# Turning Trash Into Treasure
# —A Comparative Study of E-Waste Recycling in China and the U.S. Through Systems Thinking

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## Part I INTRODUCTION

### 1.1 Background

Electronic waste, or e-waste, contains toxic substances such as lead, mercury, arsenic and cadmium. Once in landfill, these toxic materials seep out into the environment, contaminating land, water and the air. Burning and dismantling e-waste also causes pollution of air, water and soil at recycling facilities and surrounding communities. Workers without proper protection at scrap yards are exposed to dangerous toxins. The spirit of NIMBYs—Not In My Back Yard—is prevalent in the developed countries, especially the United States and the EU countries. Looking back history, they have dumped abroad what their people do not want. Due to relaxed regulation and governance from the importing countries, mostly poor countries in Africa and Asia, e-waste from the rich world is exported in the name of "recycling" by ship containers and trucks to faraway destinations (Figure 1). It is not uncommon that foreign e-waste is smuggled into the developing countries mislabeled as scrap, or plastic. A report released by the United Nations Environment Programme (UNEP) found that up to 90% of the world's electronic waste, worth nearly US $19 billion, is illegally traded or dumped each year (UNEP, 2015).


*Figure 1. Flow of e-waste exports. Retrieved from [the Basel Action Network](#).*

China used to be the world's largest importer of plastic waste and hard-to-recycle processed plastics for other countries. The world's factory accepted two-thirds of global plastic waste as recently as 2016 (Crawford and Warren, 2020). Nevertheless, since 2017, China has said no to "foreign trash" which ended its long-standing record as the world's biggest junkyard (Figure 2). China's ban on solid waste imports has "upended the politics of plastic" as Bloomberg Green, a climate


*Figure 2. China has said no to foreign trash. Courtesy of [Chinese media](#).*

change website, puts it (Crawford and Warren, 2020). From flat screen TVs to smartphones, the electronic industry is one of the world's largest and fastest-growing industries. As rapid technology advances, so is the speed of our electrical and electronic goods for renewal and upgrades. In the advent of the next generation of lightning-fast 5G networks, the stream of electronic discards is expected to turn into a toxic deluge.

According to the Global E-Waste Monitor 2020, a record 53.6 million metric tonnes (Mt) of e-waste—discarded products with a battery or plug such as computers and mobile phones—is reported generated worldwide in 2019, up 9.2 Mt in five years (Forti et.al., 2020). E-waste has become "unsustainable" as the UN-led report described. China, with 10.1 million tons, was the world's biggest contributor to e-waste, and the United States was second with 6.9 million tons (Forti et.al., 2020). However, at 21 kg per capita, the United States generated three times more e-waste per person than China (7.2 kg per capita) last year. As the two world's largest economies are in the heat of a tech cold war, the United States and China are likely to accelerate the pace of electronic discards.

On the regulatory front, the United States is the only nation in the developed world that has signed but not yet ratified the 1989 Basel Convention on the Transboundary Movement of Hazardous Waste (Basel Convention, n.d.). Although there is local legislation that varies by states, there is no U.S. federal law that requires the recycling of e-waste or includes a ban on foreign export. In December 2019, the Basel Ban Amendment, adopted by the parties to the Basel Convention, became international law. The amendment that prohibits all hazardous waste exports from developed to developing countries will push pressure on tightening national e-waste legislation in all signatory countries as increasing numbers of developing countries, including China, refuse to accept e-waste imports. Furthermore, multiple academic reports and business insights indicate the potential of e-waste in a circular economy. Such projection provides me with a tremendous opportunity to conduct the following in-depth study of e-waste recycling in China and the United States, and to explore how we can turn trash into treasure.

### 1.2 Scope and Limitation

This study focuses on e-waste recycling of the world's top two e-waste contributors, China and the United States, with the global impact of e-waste in mind. Thus, systems thinking will enable me to conduct a comprehensive study of these two countries with a holistic view of the e-waste problem. A brief overview of systems thinking will be given in this study to bring context to the interconnectedness of the management and disposal of e-waste. Among a number of electrical and electronic goods, I will look into smartphones particularly as a sample to illustrate the lifecycle of an electronic device from cradle to grave. I will also provide place-based case studies from China, the United States as well as other countries to examine local e-waste recycling practices and the potential of e-waste in a circular economy.

The topic of e-waste recycling is topical and evolving. So are the changing policies and measures taken by different countries and local communities. I acknowledge that my understanding of e-waste recycling is limited to information available within the public domain, in particular in print and on the internet in original languages if accessible. I aim to gather data and sources that are most relevant but not necessarily the most current to the study. Given the VUCA (short for volatility, uncertainty, complexity, and ambiguity (Bennett and Lemoine, 2014) world of e-waste recycling against the backdrop of the current covid pandemic and the hostile US-China bilateral relationship, I intent to complete this study within required time frame of three months with inattentional blindness.

### 1.3 Methodology

This study is to be carried out through mixed qualitative research methods such as participant observation and secondary data analysis. Systems thinking gives me flexibility to gauge which is the best method for delivering my analytical insights based on the narrative of the paper as a whole. The qualitative data are to be gathered through multiple sources including but not limited to literature and online publications by credible organizations and institutions. In addition, my multilingual capability enables me to dig deeper into the subject matter in an original language, and maintain research integrity for accuracy and objectivity. I will apply to systems diagrams, graphs and images when necessary throughout this paper.

"*Everything you know, and everything everyone knows, is only a model. Get your model out there where it can be viewed. Invite others to challenge your assumptions and add their own.*"

---Donella H. Meadows, author of *Thinking in Systems* (2008)

# Part II SYSTEMS THINKING

## 2.1 What is systems thinking?

The concept of systems thinking has been around for centuries. It was explored and developed by philosophers, biologists, astronomers, geologists and scientific thinkers from East and West. Systems thinking transcends disciplines and cultures. When it is done right, it overarches history as well (Meadows, 2008). For this paper, I am going to apply the systems theory created by Jay W. Forrester at the Sloan School of Management at MIT. This is a brief introduction of systems thinking in order to lay the groundwork for understanding the interconnectedness of e-waste recycling process in the wheels of international trade.

To understand systems thinking, we need to first understand what a system is. In her seminal work, *Thinking in Systems: A Primer*, Donella H. Meadows defines a system as "an interconnected set of elements that is coherently organized in a way that achieves something. (Meadows, 2008)" We are living in a world of systems. Water system, energy system, banking system, rocket system, education system, medical alert system, legal system and so forth, we can easily create phrases with the word "system." The human body is made up of a number of interrelated systems, so is a biome. A biome is made up of many ecosystems. As American systems scientist Peter Senge summarized it, "Systems are how we are going to embrace the extraordinary levels of connectedness and interdependence that exist among the living.(Senge, 2016)"

Systems thinking is an approach to understand how different parts of a system interrelate and how systems work within the context of other systems. It is a holistic approach to "conceptualize the socio-eco-bio-physical system" in order to understand its parts and how it behaves (Hull, n.d.). A system must consist of three kinds of things: elements, interconnections, and a function or purpose (Meadows, 2008). The elements of a system are called stocks. They are the easiest parts to notice because many of them are visible. In a house, doors, windows, roof, frame, plumbing, and the electricity are elements of a system. Stocks can also be intangible such as team morale and athletic prowess of a football team. Interconnections are the relationships that hold the stocks together. Many of the interconnections in systems operate through the flow of information—signals that go to decision points or action points within a system (Meadows, 2008). For instance, a flagger who guides traffic in a construction zone may use information from her timer, visual counting of traffic on her side, and exchange information with her counterpart from the opposite direction. The purpose of a system is not a stated goal but is a property of the system as a whole. Systems thinking recognizes that systems are dynamic and usually include multiple feedback loops. A feedback loop is the consistent behavior pattern over a long period of time that is the first hint of the existence of a feedback loop (Meadows, 2008). The best way to deduce a system's purpose is to watch how the system behaves (Figure 3).

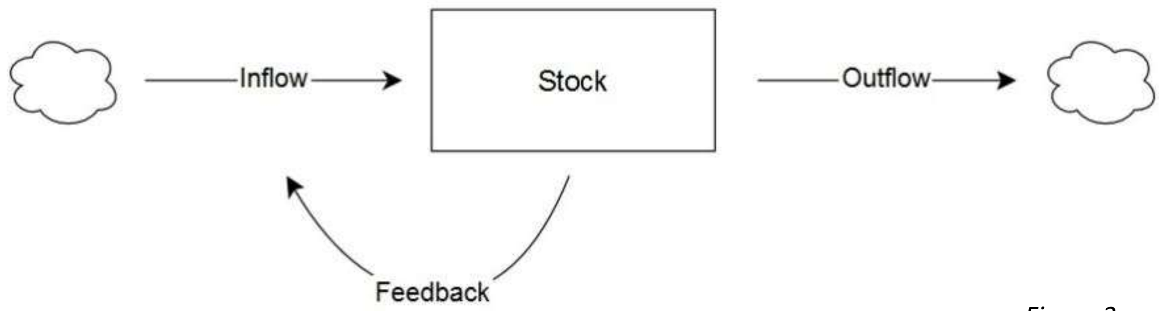
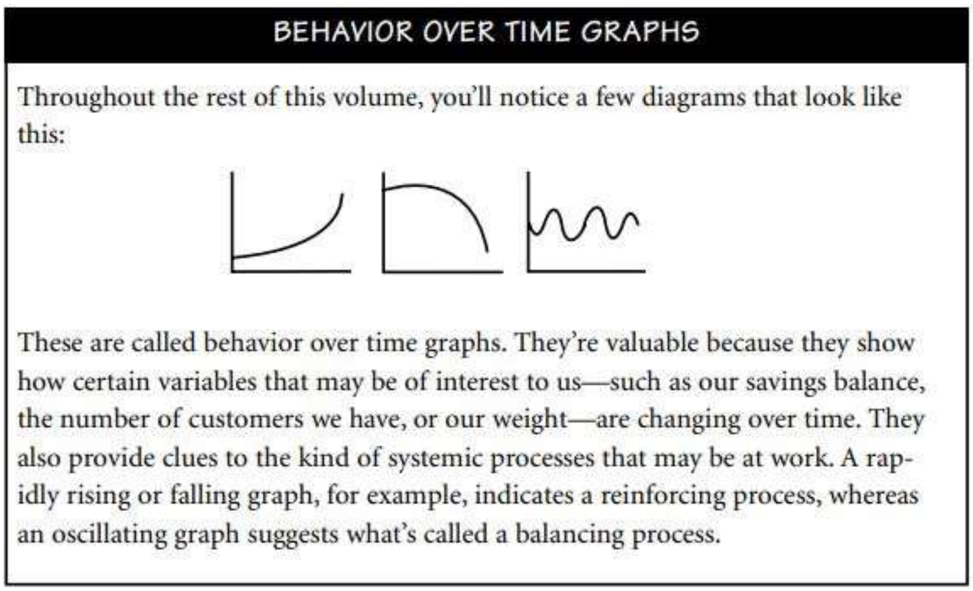



*Figure 3.*

Almost every system attempts to ensure its own perpetuation. Feedback provides information to the system that tells it how it is doing relative to some desired state. For example, when you get your bank statement for your checking account each month, if the net cash balance (a stock) is lower than last month, you may decide to spend less this month or work more hours to earn more money. The money entering your bank account is a flow that you can adjust in order to increase your stock of cash to a more desirable level. Systems thinking goes back and forth constantly between structure and behavior of a system. Systems thinkers use diagrams of stocks, flows, feedback loops (i.e. structure) and time graphs (i.e. behavior) to understand the nonlinear behavior of complex systems (Figure 4).



BEHAVIOR OVER TIME GRAPHS

Throughout the rest of this volume, you'll notice a few diagrams that look like this:

These are called behavior over time graphs. They're valuable because they show how certain variables that may be of interest to us—such as our savings balance, the number of customers we have, or our weight—are changing over time. They also provide clues to the kind of systemic processes that may be at work. A rapidly rising or falling graph, for example, indicates a reinforcing process, whereas an oscillating graph suggests what's called a balancing process.

*Figure 4. Behavior over time graphs. Retrieved from thesystemthinker.com*

There are two types of feedback loops: stabilizing loops and reinforcing loops. Stabilizing loops are "goal-seeking or stability-seeking.(Meadows, 2008)" A balancing feedback loop resist change in one direction by producing change in the opposite direction, which negates the previous effects. This is why stabilizing loops, as the name suggests, are continually stabilizing the stock level to keep a system at some desired level of performance. Another kind of feedback loop is a vicious or virtuous circle that can cause healthy growth or runaway destruction (Meadows, 2008). This is a reinforcing feedback loop which enhances whatever direction of change is imposed on a system. A reinforcing feedback loop can be powerful as it generates more input to a stock which becomes a leverage point in a system. A leverage point is an area where a small shift can produce big changes throughout the system. It can be in stabilizing loops as well. In Donella H. Meadows's classic "Leverage Points" framework, the author explained twelve places to intervene in a system in the increasing order of the effectiveness. I find this framework illuminating and I will apply to my comparative study of e-waste recycling in China and the United States.

These are the very basic systems thinking terms. I hope my audience has a basic understanding of the system that I refer to in the following writing. It is different from the colloquial meaning of "system" which in itself is a crummy word. When something goes wrong, we tend to blame the system to express our frustration and helplessness. Nevertheless, a highly functional system consists of three characteristics: resilience, self-organization and hierarchy. It makes greater sense today to understand complex systems in a digital world which overloads us with information. We may ask better problem-solving questions if we focus on relationships among system components as opposed to the components themselves. Jay W. Forrester described it nicely, "Systems of information-feedback control are fundamental to all life and human endeavor, from the slow pace of biological evolution to the launching of the latest space satellite….Everything we do as individuals, as an industry, or as a society is done in the context of an information-feedback system.(Meadows, 2008)"

**2.2 What is the context?**

Taking Donella H. Meadows's initiative, I get my model of e-waste recycling system out and invite the audience to challenge my assumptions and add your own. E-waste recycling is a systemic problem. Utilizing systems thinking to understand e-waste recycling may alleviate, if not completely eradicate, a systemic problem that is universal in developed and developing worlds.

Technology has become more integrated into every aspect of our lives, in particular during the current covid pandemic. While practicing social distancing, our virtual social life and work-from-home and distance-learning lifestyles have put us ever more dependent on technology in 2020. Gartner's preliminary PC sales results show for the second quarter of 2020 huge gains that top the sales chart of several leading PC makers include Lenovo from China and HP from the United States (Collins, 2020). The relationship between the quantity of electronic devices that producers wish to sell at various prices (i.e. supply) and the quantity that consumers wish to buy (i.e. demand) is a causal factor in the price of the commodity. Put simply, prices of

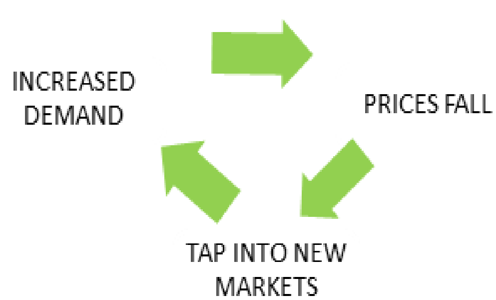



*Figure 5. A reinforcing loop between demand and price.*

smartphones are dropping as the number of users increase. As prices fall, more funds will be tapped into research and development for newer technology and more customers can afford cheaper smartphones (Figure 5). Perhaps it is fair to say without interruption (e.g. limits to growth, a new fungible commodity or service, purchasing power loss), the use of smart devices will continue steadily since the market will not run out of smart device buyers as long as new babies are born every day, and gadgets and humans become ever more inseparable.

According to the European Commission forecast of growing consumerism (European Commission, n.d.), the global middle class is expected to grow and reach 5.5 billion by 2030. Some 87% of the additional middle class population will be Asians. China and India, which have the world's top two largest population by country (and also the leading e-waste producers), account for a majority of the burgeoning Asian middle class. As a growing middle class around the world goes digital, from smartphones and laptops to a myriad of voice-control gadgets, electronic devices are also in greater demand. In some markets such as in mainland China, Hong Kong and Taiwan, smart devices are becoming so affordable that it is not uncommon that an individual consumer owns multiple smart devices. The same phenomenon is seen in American middle class families. I see this trend as an unlimited growth in a system (Figure 6).

