum content of biosourced content (50% in 2020 and 60% in 2025) and the ability to biodegrade in domestic composting (according to standard NF T 51-800), have been confirmed for this type of product.

Pacte Legislation (2019)

> Ban on disposable plastic tableware (2020)

Article 8 bis A of the Covenant Act (Action Plan for the Growth and Transformation of Enterprises), the text of which was adopted by the National Assembly at a new reading on March 15, 2019 after being amended by the Senate, confirms the LCETV energy transition for green growth act with regard to the prohibition *“as well as disposable kitchen tableware, with the exception of cups and glasses that are not made of expanded polystyrene, are home compostable and made up, in whole or in part, of biosourced materials*“ .

European Single-Use Plastics Directive (2019)

At the European level, the Single-Use Plastics (SUP) Directive, approved by the European Parliament on March 27, 2019, also bans eight single-use products for which there are alternatives: cotton sticks, cutlery, plates, straws, food containers and cups made of EPS, plastic spoons and balloon sticks. To date, there is no mention of any exemption for home-compostable biodegradable bioplastics.

The Directive also sets a separate collection target of 90% for plastic bottles by 2029 (77% by 2025) and the introduction of design obligations for connecting caps to bottles, as well as the target of incorporating 25% of recycled plastic into PET bottles as from 2025 and 30% into all plastic bottles as from 2030.

FOR WHICH END-USES? FIELDS OF APPLICATION FOR BIODEGRADABLE PLASTICS

The appeal of biodegradable bioplastics is particularly relevant for single-use objects. Packaging and in particular plastic bags are among the primary applications of biodegradable bioplastics: collection bags for green and organic waste, food packaging for fresh products, etc. Biodegradability, particularly when there is an organic waste treatment system, helps avoid the step of separating bags from bio-waste during collection and treatment.

Plastic tableware (cutlery, cups, etc.) and certain hygiene products (cotton swabs, exfoliating micro-beads etc.), covered by legislation, are also some of the applications that have been developed... Just like coffee capsules or golf tees.

"*In some specific applications, industrially compostable packaging could be an attractive mechanism for returning nutrients to the soil,*" says the Ellen MacArthur Foundation(1). These targeted uses include in particular bin bags for organic waste or food packaging used at events by fast food companies, canteens or other closed systems - where the risks of their being mixed with the recycled waste stream are low.

Compostable materials are also of interest for plastic packaging that cannot be reused or recycled. This category accounts for at least half of all plastic packaging and nearly 30 % of the total market(1). This is particularly the case for small-format packaging (about 10% of the market, and 35 to 50% of total quantities of packaging), such as bags, removable films, lids, straw packaging, confectionery wrappers and small jars, which often escape collection or sorting systems and do not follow a reuse or recycling path.

The same goes for "multi-material" packaging (about 13% of the market) and of course for packaging contaminated with nutrients "*in order to restore organic matter to the soil and promote the conservation of natural capital*"(1). For example, fast-food packaging made of compostable materials could be disposed of, with its left-over contents, in an organic waste bin. This would increase the volume of organic waste that can be recovered through composting or methanization. Compostable materials could also help to limit the impact of unintentional spillage into the environment.

Biodegradable materials may also provide solutions in the area of films for agricultural mulching and other products for agriculture, horticulture and forestry (string, clips, etc.). These are products that are also single-use with a short life-span, but difficult and expensive to collect in the field and then transport to recycling plants. As a result, today, many plastic objects, used in significant quantities in the agricultural sector, end up in the ground(9, 12, 14).

Stéphane Bruzaud also emphasized the importance of biodegradable bioplastics in the marine environment, such as PHAs, for all products likely to be found in the sea, such as fishing nets, fishing line, lobster pots, etc. "*We are currently working on biodegradable plastics that would be directly used for fishing applications likely to be lost at sea,*" says the researcher(9).

For Stéphane Bruzaud, everything related to the formulation of liquid ingredients (cosmetics, detergents, washing powder, etc.) is also an area of application for biodegradable bioplastics. This is because there are many polymers inside these products, which are discharged by wastewater, are not filtered by wastewater treatment plants, and permanently contaminate our seas and oceans. This concerns, for example, exfoliating micro-particles, which are now banned from sale if they are not biosourced and biodegradable(9).

For Jean-François Ghiglione, research and innovation on bio-based, biodegradable and recyclable plastics must be even more active. "*In a study commissioned by the Ministry of Ecological Transition and Solidarity , we tested different substitutes for conventional plastics to replace their use for micro-beads used as exfoliants or for cotton swabs. Biopolymers can effectively replace conventional plastics for these uses. It is now necessary to continue research into new formulations to reduce their cost and extend the range of their mechanical properties, which would make it possible to offer them more systematically as substitutes for other consumer products*" (4).

