Jianming Yang

From Zero Waste to Material Closed Loop

The Way Towards Circular Economy

Chemical Industry Press Co., Ltd.

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Für alle, die ich liebe und die mich lieben

Foreword

A lui seul le titre de ce livre «From Zero Waste to Material Closed Loop—the Way towards Circular Economy» exprime très clairement l'immense domaine à traiter qui est tentaculaire avec des ramifications partout, dans tout l'ensemble de notre quotidien.

Le fil rouge de ce livre peut s'appuyer sur la citation d'Antoine-Laurent Lavoisier (1743–1794) : *Rien ne se perd, rien ne se crée: tout se transforme.*

Cette phrase reste très actuelle et se retrouve dans la suite du titre de ce livre «From Zero Waste to Material Closed Loop—the Way towards Circular Economy».

Les premières pollutions dues aux Hommes sont apparues lorsque ceux-ci ont accumulés de grandes quantités de déchets sur un même lieu ; c'est donc la sédentarisation (abandon du nomadisme et fixation en un lieu), il y a 11,000 ans et l'accroissement démographique que le phénomène de pollution est apparu.

Puis la révolution industrielle est le processus historique du XIX$^{\text{ème}}$ siècle qui fait basculer une société à dominante agraire et artisanale vers une société commerciale et industrielle avec—(i) l'invention de la machine à vapeur,—(ii) l'apparition des chemins de fer et—(iii) l'accroissement démographique important. En conséquence de cette industrialisation, pollution des voies navigables, pollution de l'air par les fumées des usines de fabrications et pollution des sols par les résidus industriels.

Le réchauffement climatique a commencé vers 1830 concernant l'Arctique et les océans tropicaux. Les débuts de la dépollution ont apparu vers 1980; la première voiture équipée d'un pot catalytique fut une Opel en 1985. Il s'en est suivi une prise de conscience dès cette période et qui n'a fait que croitre depuis et de jeunes scientifiques ont pris à bras le corps cet immense problème comme le Dr. Jianming Yang.

Jianming Yang, après un cursus en «Environmental Engineering» en Chine à l'ECUST, il entreprit en France, dès 2001 des études d'ingénieur en environnement à l'ENSCMu de Mulhouse et poursuit un travail de thèse dans le laboratoire «Risque et Environnement»; thèse soutenue en 2008.

Reprenons un autre proverbe écrit vers 1672 par Jean de La Fontaine (1621–1693) dans la fable «le lièvre et la tortue»: *Rien ne sert de courir, il faut partir à point*.

La question qui en découle est: Sommes-nous partis à point?

Le Dr. Jianming Yang nous explique dès la lecture de la table des matières que son approche sera scientifique pour traiter se sujet concernant la «pollution», ce qui n'est que très rarement le cas. Ce thème est plutôt traité du côté sociologique, économique en mettant l'accent sur les contraintes à venir et en culpabilisant les populations précédentes.

Ce livre est une mine d'informations sur la situation actuelle et les chemins à suivre dès maintenant. Une vaste palette de domaines sont traités comme la thermodynamique de l'ensemble de la situation, les conventions internationales existantes, les lois nationales actuelles, les standards nationaux, les divers chemins à prendre pour le traitement des polluants, la chimie verte et le «zéro déchet», le recyclage, l'économie circulaire et les certifications à faire évoluer.

Le travail réalisé par le Dr. Jianming Yang est très important; il traite en profondeur ce sujet actuel qui nous touche tous et dont les effets à long terme sont dangereux pour le bien être.

Ce livre répond aux questions que l'on se pose actuellement:

- Comment faire pour éliminer les déchets actuels?
- Comment faire pour ne plus polluer?

L'analyse scientifique des causes et des remèdes liés à la pollution est très bien traitée et bien développée par le Dr. Jianming Yang. Ce livre est très didactique ce qui permet de comprendre la situation actuelle, de pouvoir y remédier et de voir le futur, pour nos enfants et petits enfants avec espoir et conscient que ce travail de dépollution en général, qui est entrepris va nous permettre de renouer plus efficacement avec la nature.