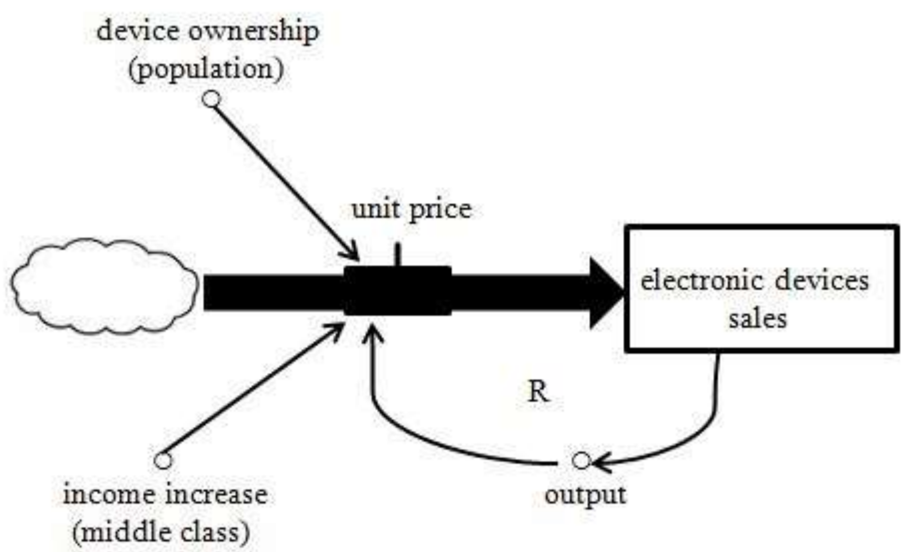



*Figure 6. A reinforcing loop (R) of electronic device sales.*

Techno-optimist Andrew McAfee in his book, *More From Less*, expounds two pairs of forces that drive dematerialization, that is, to do more with less; to prosper using fewer resources. He claims that capitalism and technological progress are the first pair of forces. And capitalism and tech progress don't deal with negative externalities (e.g. pollution) (McAfee, 2019). I am skeptical about dematerialization through technological innovations. I will explain further in the next part of this paper. Nonetheless, tech companies, in particular hardware companies in the United States, exemplify how the mechanism of profit can work resiliently in McAfee's socially-irresponsible capitalism. Electronic devices are infamous for their rapid obsolescence. Tech companies constantly update the design or software of their goods, partly because they invest funds in research and development in order to compete for markets with new products, and partly because the shorter life span of devices prompts users to replace them with new devices, subsequently, ensuring perpetual cash flow for the tech companies. Moreover, discontinuing support for older models is like a silent forced eviction of current occupants. In tech-saturated economic markets, buying a new product for many a consumer is usually cheaper and easier than to repair an old one. Meanwhile, the companies continue to profit from steady sales (Figure 7).

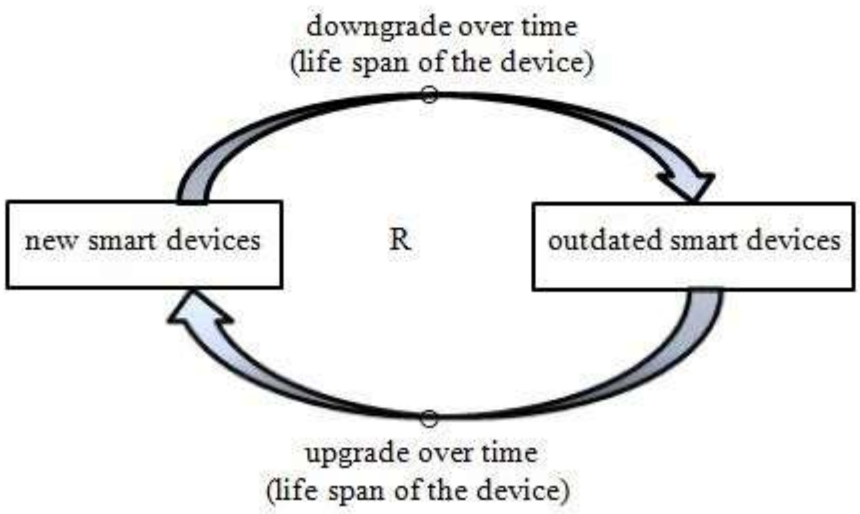



*Figure 7. A reinforcing loop (R) of old and new devices.*

It is not complete to have a deeper dive into the United States and China without recognizing these two countries have completely contrary forms of government, precisely, a dichotomy between a constitutional republic and an authoritarianism. Regardless of current politics, the United States was founded as a constitutional republic in which the chief executive and representatives are democratically elected by the people. Whereas under one party rule, China's form of government is authoritarian. I may oversimplify the nuances of these two forms of government in political science by comparing them to the two kinds of feedback loops. The principle of checks and balances in a democratic government is like a stabilizing feedback loop. Whereas centralization of power in an authoritarian government is like a reinforcing feedback loop. I will explain further in the next part of this paper.

### 2.3 What's in the e-waste?

As mentioned, among a number of electrical and electronic goods, I will look into smartphones particularly as a sample to illustrate the lifecycle of an electronic device from cradle to grave. So, what's in a smartphone? A smartphone is a handheld system composed of multiple parts—display, battery, System-on-a-chip or SoC for short, memory (RAM), modems, camera, and sensors (Figure 8). Each component in and of itself is a system. For example, a system-on-a-chip (SoC) is the brain of a smartphone. It connects other components such as cameras, a display, flash storage and much more on one integrated circuit. This is where the ARM Architecture comes into

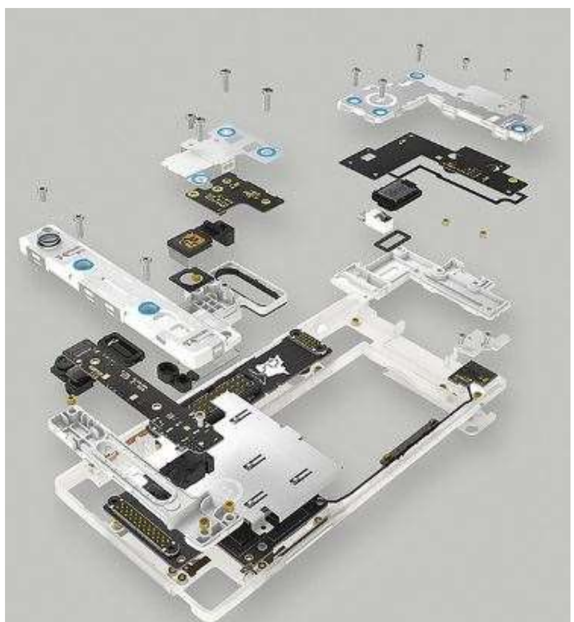


*Figure 8. Multiple systems inside a smartphone. Retrieved from 1843.*

play. ARM provides the foundation for the design of a processor or core used in a range of technologies, integrated into SoC devices such as smartphones, microcomputers, embedded devices and servers (ARM Developer, n.d.). The architecture is like the rules in a system, exposing a common instruction set and workflow for software developers. The rules of the system define its scope, its boundaries, and its degrees of freedom (Casali, n.d.). In the case of ARM architecture, it can be a strong leverage point because its development can change the purpose of a SoC. Major SoC chip manufacturers include Qualcomm, Samsung, Huawei's own Kirin and Apple's own SoC based on the ARM design. ARM technology runs with a limited instruction set that smaller processors can handle, as a result, the ARM processor can complete a lot of simple tasks at a higher frequency while using less energy. It basically increases the efficiency of the processor by eliminating unnecessary instructions, as well as transistors, allowing for a simple circuit to be created (TCR, 2019). This echoes with Andrew McAfee's view about doing more with less in his new book, *More From Less*.

The interactions of the components of a smartphone are both physical and chemical. Together with zillions of applications that could be installed in the device, a smartphone can do many things beyond basic telephony with a tap of our fingers. If we look closely at the chemical components of the materials that make up a smartphone, there is a complex mix of valuable elements, some of which are toxic heavy metals like lead, mercury, cadmium and beryllium. If they are not recycled properly, these hazardous chemicals can harm human health and the environment. According to the *Global E-waste Monitor 2020* (Forti et.al., 2020), up to 69 elements from the periodic table can be found in electrical and electronic equipment, including precious metals (e.g. gold, silver, copper, platinum, palladium, ruthenium, rhodium, iridium, and osmium), Critical Raw Materials (e.g. cobalt, palladium, indium, germanium, bismuth, and antimony), and noncritical metals, such as aluminum and iron. Dr. Arjan Dijkstra from University of Plymouth, Great Britain, launched an experiment in his lab to find out what elements were in a smartphone. In his video, he explains what elements are and how much they weigh in one unit of a smartphone (Dijkstra, 2019). Imagine annual smartphone production is 1,457 million units. How much more metals will be consumed in order to meet the growing market?

The worldwide accumulation of e-waste has more than doubled in the last nine years. According to the United Nations University, a research arm of the UN, the raw materials contained in e-waste were worth roughly $61 billion in 2016, more than the gross domestic product (GDP) of middle-income countries like Croatia or Costa Rica (Larmer, 2018). Only 20% of e-waste was properly recycled to enable recovery of the valuable materials (UN University, 2017). The risk of linear consumption is apparent. The global supply chain for smart devices is increasing but the materials that make up these devices are declining. If we cannot find a way to recover the valuable materials hidden in the increasing stock of e-waste, the equilibrium stock of natural resources will be unstable, causing shortages of certain materials and harming the manufacturing process of new products.

Systems scientists like Donella H. Meadows and others more than two decades ago cautioned such unsustainable system of any given nonrenewable resource. In *Thinking in Systems*, Meadows wrote succinctly about a balancing feedback loop in the interrelationship between capital and extraction rate: "The more capital, the higher the extraction rate. The higher the extraction rate, the lower the resource stock. . . I could assume that resource depletion feeds back through operating cost as well as capital efficiency. In the real world it does both. In either case, the ensuring behavior pattern is the same—the classic dynamics of depletion. (Meadows, 2008)" See Figure 9.

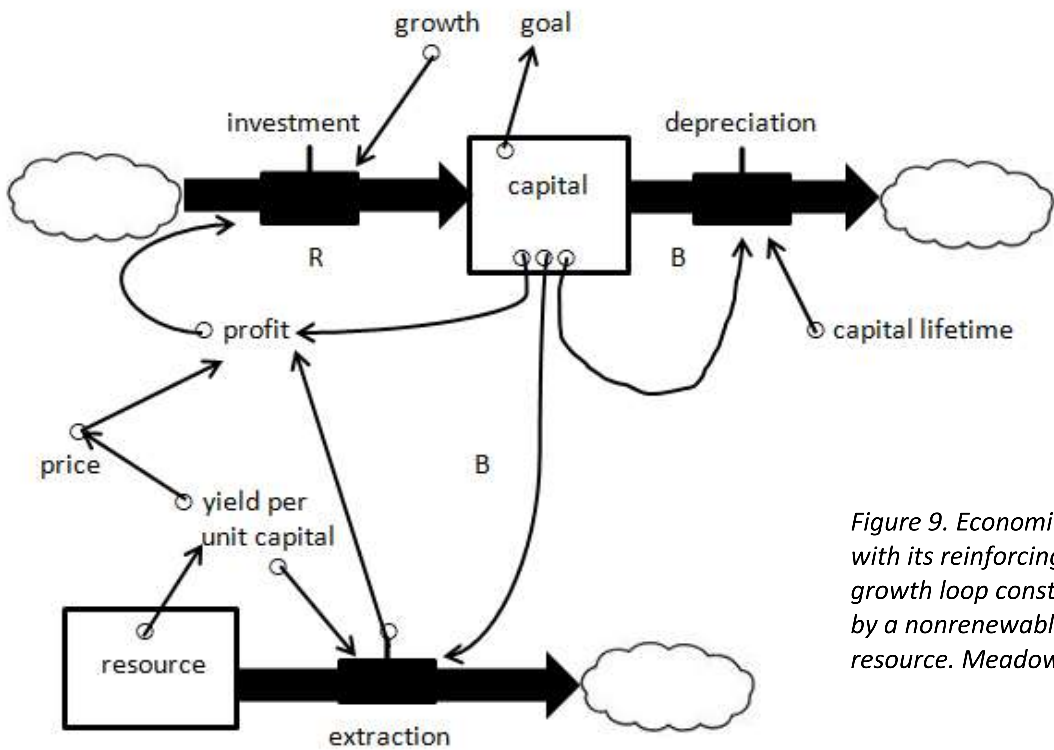



*Figure 9. Economic capital with its reinforcing growth loop constrained by a nonrenewable resource. Meadows, 2008.*

If we look at this classic dynamics of depletion in the lens of today's demand and supply of smartphones, the increasing demand of smartphone only speeds up the extraction rate of minerals that are used for smartphones. Nonrenewable resources are stock-limited. Since the stock is not renewed, the faster the extraction rate, the shorter the lifetime of the resource (Meadows, 2008). This is not a doom-and-gloom prospect for some minerals to be exhausted in the near future. It is a fact that essential minerals for laptops, cellphones and wiring are "in danger of running out" as BBC's *Science Focus* magazine predicted on March 1st last year to mark the 150th anniversary of the publication of the world's first recognizable version of the periodic table by a Russian chemist named Dmitri Mendeleev (Science Focus, 2019). Critical and rare metals, including rare earth elements (REEs) which have been politicized as a result of China's global dominance of REEs. Indeed, they are prized by countries for the development of modern technologies and telecommunications. An article published by Stanford University warned the scarcity of critical minerals could "threaten renewable energy future. (Than, 2018)" In 2017, a group of scientists published a paper in *Nature* to address their concern and call for "resource governance" including metal recycling and technological change in order to achieve sustainable mineral supply (Ali et al., 2017). Like the predicament of water and forests, the loss of minerals and elements is at an unprecedented pace as a result of our ravenous consumption of metals and slow action to reduce critical mineral waste. I close this chapter with a diagram that appeared in *The Global E-Waste Monitor 2020* (Figure 10).

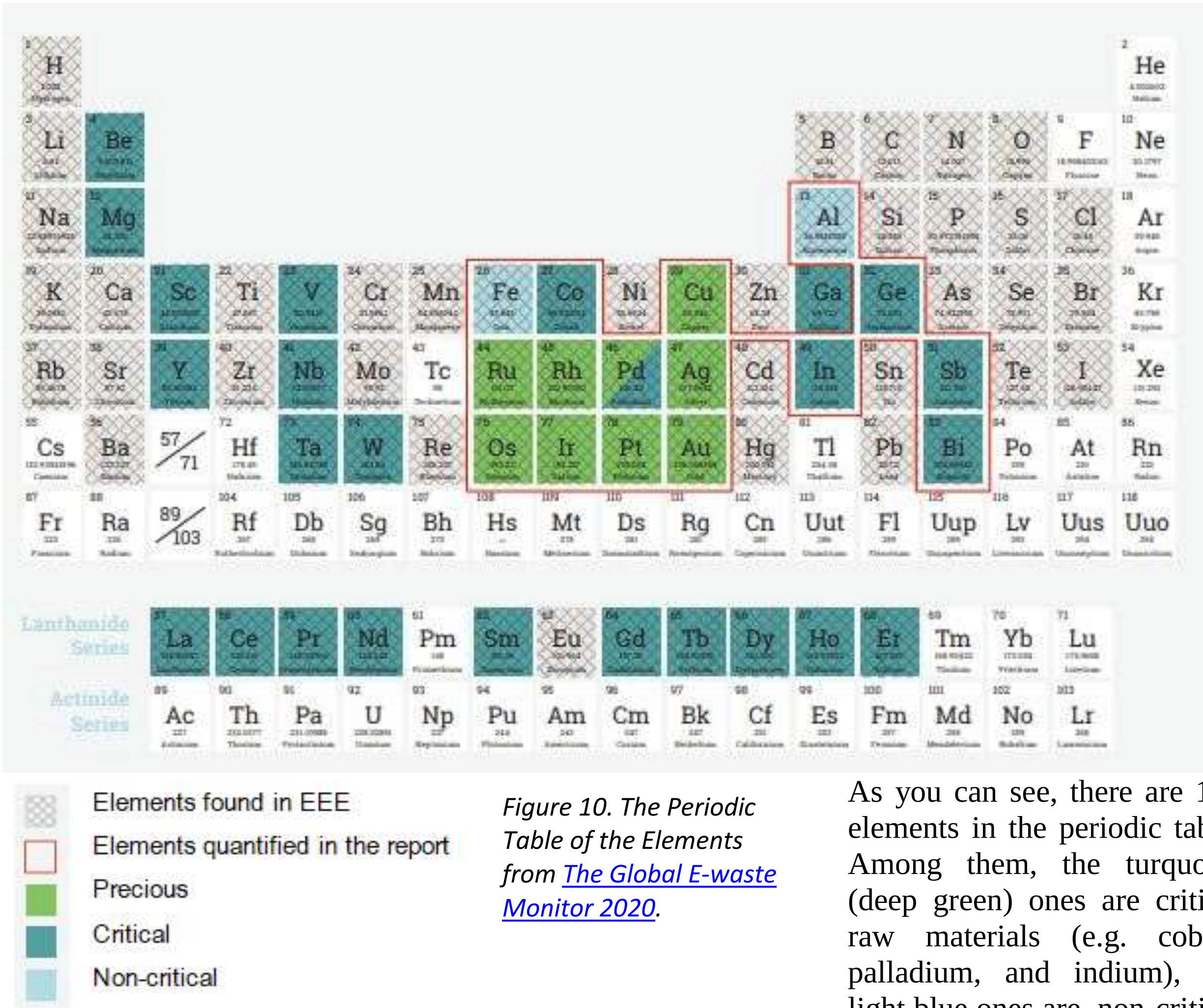



*Figure 10. The Periodic Table of the Elements from [The Global E-waste Monitor 2020](#).*

As you can see, there are 118 elements in the periodic table. Among them, the turquoise (deep green) ones are critical raw materials (e.g. cobalt, palladium, and indium), the light blue ones are non-critical metals such as aluminum and iron, and the light green ones are precious metals. Precious metals are gold, silver, copper, platinum, and a number of metals ended with an *-ium* suffix. Up to 69 elements including precious metals from the periodic table can be found in the UN e-waste report. Looking closely, an average smartphone may contain up to 62 different types of metals which are the ingredients that make smartphones so "smart." The rare earth metals play a vital role. They include scandium (Sc), yttrium (Y), and elements 57-71, the lanthanides. Rare earth metals are also used in many other high-tech devices such as television sets, computers, camera lenses, fluorescent light bulbs and missiles. Several nations dominate production of critical materials including the rare earth metals. A 2017 RAND study found that China has a greater than 50-percent market share for ten different critical materials. China is also a major supplier of more than 19 of the 30 materials for which the U.S. is more than 50 percent reliant on imports (Silberglitt, 2017). As such, there are significant reasons behind the ongoing US-China geopolitical tug of war. Could e-waste recycling in these two superpowers shed light on their respective strategies for sustainable development? Could the unique economic interdependence between China and the US form new feedback loops into their respective e-waste legislation? How do other countries fare in the toxic deluge of e-waste? Are there any lessons learned from these two e-waste giants? I will unpack some of these questions in the following chapter.