Finally, it may well be in the interests of the industrial packaging, chemical or pharmaceutical sectors, among others, to use biodegradable bioplastics.

Compostable materials are also of interest for plastic packaging that cannot be reused or recycled. This category represents at least half of the plastic packaging and nearly 30% of the total market

THE BIOPLASTICS MARKET IN A FEW FIGURES

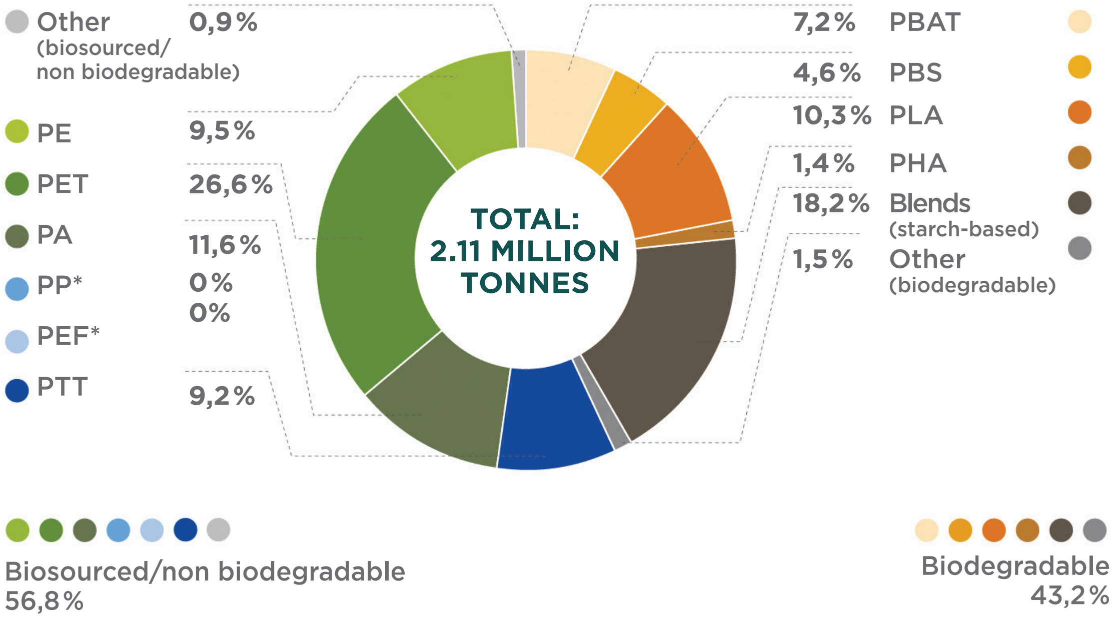
According to the European Bioplastics Association and Nova-Institut, an independent environmental research institute based in Germany, global capacities for the production of biosourced and/or biodegradable polymers were estimated at 2.11 million tonnes in 2018, representing just under 1% of all plastics produced annually. Of these, 43 % are biodegradable, which 30 % are both biosourced and biodegradable(11).

The bioplastics market is still driven by bio-based PET (non-biodegradable), which represents 27% of the market, and biodegradable starch-based blends (18%). Next, at around 10% of the market, come biosourced PA (non-biodegradable), PLA (biodegradable into industrial compost) and biosourced PE (non-biodegradable). According to the Association, PLA and PHA (biodegradable) will be the main market drivers in the coming years.

Packaging alone accounts for 65% of the outlets for these materials, ahead of textiles, consumer goods, automobiles and transportation or construction.

European Bioplastics expects global bioplastics production capacity to increase by 24% by 2023 to 2.62 million tonnes.

Global capacities for the production of bioplastics in 2018 (per type of resin)



*Biosourced PP and PEF are currently under development, marketing is scheduled for 2023.

Sources: European Bioplastics, Nova Institute (2018)

HOW DO WE CHANGE BEHAVIOURS?

THE NECESSITY TO INFORM AND EDUCATE

Today, one of the obstacles to the recovery of this packaging and these bags is the difficulty for the consumer to identify them. The problem is that any sorting error can firstly disrupt the flow of recycled plastics and secondly degrade the quality of the compost produced.

For the ADEME, "*we need to inform and educate consumers about the benefits and drawbacks of these products, the need to separate fractions of compostable waste at source, and their own responsibility when scattering them in the wild*"(14).