Août, 2021

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Preface

Circular economy is a hot topic.

The definition of circular economy is complicated, and the standards vary in different countries, regions and industries. But there is a relatively general and popular definition.

Circular economy is also known as “resource cycling economy”. The economy development pattern features resource conservation and recycling, in order to stay in harmony with the environment. It emphasizes on organizing economic activities in a feedback process of “resources-product-renewable resources”. Low exaction, high utilization and low discharge are the key. All materials and energy are reasonably and sustainably used in this ongoing cycle, keeping the impact of economic activities on environment to the smallest possible extent.

The way to a circular economy is also different from country to country, region to region or industry to industry. But, it always has to work for one’s development. Many researches on this topic emerge in recent years, together with lots of theoretical books and practical thesis in China and overseas.

This book will start with the end of traditional economy—the waste. It goes from the compliance management of waste through material closed-loop material, threaded by waste diversion and utilization. This book will expound on the current inflection point of circular economy, explaining the opportunities and challenges of zero waste in different industries, and at the same time, points out a feasible roadmap to zero waste.

The waste discussed in this book, for the purpose of theoretical studies, refers to a broad sense of waste including solid, liquid and gas, etc.; but when dealing with various regulations and standards, unless otherwise specified, it only refers to a narrow sense of waste mainly in solid, as a common practice. This is in correspondence with the waste in material closed loop. Due to logistics challenge, liquid and gas are rarely discussed in material closed loop.

Moreover, this book uses entropy principle in traditional thermodynamics, from the perspective of mass balance and energy consumption, to analyse the most possible theoretical result of zero waste and material closed-loop strategy and development, as well as their influence on present society.

Last but not least, zero waste-related philosophy and ethics have also been discussed a little in this book.

Shanghai, China Jianming Yang

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Chapter 1
A Brief History on Waste

Strictly speaking, the universe is a circular universe. Ever since the big bang, matter and energy emerges and disappears, transforming into each other. There are three popularly believed destinations of a stellar life in astronomy: for stars with relatively small masses, most of the material will return to cosmic space through red giant explosions or white dwarf explosions; for stars with relatively large masses, most of the material will return to cosmic space through supernova explosions (leaving behind neutron stars); for stars with extremely large masses, most of the material will go through the special phase of black holes, and, according to the speculations and predictions of Hawking's theory, will probably eventually return to cosmic space in the form of radiation or explosions.

Thus, there's no so-called waste in the universe—all materials in the universe are perfectly operating in a closed loop.

So, do we have waste on the Earth? Objectively speaking, no! From the birth of the Earth 4.6 billion years ago, every substance exists and transforms into different elements of different forms. All matter works in the same perfect closed loop in the atmosphere, the hydrosphere and the surface of the Earth's crust, like the nitrogen cycle in the early anaerobic era and the carbon cycle, which manifests itself in the form of life after aerobic times, although the Earth's mantle also occasionally replenish materials by volcanic eruptions from deep underground to the surface of the Earth.

Waste is actually a very objective matter and at the same time, a very subjective concept—the term "waste" is born with human consciousness, not produced by industrial civilization—industrial civilization only reinforced this consciousness.

Like all living species that exist and have existed on the Earth, human beings in early primitive societies sought carbon sources from nature to provide material and energy for their own reproduction. Even if there were fruit peels and crumbs, they were purely natural and not considered as waste. Humans, unlike animals, later invented working tools. And a tool must have a service life. Though discarded at the end of their service life, those tools still would return perfectly to the environment thanks to their natural nature (stone or wood until early pottery). Then the problem begins—the Earth does not consider these discarded tools as waste, it is the humans

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themselves regard the worn-out tools as "waste" and throw them away! But of course, the impact of these discarded tools on the natural environment should be none, no matter how one thinks of it.