*"Wicked problems result from the mismatch between how real-world systems work and how we think they work."*

---Derek Cabrera,
author of *Systems Thinking: Four Universal Patterns of Thinking* (2009)

# Part III  E-WASTE RECYCLING

## 3.1 The United States—Out of Sight, Out of Mind

### 3.1.1 Overview

In *Junkyard Planet* by Adam Minter, the author estimated the global recycling industry turned over as much as $500 billion annually. (This was an estimate figure in 2012 as of the publication of the book.) This astronomical figure with eleven zeros—$500,000,000,000—was roughly equivalent to the GDP of Norway as Minter analogized. Recycling is not a novel practice in the United States, given the fact that the world's largest economy touts its entrepreneurship and capitalism. Back in the 1800s, Americans recycled instinctively without blue recycling bins, sorting, and recycling trucks rumbling down the alley. Susan Strasser, author of *Waste and Want: A Social History of Trash*, accounted that American people "recycled far more than we do now. (Eldred, 2020)" Before there was municipal solid waste disposal, Americans had long learned to reuse material goods. They saw the value of using material goods more than once or converting them into a new use. Put simply, people understood and cherished the value of reuse and recycle.

Municipal Solid Waste (MSW), or more commonly known as trash or garbage, consists of everyday items we use and then throw away from our homes, schools, hospitals, and businesses. I need to refer to MSW often about e-waste recycling, especially in the United States. When garbage pickup started in the late 19th century, cities began separating reusable trash from garbage designated for a landfill. The cities sold the reusable trash to industries while households saved their organics to feed animals. Evidently, an end-of-life product in the United States entails two different fates: reusable or landfilled. The former is circular, the latter is linear. I will come back to this thought. Apart from metal at scrapyards, source separation was not happening until World War II when people recycled nylons, tin cans and even the tin in toothpaste tubes for the war effort. By recycling unused or unwanted metal, the government could build ships, airplanes and other equipment needed to fight the war (Fishman, 2015) (Figure 11). The idea that recycling helps protect the environment was more or less an add-on benefit


*Figure 11. Poster for the Philadelphia Salvage Committee encouraging scrap drives to aid the war effort. Courtesy of [Library of Congress](#).*

of recycling. After the environmental movement in the 1960s and 70s, a tumultuous time in the U.S. history that catalyzed the success of the environmental movement, the first recycling programs linked to people's concern for the environment started popping up. The connection of recycling and the environment began to take shape. A series of bipartisan environmental legislation and the creation of the United States Environmental Protection Agency (EPA) also took effect on a national scale.

Nevertheless, recycling in the United States is more than the reuse of an end-of-life product. Recycling is a profit-driven industry, as is the case in China and many other newly industrialized countries (NICs). The steel industry, for instance, has been recycling steel scrap for more than 150 years (USGS, n.d.). According to the Institute of Scrap Recycling Industries (ISRI), a U.S.-based private, non-profit trade association, the U.S. scrap recycling industry accounted for 0.54 percent of the nation's total economic activity in 2019, making it similar in size to the warehousing and storage industry (ISRI, 2019). From automobile recycling to today's e-waste recycling, scrap metals such as copper, brass, silver, gold, aluminum, stainless steel and alike are the sought-after raw materials. A mobile phone is typically composed of about 40 percent of plastic, 32 percent of non-ferrous metal, 20 percent of glass and ceramics, 3 percent of ferrous metal, and 5 percent other (Basel Convention, n.d.). According to the EPA, Americans generated 2.84 million tons of consumer electronics goods in 2017, representing less than 2 percent of all MSW generation (EPA, 2020) (Figure 12). Nonetheless, e-waste is the fastest growing municipal waste stream in the country, accounting for 70 percent of overall toxic waste (Do Something, n.d.). According to a United Nations estimate, only 20 percent of electronic waste worldwide was recycled in some shape or form in 2016, the remaining 80 percent ended up in landfills (Baldé et al., 2017). In the U.S, the rate of recycling is close to 25 percent whereas the rate of responsible e-waste recycling worldwide is at an abysmal 15.5 percent (Vaute, 2018).

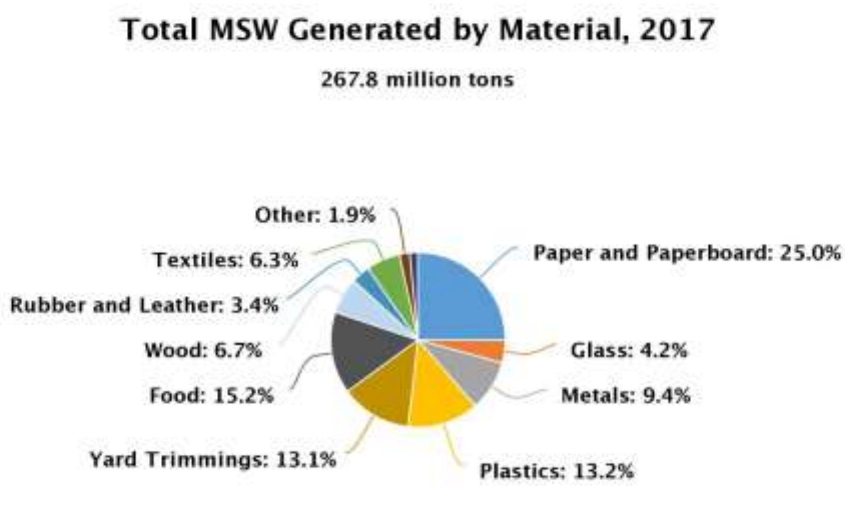



*Figure 12. Retrieved from EPA.*

So, if e-waste is not waste at all as it contains profitable raw materials, why can't the efforts to sustainable recycling keep pace with the massive consumption rates for new devices? Why is less than a quarter of all American e-waste recycled, the rest incinerated or landfilled? Adam Minter wrote in his book *Junkyard Planet*: "Recycling is what happens after the recycling bin leaves your curb. Home recycling—what you most likely do—is just the first step. (Minter, 2015)" I compare the act of faith when consumers queue up at the door of "recyclers" to donate their secondhand e-goods, or when they simply trade in their old devices with the cellphone providers for a new model, to an eco-friendly crusade: the consumers themselves have done the right thing, and they expect the recyclers would also do the environmentally sound thing as they do in the first place. But the reality is a mixed bag.

This is how Minter described the linear lifecycle of commodities in the United States: "U.S. manufacturers (second only to China in total output) still use roughly two-thirds of the recycled materials that are generated within U.S. borders. The problem, if you care to view it as a problem, is that Americans don't just buy U.S.-made products; they also import vast amounts of manufactured merchandise. (Minter, 2015)" He further explained that the American economy is a model that drives people to consume and throw away much more than what is manufactured at home. "That excess recyclable waste has to go somewhere. Export is one option, landfill another," he wrote (Minter, 2015). Having lived in China for more than two decades and traveled extensively in the developing world, I have witnessed how desperate locals make do with the offloaded defunct e-waste from somewhere else. My observation resonates with Minter's throughout his book. I am going to do my own interpretation of "follow the money" and look into three possible fates of e-waste from the perspective of the United States. They are e-waste to export, to landfills, and to achieve Zero Waste, that is, the redesign of resource lifecycles of electronic goods so that all products are reused. The concept of Zero Waste is similar to circular economy and can be summarized in a 5R framework—Reduce, Reuse, Refurbish, Repair and Recycle (Figure 13).

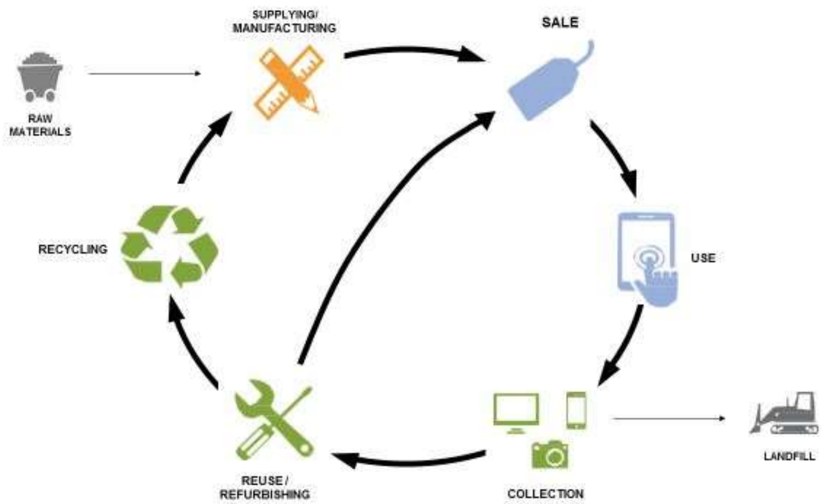


*Figure 13. Life Cycle Stages of Electronics. Retrieved from EPA.*

### 3.1.2 The DSRP Thinking Method

To begin the "fate searching" of e-waste lifecycle, I need to briefly introduce the methodology of my thinking process. The theory of DSRP is extremely insightful for me to understand wicked problems like e-waste recycling. Developed by Derek Cabrera, a systems theorist and cognitive scientist, DSRP is an acronym that stands for Distinctions, Systems, Relationships, and Perspectives. Systems thinking with the DSRP method enables me to make distinctions between ideas, objects and things (distinctions), organize things into part-whole groupings (systems), make connections between and among things (relationships), and take different perspectives on and from things (perspectives). The concept of DSRP resonates with me in many ways. As mentioned in Chapter 2, systems thinking is not typical of western civilization. It has been explored and developed in different variations in the East as well. For example, the ancient

Chinese teachings were modernized by neo-Confucianism that studies the relationship between systems thinking and Chinese philosophy. The world is full of nonlinearities, thus systems surprise our linear-thinking minds. Donella H. Meadows summed up beautifully in *Thinking in Systems*, she wrote: "Nonlinearities are important only because they confound our expectations about the relationship between action and response. They are even more important because they change the relative strengths of feedback loops. They can flip a system from one mode of behavior to another. (Meadows, 2008)" With DSRP in mind, we will be able to understand further the interconnectedness of the wicked problem and its relationships with variables. Derek Cabrera once said, "Wicked problems result from the mismatch between how real-world systems work and how we think they work."

We are constantly making distinctions because they are often plagued by our biases. Without factoring the systems of global trade and cost accounting in my problem-solving thinking, I would conclude prematurely recycling is the answer to the e-waste crisis in the United States. Supposed e-waste recycling is a global business opportunity, especially for the U.S.-China trade deal. Take semiconductor chips manufacturing for an example. China is the leading hub for assembling finished chips into circuit boards, making it an important end-market for U.S. semiconductors. Chips to electronic products such as laptops and smartphones are akin to water to fish. According to the Semiconductor Industry Association (SIA), a U.S. trade association, the U.S. share of semiconductor manufacturing today only accounts for 12 percent of global capacity, and more chips designed by U.S. firms are made overseas than in America (Keller, Goodrich and Su, 2020). China immediately becomes the scapegoat for the decline of U.S. domestic chip production. SIA finds that most U.S. chips are not produced in China. Singapore, Taiwan, and Europe have bigger share of all U.S.-owned and operated fabs (short for semiconductor fabrication plants) than China (Figure 14). This is one of many examples I encountered during my research of this paper that we need to apply systems thinking with DSRP model to tackle wicked problems. If policymakers take note of the **relationships** in geographic locations—China, Taiwan, Singapore, Japan are Asian chipmakers within the U.S. supply chain; if they make **distinctions** between the U.S. domestic fabs and those in each location in the "chip manufacturing capacity" **system**; and if they understand the profit-seeking-and-cost-cutting nature of American Inc. from the U.S.

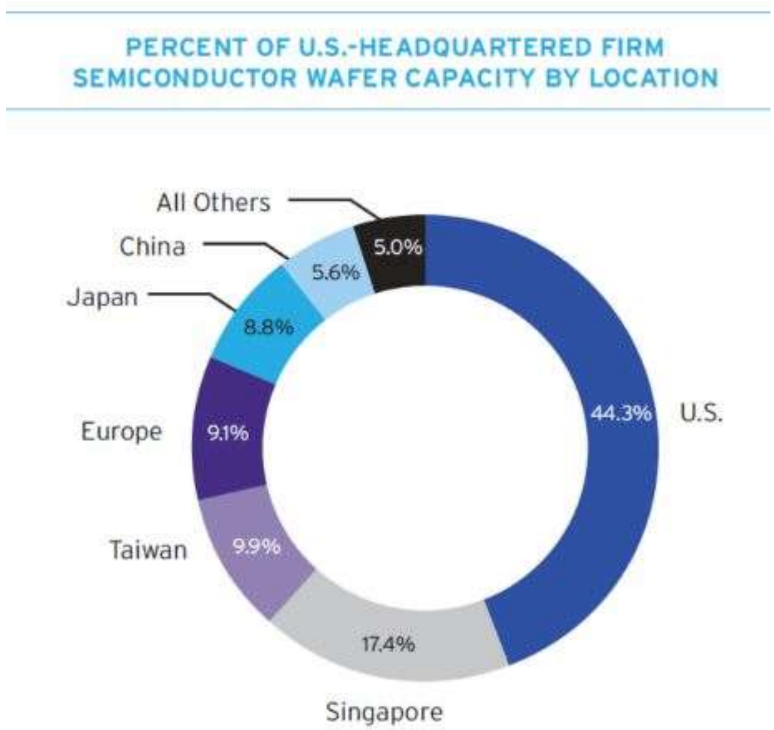



*Figure 14. Retrieved from SIA.*

manufacturer’s **perspective**. Perhaps it will not be hard to draw a conclusion similar to SIA’s key takeaways in the report that the U.S. needs “more attractive incentives that rival incentives offered by other governments around the world,” or it will “see a further decline as more fabs will be built in Asian countries—not the USA. (Keller, Goodrich and Su, 2020)”

I also would like to make a distinction that I have my limitation of this analytical writing, that is my confirmation bias. As Cabrera cautioned: You are one big biased perspective-taking machine (Cabrera, 2018). And now, I will take a look into three possible scenarios, or fates, if you will, of e-waste lifecycle from the perspective of the United States.

### 3.1.3 E-waste to export

Reduce, reuse, and recycle. This familiar phrase has been around since the American environmental movement spread rapidly in the 1970s. Minimize the amount of waste we create, use items more than once, and put a product to a new use instead of throwing it away. How many of us have done all three? As mentioned, the American economy is a model that drives people to consume and throw away much more than what is manufactured at home. Overconsumption in the United States has a linkage to China’s manufacturing overcapacity. In other words, the more Americans consume, the more Chinese factories produce. This is a reinforcing feedback loop.