"*There is also a whole load of communication and education to be done, because these biodegradation and composting issues are not simple,*" says Stéphane Bruzaud. "*It is not easy for citizens and policy-makers to grasp the finer details*"(9).

"*It is therefore essential to be able firstly to easily identify biodegradable plastics, but also know whether they can be recovered in individual composters or only in industrial environments, in order to direct them to the appropriate sectors whenever they exist in a given area*", the ADEME(13) also stresses. This is the purpose of labels such as "OK Compost INDUSTRIAL" (industrially compostable) or "OK Compost HOME" (domestically compostable), based on applicable standards (NF EN 13432 and NF T5-1800 respectively).

The ADEME also feels that the use of the term "biodegradable", when it does not concern packaging (regulated for this sector by these standards), must be accompanied by details as to the extent of biodegradation over a given time or as to the time needed for complete biodegradation under given environmental conditions(15). Finally, the ADEME naturally reminds us that the designation "biodegradable" or "compostable" may under no circumstances be used as a pretext for abandoning the product in the wild.

3. A GREAT EXAMPLE OF THE CIRCULAR ECONOMY

CLOSE THE CARBON CYCLE

"*Nature's biogeochemical cycle is the most beautiful circular economy system that exists,*" says Nathalie Gontard. "*Organic matter is naturally biodegraded by microorganisms and physico-chemical processes.... And then phenomena of re-assimilation of the basic elements help produce new organic matter by photosynthesis. It is perfectly circular*"(8).

"*Nature does not produce waste that is not recycled. Long-term waste is a human invention,*" confirms Jean-François Ghiglione. "*Drawing on planet's resources, consuming and disposing of non-recyclable products is an unsustainable consumption pattern. The solution necessarily involves the circular economy, as nature has done for millennia*" (4).

"*If the bioplastic is biosourced and biodegradable, the carbon cycle is complete,*" explains Stéphane Bruzaud, "*since all the carbon in the biomass of the plant used to make the plastic is returned at the end of biodegradation. Bio-degradation will ultimately produce a mixture of carbon dioxide (CO_2) and water (H_2O)... This same mixture that is used by the photosynthesis process and will be at the origin of the growth of a new plant mass. So we are really on a closed cycle in terms of carbon*"(9).

"*When we talk about a circular economy, it is important to consider the length of a cycle, it must be compatible with human activity,*" adds Nathalie Gontard. "*This is the case of the biodegradation/photosynthesis cycle, which is completed relatively quickly*"(8).

> **"If the bioplastic is biosourced and biodegradable, the carbon cycle is closed since all the carbon in the biomass of the plant used to make the plastic is returned at the end of biodegradation"**

IN PHASE WITH THE FRENCH AND EUROPEAN ROADMAPS FOR THE CIRCULAR ECONOMY

Biodegradable and compostable bioplastics meet the challenges of the circular economy because they can be recovered by organic recycling, i.e. by composting (domestic or industrial).

The circular economy sets out to replace the linear economic model of “produce, consume, dump“ by promoting a circular model where the entire life cycle of products is fully integrated, from eco-design to waste management, including their consumption with limited waste. In other words, put more schematically, produce better, consume better and waste better.

In this perspective, the French government has adopted a roadmap for the circular economy, which includes a target of 100% recycled plastics by 2025, a 50% reduction in the amount of non-hazardous waste landfilled in 2025 compared to 2010, and the sorting and recovery of bio-waste.

In this roadmap, the government has also recognized the value of biodegradable and compostable bioplastic bags that comply with current standards for the separate collection of bio-waste. It also wishes to promote the learning of technical solutions for local composting(19).

The European Union’s Action Plan for the Circular Economy also takes on board the importance of bioplastics, considered to be “*a key component for the development of a fully sustainable and circular bio-economy*“(20). The EU has actively supported the development of these materials through ambitious collaborative research aimed at “*generalizing their adoption and supporting the transformation of the European plastics industry in the coming years*“(20).

For example, as part of the EU-funded EUROPHA project, researchers have developed 100% natural and biodegradable (PHA) bioplastics formulations for food packaging. “*These bioplastics can be disposed of with food and managed as organic waste through industrial composting and anaerobic digestion that meet EU standards*“, said the project coordinator(21).

4. DEVELOP THE RECOVERY PROCESS FOR BIO-WASTE

Even though some are also recyclable, biodegradable bioplastics are particularly relevant in an end-of-life scenario by composting (domestic or industrial) or by methanization. Their biodegradability effectively helps them integrate the organic recovery process of bio-waste.