However, men generated more ideas along the way from slave society through feudal society. Production and consumption began to differ by district or social stratum. This difference, in turn, led directly to the creation of surplus goods and surplus food. Part of the population started to own what they can't all use or use out. They then discarded what they own for the sake of having new ones. Food was not scarce to them anymore. Instead, there began to be food leftovers. But fortunately, almost all the man-made goods or food, though discarded or left over, were either natural or biodegradable, due to limited technology. Coupled with the fact that there were a rather smaller population worldwide at that time, the nature was able to digest all the human stuff without much effort. Waste, for humans at that time, was just a vague idea.

But civilization changed it all. Industrial civilization arrived as the definite product of any higher species' development. The First Industrial Revolution made it possible for humans to be truly aware of waste for two reasons. Firstly, the fast development of production technology gave men the opportunity to make lots of materials that would by no means be created naturally. Such materials, to meet the requirement of men's living and production (like durability), were made not to be easily decomposed or digested by nature in a short time. Secondly, production and consumption (supply and demand) were normally not synchronized or balanced. Newly created substance may be over demand in a region or during a certain time. The surplus ones would, as a result, be stored and accumulated in human society and in nature.

Unfortunately, it didn't occur to men at the early stage of industrial civilization that whether nature could take in and digest all the surplus materials, nor did it come to their mind what problems the accumulated materials would cause to nature, until the beginning of the Second Industrial Revolution.

The Second Industrial Revolution, has basically led humans to an electrical age, while also brought chemical industry into history. Chemical industry was built to create substances that do not exist in nature, in order to meet the growing needs of human society. The rapid development of chemical industry has resulted in the creation of a lot of new substances and the intermediate substance (e.g. catalyst) needed for industrial production. When humans used these industrial products and discarded them after they served their purpose, it became also clear that nature didn't seem to grow any likings for those artificial materials.

As a matter of fact, the nature can absorb them. It just takes time, and the time could be exponential of geological time scale in order to break down certain man-made material like polyvinyl chloride plastic. Besides, even if a few man-made substances could be degraded by nature in a short time, the cost would be environmental pollution in a given time and space, for instance the soluble organics discharged into water.

When industrial products, especially chemical industry products, became either hard to return to nature by degradation, or brought along with them local pollution, the concept of waste finally settled in human cognition—humans created them, but humans didn't like them! A new academic discipline thus emerged in the middle of twentieth century—environmental science. In this new discipline, science and technology related to waste treatment and disposal became a significant part.

In the past decades, humans have made enormous progress in waste treatment and disposal, led by the effort of worldwide environmental scientists and engineers. Most of the commonly seen waste can be treated and disposed in economical and non-hazardous ways.

We are facing new challenges now, however. The waste produced by human beings can't be 100% non-hazardous due to economic and geographical reasons. And a challenge even greater is that the scientific researches and engineering projects can't keep pace with the growth of waste produced, in terms of variety and volume. Waste will eventually and gradually be accumulated on the Earth, at its own pace.

In twenty-first century, humans finally come to the conclusion that it won't work like this. The ultimate or the fundamental solution to this problem, should not just be to deal with how to treat and dispose of waste. Rather, the concept of waste should be removed from our mind again—because it doesn't exist in the first place.

There are two ways to completely remove the concept of waste. One, by maximizing the utilization of materials so that the production process doesn't generate industrial waste (pre-consumer waste). Two, by reintroducing into raw materials the industrial waste which is unavoidable at current stage and the products at the end of their normal life cycle (post-consumer waste).

These two ways are indeed the theory of zero waste and material closed loop, which will be discussed in this book.

Chapter 2
Waste Morphology and Types

Simply speaking, any material that is produced by human activities but is no longer of use value to the owner thus neglected is called waste. In other words, anything that is produced during the course of construction, production, daily activities and other social activities of human beings, loses most or all of the use value within certain period of time and space, and can't be recycled or reused is waste.

Wastes are in essence substances; therefore, their forms and types shouldn't be different from those of other substances in nature. A substance in nature has three basic forms—solid, liquid and gas, though under certain conditions there can also be ionic and neutron states. As we are only discussing waste in the normal sense, we will adopt what is academically agreed of the waste forms, respectively gas, liquid and solid. They are also known as the "three kinds of waste", off-gas, effluent and rubbish.