In China’s modern economic history, the Open Door Policy in 1978 provided a golden opportunity for the country as well as foreign investors to prosper. Suppose you are an American manufacturer who needs: one, to ensure workers receive a decent salary so that they will not take their grievances to the streets or file a lawsuit against the employer; two, bear the expense of the rising factory overhead over time; three, comply with stringent environmental regulations at home in the aftermath of environmental movement. Seeing a market of 1.1 billion people (China’s population in 1990s) and lucrative incentives waving at you from a big country across the Pacific Ocean, why not give a shot to invest overseas? Award-winning economist Jeffrey D. Sachs detailed the history of the American manufacturing sector when he talked about social inclusion. He said the United States had its peak of employment in the manufacturing sector in 1979. From then on, there was a significant decline due to the shift of work to lower-wage economies. The confluence of events at the turn of 1970s and 80s was timely for both the U.S. and China to build a pragmatic business partnership. China had the foreign capital it needed for economic development whereas the United States had the low manufacturing cost it desired. Sachs revealed, “For many low-wage economies, and notably China, there was a huge benefit. A key part of their rapid economic growth was due to this gain in jobs from the United States and Europe. (Sachs, 2015)”

Aside from globalization, political forces in the United States “amplify rather than lean against the market forces,” wrote Sachs in *The Age of Sustainable Development* (Sachs, 2015). With relaxed regulation and lower labor cost, coupling with a huge consumer market in China, why wouldn’t an American manufacturer be attracted to the idea of relocating the factory to China? A U.S. congressional report in 2018 pointed out that the United States is by various measures “falling behind other countries in manufacturing (Levinson, 2018).” The U.S. manufacturing position in the world has shifted dramatically. The U.S. share of global manufacturing activity declined from 28 percent in 2002 to 16.5 percent in 2011 (Levinson, 2018). Another main finding in the report was that China displaced the United States as the largest manufacturing country in 2010, and part of China's rise by this measure has been due to the appreciation of its currency, the renminbi, against the U.S. dollar (Levinson, 2018). Without a robust domestic manufacturing industry, there would be fewer doors open to give electronic waste a second or third lifecycle domestically. As Minter explained in *Junkyard Planet* the fall of American scrap recycling, "rising labor prices made the practice unaffordable, and environmental crackdowns shuttered the refineries and smelters that could do it chemically.(Minter, 2015)"

From a recycler's perspective, cost is a pivotal factor in determining where to dump scrap. Because of overconsumption and inadequate manufacturing capacity, many scrap traders in *Junkyard Planet* dubbed the United States "the Saudi Arabia of Scrap," a land where there is more scrap than the people can handle on their own (Minter, 2015). On top of that, shipping by sea is more cost efficient than shipping on land. With the ever intimate US-China trade relations between 1980s and 2010s, the sea freight activities over the Pacific Ocean increased substantially, as a result, reducing the shipping cost significantly. The cost benefit principle is fundamental to almost all environmental initiatives if we need to make a systemic change. We need incentives to act for or against a status quo. American scrapyards often found it cheaper to send their goods to China (before 2018) and other developing countries than to any geographically distant cities in the United States. Minter in *Junkyard Planet* pointed out that "shipping empty containers is one options, but not a very profitable one. (Minter, 2015)" It is like getting a round-trip airplane ticket that is cheaper than two one-way tickets. Shipping companies hauling goods to America would rather not return to China empty, and so they offer discounts on backhauls. In logistics, a backhaul is hauling cargo back from point B to the originating point A. Before China's ban on recycled waste imports, taking effect in 2018, American demand for Chinese goods was tightly connected to Chinese demand for American recycling. China needed raw materials to build bridges, roads, cities, and produce commodities for domestic and oversea markets. While the U.S. is "the Saudi Arabia of Scrap," China was the Scrapyard of the World before 2018.

On the regulatory front, the United States is inactive to e-waste recycling, or broadly speaking, to plastic waste as well. I will explain shortly why e-waste is associated with plastic waste in scrap dumping abroad. The United States is the only nation in the developed world that has signed but not yet ratified the 1989 Basel Convention on hazardous waste (Basel Convention, n.d.). Local legislation on e-waste recycling varies by states. Only 19 states have laws banning electronics from the regular trash (Semuels, 2019). Without such rules, there have been reports about an uptick in fires in recycling centers because of compacting flammable lithium-ion batteries with paper recycling. There is no U.S. federal law that requires across-the-board e-waste recycling or includes a ban on foreign export of e-waste. An environmental report in 2016 shows 40 percent of the U.S. e-waste was dumped illegally in Hong Kong (Choi, 2016). In the name of "green laundering," which is synonymous with money laundering, electronic waste traveled illegally from U.S. recycling companies to Taiwan, Hong Kong and other regions and states with relaxed to none regulations on scrap imports. According to a 2015 United Nations report, up to 90 percent of the world's electronic waste, worth nearly US$19 billion, is illegally traded or dumped each year (UNEP, 2015). Thousands of tons of e-waste are falsely declared as second-hand goods or "harmless" plastic waste and exported from developed to developing countries, including waste batteries falsely described as plastic or mixed metal scrap. The UN report finds

Africa and Asia are key destinations for large-scale shipments of hazardous waste for dumping, and sometimes for recycling.

So, is it fair to say when the best-intentioned consumer drops off recyclable electronic goods at a recycler, she is challenged to know how or where the electronic goods will end up. This is only a portion of an out-of-sight-out-of-mind recycling process. What's next? When the recycler decides to ship e-waste elsewhere outside the United States, this is the second phase of this out-of-sight-out-of-mind recycling journey. If we look at the journey from the e-goods perspective, it feels a bit like Sheriff Woody in *Toy Story* being changed ownership hand to hand. The system of e-waste export was intervened in December 2019. The Basel Ban Amendment to the Basel Convention came into force in December 2019 to prohibit shipments of hazardous waste from OECD countries to non-OECD countries for disposal or recovery. This piece of international legislation gives a lever to increasing numbers of signatory countries, including China, to refuse to accept hazardous waste. When the doors of other countries are closing gradually to e-waste imports, where can that mountain of American e-waste go?

### 3.1.4 E-waste to landfills

To laborers at scrapyards in the United States or as far as Ghana or Malaysia, a bale of recycled detergent bottles is no more or less eco-friendlier than the barrel of oil from which those bottles were originally made. Nor do Chinese recyclers concern about the working condition of the scrapyards. In the early stage of its economic reform, China steered toward growth and profitability at the expense of citizens' health and wellbeing. The profit-driven nature of industrialization resembles that of the United States at the turn of the 20$^{th}$ century when many cities and towns were polluted and labor strikes were commonplace. "There's nothing sentimental in the work that these men, and women do, nothing particularly green or eco-conscious. Their job, pure and simple, is to obtain the best price," wrote Adam Minter in *Junkyard Planet* (Minter, 2015). So, it is cost that determines e-waste recycling in the United States. Precisely, neither labor cost nor land freight transportation is competitive, not to mention that America's manufacturing sector is in decline. The other option is e-waste to landfill.

In the United States, there are more than one thousand Superfund sites which are emergency and hazardous waste sites funded by the federal government. A general understanding of Superfund sites confirms to me the complexity and urgency of e-waste recycling in America. Constrained by time and the scope of this study, I will highlight a few takeaways. The Superfund has been fraught with dissension and controversy since its inception in 1980 when Congress established the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). The cleanup of the Love Canal in Niagara Falls, New York, is one of the noteworthy Superfund case studies. It took two decades and a cost close to $400 million to complete (Depalma, 2004). Due to understaffed management and lack of leadership and money, there are still many Superfund sites that "have been on the National Priority List for decades," according to an EPA officer in an interview with NPR (Wertz, 2017). The Superfund was initially paid for by taxes on crude oil, chemicals and corporations, the companies that created the toxic waste sites. Congress repealed this tax in 1995, meaning the Superfund did not have as much money to clean all the hazardous-waste sites found by the program (Schons, 2011). Most Superfund cleanup money now comes from taxpayers. And that congressional funding has declined for nearly two decades, leaving states strapped. Here is what I find corporate social responsibility (CSR) most needed but lacks when governance fails. If these decades-old hazardous waste sites cannot be removed from the Superfund list, it is natural for us to raise a question about the capability of the domestic landfills managing electronic waste safely and profitably.

According to the Global E-waste Monitor report, only 17.4 percent of 2019's e-waste was collected and recycled. This means that gold, silver, copper, platinum and other high-value, recoverable materials conservatively valued at US$57 billion—a sum greater than the GDP of most countries—were mostly dumped or burned rather than being collected for treatment and reuse (E-waste Monitor, 2020). In the United States, out of 267.8 million tons of MSW generated in 2017, or 4.51 pounds per person per day, more than 139 million tons of MSW (52.1 percent) were landfilled (Facts and Figures, 2020). And e-waste accounted for less than 2 percent of all MSW generation, according to the EPA (EPA, 2020). With 6.9 million tons e-waste generated in 2019, the United States is world's second biggest e-waste producer, following China (Forti et.al., 2020). As China has tightened environmental regulations on hazardous waste since 2017, it has become a major driver for the decrease in landfill capacity in the United States (Figure 15). A report by SWEEP, a voluntary performance standard for MSW industry, shows the U.S. is on pace to run out of landfills within 18 years with the Northeast decling at the fastest pace while Western states have the most remaining space (McCarthy, 2018).

| Region | Remaining Capacity (years) | Annual rate of loss |
|---|---|---|
| Northeast | 8 | -5.0% |
| Southeast | 14 | -2.5% |
| Midwest | 11 | -4.0% |
| Western | 22 | -1.5% |
| Pacific | 17 | -1.9% |
| USA | 15 | -2.6% |

Remaining landfill capacity in 20201 and annual rate of capacity loss

*Waste Business Journal*

*Figure 15. U.S. landfill capacity is declining. Retrieved from WASTEDIVE.*

E-waste contains hazardous chemicals. When a small amount of e-waste is exposed to the heat, toxic chemicals are released into the air damaging the atmosphere. If they are exposed to rain, toxic materials can seep into the groundwater, affecting plants and animals on land and at sea. Global warming and climate change-induced unexpected extreme weather patterns create complications. Not to mention the preservationist attitude largely embodied by NIMBYism (Not In My Back Yard) and LULUism (Locally Unwanted Land Uses) in the United States. Sending e-waste to landfills may arouse potential conflicts with NIMBY localism. Landfill disposal has negative environmental impacts, including loss of land area, and emissions of methane and other greenhouse gases. Landfills were the third source of U.S. anthropogenic methane emissions in 2017, accounting for 108 million metric tons $CO_2$-equivalent emissions, about 1.7 percent of total GHG emissions (Center for Sustainable Systems. 2020). It seems we are fighting a losing battle if we uphold the linear end-of-life economy by sending e-waste to landfills.

### 3.1.5 E-waste to achieve Zero Waste

If the environmental movement in 1960s redefined recycling, the coronavirus pandemic of 2020 allows us to rethink zero waste, especially for electronic goods. On a global scale, the statistics shows that in 2019, the continent with the highest collection and recycling rate was Europe with 42.5%, Asia ranked second at 11.7%, the Americans and Oceania were similar at 9.4% and 8.8%, respectively, and Africa had the lowest rate at 0.9% (Forti et.al., 2020). The United States is not yet a recycling leader in the continent. But American entrepreneurship and a free-market economy incentivize inventors and investors to tackle e-waste recycling. I will provide a few suggestions at the end of this segment.

To achieve zero waste, the most direct and also the best solution is to stop throwing away electronic goods so quickly in a large quantity within a short period of time. Back to the basic principle—reduce, reuse, recycle. Reduce is the way to go, and yet cutting back consumption in the United States is unpopular, especially to profit-driven manufacturers or policymakers whose political careers are closely tied to American Inc. What will make consumers change smartphones less frequently? Lisa Jackson, Apple's vice president of Environment, Policy and Social Initiatives, told the interviewer in a video that Apple was working toward the extension of the lifecycle of their products. In her view, product durability should be prioritized over repair (TechCrunch, 2017). Apart from a linear consumption model where resources are extracted, transformed, used and discarded, Apple Inc. has its interpretation of circular economy. Nonetheless, a sustainable model championed by the Ellen MacArthur Foundation consists of a closed loop based on the 7Rs—Reduce, Reuse, Refurbish, Repair, Recycle, Redesign, and Remanufacturing. In reality, Apple and its competitors do just the opposite of expanding product durability.

Environmental groups find technology companies are speeding the pace of obsolescence. Author Adam Minter used his MacBook Air as example to make the case. He wrote, "…[its] thin profile means that its components—memory chips, solid state drive, and processor—are packed so tightly in the case that there's no room for upgrades. . .In effect, the MacBook Air is a machine built to be shredded, not repaired, upgraded, and reused. (Minter, 2015)" Time Magazine also raised the red flag. "Most smartphone batteries can't be easily replaced when they stop holding a charge," the magazine read, "new laptops don't accept old cables, and software companies push upgrades that won't run on old devices." The last description is a woe to many Apple fans including myself. The new models of iPhone are ingenious but also are exclusive for certain accessories. In order to showcase the corporate social responsibility of reducing carbon footprint, Apple Inc. releases an annual environmental progress report. Each latest report seems to be lengthier than the previous year (76 pages in 2018 vs. 99 pages in 2020). And yet its carbon footprint in 2018 was an itsy-bitsy less than that in 2020. In 2018, Apple committed to 77 percent of the carbon footprint of their electronics coming from their manufacture, versus the 17 percent from its actual use (Apple, 2018). In 2020, 76 percent of the carbon footprint of their electronics comes from product manufacturing whereas 14 percent from product use (Apple, 2020). If Andrew McAfee's *More From Less* gives us a hope for dematerialization, how would he explain technological innovation that requires shorter upgrade lifecycles of our smart devices? Why does the size of an iPhone new model become bigger over time, not smaller with fewer materials (Figure 16)?


*Figure 16. Size comparison of iPhone 12 and existing iPhone models. Retrieved from [MacRumors](#).*

Based on my observation, overconsumption in the United States has two typical characteristics: one, electronic manufacturers make profits from mass production rather than service upgrades; and two, the short lifecycles of new devices prompt eager consumers to replace their smartphones within two-to-three years. Do you remember the classic dynamics of depletion in Chapter 2? Increasing quantity in a short period of time creates short-term profits but diminishes nonrenewable resources as they are stock-limited. There will be sometime when market reaches saturation. When smartphone ownership nears a majority of the population, consumers may slow the pace of replacing their smartphones. When the overseas supply chain runs short of raw materials or is challenged by other uncertainties such as a pandemic or a trade war, smartphone sales will be affected, too. This February, a group of Democratic legislators proposed a bill called "Break Free From Plastic Pollution Act" to seek to make companies responsible for the plastic waste problem. I find this motion enlightening in a sense that it assures the public that market-based solution may be the way to go. The partisan government at the moment can neither ratify treaties if any, nor pass a bipartisan bill. Judging from the handling of covid pandemic, the partnership between local governments and businesses will become more necessary if we share a common goal of reducing e-waste.

The call for 5G networks is high around the world. The escalating US-China tech war includes disputes over 5G networks and equipment. Millions of smartphones, modems and gadgets incompatible with 5G networks will be made obsolete. This e-waste problem is not only an American problem, it is a problem for the world. It is crucial to tackle the current e-waste problem before the advent of a new wave of toxic deluge. Like Apple Inc. which aims to reach carbon neutral by 2030, Microsoft makes a bolder vow to be carbon negative by 2030. Carbon negative—by Microsoft's definition—is to remove more carbon than the company emits each year (Smith, 2020). In systems thinking, setting goals is one of the twelve places that Donella H. Meadows proposed to intervene a system. Extending the lifecycle of electronic goods can extend the length of time of a user's experience with the goods. If manufacturers can provide service upgrades (software) more often than product upgrades (hardware), from a consumer's perspective, it is a money-saving solution and it will increase consumer's loyalty to the brand. Some U.S. states have passed Extended Producer Responsibility (EPR) laws which require manufacturers to establish and fund systems to recycle or collect obsolete products. China has adopted EPR nationwide. I will explain further in the next segment. Regulation is important to monitor malpractice of e-waste recycling. The e-Stewards Initiative (e-stewards.org) is an e-waste recycling standard created by the Basel Action Network. There is another accredited certification called the Responsible Recycling, or R2. Both programs are recommended by the EPA. Expanding these programs will help consumers to raise awareness of proper e-waste recycling (Certified Electronic Recyclers, 2019). There are multiple ways to extend the lifecycle of electronics (Figure 17). Urban mining is also a good start to recover raw materials from MSW in the cities. CEAR Inc, a California-based e-Stewards certified recycler, is a leader of turning e-waste into treasure. To see is to believe. I recommend the videos on a sustainability website (Great Forest, n.d.).