WHAT DO WE MEAN BY BIO-WASTE?

ORGANIC WASTE FROM NATURAL RESOURCES

According to the Environmental Code, “bio-waste“ is considered to be “*any biodegradable non-hazardous garden or park waste, any non-hazardous food or kitchen waste, including waste from households, restaurants, caterers or retail stores, as well as any comparable waste from food production or food processing establishments.*“ (Article 541-8 of the Environment Code).

Bio-waste is therefore organic waste from natural plant or animal resources. For households, it consists of kitchen waste (vegetable peels and other food scraps) and green garden waste (hedge trimming, grass cuttings, dead leaves, etc.).

WHY SEPARATE BIO-WASTE FROM OTHER HOUSEHOLD WASTE?

PROMOTING ORGANIC RECYCLING

Bio-waste represents 30% of the household waste used by the French population. When this waste is not isolated at source and treated separately, it is either landfilled or incinerated.

“*This is a significant amount, and it must now be diverted away from elimination in order to create a circular economy for organic matter,*“ says the Ministry of Ecological Transition and Solidarity (22). Disposing of bio-waste by incineration or landfill, when it represents an important resource of organic matter for the soil, is indeed a waste. This is why the law for ecological transition for green growth stipulates that all individuals should have a practical solution for sorting their bio-waste at source before 2025... In order to have the capacity to compost this waste either at home or in a neighbourhood composting facility, or to transfer it to a selective bio-waste collection facility en route to an industrial composting centre.

Sorting bio-waste at source and recycling it not only reduce the environmental impact but also help to combat global warming.

Landfilling organic waste can cause pollution. As it decomposes, the bio-waste loses water that will form a juice called “leachate“. These juices may contain polluting and toxic substances that are produced from maceration with other waste (metals, mercury, etc.).

Additionally, the landfilling of bio-waste releases greenhouse gas emissions. As it settles, it causes the fermentation of bio-waste in an oxygen-free environment, a process that causes the emission of methane (CH_4) into the atmosphere. This is a gas that has a global warming power 25 times higher than CO_2. Likewise, the incineration of this waste also produces greenhouse gas (22).

The carbon footprint is also poor when unsorted organic waste is sent for incineration with other waste. Since bio-waste is composed of 60 to 90% water, incinerating it is like burning water, i.e. very energy consuming and emitting greenhouse gases during combustion. Conversely, organic recovery through composting or methanization (followed by composting of the digestate) makes it possible to return raw organic matter to the soil or transform it into a recoverable material, compost, adapted to the agronomic needs of the soil(22).

In the current context of the depletion of organic matter in soils, there is a real need for natural organic amendments as highlighted by the “4 per 1000“ initiative launched by France at COP 21. Bio-waste composts can partly offset this depletion(22).

In addition, the substitution of synthetic fertilizers with organic fertilizers is a very attractive proposition environmentally speaking. The manu-facture of synthetic fertilizers is based in particular on non-renewable mining resources that are not available in France (phosphorus and potash), and it has a considerable impact on the overall energy balance, especially nitrogen synthesis, which is highly energy-intensive(22).

Finally, the separate collection of bio-waste helps improve sorting and the collection of recyclable materials by encouraging consumers to sort their waste more efficiently. In its 2016 technical and economic study of the separate collection of bio-waste, the ADEME noted that the collection of bio-waste has a positive effect on the collection of recyclables(23).
“*The collection of bio-waste has a positive effect on the collection of recyclables,*“ writes the Agency. “*It would appear to encourage the user to sort all household and similar waste flows more efficiently. The means of communication used when setting up the separate collection of bio-waste are also an opportunity to communicate for all flows. Local authorities have confirmed that there is a knock-on effect for sorting linked to the separate collection of bio-waste*“. The example of Lorient *(see page 39)* is very much a step in this direction.

Once sorted at source, bio-waste can be recovered, particularly through composting, to allow organic matter to return to the soil:

- on a professional scale, it can be transformed into an agricultural amendment (compost) that can be used by professionals as long as it meets certain standards. Its recovery can also involve methanization, an industrial technique that helps recover the biogas (methane) generated by bio-waste and use it as an energy source, returning the digestate (methanization residue) to the soil after composting;
- at the domestic or local level, it can be transformed into soil or fertilizer used for gardening by way of a garden composter or a vermicomposte(22).