2.1 Off-Gas

Off-gas has not been regarded as waste for a very long time, fundamentally because it can't be seen or touched, except for a few ones with color and odor. Yet off-gas has long played a part in history and has a huge impact on the fate of mankind.

There are two sources of off-gas. One is biological activities in nature, and the other is industrial emissions by human. Natural activities like volcanic eruptions will not be discussed in this book, simply because volcanic eruption is not caused by human activities and is in no ways controlled by human being. At the same time, volcanic eruption is part of the matter and energy cycle of the Earth. Gases emitted by volcano directly become part of the atmosphere and start circulation. They are not the off-gas we talk about here.

Then why the emission of biological activities in nature—mainly greenhouse gases like carbon dioxide and methane should be included in off-gas? Before there were ever human-kind on the Earth, carbon dioxide in nature was basically produced

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by the respiration of animals, and methane generated as a result of ruminant animals' digestion and metabolism (such as excrement). But since the advent of men, crop farming and livestock farming came into being, the domestic animals had greatly satisfied men's needs for meat and milk, whether they lived on natural grass or fed on planted fodder. Therefore, humans enlarged the livestock farming and protected the animals from carnivores. Those domestic animals multiplied, which in turn sped up the conversion of carbon in the plants into carbon dioxide and methane which then emitting into atmosphere. That's why we say, whether it's human beings or ruminants producing carbon dioxide, the living organism in nature is a source of off-gas (greenhouse gases).

The off-gas emitted by human industrial activities are more complicated in terms of types. Generally speaking, it refers to the gases with pollutants emitted into the air during the plant's fuel combustion and production process in the plant itself. These gases could be, in terms of substance types, carbon dioxide, carbon disulfide, hydrogen sulfide, fluoride, nitrogen oxides, chlorine, hydrogen chloride, carbon monoxide, sulfuric acid (fog), lead and mercury, beryllide, soot and production dust, etc. In terms of substance forms, the industrial off-gas can be divided into particulate exhaust and gaseous exhaust.

Particulate exhaust—these pollutants are mainly the polluting soot from the manufacturing process. It could come from cement plants, heavy industrial material manufacturing plants, heavy metal manufacturing plants and chemical plants. During their production, the raw materials need to be processed or purified, and the residue cannot be completely burned or decomposed, so they exist in the form of smoke and soot. If the plant facilities are not efficient enough to capture the smoke and soot particles, it will cause air pollution in the process of emission to the atmosphere.

Gaseous exhaust—these pollutants tend to be the most hazardous among all the industrial off-gases. The main gaseous exhaust currently includes nitrogenous off-gas, sulfuric off-gas and hydrocarbon off-gas.

Nitrogenous off-gas will damage the air's component and change the atmosphere's composition. Particularly, petroleum products contain large amount of nitride in it, while the combustion of petroleum products takes a significant part in industrial production, which means the off-gas will contain lots of nitrogen oxide. If emitted into air directly, it will increase the nitrogen oxide content, affecting the atmospheric circulation.

Sulfuric off-gas will cause damage to human life and environment directly. This is because it can combine with water in the air to form acid (sulfuric) rain. And acid rain will hurt plants, buildings and human health, especially human's respiratory system. Meanwhile, acid rain in earth and water will cause secondary pollution.

Hydrocarbon off-gases, collectively known as hydrocarbons, are organic compounds consisting mainly of carbon and hydrogen atoms. The diffusion of such gases into the atmosphere will cause damage to the ozone layer, which can lead to a series of problems in the long run. The destruction of the ozone layer increases the exposure to ultraviolet light, which can cause skin injury and health problems. Changes in ultraviolet radiation can also affect the ecosystem and the climate.

2.2 Effluent

Effluent can be classified into two kinds: organic and inorganic, which respectively refer to waste organics (commonly known as waste oil) and waste water (commonly known as sewage). Relatively speaking, mankind has the longest history, the most pains and the most experience in the treatment of waste water. But the treatment of waste organics only started within the last hundred years.