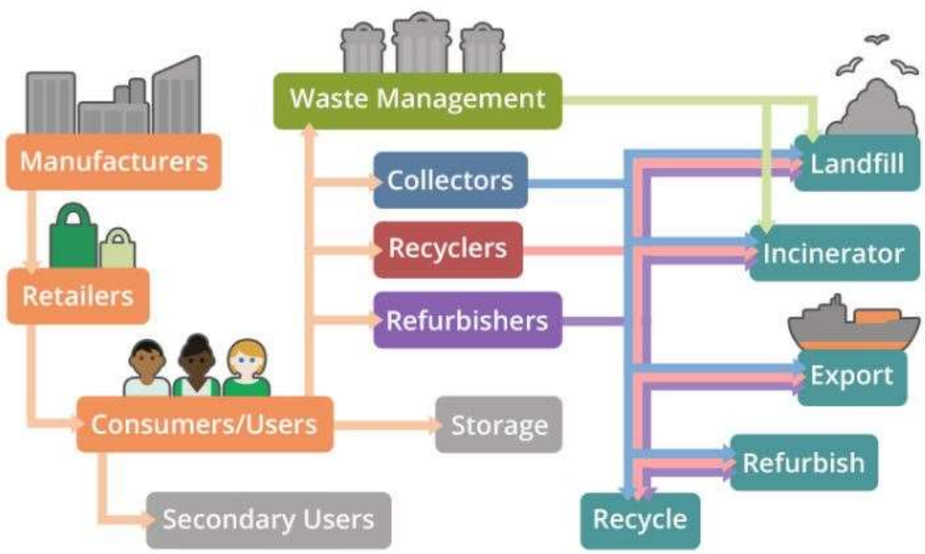



*Figure 17. Lifecycle of Electronics. Retrieved from Great Forest.*

In a nutshell, whether we export e-waste to another country for recycling or send it to in-state or out-of-state landfills, someone will benefit from a pre-owned electronic device and someone will also get the downstream pollution from e-waste recycling. E-waste recycling cannot be out of sight and out of mind. The rebound effect of recycling that people who recycle feel less guilt about consumption might do the opposite of a righteous act of recycling. In economics, the Jevons paradox explains this dilemma where chasing efficiency alone might have opposite effect on the total consumption. If we assume e-waste recycling can improve energy efficiency which will lower the relative cost of producing a new device, as a result, the demand for a cheaper device will increase, too. As Adam Minter warned in *Junkyard Planet*: "Recycling is a morally complicated act. [To reduce waste]. . . is to educate consumers that recycling isn't a get-out-of-jail-free-card for their consumption. (Minter, 2015)"

## 3.2 China—Green Economy in the Making

### 3.2.1 Overview

China's e-waste recycling came to a watershed after its waste import ban came into effect on January 1, 2018. China's Ministry of Ecology and Environment (MEE) and four other ministry-level agencies published the Solid Waste Import Control Catalog (SWICC) (MEE, 2019), banning the imports of 24 types of solid waste including plastics, paper products and textiles from foreign countries. In the following years, China continued to expand the import ban on at least 48 types of scrap material (Redling and Toto, 2018), among which are lower-grade copper, aluminum scrap and mixed-metal scrap. According to MEE, China will ban the import of solid waste completely by 2021. Common ferrous metals including steel and iron components make up around 65 percent of an average vehicle. While China is tightening foreign trash imports (Figure 18), in order to reach its 2025 electrified-car sales target for about 25 percent of new cars sold to be electrified (Bloomberg, 2019), China, as the world's largest car manufacturing country, delayed the reclassification of nonferrous scrap this July. After ferrous scrap was approved to be renamed as recycling steel material this March, China is currently completing new standards to prep for reviving ferrous scrap imports (Argus Media, 2020). It is not incidental to mention China's auto industry. Electrified vehicles including electric cars (EV) are becoming more and more digital and compatible to consumers' electronic personal devices (Glon, 2017). Should our electronic goods need upgrades or replacement with new technologies, the electrified vehicles will be confronted with the similar problem of timely software update, and an extended life span of in-vehicle services will be required. Judging from China's environmental legislative progress in recent years, together with the escalation of the US-China trade and tech war, momentum about China's e-waste recycling will continue but it is subject to the country's green economic recovery triggered by the covid pandemic.


*Figure 18. The global waste flow before China's waste import ban enacted in 2018. Retrieved from DW.*

Systems thinkers have reminded us of taking limiting factors, nonlinearities and delay into account. Dynamic systems are often surprising; as a result, we are often surprised by the amount of growth and exponential process that can be generated. The uncertainty about the future and about technological development, coupled with many other variables that could change the stocks and flows (e.g. the lead time used in an electronic supply chain, extreme weather events), will constantly change our perspective of understanding this complex and interconnected system. Donella H. Meadows once said, "Everything we think we know about the world is a model. Our models do have a strong congruence with the world. Our models fall far short of representing the real world fully. (Meadows, 2008)" Keeping that in my mind, I am about to navigate China's e-waste recycling before and after its waste import ban as a seminal event. How was China's yesterday like when environmental regulation was lax, or, to a greater degree, was lacking? What are the implications caused by negligence of environmental protection during recycling e-waste? What is the impact of China's tightening the environmental rules on industries at home and abroad? Will there be opportunities for a circular economy?

### 3.2.2 E-waste Hub: Hong Kong

Before the implementation of China's waste import ban, the country had been notoriously known as the world's largest importer of waste since the 1980s. In 2012, up to 56 percent of global exported plastic waste ended up in China (Greenpeace, 2017). The dependency of exporter countries on China's market was striking—60 percent from the United States, and more than 70 percent from Europe (DW, n.d.). In 2012, China produced 5.6 million tons of copper, of which 2.75 million tons was made from scrap (Minter, 2015). After China's economic reform to allow foreign direct investment into the country in 1978, the country was desperately short of metal resources of its own, thus, it made a deal with the Western countries to process their unwanted municipal solid waste for reuse and recovery of valuable materials. To some extent, China had been a leader of circular economy long before the term "circular economy" was recognized internationally. Raw materials that were recovered from the junk were reused and remanufactured for new products. Nevertheless, the downside of this recycling deal is China had to eat up the external cost of pollution during the process of manufacturing and recycling. Developed countries simply offload their defunct electronics on developing countries (Figure 19). They also offload pollution elsewhere. Would Americans who enjoy the fresh air in their


*Figure 19. Illegal e-waste dumping on the map. Hong Kong is an international e-waste hub for imports and exports.*

backyards think of the overcast sky pervaded with toxic pollutants in China? Or water contaminated with lead that was almost a regular news headline in Chinese villages? It has been controversial that international trade shifts the burden of pollution-related manufacturing from countries that import goods to those that produce them (Normile, 2017). The “Out-of-Sight-Out-of-Mind” e-waste recycling approach in developed countries, especially in the United States, heightens the severity of health risks and environmental degradation in poor countries that receive foreign trash because they are desperately in need of scrap recycling and sorting as a source of income.

As mentioned in **SEG. 3.1.3 E-waste to export**, thousands of tons of e-waste are falsely declared as second-hand goods or “harmless” plastic waste during green laundering. Hong Kong, which used to be the largest container port for foreign imports entering mainland China, is also an e-waste dumping hub, legally and illegally, depending on how the shipment is labeled in customs clearance. Moreover, Hong Kong is the world’s leading cargo transshipment hub. After China shut its door to foreign trash, Hong Kong was quickly overwhelmed by the sheer volume that China once easily absorbed. As an international economic hub and one of the most densely populated places in the world, Hong Kong generates about 70,000 metric tons of e-waste equipment annually, according to the city’s environmental protection department (EPD, n.d.). Eighty percent of e-waste that is disposed of in Hong Kong each year is exported to Africa or Southeast Asia for reuse or recovery of valuable materials, while the rest is dumped locally in a landfill.


*Figure 20. Illegal e-waste imports were found in a Hong Kong scrap yard. Old printed circuit boards (PCB) are commonly found in the stockpile. Image courtesy of Hong Kong media.*

What we might be able to see in Hong Kong electronics junk yards behind closed doors today mirrors some Chinese coastal cities and towns that used to be the world’s e-waste dumping sites (Figure 20). This is where desperate people do desperate things; this is also where, perhaps, hand labor has an edge over shredding machines in terms of distinguishing materials, sorting and even extraction through burning. At any given junk yards, Chinese women usually take the lighter work such as using tools to pull away the insulation of the copper wire or flattening the plastic bottles and cans. Men would feed scrap cables into machines that run an incision along the insulation or melt the solder on the circuit board like alchemists. A suburban recycling station could be makeshift in a closure or outdoors. I had frequented some of these makeshift recyclers during my years living in mainland China. Rural women usually rode their tricycles on which was a flatbed to residential communities. They bought back used newspaper, cardboards, plastics, cans, old home goods from residents. During down time with no customers, they sat by the tricycles and painstakingly sorted their wares—piles of metal fragments, giant bales of wire, mountain high cardboards stacking up in the flatbed. They did not wear gloves or any protecting outfits. Bare, dirty hands were often marked with scars or healing wounds for which an American worker would claim a "workplace injury." The Basel Action Network (BAN), a Seattle-based watchdog group, has long criticized American unethical companies that greenwash themselves as "recyclers" and dump toxic chemicals overseas, including the junk yards in Hong Kong where "workers and the environment are exposed to dangerous toxins, such as mercury. (Recycling Today, 2016)"

A BAN project in 2016 revealed that 40 percent of printers and monitors that were planted with GPS trackers had been exported from the U.S. to "highly polluting and unsafe operations in developing countries—mostly in Asia." Hong Kong topped the list of favorite destinations which received the most electronic junk, with 37 tracked devices, following by mainland China with 11 tracked devices. Most of the tracked devices were found in 48 locations in the suburban New Territories (Figure 21), the largest region of Hong Kong (Choi, 2016). Since 2018, China's waste import bans has removed the "collect, sort, export" system on which the West had long relied, quickly driving neighboring Southeast Asian countries to follow suit and refuse foreign waste. Malaysia, Indonesia and the Philippines are taking progressive action (SCMP, 2019). Last summer, the Philippines shipped back the e-waste to Hong Kong after the former U.S. territory returned 69 containers of trash to Canada (BAN, 2019).

*Figure 21. Toxic electronic discards are exposed to air, water and heat at a Hong Kong scrap yard. Retrieved from The News Lens.*

As the demand for second-hand electronic goods in Southeast Asia, in particular, will ultimately decline as a result of their progressive economic development and tightening of import control over e-waste, Hong Kong is one of the many developed economies that see exporting the waste unsustainable in the long run. Other like-minded jurisdictions, including California and the European Union, whose landfills are being gradually regulated, and governments are mandating cuts to the volume of waste being landfilled (The Economist, 2018). In Hong Kong, the business-as-usual reliance on shipping one's own e-waste problem to other jurisdictions was disrupted at the end of 2018 following the implementation of the Producer Responsibility Scheme on Waste Electrical and Electronic Equipment (WPRS) (HKGOV, 2018). The WPRS allows the public to have old fridges, washing machines, computers, printers and other household items taken away free of charge (Kao and Gurung, 2018). The licensed recyclers are paid to store, treat, reprocess or recycle the waste appliance locally. Civil societies also partner with the licensed recyclers to refurbish and redistribute second-hand personal electronic goods to underprivileged families, especially those with schoolchildren who do not have electronic devices to continue remote learning during the covid months.

Hong Kong has one of Asia's highest rates of e-waste generation per capita. Compared to mainland China, Hong Kong may lead in transparent governance, free flow of information, goods and services, and worldly Hong Kongers may be more engaged in WPRS in response to the increasing awareness of environmental protection. Nonetheless, living under the shadow of Beijing's overreach, Hong Kong's environmental policies may raise eyebrows amid democracy-loving citizens, many of whom are millennials and generations born after 2000. It is too early to tell if the new e-waste management system can stand the test of time, especially in response to the rapid technological change in the Asia-Pacific region, a geographical advantage that Hong Kong embraces.

### 3.2.3 E-waste Hub: Guangdong Province

Across the river from Hong Kong is Shenzhen, China's technology and innovation hub. Dubbed by media as China's Silicon Valley, Shenzhen is a thriving metropolis with a population of 13 million people (Leju, 2020), ranking as the second largest city in Guangdong province in 2019. Guangdong province is the closet mainland province to Hong Kong geographically and culturally. Located in South China, Guangdong has been China's southern gateway to the world for many centuries as well as China's economic powerhouse in the past four decades. As such, China's electronic industry is mainly in Guangdong, accounting for 33 percent of the industry manufacturing (Figure 22). As you can see in Figure 22, the Pearl River Delta region in South China and the Yangtze River Delta region are the cradles of China's electronic manufacturing. About 70 percent of the world's smartphones are assembled

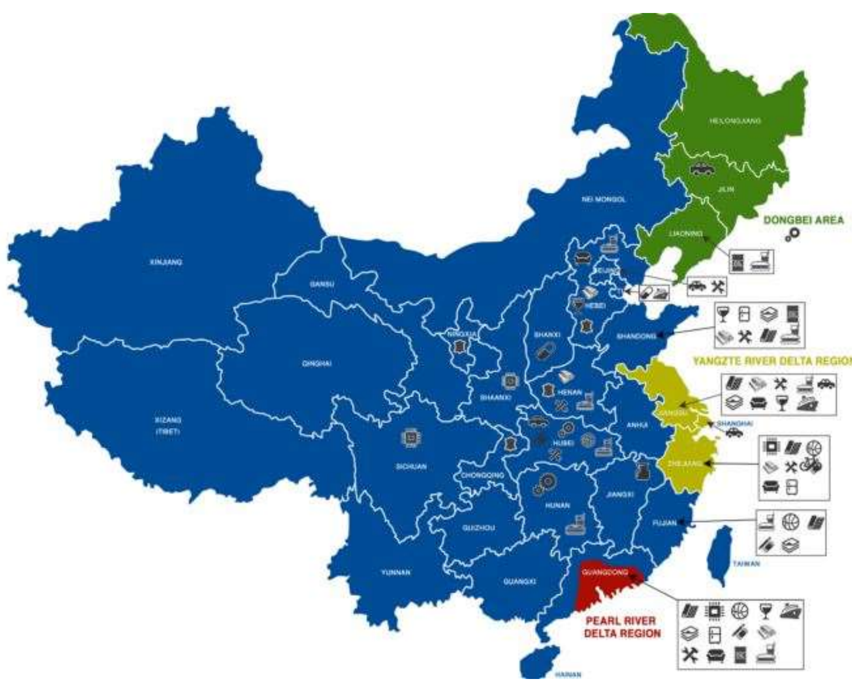



*Figure 22. Map of China Manufacturing Distribution. The world's factories are mainly located on the east coast. The Pearl River Delta region in South China leads the pack in innovation power. Retrieved from [Berkeley Sourcing Group](Berkeley Sourcing Group).*

in one region of China. Another sub-region accounts for half of global laptop production (The Economist, 2020). China's Huawei is headquartered in Shenzhen. So are many a global IT brand.

Because Guangdong is the first province in China to fully open to the world for trade and tourism since the 1980s, it is no doubt the first province to be exposed to hazardous electronic waste imported from foreign countries. Adam Minter recounted in his book *Junkyard Planet* that among the top five Chinese scrap-importing provinces that conform perfectly to China's top five provincial GDPs, Guangdong was the first (Minter, 2015). He continued, "By the late 1990s Shenzhen and the cities around it had also become the world's leading importers of scrap metal, paper, and plastic. They had become, quietly, the Scrapyard to the World, a place where wealthy countries sent the stuff that they couldn't or wouldn't recycle themselves. (Minter, 2015)" Today, Shenzhen would turn itself into a perfect place for urban mining. An urban mine is the stockpile of rare metals in the discarded electrical and electronic equipment waste of a society. Urban mining is the process of recovering the compounds and elements from municipal solid waste through mechanical and chemical treatments. I will elaborate on this idea about urban mining in the following pages. But first, let us look into China's middle class as the major makeup of electronics consumers and e-waste contributors.

Homemade e-waste in China is growing dramatically partly because of the increase in middle-class urban dwellers. And China's tightening environmental screw reflects the central government's response to the demand of the burgeoning middle class. According to a study by McKinsey & Company, a consulting firm, 76 percent of China's urban population will be considered middle class by 2022 (Iskyan, 2016). If the middle class in the United States and its counterpart in China are comparable, and if the middle class symbolizes the purchasing power of a country, I argue that the Chinese middle class may also fall into the Diderot effect that is seen among the American middle class. Named after the French philosopher Denis Diderot (1713-1784), the Diderot effect is a social phenomenon to describe all the products that are purchased by a consumer aim to be cohesive with that consumer's identity. The introduction of a new, atypical product can trigger a process of spiraling consumption (Nerdwriter1, 2014). In other words, America's overconsumption as mentioned in **SEG. 3.1.3 E-waste to export** might also happen in any given affluent society, in particular, the wealthy coastal cities in China where the Chinese middle class concentrates. The Chinese middle class is often portrayed as patrons of international high-end luxury brands. From the Apple Watch to Samsung's $2,000-worth foldable phone (Liedtke, 2020), electronic personal devices are beyond average consumer goods but become class identifiers. The current covid pandemic shows that not every middle class American family has stable internet at home or a digital device for telework or remote learning. There have been active studies about how income is an important determinant of environmental impact (Monbiot, 2019). The Chinese middle class may just spend as much as they see fit on electronic devices. In addition, since repair is more expensive than replacing a smartphone, Chinese consumers, now richer and, like their American counterparts, more and more prefer to buy new. The dynamics of consumption patterns in socioeconomics are complex systems being studied in the field. We should not overlook the impact of consumer behavior on electronics consumption and disposal.