HOW DO THINGS STAND TODAY? THE COLLECTION OF BIO-WASTE IN FRANCE AND IN EUROPE

> The regulatory framework: moving towards the generalisation of sorting at source

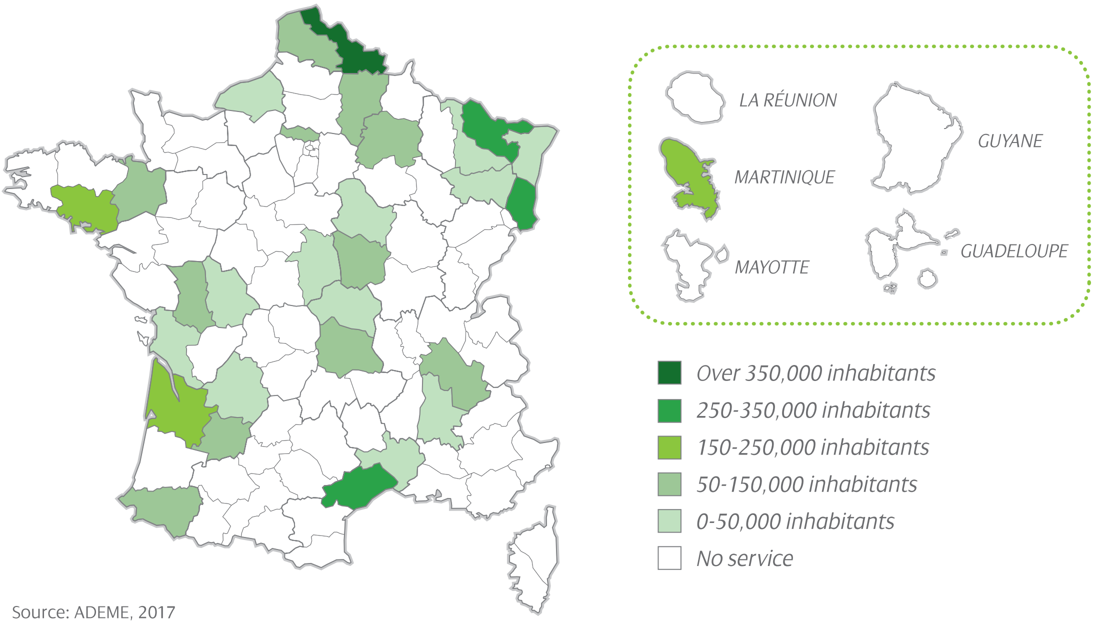
In France, the energy transition for green growth act provides for: "*the development of sorting at source of organic waste, until it becomes widespread for all waste producers before 2025, so that each citizen has at his or her disposal a solution allowing him or her not to throw bio-waste away with residual household waste, so that it is no longer eliminated, but recovered*". It is up to local authorities to produce technical solutions for local composting or separate collection of bio-waste at a speed of deployment set to suit their territory.

Since January 1st, 2012, people who produce or hold a significant quantity of bio-waste have already been required to sort it and have it recycled through the appropriate channels (such as composting or methanization). Since January 1st, 2016, all professional operators producing more than 10 tonnes of bio-waste per year, and 60 litres per year for oils, have been covered by this obligation.

At the European level, Directive 2018/851 of May 30, 2018, amending Directive 2008/98/EC on waste, requires Member States to either sort and recycle bio-waste at source, or collect it separately and not mixed with other types of waste by December 31, 2023. France will therefore need to bring forward the 2025 deadline, provided for in the law on energy transition for green growth.

Geographic split of the separate collection of bio-waste in France

Population with a separate collection of bio-waste service



Source: ADEME, 2017

> Situational analysis: France must catch up, and quickly

Today in France, according to the ADEME, the practice of sorting organic waste by private individuals is estimated at about 30% of households (25% by domestic composting and 5% by separate collection)(24).

As of January 1st, 2016, 101 local authorities had set up separate bio-waste collection facilities for households. In all, this concerns 3,282,000 inhabitants, or 5.8 % of the French population(23).

These hundred or so local authorities, spread throughout the country, in dense urban areas such as Lille, Montpellier or Rennes but also in medium-sized cities such as Niort, Lorient, Nevers, Pau, Arras or Clermont-Ferrand, are already involved in a process of sorting at source and collecting bio-waste separately. “*Feedback from the field shows that the communities that have engaged in the process are satisfied: the separate collection of food waste often has the advantage of increasing the sorting performance of other waste streams,*“ notes the Ministry of Ecological Transition and Solidarity(22).

As part of its “zero waste“ strategy, the Paris City Hall launched an experiment in June 2017 on the collection of food waste in the 2nd and 12th arrondissements, the objective being, in the light of feedback, to eventually generalize this collection for all residents of the capital. The residents of the two districts were given personally a “P’tit bac“ and two lots of fully compostable “P’tit sacs“.