Looking back at human history, there was no man-made organics before industrial age, thus there was no waste organics (as used natural organic liquid can be easily degraded). When chemical industry bloomed, men found the organics can be widely applied as solvent, lubricant and others. On the other hand, the liquid organics are basically auxiliary in production and won't be made into the final product. That means they will be discharged as waste organics after they finish the auxiliary mission in the production process. Residual loss in containers during the production, storage and transportation process is another substantial source of waste organics.

Waste water usually refers to domestic sewage, industrial waste water and primary rainwater polluted by atmosphere or the surface.

Domestic sewage is discharged from residents' daily lives, mainly from residential buildings and public buildings, such as residences, institutions, schools, hospitals, shops, public places and toilets of industrial plants. The pollutants in domestic effluent are mainly organic substances (such as proteins, carbohydrates, fats, urea, ammonia, etc.) and a large number of pathogenic microorganisms (such as parasite eggs and intestinal infectious viruses). The organic substances living in domestic sewage are extremely unstable, easy to decompose and stink. Germs and pathogens can live on those organic substances in the domestic effluent and multiply rapidly, causing contagious diseases to spread among people.

Industrial waste water includes production waste water, manufacturing waste water and cooling water, referring to the waste water and other waste liquids produced during industrial production, which contain industrial raw materials, intermediate products, by-products and pollutants formed during the production process that are lost with the water. There are various types of industrial waste water with complex composition. To name just a few, mercury contained in electrolysis industrial waste water, lead and cadmium contained in heavy metal smelting industrial waste water, cyanide and chromium contained in electroplating industrial waste water, phenol contained in petrol refining industrial waste water and different pesticides in pesticide manufacturing industrial waste water.

Domestic sewage or industrial waste water in nature is the aqueous solution or hydrosol of various waste substances. It is human beings proactively using water as the vehicle to transport waste substances out of their residential and production area, and discharging the waste water directly or indirectly (through water treatment facilities) into natural waters. However, the polluting primary rainwater is formed by the pollutants on surface or atmosphere passively being taken into the aqueous solution or hydrosol by the effect of rain. It directly flows into (normally without any treatment) natural waters via surface runoff. Compared to domestic sewage and industrial waste water, primary rainwater, though containing limited volume of pollutants, can still exert hazardous effect to environment due to lack of effective treatment.

2.3 Rubbish

Rubbish is commonly known as waste solid, which as the name implies, refers to the solid or semi-solid waste produced by human in production, consumption, living and other activities, or more popularly called "garbage". Waste solid mainly includes ore particles, slag, sludge, discarded products, broken utensils, defective products, animal carcasses, spoiled food, human and animal waste, etc. In some countries, highly concentrated liquids such as waste acid, waste alkali, waste oil, and waste organic solvents are also classified as waste solid.

Waste solid is basically classified by its source, generally as domestic waste solid, industrial waste solid and agricultural waste solid. Domestic waste solid mainly refers to the solid waste produced in the process of urban livelihood or activities servicing urban livelihood, also known as urban domestic garbage. It includes the residents' living garbage, medical garbage, commercial garbage, construction garbage (spoil), etc. Industrial waste solid refers to the solid waste produced in the course of production, storage, logistic activities, also known as industrial rubbish or industrial garbage, including defective products, scraps, sludge and tailings. Agricultural waste solid is also called agricultural garbage, referring to the solid waste produced by agricultural actives (including scientific researches), including the waste produced by five agricultural industries, namely farming, forestry, livestock, fishery and agricultural sideline.

The influence of waste solid on nature and human beings is undoubtedly long-lasting and far-reaching, though only until recent decades it has been recognized as a problem.

Chapter 3
Thermodynamic Principle for Waste

In the previous chapter, the historical background and social conditions of waste generation are briefly described. From a more scientific point of view, we will discuss the thermodynamic principle of waste generation.

Thermodynamics is a subject that studies the thermal properties and laws of matter from the macroscopic aspect. Thermodynamics mainly studies the thermal properties of matter from the energy conversion. It points out the macroscopic law of energy conversion from one form to another, and summarizes the macroscopic phenomena of matter. Thermodynamics does not focus on the microstructure of a matter composed by a large number of micro particles, but only on the thermal phenomena and the fundamental laws that must be followed by the change and evolution of the system as a whole.