With respect to China's Extended Producer Responsibility (EPR) system, a signature legislative move in China's green economy, I have read and compared a number of research papers and articles in both English and the Chinese language. It is not surprising to me that China's government hierarchy is siloed and onerous, leading to a poorly coordinated system. As a commentary in *Nature* read: "[China's system] involves more than ten departments publishing regulations, imposing disposal fees, providing subsidies and monitoring pollution and illegal imports with little crosstalk. (Wang, Zhang and Guan, 2016)" I constantly bumped into conflicted and confusing information and data. For example, in terms of the inception time of China's EPR system, one Science Direct article (Cao et al., 2016) timestamped the government implementation in 2012 whereas the article from China Dialogue, a think tank, gave credit to the year of 2017 (Feng, 2017). The Chinese official announcement about the EPR system was made on December 25, 2016 (State Council, 2016). Come what may, China is testing the waters by pushing for the EPR system, in which a government-backed fund is established for the treatment of waste electronical and electronic equipment, also known as the WEEE treatment fund. Before I go deeper into the domestic e-waste recycling, I'll take a broad-brush approach to understand the history of the system. Donella H. Meadows once wrote, "Long-term behavior provides clues to the underlying system structure. And structure is the key to understanding not just what is happening, but why. (Meadows, 2008)" That accurately explains why a system thinker first look for data, time graphs, and the history of the system when she encounters a problem.

China's environmental record was not as impressive as its economic achievement, by a long shot. What we might see today in some hidden Hong Kong's junk yards or those in Ghana's Agbobloshie, Nigeria's Olusosum, and Bangladesh's Dholaikhal are not too far behind from Chinese people's memory, especially for those who live around the scrap yards. From unbreathable air in major cities to water and food security problems, China's economic growth is a trade-off between development and environment. The notorious Guiyu, a river town in Guangdong province, is a testament to the transformation of China's e-waste recycling practices. As an e-waste dumping ground, Guiyu's soil, air and water were extremely contaminated after e-scrap and other municipal solid waste were strewn along the river, by the roadside, and even as close as to locals' dwellings. Elevated blood lead levels were found in local children, and more newborns were afflicted with cerebral palsy and other diseases. Following international exposure and the Chinese government's fervent cleanup for two decades, the river town now has become China's pride to showcase a recycling economy in a regulated industrial park (Figure 23). As you see in the right panel, this is post-cleanup Guiyu in a screenshot from Nanfang Daily, a state


*Figure 23. China's e-waste hub Guiyu before and after cleanup. On the left, villagers were searching for valuable materials from e-scrap. On the right, the recycling operation has been moved into a circular economy industrial park. Image courtesy of Associated Press and Sina Tech.*

news group. At the entrance of the Guiyu industrial park, the Chinese characters read: Chaoyang Guiyu Circular Economy Industrial Park. The video (SCMP, 2017) from South China Morning Post, an English newspaper owned by Chinese billionaire Jack Ma, gives a lively before-and-after overview of the e-waste hub. So, we may deduce that some of the keywords that are hotly-debated, well-researched in the Western academia are now applied to China's sustainable development. Circular economy is a great example.

In contrast to the current linear economy which follows a take-make-dispose consumption pattern (Figure 24), circular economy aims to gradually decouple growth from the consumption of finite resources. It consists of three principles: design out waste and pollution; keep products and materials in use; and regenerate natural systems (Ellen MacArthur Foundation, n.d.). As mentioned in **SEG. 3.1.1 Overview**, a circular economy is similar to the concept of Zero Waste. In theory, if we can reuse our waste 100 percent and create new value from waste, the circle of resources and services will keep spinning. But our economic life involves negative externalities. They occur when production and consumption impose external costs on third parties outside of the market. Simply put, pollution causes social costs to exceed private costs. If the pollution is too serious such as that in Guiyu before cleanup, locals got sick and wounded, harming supply chain flow. Not only that unhealthy laborers might lose productivity but their physical inability and their unhealthy children due to pollution would also burden the society. A classic reinforcing feedback loop.

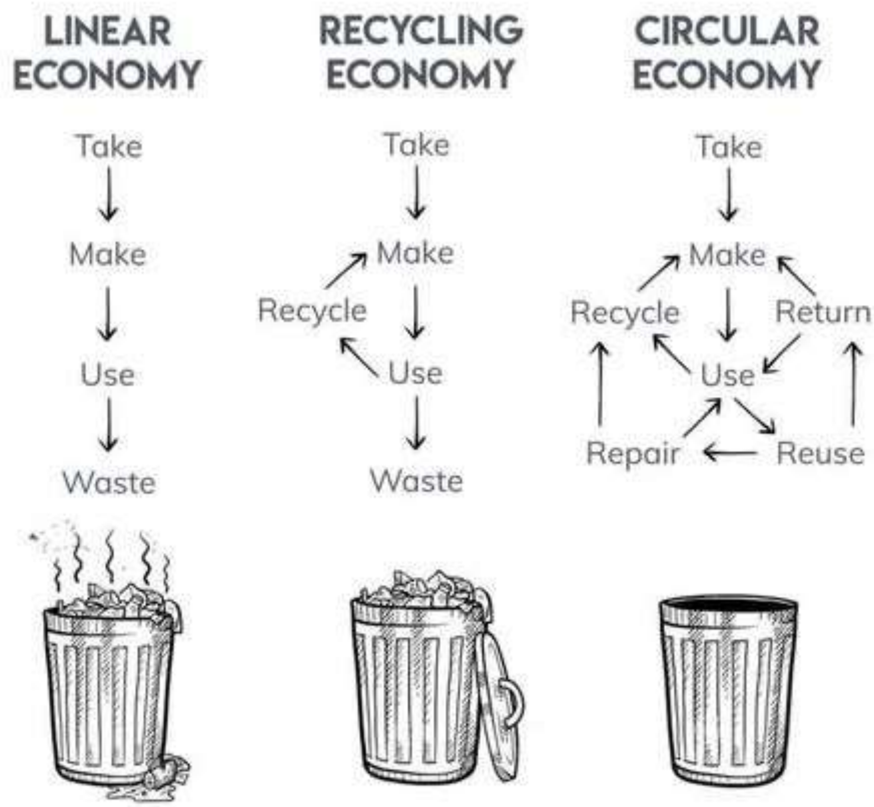



*Figure 24. Circular economy vs. Linear Economy. Retrieved from The R Collective.*

That said, when we remanufacture new products and recreate new values from end-of-life materials, we need to factor in how resource-intensive the recycling process could be that might compromise overall sustainability. Will there be "unintended consequences (Moss, 2019)" when we rush to realize a circular economy? In my opinion, the human-centered design or the disposal-center design is a matter of perspective. The DSRP theory reminds us to think from

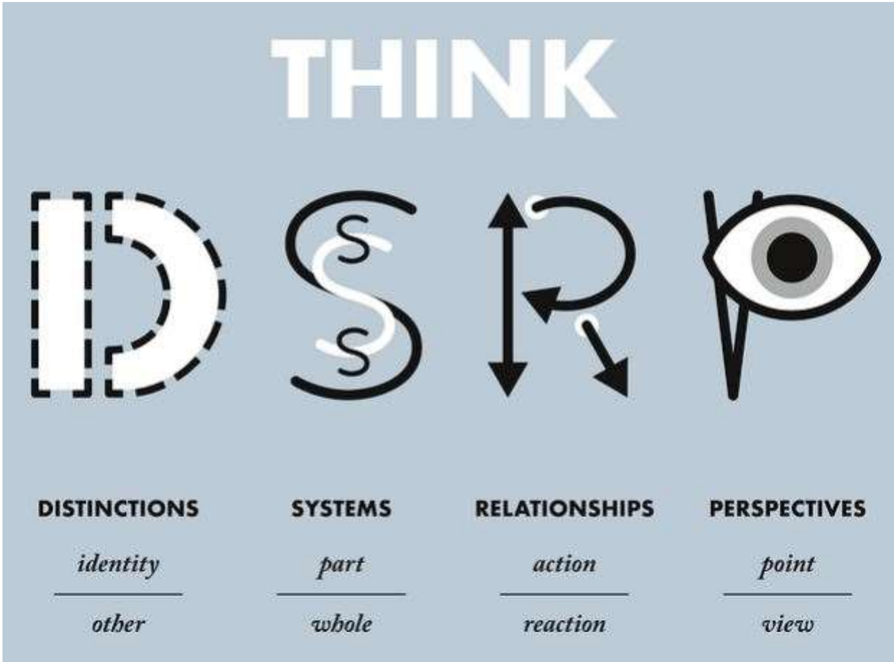



*Figure 25. The DSRP Theory in a poster. Infographic by Scott Moehring.*

Distinctions, Systems, Relationships, and Perspectives (Figure 25). We cannot ignore pollution generated from production and consumption. We have made a distinction out of it. With respect to e-waste recycling, how we can turn trash into treasure is an ongoing research subject both for manufacturers (e.g. industrial design, value chain restructuring) and for consumers (e.g. consumer behavior, consumer experience). We would need systems thinking as well as grasp the relationships between different systems in the hope of searching for a solution that shares the commonalities and interests of as many stakeholders as possible.

Tackling waste with human-centered design requires ingenuity and innovation. Circular economy's three principles allow intelligent people to redesign our finite world. Perhaps this is what makes the experiment of circular economy exciting and full of expectation and hope. Necessity is the mother of invention. China's decision to reinforce green economic recovery from covid is not only because of environmentalism but because of survival—both for the ruling Communist party and for the competitiveness of the country. According to Greenpeace, the value of metals discarded as electronic waste in China will total $23.8 billion USD by 2030, a sum that can be reclaimed through recycling and "urban mining" at cheaper costs than retrieving the same amount of metals through virgin ore mining (Greenpeace, 2019). After reading multiple research papers and talking to Chinese professionals in the field, I am confident to validate my view that China's biggest interest in e-waste recycling is rare metals and battery recovery. China may not have the industrial technology and legacy to compete with fossil-energy vehicle manufacturers in the U.S. or even with the neighboring Japan and Korea. Nonetheless, with the world's largest automobile market, both in terms of demand and supply, China is expected to lower the cost of auto electrification just as it did with the lower-priced solar panels. The World Economic Forum, citing a study, finds solar now is "cheaper than grid electricity" in every Chinese city (Gabbatiss, 2019).

I have brought up Shenzhen in the beginning of this segment. Shenzhen has been China's first special economic zone since May 1980, meaning the city is one of the earliest beneficiaries of foreign direct investment after China's economic reform. Dubbed as "the metropolis of migrants," Shenzhen mirrors all the traits that a boom town in industrialized America had—a marketplace of new ideas, young workforce from immigrants, experimental, globally open, and government-backed incentives. The latter is the very ingredient to success for any Chinese municipality under a one-party system. Similar to the top-down, subsidy-fueled approach given to Chinese automakers and car owners for the electrification of transportation, China introduced the WEEE treatment fund (WEEE stands for Waste Electrical & Electronic Equipment) in 2012 (Cao et al., 2016; Zhao and Yang, 2018). The technicality of WEEE treatment fund is complex and lacks consistent data for analysis. But it is an interesting system in and of itself that is overseen and implemented by multiple governmental agencies and their contractors.

Shenzhen is home of many unicorn startups as well as IT giants. Among them is GEM, the world's biggest battery recycler. Heavily favored by stock analysts according to a Bloomberg report (Bloomberg, 2019), GEM aims to collect and process 30 percent of China's discarded electric vehicle batteries, projecting that some 39,000 tons of cobalt and 125,000 tons of nickel could come from spent batteries by 2030. No home base is better than Shenzhen for GEM to realize its Chinese Dream of urban mining. Inspiring success stories like this are plenty in China, especially in coastal cities and provinces. Since 2009, the Chinese government has continuously issued a series of laws and regulations in order to establish an e-waste management system based on EPR principles (Cao et al., 2016). Similar to the frustrating situation in the United States, Chinese recyclers have been stockpiling millions of pounds of old cathode ray tube (CRT) TVs and monitors (Figure 26). An old-style CRT computer screen can contain up to 6 pounds of lead (Vidal, 2013). In the past, the glass tubes of a legacy TV could be melted down to make new CRTs. But people who abandoned CRT sets have largely replaced them with LED and plasma televisions, which don't contain lead. That means there is very weak demand for the lead-filled glass (Wagstaff, 2016), thus lowering incentives for recyclers to collect and for manufacturers to reuse and remanufacture. After four decades of economic development, China has the capability and capacity of recycling its domestic, overwhelmingly unwanted electronic goods. Drawing experience from mainly European countries, China adopted the extended producer responsibility strategy to incentivize manufacturers to increase the end-of-life (EoL) recovery processes.

*Figure 26. Recyclers are stockpiling millions of pounds of toxic glass from cathode ray tube TVs or monitors. Retrieved from Dreamstime.*

As part of China's EPR system that requires manufacturers to take responsibility for the entire lifecycle of a product, especially for the collection, dismantling and reuse at its end-of-life stage (Cao et al., 2016), the WEEE treatment fund is composed of two parts by design: taxation (the inflow of capital) and subsidies (the outflow of capital). The responsibilities of producers, importers and recyclers are exemplified in their regular payments for each unit they produce or import—the producers would pay into the fund quarterly via the tax authority whereas the importers pay when declaring their import products to Customs via the customs authority. The certified recyclers must provide the necessary proof of the e-waste they have recycled or disposed of in order to apply for a subsidy (Liu, 2014). As of 2018, a total of 109 recycling companies have been authorized to be funded, with total treatment capacity of about 152 million units WEEE per year (Zhao and Yang, 2018; Tan, 2019). The WEEE treatment fund is valid for at least five categories of WEEE—the TV set, refrigerator, washing machine, air-conditioner, and personal computer, with a potential of expansion of categories beyond my knowledge. The subsidy rates are adjusted and graded at the discretion of the government. According to Wind-Financial Terminal, a Chinese financial firm, between 2012 and 2017, about 14.3 billion RMB of treatment subsidy was paid to the funded companies, recording 7.8 billion RMB shortfall in budgeted expenditure of 22 billion RMB. As for the inflow of capital via taxation and fee payments, the treatment fund received 14.6 billion RMB, recording about 4 billion RMB shortfall in budgeted revenue of 18.6 billion RMB (NBD, 2019).

Here, I have a couple of observations from the perspective of the manufacturers and recyclers. First, regardless of the astronomical figures by comparison, the WEEE treatment fund needs more engagement from stakeholders instead of government-directed resources and capital flow. Without taking time graphs into account, Chinese manufacturers are less motivated to pay disposal fees for old home appliances that might be even older than the history of the new tech companies. Not to mention private firms tend to have a harder time to compete with state-owned enterprises for state subsidies.

Second, smart devices including smartphones, iPads, Apple Watches, e-readers and many other smart and small digital gadgets should be included in the subsidy categories. Their end-of-life pollution in the landfill or scrap yards could be greater than home appliances because of their quantities and component makeup. The small size of a smartphone makes it convenient to carry and get broken or lost as well. With time graphs in mind, how often do we replace a smartphone as opposed to replacing a flat screen TV? How often does a manufacturer introduce a new model of portable computer as opposed to a new model of washing machine? We may be achieving more from using fewer resources as Andrew McAfee advocated in his book *More From Less*, but we should not easily fall into a trap in a system that systems thinkers warn or into complacency shared by technocrats. Because a smartphone is small in size, it is much easier for us to find a replacement for it than, say, replacing a car with an electric motor. It is also because a smartphone is small in size and is becoming a personal item in emerging markets, manufacturers are more engaged in producing more small personal gadgets than, say, investing in redesigning a refrigerator that could achieve net zero emission in its entire lifecycle.

One of the multifaceted solutions to creating a circular economy is to extend a product's life span and to prolong user experience of a product. If a smartphone's lifecycle is extended, meaning a user would hold onto her phone longer; subsequently, revenue will be slower to generate—supposedly there is no increase of buyers or prices per unit—resulting in slower-to-stagnant capital flows for investment. An alternative to generate profits would be tackling the luxury good market in which expensive smart devices are produced and sold to an exclusive consumer group. The Diderot effect as mentioned previously allows us to dream of the customer demographics for those $2,000 Samsung foldable phones. All said, China's e-waste subsidy scheme to certified recyclers can curb illegal e-waste recycling but the fund ledger that looks seemingly red calls for a diversified and flexible fund management.