By way of comparison, the proportion of the population served by separate collection of bio-waste is, according to the ADEME, between 70% and 80% in Austria, between 55% and 60% in Germany, 41% in Italy and 53% in England. In these countries, organic matter recovery rates in 2011 were 55% in Germany and Austria, 35% in Italy and 40% in the United Kingdom(25).

In many European countries (Germany, Switzerland, Austria, Italy, Spain, Belgium), the selective sorting and organic recovery of bio-waste has effectively grown considerably over the past ten years.

WHAT IS THE APPEAL OF BIODEGRADABLE PACKAGING?

BIOPLASTICS: AN ASSET TO HELP THE COLLECTION OF BIO-WASTE

Biodegradable garbage bags facilitate the collection of bio-waste, help to establish composting processes, and contribute to the achievement of quality compost.
If compostable, “fruit and vegetable“ bags can also be reused to collect bio-waste.

The city of Milan, for example, has more than tripled its food waste collection - from 28 kg to 95 kg per capita per year - when it launched compostable bags for organic waste collection(1). As the second largest city in Italy with 1.35 million inhabitants, Milan launched at source separation and door-to-door collection of household food waste in 2012, and the system will be extended to all residents in 2014. People use compostable bags to EN 13432 (industrial composting), distributed at checkouts in stores. Food waste is put into these compostable bags, which are then placed in a bio-bin. Pre-collection devices to make things more comfortable for inhabitants by reducing smells, mould and weight through loss of moisture, facilitate the sorting process in the kitchen and lower the environmental impact by reducing the quantity of juice and therefore the weight of bio-waste being transported.

“*The use of biodegradable bags can be considered for the collection of bio-waste, the latter having the advantage of limiting inconvenience (smells, insect growth, juice flows),*“ says the ADEME.
Provided, of course, that the biodegradation characteristics of the bag are suited to the composting method (local or industrial) in order to ensure proper degradation under composting conditions(15).

“*The biodegradable single-use plastic bags referred to in article 75 of the energy transition for green growth Act have the advantage of being biodegradable in both industrial and domestic composting (NF T51-800 standard) and would therefore be excellent candidates for reuse as a bag for collecting bio-waste*“, says the ADEME again(15).

“*The idea, already applied in Lorient, is to have a bio-waste bin in which we can also put biodegradable plastics, and/or to use biodegradable plastic bags in which we can put bio-waste,*“ says Stéphane Bruzaud(9).

“*The development of biodegradable packaging materials simplifies the bio-waste recovery process hugely,*“ says Nathalie Gontard. *“Ideally, there would no longer be any need to separate plastics from organic waste*“(8).

“*The main challenge of research and development today is to improve the environmental impact of the “*packaged food“ *system as a whole, not only by minimizing the negative impact of packaging material on the environment, but also by improving its positive role in reducing food losses and waste that also have a very strong impact on our environment,*“ writes Nathalie Gontard(5).

THE EXAMPLE OF LORIENT: SPECIAL COLLECTION FACILITY FOR BIO-WASTE THANKS TO BIOPLASTICS

In the Lorient urban area (25 municipalities, nearly 207,000 inhabitants), organic waste such as peelings, meal left-overs, coffee filters, tea bags, egg-shells, nuts, shellfish and other soiled cartons from the kitchen (pizza, pastries) are collected and given special treatment.

To facilitate the collection of this bio-waste across its territory, “*Lorient Agglomération*“ has set up a number of tools: dedicated 35-litre or 80-litre bins, individual composters, biosolid and biodegradable bags made of bioplastic. “*Thanks to high awareness, efficient door-to-door collection and the tools made available to citizens, including the use of bioplastic bags*“, around 8,000 tonnes of bio-waste are collected each year, “with an excellent understanding of sorting by the inhabitants of the urban area and levels of undesirable waste remaining very low (from 1 to 5% by weight)“, explains urban officials.

Bio-waste collected by tipper-trucks on specific collection days is sent to the Caudan biological waste treatment unit, located in the Lorient urban area. Bio-waste is mixed with dry ground vegetable waste to allow it to be transformed into compost in composting tunnels.

Each year, approximately 3,700 tonnes of compost are produced. Compliant with the requirements of the European “eco-label“ standard and even the organic farming standard (“AB“), the quality of the compost produced means it can be marketed to local farmers, landscape gardeners and nursery owners, and made available free of charge to municipal green spaces and local residents during events.