The first step to describe the state of a thermodynamic system, is to identify the scope of system. Thermodynamics defines systems into the following three categories: open system—there is energy and matter transfer between the system and the environment; closed system—there is only energy transfer and no matter transfer between the system and the environment; isolated system—there is neither energy transfer nor matter transfer between the system and the environment.

Since waste is mainly generated in the area of human activities on the Earth's surface, when we use thermodynamic principles to study waste diversion, we first define this area of human activity as a system. It is obvious that the biosphere in which human activities take place—the bottom of the atmosphere, most of the hydrosphere and the surface of the lithosphere—is an open system, since it not only transfers energy from solar radiation, but also transfers matter with the atmosphere, hydrosphere and lithosphere.

At present, the biosphere system of human activities on the Earth is in a thermodynamic stable state for a relatively short period (non-geological age). We can use entropy, one of the three basic state functions of thermodynamics, to analyze the evolution trend of the system.

Let's go back and look at the evolution of life. Biosphere system has already been in a relatively stable thermodynamic state before the emergence of life. Due

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to various uncertainties, the probability of inorganic molecules forming complex organic macromolecules by chance through various chemical reactions is very small. That is, the probability of occurrence is very low. According to the mathematical interpretation of the second law of thermodynamics, a system with a low incidence of a particular event has a higher entropy value. However, as solar radiation continues to energize this system, the entropy of the system decreases as it becomes ordered according to the physicochemical interpretation of the second law of thermodynamics. At first, it is only a small quantitative change, which may be a slight shift of chemical reaction equilibrium of water vapor, ammonia and other substances. But quantitative change leads to qualitative change. After amino acids are synthesized under the condition of lightning, an accidental phenomenon in the atmosphere, the initial elements of life appear, and the entropy decreasing is also accelerated. From amino acids to organic macromolecules to primitive single-cell life, a "frightening" property emerged, that is, a class of matter with DNA and RNA that could replicate itself. The significance of self-replication is that the cell can autonomously absorb and metabolize small molecules free from the external environment to obtain its own life continuity—to make order out of disorder. Life, at its very beginning, knows how to use external matters and energy to reduce entropy, the higher the degree of its evolution, the faster the rate of entropy reduction.

Humans, the highest level of living things on the Earth, appeared. Their wisdom to reproduce increases greatly, bringing about more significant entropy reduction to biosphere. But more entropy reduction means increased need of matters and energy. The amount of minerals that can be easily mined and processed every year is limited and the energy that solar radiation brings to biosphere in unit time is relatively constant. As a result, not only the surface mining is getting deeper, but a large number of continental shelf and seabed minerals are exploited; the fossil energy stored from the solar radiation of geological age is developed and used, together with the development of micro-scale thermonuclear. Furthermore, renewable energy such as solar energy and wind energy also come into sight of the human kind.

One of the results from humans reforming biosphere using matters and energy is that the system becomes highly organized thanks to the continuous entropy reduction, and the probability of elements returning to nature is greatly reduced. In other words, matters become more indecomposable, or the chances of natural degradation of man-made matters is getting much lower. As we mentioned earlier, industrial civilization will produce surplus materials, and those non-biodegradable surplus materials are the thermodynamic results of waste generated by entropy reduction of biosphere system!

By the way, does this entropy reduction have an end? Intelligent life can only reduce entropy to meet its various desires, so the human demand for matter and energy is endless. We all know that the minerals and energy on the Earth will be exhausted sooner or later. When the day comes, the mineral resources are completely exhausted and renewable energy can't meet the huge demand of human beings, the entropy reduction of the Earth's biosphere system will naturally end. In other words, the entropy reduction of biosphere system will reach a theoretical limit.