The Chinese government has deployed an array of policies to gain an advantage in a strategic technology while the United States falls behind. There is no federal-level e-waste legislation at present. However, e-waste treatment bills based on producer responsibility have been passed in 24 states since 2004 (Cao et al., 2016). In addition to the WEEE treatment fund as a top-down, subsidy-fueled approach in China, the bottom-up participation of e-waste recycling via e-commerce platform is taking shape and thrive in recent years. In general, there are two types of online secondary electronics recyclers—Customer to customer (C2C) and consumer-to-business (C2B). Here are a few examples for readers to explore:

C2C model:

- Xianyu (https://2.taobao.com/), or literally, Idle Fish, is a mobile app connected with Alibaba's Taobao for secondhand goods trading. Launched in June 2014, the C2C platform is somewhat similar to Facebook Marketplace or Craigslist.

- Zhuanzhuan (http://www.zhuanzhuan.com/), meaning "exchange exchange" in colloquial Mandarin, is another mobile app for secondhand goods trading.

C2B model:

- Huishoubao (https://www.huishoubao.com/), "the recycled gem" in Chinese, is a C2B online platform that focuses on recycling mobile phones, iPads and other digital gadgets. Headquartered in Shenzhen, Huishoubao Tech Ltd. received strategic investment from e-commerce giant Alibaba in 2018. The company has provided trade-in services to drive the sales volume of several leading Chinese smartphone brands (Huishoubao, 2019).

- Aihuishou (https://www.aihuishou.com/), "Love Recycling" in Chinese, is Huishoubao's top competitor. The C2B online platform is for secondhand 3C products, that is, Computer, Communication, and Consumer electronic goods. Headquartered in Shanghai, Aihuishou welcomed a merger last year with another secondhand e-commerce platform Paipai from JD.com, China's second largest e-commerce company (Heles, 2019).

- Alahuanbao (http://www.alahb.com/) is an online recycling platform endorsed by the Shanghai municipal government. It is an experiment of a regulated e-waste collecting system in which consumers and recyclers can track and manage electronic disposal (Tan, 2019).

China's formal e-waste recycling has just begun. But China's informal recycling has been in business for as long as the country has been open to the world for trade and trials. China's projects are in big scale, both in implementation and in impact. So, to better understand China, I would do as the Chinese classic philosophers did and think systematically as if I were their pupil. Chinese traditional thoughts have long emphasized the relationship and structure of the object (Xu, 2005). For example, the teaching of Confucius studied man and society from a perspective of relationship and structure. It thinks the society is a system with a structure of several levels. The structure is arranged in increasing order of importance: the first level is the world, the second level is the country, the third level is the family and the fourth level is the man. The heart, thoughts, and knowledge of a man are the most important leverage points for improvement. The original literature can be retrieved from these two sources (Baidu Baike, n.d.; UCSD, 2020).

If we need a critical eye for everything about China, perhaps the Chinese systems thinking overlooks the ubiquitous delays in systems. Every stock is a delay. Most flows have delays. When Chinese leadership touts the exceptional speed in completing the state-funded projects or the rollout of a policy, it will take much longer for the systems to respond and react. For example, in relation to waste management as some of the e-waste will be landfilled, the world's largest waste-to-energy plant is being sketched on the outskirts of Shenzhen. Once completion, the plant is expected to process up to 5,000 tons of waste each day, accounting for about one third of the city's total daily municipal solid waste, and to produce electricity for 20 million plus people (Wood, 2019). Good news as it sounds, but the amount of waste in the city is increasing by 7 percent a year. How should the city cope with an increasing urban population and its waste problem? Doing so requires a regular review of the current system and planning with a much longer-term vision.

### 3.3 Global examples

E-waste recycling is not only an American problem or a Chinese problem. It is the world's problem. According to a report by the United Nations Environment Programme (UNEP), Africa and Asia are key destinations for large-scale shipments of hazardous wastes for dumping, and sometimes for recycling (UNEP, 2015). Ghana and Nigeria are among the largest recipients in West Africa while Hong Kong, India, Bangladesh appear to bear the brunt of illegal e-waste shipments. Many poor nations, especially in Africa, have "few or no laws on e-waste" as a study by *Nature* found (Wang, Zhang and Guan, 2016). So, it lays out clear to us that regulations and international cooperation are necessary to tackle this wicked problem. As mentioned previously, the Basel Ban Amendment to ban hazardous waste exporting from developed countries to developing countries is an international law. Despite the achievement of the Ban Amendment, the powerful industries such as the electronics and shipping industries are now trying to change the definition of the ban to which it applies (Recycling, 2019)—an area that concerned global citizens should watch out. International law enforcement is crucial to crack down illegal e-waste smuggling. A good example is the dismantling a "green laundering" criminal network by Spanish authorities this summer (BAN, 2020). Some 2,500 tons of waste including hazardous electronic equipment has been seized and 34 people arrested. China's waste import ban has upended the politics of plastic waste and waste management in developed countries as well as emerging markets. Thailand will ban foreign plastic waste by 2021, with Vietnam to follow suit by 2025. Malaysia, which took the largest share of trash after China's import ban, has cracked down on illegal plants burning plastic without a permit (DW Environment, n.d.). If the legislation of plastic waste is gradually in place, will that of e-waste be far behind?

On the circular economy front, the European Union has mandates promoting product redesign so that the materials can be captured and reused. Billed as "the right to repair," the European Commission wants manufacturers of phones, tablets and laptops to set standards so these goods consist of changeable and repairable parts (Rankin, 2020). In fact, Fairphone, a Dutch company, has introduced a replaceable model that is designed for easy repair, upgrade and eventual recycling (Figure 27). The life span of the Android-powered Fairphone 2 is estimated three and five years before needing replacement (Harris, 2017). Readers would be amused by the way the

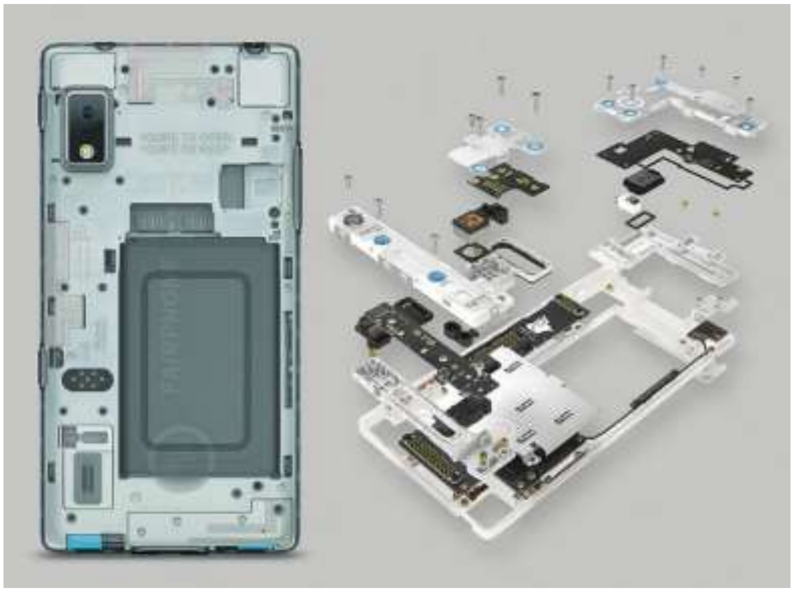


*Figure 27. Amsterdam-based Fairphone 2 is designed to be easily repaired and upgraded. Retrieved from 1843.*

company boasts on its website Fairphone 2 is “the world’s first ethical, modular smartphone. (Fairphone, n.d.)” Post-Brexit UK also plans to get its first commercial bio-refinery for extracting precious metals from electronic waste. The recycling process will be the world’s first to use bacteria (Palmer, 2020). Scientists around the world are looking for bio-based substitutes in our finite world. I find these two examples in battery recovery and replacement illuminating: one is from Virginia Tech researchers who have developed a battery that runs on sugar and has an unmatched energy density (Virginia Tech, 2014). The other is from Singaporean scientists who have developed a novel method of using fruit peel to extract and reuse precious metals from used lithium-ion batteries (Nanyang Technological University, 2020). To back up circular economy, urban mining is a promising playground for entrepreneurs, treasure hunters and dreamers (DW Natural Resources, n.d.).

*"Living successfully in a world of systems requires more of us than our ability to calculate. It requires our full humanity—our rationality, our ability to sort out truth from falsehood, our intuition, our compassion, our vision, and our morality."*

---Peter Senge,
author of *The Fifth Discipline: The Art and Practice of the Learning Organization* (1990)

## PART IV CONCLUSION

As former U.S. President Barack Obama once said, the U.S.-China relationship is "the most important bilateral relationship of the 21st century. (Li, 2016)" Politicians of both countries see more distinctions than commonalities of one another. The DSRP theory guides us to think farther and look from a higher vantage point. Although both countries have their own distinctive systems varying from governance to business practices, international trade and irreversible damage from climate change push these two systems closer rather than far apart. The finite world is a complex system in and of itself. The planet Earth does not speak a human language but it has shown all kinds of aches and pains while its high temperature is so relentless that extreme wildfires and draught persist. The world's two biggest economies and e-waste producers are one of, if not the most, determining intergovernmental partnership to promote peaceful sustainable development and to lead humanity out of havoc. While owning a smartphone is no longer a rarity, the components that make up of a smartphone are rarer and rarer, especially when demand grows by numbers and by rate of replacement. Prospectors are looking for natural ores in places once considered too remote to mine such as the Arctic, the deep sea and even the asteroids nearest Earth (Lim, 2020). The other alternative would be a wealth of human waste products: from wastewater and discarded consumer electronics to gaseous waste and urban mines, you name it. After this research, one of my biggest revelation is we don't run out of solutions—in fact we have plenty of them, we just need momentum to translate ideas into action.

Taking a historical perspective, China is undergoing a similar trajectory of industrialization to that of the United States in the 19th century when America's economy shifted from agriculture to manufacturing. Pollution is a price humanity has to pay for sustaining growth propelled by new technology. Manufacturing created new products as well as new wasteful byproducts. As more factories were built, the mount of hazardous waste began to grow. Pittsburgh used to be one of the most polluted American cities and it was also an affluent city in the glory days of steel and coal mining (Figure 28). There are many Chinese cities with factories sharing similar urban history like Pittsburgh's yesterday. Many of them used to be in Guangdong province which is headquarters of the world's manufacturing factories. Rome wasn't built in a day. Grievances about poor air and water quality accumulate in the course of development. When a business ecosystem cannot tolerate pollution generated from production and consumption, or when a system reaches its breaking point, its intrinsic mechanism with one of three characteristics—resilience, self-organization, or hierarchy—will appear to restore a system (Meadows, 2008). The environmental movement in the U.S., the establishment of the Environmental Protection

Agency, and a string of environmental legislation and enforcement are analogous to resilience in a system. China's environmentalism, including policymaking in e-waste recycling, creates a new structure to learn, diversify, and complexify—the property of self-organization in a system.

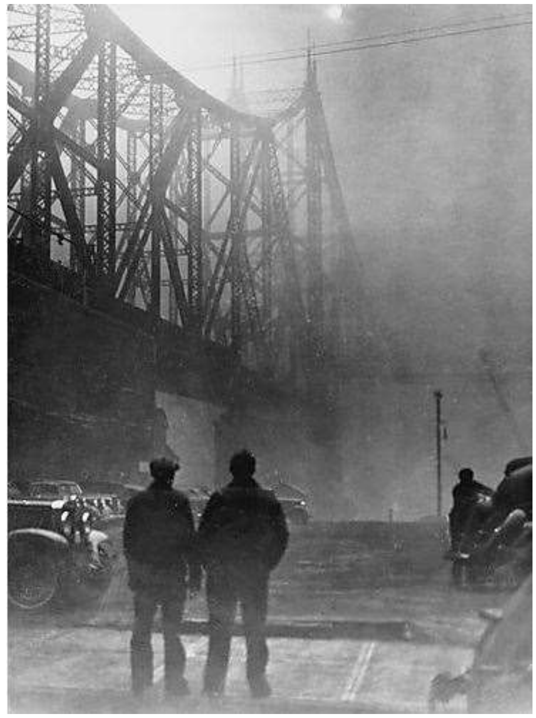


*Figure 28. Two men stood in the smoky Pittsburgh downtown around 1940s. Courtesy of the University of Pittsburgh's [Smoke Control Lantern Slide Collection](). *

As mentioned, China's form of government is authoritarian comparable to a reinforcing feedback loop whereas the United States presents itself, in spite of the incumbent administration, as a democracy, which is comparable to a balancing feedback loop. If e-waste recycling is a political issue in the eyes of policymakers, perhaps these two feedback loops can do magic together rather than harm. I second Adam Minter's view in his book, *Junkyard Planet*, that "how tightly connected Chinese demand for American recycling is to American demand for Chinese goods." Given the intertwined financial coupling as a result of China's green finance policies to entice foreign investment, it would be harder for the U.S. to decouple from China than rebuild trust for a shared interest. More important, scrap recycling in general is more of a business than an environmental crusade. Formal e-waste recycling requires public-private partnership and change of consumer behavior. The latter is harder to do due to uncertainties derived from demographics, socioeconomic variables, knowledge gap, and can-do spirit. But in terms of digital possessions, one thing in common for both American and Chinese consumers is that majority of middle class consumers are victims of overconsumption. Lax regulation and fiercely competitive consumer electronics market are largely to blame, leading to a toxic deluge of e-waste in both markets.

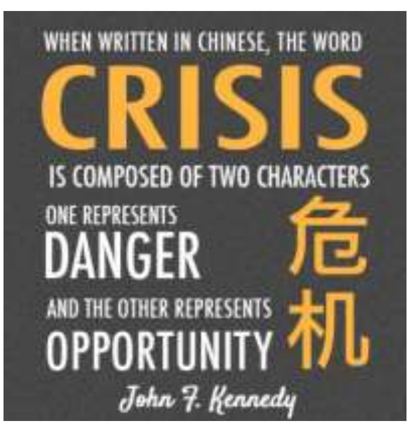



*Figure 29. The word "crisis" in Chinese has two meanings. Retrieved from Workplace Psychology.*

China may lead in e-waste management regulation and efficiency but lacks transparency in performance evaluation and stakeholder coordination. China's state capitalism sheds suspicion on favoritism to state-owned enterprises, potentially leading to diminishing competitiveness and innovation from private companies. The U.S. falls behind in e-waste management regulations and the out-of-sight-out-of-mind recycling approach faces pushback from an increasing number of environmentally conscious citizens and developing countries. The word "crisis" in Chinese is composed of two characters, *wēi* means danger, and *jī* means opportunity (Figure 29). China's waste import ban may create a waste crisis in the waste export countries but it may also expedite the transformation of turning waste into treasure. The United

States lacks a strong and low-cost manufacturing workforce but it may inspire the integration of artificial intelligence and robotics to select and sort recyclable electronic goods. After all, which manufacturer will turn down a money-making opportunity that focuses on efficiency, product design, and reuse of material? The U.S. is still the "Saudi Arabia of Scrap" while Chinese cities are shifting from the "Scrapyard to the World" to livable communities with hidden mines of treasure.

The double crises of the covid pandemic and climate change make e-waste management more challenging. People stuck at home are de-cluttering whereas fewer workers than normal time are collecting and recycling the junk. In the longer term, e-waste volume is predicted to increase as a result of COVID-19 (Wilkinson, 2020). We may assume American recyclers will face a heavy backlog after shutdown. Global warming increases risks of toxic chemicals from e-waste being released into the atmosphere during inadequate recycling. Hurricanes and wildfires in the U.S. and severe floods and torrential rain in China are extreme weather events of 2020 caused by climate change. Amid the escalating tech war between the U.S. and China, both countries are expected to produce more e-waste on grounds of national security and technological independence than reuse and share technogical achievements and infrastructure. Also, millions of smartphones, modems and gadgets incompatible with 5G networks will be made obsolete in the near future. As a result, the e-waste problem, if not alleviated timely, will create its own crisis. Confronting the conundrum of nonrenewable metals that make smartphones so "smart" in our ever technologically-integrated world, reimagining e-waste recycling is a no brainer.