“*This return to the earth of plant carbon from bio-waste, like that of bioplastic bags made from a plant raw material, is a perfect illustration of loop-the-loop recovery, the founding principle of the circular economy,*“ said urban officials.

LIFT THE BARRIERS

> Lower production costs

Today, biosourced and biodegradable bioplastics are at least twice as expensive as conventional petrochemical plastics. “*This difference is geared to the cost of raw materials and their transformation, but also to research and the amortisation of investments*“, explains the ADEME(10).

However, the increase in volumes and the economies of scale they generate, as well as the improvement in manufacturing processes and the rise in oil prices, are tending to make bio-based and biodegradable bioplastics increasingly competitive with petrochemical plastics. The reduction in bioplastics production costs and the development of viable business models are consequently one of the major objectives of research and innovation.

> Pending legislative incentives

“Today, the bioplastics industry is young, materials are expensive and availability low, so customers are reluctant; it’s a bit like a snake biting its own tail,“ says Stéphane Bruzaud. *“And this is likely to continue as long as there is no incentive from the law-makers“(3).*

“The absence of international legislation to promote or even impose the use of biodegradable materials from renewable resources for certain applications is badly lacking“, noted the ADEME as early as 2006“(14).

French law provides that biosourced bags (with a minimum plant matter content of 40% since 2018, 50% in 2020 and 60% in 2025) that are compostable at home (to standard NF T 51-800) are exempt from the ban on plastic bags distributed in fresh food outlets and certain plastic utensils. This is a first step.

Today, the European Union also plans to ban eight single-use products: cutlery, plates, straws, EPS food containers and cups, cotton swabs, cocktail mixers and plastic balloon sticks. While this Directive has just been published, the possibility of using the alternative of biosourced and biodegradable plastics for these products is not currently under discussion. It would be a pity, however, to let this solution pass us by and to let this type of decision slow down research and innovation.

> Develop the bio-waste recovery process

Today, biosourced and biodegradable bioplastics are relevant in an end-of-life scenario using composting (domestic or industrial) or methanization. Their biodegradability, in particular, allows them to integrate the organic waste recovery process, which represents 1/3 of household waste thrown away by the French population.

Although the business of sorting, collection and recovering bio-waste is now highly developed in many European countries and in some French cities, it is still in its infancy in most regions of our country. “*The absence of an organised sector dedicated to the elimination and recovery of organic waste“ is one of the “chains to be unlocked*“, to quote the ADEME(14).

The objective must be to divert this significant source of bio-waste from disposal (incineration or landfill) in order to integrate it into an organic matter circular economy. This is why there is an urgent need to develop the sorting, collection and recovery of bio-waste in France.

> Better inform citizen consumers

Consumer communication and awareness of these complex concepts of biodegradability and compostability are key. As the ADEME points out, it is necessary to inform and educate consumers about the benefits and drawbacks of these products, about the need to separate fractions of compostable waste at source, and about their responsibility for their dissemination in the wild.

To avoid any confusion for users, it is of key importance that they be able to easily identify biodegradable plastics, but also to know whether they can be recovered in individual composters or only in industrial environments in order to direct them to the appropriate channels.

In conclusion, it is important to stress that research on biosourced and biodegradable materials is particularly dynamic at the present time. It has been the subject of more than 1,400 scientific publications a year over the past ten years, according to Nathalie Gontard(7). On this specific subject, research is progressing and innovation is growing right around the globe. Europe cannot afford to let these new materials slip through the net.

GLOSSARY

Bio-waste
Bio-waste is organic waste from natural plant or animal resources. For households, it consists of kitchen waste (vegetable peels and other food scraps) and green garden waste (hedge trimming, grass cuttings, dead leaves, etc.).

Biodegradable
A material is said to be "biodegradable" if it can be decomposed under the action of microorganisms (bacteria, fungi, algae, earthworms, etc.). The result is the formation of water (H_2O), carbon dioxide (CO_2) and/or methane (CH_4), and by-products (residues, new biomass) that are not toxic for the environment.
Biodegradation is influenced by the physico-chemical (temperature, humidity, pH) and microbiological parameters (quantity and nature of microorganisms) of the environment in which it occurs. To be truly meaningful, the term "biodegradable" must therefore be clarified and linked not only to a duration in time, compatible with a human scale, but also to conditions of biodegradation.

Biomass
Renewable resources consisting of agricultural and forestry resources, co-products of agro-industries and organic waste.