What does the end of entropy reduction of the Earth's biosphere system mean? First of all, the smaller the entropy of the system, the more inevitability of the things in the system, and biodiversity will no longer exist. Furthermore, the time and space available for human survival are becoming more and more limited. In other words, human beings will not have too many choices and can only survive as simple as machines. Secondly, the universe is an isolated system, and it evolves in the direction of entropy increase. When a micro system in the universe goes against its way and keeps decreasing entropy, there will be a huge entropy difference around the system. According to the entropy flow theory of I. Prigogine, a Belgian scientist, the Earth biosphere system is a dissipative structure, which relies on the constant supply of matter and energy from the surroundings. That is to say, through the exchange of matter and energy, the Earth biosphere system can obtain negative entropy from the surrounding (giving entropy to the surroundings) so that it can be maintained and developed. Once the system can't gain constant and stable negative entropy from the surroundings, it tends to stagnate and die, and eventually becomes a disordered ruin, which we can call it entropy collapse.

Even for the dissipative structure, there's another problem in front of us. The dissipative structure must release the waste generated from the inside while receiving matter and energy from the outside. However, it is absolutely impossible for human beings to remove all wastes from the Earth's biosphere system on a large scale, which means that wastes will accumulate in the system. This accumulation process will further accelerate the evolution of dissipative structure, and the process of entropy collapse will come earlier than in theory.

If it is a social challenge to produce less waste, while it is a scientific challenge to divert waste as much as possible. There are many kinds of waste diversion technologies, but the goal is basically to decompose the waste into primary raw materials for human production, or to use the waste as energy directly or indirectly. The first scenario is the material recycling and material closed loop which we will discuss in detail later. We think that the partial replacement of the virgin mineral mining can effectively reduce the dependence on the external negative entropy, and also can partially inhibit the evolution process of the dissipative structure. The second scenario is more complex. On the one hand, as energy, waste can reduce the demand for external energy; on the other hand, it will inevitably continue to produce waste (whether residue or off-gas), and cannot be discharged from the system, which still needs external negative entropy. Whether the positive and negative effects can be offset depends on the waste composition and energy efficiency. In short, there is great uncertainty.

Therefore, since the evolution of higher life inevitably leads to the emergence of waste, only generating less waste and diverting waste as much as possible to partially replace the required external matters, the Earth biosphere system can maintain thermodynamic stability in a relatively long period of time (but not geological age), and various biological forms, including human society, can also have a sustainable development.

Of course, if human evolution can transcend the geological age and jump out of the constraints of the Earth, making use of the matter and energy of the solar system and even the whole universe, or can enter Planck scale to continue to reform our biosphere system with the matter and energy of the quantum world, it will be a different story, as it is not the simple space and time scope of the Earth biosphere system that we defined in the first place.

Chapter 4
Mass Balance and Unorganized Emission

With the understanding of the historical and social causes of waste generation, and the discussion of the thermodynamic principle of waste generation in mind, let's re-focus on human industrial civilization and see the actual situation of waste generation.

From the previous chapter on the morphology and types of waste, we can see that in fact, the waste can be simply divided into two categories: pre-consumer (or post-industry) waste and post-consumer waste. If the development of human industrial civilization makes it difficult to reduce or eliminate its own post-consumer waste, it's still hopeful to reduce (completely elimination is almost impossible) the generation of pre-consumer waste through process improvement. In fact, we should firstly talk about mass balance, whether the waste is pre-consumer or post-consumer.

The direct application of mass balance in environmental management is to calculate the unorganized emission of pollutants through the amount of organized emission of pollutants. This calculation has great significance for zero waste in industry and for environmental authority enforcement.

4.1 Mass Balance

We are all familiar with the law of mass conservation. The law of mass conservation means that the change of the mass of a system is always equal to the difference between the input and output masses of the system. The law of mass conservation is one of the fundamental laws in nature. It shows that mass will neither be created nor destroyed, but will only be transferred from one substance to another, and the total amount remains unchanged.

Mass balance is actually an industrial application of mass conservation. In a given space and time of production or consumption, the amount of material entering the system should be equal to the amount of material leaving the system. For the production system, if the input is greater than the output, the products cannot be sold, so the inventory will increase, resulting in the overstock of products; if the output

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