Bioplastic
Bioplastics are materials that are either biosourced, biodegradable or both. It is for this reason that the term "bioplastic" should never stand alone and why it is necessary to specify, each time this word is used, the plastic's origin (biosourced or not) and end of life (biodegradable or not). Moreover, the French definition, published in the Official Journal of December 22, 2016, reserves the term "bioplastic" for materials that are both biosourced and biodegradable.

Biopolymers
These are natural polymers derived from renewable resources of plants or animals. They can be directly synthesized by plants or animals such as polysaccharides (starch, cellulose, chitosan, etc.), proteins (collagen, gelatin, casein, etc.) and lignins, or synthesized from biological resources such as vegetable oils (rape, soybean, sunflower, etc.). Other biopolymers, such as PHA, are produced by microorganisms (bacteria) through fermentation from sugars and starch.

Biosourced
Biosourced materials are manufactured, in part or in whole, from renewable biological resources, most often vegetable. The sources of raw materials are very varied. We find everything related to biomass, organic matter, in particular starches, sugars and vegetable oils.

Compostable
Literally, anything that can be composted or be involved in a composting *(see below)*.
Today in France, two standards govern the designation "compostable" for packaging: NF EN 13432 for industrial compostability and NF T51800 for domestic compostability. Plastic packaging that complies with these standards can therefore be recovered organically either by industrial composting (NF EN 13432) or by domestic composting (NF T51800), in the same way as organic waste (food waste, green waste, etc.).

Composting
According to the ADEME definition, composting is an aerobic transformation process (i.e. in the presence of oxygen, unlike methanization which is an anaerobic reaction, i.e. without oxygen) of fermentable materials under controlled conditions. It helps obtain a stabilized fertilizing material, rich in humic compounds, called compost. It is accompanied by the release of heat and carbon dioxide.
It is a process widely used, especially in agricultural environments, because compost helps amend soil by improving its structure and fertility.

Circular economy
For the ADEME, the circular economy is "an economic system of exchange and production that aims to increase the efficiency of resource use and reduce our impact on the environment." The aim is to disconnect resource consumption from growth in gross domestic product (GDP) whilst ensuring that environmental impacts are lowered and well-being is enhanced.
The circular economy refers to an economic model whose objective is to produce goods and services in a sustainable way, limiting the consumption and waste of resources (raw materials, water, energy) and the production of waste. It is a question of breaking away from the linear economy model (extracting, manufacturing, consuming, dumping) in favour of a "circular" economic model where the entire life cycle of products is integrated, from eco-design through to waste management, including consumption, by limiting waste.

Methanization
Methanization (or anaerobic digestion) is the natural biological process of degrading organic matter in the absence of oxygen (anaerobic). It occurs naturally in some sediments, marshes, rice paddies, landfills, as well as in the digestive tract of some animals such as termites or ruminants. Some of the organic matter is degraded to methane, and some is used by methanogenic microorganisms for their growth. The decomposition is not complete and leaves the "digestate" (partly comparable to compost), which requires composting in order to be stabilized.
Methanization is also a technique used in "methanizers" where the process is accelerated and maintained to produce usable methane (biogas). Organic waste can thus provide energy.

Oxo-degradable
In recent years, plastics described as "oxo-degradable", "fragmentable", "oxo-fragmentable", or even "biofragmentable" or "oxo-biodegradable" have appeared on the market. These are polymers of petrochemical origin containing mineral oxidizing additives that promote their degradation into small pieces (until they become invisible to the naked eye). These plastics can fragment, under certain conditions (light, heat, etc.), but are not biodegradable according to current standards (EN 13432 or NF T51-800). In addition, these additives seem to contain heavy metals whose environmental effects are currently unknown.
These plastics have also been banned by the Energy Transition for Green Growth Act for packaging and bag applications. The new European Single-Use Plastics (SUP) directive, approved by the European Parliament on March 27, 2019, provides for the prohibition of these oxo-degradable plastics, whatever their use.

Polymer
The term polymer refers to a molecule of high molecular weight consisting of a repetitive sequence of a large number of simple molecules called monomers, which may or may not be the same. The number of monomer units constituting the macromolecule is called the degree of polymerization. Polymers are generally polymolecular, i.e. they are composed of blends of molecules of different sizes.
Sugars, starch and proteins are natural polymers synthesized by plants, animals or bacteria; these are called biopolymers. Plastics from the petrochemical industry are also polymers.

Organic recycling
Organic recycling (or recovery) refers to all modes of management and recovery of biodegradable waste (food waste, green waste, urban sludge, industrial sludge, waste from the food industry, agricultural waste, etc.). Biodegradable waste can be recycled (or recovered) through two main treatment methods: composting and methanization.

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