## REFERENCES


*Adam, Minter. (2015, April 14). Junkyard Planet: Travels in the Billion-Dollar Trash Trade. Bloomsbury Press. Illustrated Edition. (Electronic version) p.11, p.15, p.89, p.73, p.105, p.31, p.296, p.301, p.83, pp.96-97.*

*Ali, S., Giurco, D., Arndt, N. et al. (2017, March 16). Mineral Supply For Sustainable Development Requires Resource Governance. Nature 543, 367-372 (2017). https://doi.org/10.1038/nature21359*

*Apple Inc. (2018). Environmental Responsibility Report: 2018 Progress Report, Covering Fiscal Year 2017. https://www.apple.com/lae/environment/pdf/Apple_Environmental_Responsibility_Report_2018.pdf*

*Apple Inc. (2018). Environmental Progress Report: Covering Fiscal Year 2019. https://www.apple.com/environment/pdf/Apple_Environmental_Progress_Report_2020.pdf*

*Argus Media. (2020, July 2). China On Track to Revive Ferrous Scrap Imports. Argus Media. https://www.argusmedia.com/en/news/2119661-china-on-track-to-revive-ferrous-scrap-imports*

*ARM Developer. (n.d.). Introducing the Arm Architecture. Overview. https://developer.arm.com/architectures/learn-the-architecture/introducing-the-arm-architecture/single-page*

*BAN. (2020, July 23). Group Smuggling E-Waste to Africa Busted in Spanish Islands. Basel Action Network (BAN). https://www.ban.org/news/2020/7/23/group-smuggling-e-waste-to-africa-busted-in-spanish-islands*

*BAN. (2019, June 4). Hong Kong Electronic Waste To Be Shipped Back. Basel Action Network (BAN). https://www.ban.org/news/2019/6/4/hong-kong-electronic-waste-to-be-shipped-back*

*Baidu Baike. (n.d.). Xiushen Qijia Zhiguo Pingtianxia-Confucius teaching (Chinese). https://baike.baidu.com/item/%E4%BF%AE%E8%BA%AB%E9%BD%90%E5%AE%B6%E6%B2%BB%E5%9B%BD%E5%B9%B3%E5%A4%A9%E4%B8%8B*

*Baldé, C. P., Forti, V., Gray, V., Kuehr, R., and Stegmann, P. (2017). The Global E-waste Monitor 2017. United Nations University (UNU), International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Vienna. https://collections.unu.edu/eserv/UNU:6341/Global-E-waste_Monitor_2017__electronic_single_pages_.pdf*

*Basel Convention. (n.d.). Mobile Phones And The Environment. The Basel Convention. http://www.basel.int/Portals/4/download.aspx?d=UNEP-CHW-COP.11-SIDE.01A-Photoexhibition.English.pdf*

*Basel Convention. (n.d.). Parties to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal. http://www.basel.int/Countries/StatusofRatifications/PartiesSignatories/tabid/4499/Default.aspx*

*Bennett, N., and Lemoine, G. (2014, January). What VUCA Really Means For You. Harvard Business Review. January-February 2014 Issue. https://hbr.org/2014/01/what-vuca-really-means-for-you*

*Bloomberg. (2019, December 2). China Raises 2025 Electrified-Car Sales Target to About 25%. Bloomberg News.* *https://www.bloomberg.com/news/articles/2019-12-03/china-raises-2025-sales-target-for-electrified-cars-to-about-25*

*Bloomberg. (2019, November 25). The World's Biggest Battery Recycler Is Helping Fuel The Future of Cars. Bloomberg News.* *https://www.bloomberg.com/news/articles/2019-11-25/meet-the-professor-whose-firm-is-helping-fuel-the-future-of-cars*

*Cabrera, Derek. (2018, April 18). ThinkX Symposium 2018-Systems Thinking is a CAS (Video).* *https://www.youtube.com/watch?v=EdL198e3uuo*

*Cao, J., et al. (2016, September). Extended Producer Responsibility System in China Improves E-Waste Recycling: Government Policies, Enterprise, and Public Awareness. Renewable and Sustainable Energy Reviews. Volume 62, September 2016, pp.882-894.* *https://doi.org/10.1016/j.rser.2016.04.078*

*Casali, E. Folletto. (n.d.). 12 Leverage Points to Bring Change to a Complex System. Intense Minimalism.* *https://intenseminimalism.com/2015/12-leverage-points-to-bring-change-to-a-complex-system/*

*Center for Sustainable Systems. (2020). Municipal Solid Waste Factsheet. University of Michigan. Pub. No.CSS04-15.* *http://css.umich.edu/factsheets/municipal-solid-waste-factsheet*

*Certified Electronics Recyclers. (2019. May 17). The United States Environmental Protection Agency (EPA).* *https://www.epa.gov/smm-electronics/certified-electronics-recyclers*

*Choi, Y. (2016, October 5). Forty Percent of American E-Waste Imported Illegally (Chinese). The News Lens.* *https://www.thenewslens.com/article/50738*

*Collins, Barry. (2020, July 10). PC Sales Surge During Coronavirus Crisis—And HP's The Big Winner. Forbes.* *https://www.forbes.com/sites/barrycollins/2020/07/10/pc-sales-surge-during-coronavirus-crisisand-hps-the-big-winner/#2d5b7daa5227*

*Crawford, A., and Warren, H. (2020, January 21). China Upended the Politics of Plastic and the World Is Still Reeling. Bloomberg Green.* *https://www.bloomberg.com/graphics/2020-world-plastic-waste/*

*Depalma, Anthony. (2004, March 18). Love Canal Declared Clean, Ending Toxic Horror. The New York Times.* *https://www.nytimes.com/2004/03/18/nyregion/love-canal-declared-clean-ending-toxic-horror.html*

*Dijkstra, Arjan. (2019, March 13). What's In A Smartphone? (Video). University of Plymouth, United Kingdom.* *https://www.youtube.com/watch?v=bhuWmcDT05Q*

*Do Something. (n.d.). 11 Facts About E-Waste. Do Something.* *https://www.dosomething.org/us/facts/11-facts-about-e-waste*

*DW. (n.d.). After China's Import Ban, Where To With The World's Waste? Deutsche Welle (DW).* *https://www.dw.com/en/after-chinas-import-ban-where-to-with-the-worlds-waste/a-48213871*

*DW Environment. (n.d.). Amid Plastic Deluge, Southeast Asia Refuses Western Waste. Deutsche Welle (DW).* *https://www.dw.com/en/amid-plastic-deluge-southeast-asia-refuses-western-waste/a-49467769*

*DW Natural Resources. (n.d.). Urban Mining: Hidden Riches in Our Cities. Deutsche Welle (DW). https://www.dw.com/en/urban-mining-hidden-riches-in-our-cities/a-42913985*

*Eldred, Sheila M. (2020, April 14). When Did Americans Start Recycling? History. https://www.history.com/news/recycling-history-america*

*Ellen MacArthur Foundation. (n.d.). The Circular Economy In Detail. https://www.ellenmacarthurfoundation.org/explore/the-circular-economy-in-detail*

*EPA. (2020, September 18). Basic Information About Electronics Stewardship. The United States Environmental Protection Agency (EPA). https://www.epa.gov/smm-electronics/basic-information-about-electronics-stewardship*

*EPD. (n.d.). Introduction. Hong Kong Environmental Protection Department (EPD). https://weee.gov.hk/page.php?id=1.php&content=1&lang=1*

*e-Stewards official website. (n.d.). http://e-stewards.org/*

*European Commission. (n.d.). Developments and Forecasts of Growing Consumerism. https://ec.europa.eu/knowledge4policy/foresight/topic/growing-consumerism/more-developments-relevant-growing-consumerism_en*

*E-waste Monitor. (2020). The Global E-waste Monitor 2020. Home Page. http://ewastemonitor.info/*

*Facts and Figures. (2020, March 13). Facts and Figures about Materials, Waste and Recycling. The United States Environmental Protection Agency (EPA). https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials*

*Fairphone official website. https://shop.fairphone.com/en/fairphone-2*

*Feng, Hao. (2017, June 5). China to Release Plan For Tackling E-Waste by End of Year. China Dialogue. https://chinadialogue.net/en/pollution/9841-china-to-release-plan-for-tackling-e-waste-by-end-of-year/*

*Fishman, Karen. (2015, January 15). Scrap for Victory! Library of Congress. https://blogs.loc.gov/now-see-hear/2015/01/scrap-for-victory/*

*Forti, V., Baldé, C., Kuehr, R., and Bel, G. (2020, July). The Global E-waste Monitor 2020. The International Telecommunication Union (ITU). https://www.itu.int/en/ITU-D/Environment/Pages/Spotlight/Global-Ewaste-Monitor-2020.aspx*

*Gabbatiss, Josh. (2019, August 19). Solar Now "Cheaper Than Grid Electricity" in Every Chinese City, Study Finds. World Economic Forum. https://www.weforum.org/agenda/2019/08/solar-now-cheaper-than-grid-electricity-in-every-chinese-city-study-finds/*

*Glon, Ronan. (2017, November 4). Electric Car, Or Electrified Car? We Decode This Obnoxious Industry Jargon. Digital Trends. https://www.digitaltrends.com/cars/electric-car-or-electrified-car/*

*Great Forest Sustainability Solutions. (n.d.) How Is E-waste Recycled? (Video). http://greatforest.com/sustainability101/e-waste-recycled-video/*

*Greenpeace. (2017, December 29). China's Ban on Imports of 24 Types of Waste is a Wake Up Call to the World. Greenpeace East Asia. https://www.greenpeace.org/eastasia/press/1008/chinas-ban-on-imports-of-24-types-of-waste-is-a-wake-up-call-to-the-world-greenpeace/*

*Greenpeace. (2019, March 22). China's E-Waste Worth $23.8 Billion by 2030. Greenpeace East Asia. https://www.greenpeace.org/eastasia/press/1397/chinas-e-waste-worth-23-8-billion-by-2030-2/*

*Harris, Mark. (2017, January 17). Down With the Upgrade. 1843 Magazine. https://www.economist.com/1843/2017/01/17/down-with-the-upgrade*

*Heles, Thierry. (2019, June 10). Aihuishou to Process $500m JD.com-led Round. Global Impact Venturing. https://globalimpactventuring.com/aihuishou-to-process-500m-jd-com-led-round/*

*HKGOV. (2018, December 31). Disposal Licensing Control And Import/Export Control of Waste Regulated Electrical Equipment Commences. Press Releases. The Government of the Hong Kong Special Administrative Region (HKGOV). https://www.info.gov.hk/gia/general/201812/31/P2018123100747.htm?fontSize=1*

*Huishoubao. (2019, January 31). Huishoubao Announces Its 2019 Strategy to Capture More Opportunities in Global Secondhand Smartphone Market Together with China's Manufacturers and Foreign Telecom Carriers. Cision PR Newswire. https://www.prnewswire.com/news-releases/huishoubao-announces-its-2019-strategy-to-capture-more-opportunities-in-global-secondhand-smartphone-market-together-with-chinas-manufacturers-and-foreign-telecom-carriers-300787955.html*

*Hull, Bruce. (n.d.). Systems Thinking Learning Modules. Text material from the Center for Leadership in Global Sustainability. Virginia Tech University.*

*Iskan, Kim. (2016, August 27). China's Middle Class Is Exploding. Business Insider. https://www.businessinsider.com/chinas-middle-class-is-exploding-2016-8*

*ISRI. (2019). 2019 Economic Impact Study, U.S.-Based Scrap Recycling Industry. Institute of Scrap Recycling Industries (ISRI). https://www.isri.org/docs/default-source/recycling-analysis-(reports-studies)/2019-economic-impact-study-executive-summary.pdf?sfvrsn=2*

*Kao, E., and Gurung, E. (2018, August 9). Hong Kong Government Takes Greener Approach to E-Waste As New Scheme Puts Onus On Retailers to Junk Old Appliances. South China Morning Post (SCMP). https://www.scmp.com/news/hong-kong/health-environment/article/2158836/hong-kong-government-takes-greener-approach-e*

*Keller, D., Goodrich, J., Su, Z. (2020, July 10). The U.S. Should be Concerned with its Declining Share of Chip Manufacturing, Not the Tiny Fraction of U.S. Chips Made in China. Semiconductor Industry Association (SIA). https://www.semiconductors.org/the-largest-share-of-u-s-industry-fab-capacity-is-in-the-united-states-not-china-lets-keep-it-that-way/*

*Larmer, Brook. (2018, July 5). E-Waste Offers An Economic Opportunity As Well As Toxicity. The New York Times Magazine. https://www.nytimes.com/2018/07/05/magazine/e-waste-offers-an-economic-opportunity-as-well-as-toxicity.html*

*Leju. (2020, March 11). Guangdong Population Broke Record 8 Million (Chinese). Xinlang Leju. https://fs.leju.com/news/2020-03-11/14466643396581792206004.shtml*

*Levinson, Marc. (2018, February 21). U.S. Manufacturing in International Perspective. The United States Congressional Research Service. https://fas.org/sgp/crs/misc/R42135.pdf*

*Li, Cheng. (2016, August). Assessing U.S.-China Relations Under the Obama Administration. Brookings Institution. https://www.brookings.edu/opinions/assessing-u-s-china-relations-under-the-obama-administration/*

*Liedtke, Michael. (2020, September 1). Samsung Touts $2,000 Foldable Phone As A "VIP" Experience. Associated Press. https://apnews.com/article/54c5d954a11202e67afdd94e15244995*

*Lim, Xiaozhi. (2020, May 16). The World Is Running Out of Elements, and Researchers Are Looking in Unlikely Places for Replacements. Discover. https://www.discovermagazine.com/planet-earth/the-world-is-running-out-of-elements-and-researchers-are-looking-in-unlikely*

*Liu, C. (2014). How Does The Chinese E-Waste Disposal Fund Scheme Work? Case Study Prepared For the OECD. OECD. http://www.oecd.org/env/waste/gfenv-extendedproducerresponsibility-june2014.htm*

*McAfee, Andrew. (2019, Octorber 8). More from Less: The Surprising Story of How We Learned to Prosper Using Fewer Resources--and What Happens Next. Scribner. 1st ed., October 2019. p.176.*

*McCarthy, Joe. (2018, May 14). Where Will The Trash Go When All the US Landfills Are Full? Global Citizen. https://www.globalcitizen.org/en/content/us-landfills-are-filling-up/*

*Meadows, Donella. (2008, December). Thinking in Systems: A Primer. Edited by Diana Wright. Chelsea Green Publishing. p.IX, p.11, p.14, p.25, p.28, p.30, p.25, p.61, p.71, p.92, p.87, p.89, p.75.*

*MEE. (2019). Solid Waste Import Control Catalog (Chinese). The PRC Ministry of Ecology and Environment (MEE). http://www.mee.gov.cn/gkml/hbb/bgg/200910/W020090716501670116698.pdf*

*Mobiot, George. (2019, September 19). For the Sake of Life on Earth, We Must Put a Limit On Wealth. The Guardian. https://www.theguardian.com/commentisfree/2019/sep/19/life-earth-wealth-megarich-spending-power-environmental-damage*

*Moss, Kevin. (2019, August 28). Here's What Could Go Wrong With The Circular Economy—and How to Keep It on Track. World Resources Institute. https://www.wri.org/blog/2019/08/here-s-what-could-go-wrong-circular-economy-and-how-keep-it-track*

*Nanyang Technological University. (2020, August 26). Scientists Use Fruit Peel to Turn Old Batteries into New. Science Daily. www.sciencedaily.com/releases/2020/08/200826101623.htm*

*NBD. (2019, March 22). Subsidy Deficit Nears 8 Billion Yuan (Chinese). Meijingwang (NBD). http://www.nbd.com.cn/articles/2019-03-22/1313009.html*

*Nerdwriter1. (2014, May 23). The Diderot Effect (Video). https://www.youtube.com/watch?v=_vGLo_VTVv8*

*Normile, Dennis. (2017, March 29). International Trade Shifts the Burden of Pollution-Related Deaths. Science. doi:10.1126/science.aal0979. https://www.sciencemag.org/news/2017/03/international-trade-shifts-burden-pollution-related-deaths*

*Palmer, Caroline. (2020, August 22). Britain to Get First Commercial Refinery for Extracting Precious Metals from E-Waste. The Guardian. https://www.theguardian.com/environment/2020/aug/22/britain-first-commercial-refinery-extracting-precious-metals-e-waste-mint-innovation*

*Rankin, Jennifer. (2020, March 11). EU Plans "Right to Repair" Rules for Phones and Tablets. The Guardian. https://www.theguardian.com/world/2020/mar/11/eu-brings-in-right-to-repair-rules-for-phones-and-tablets*

*Recycling. (2019, May 12). Global Ban on Exporting Hazardous Waste Becomes Law Today. Recycling Magazine. https://www.recycling-magazine.com/2019/12/05/global-ban-on-exporting-hazardous-waste-becomes-law-today/*

*Recycling Today. (2016, September 16). BAN Project Reveals That 40 Percent of Tracked E-Scrap Was Exported. Recycling Today. https://www.recyclingtoday.com/article/ban-trash-transparency-study/*

*Redling, A., and Toto, D. (2018, April 19). China Announces Import Ban on an Additional 32 Scrap Materials. Recycling Today. https://www.recyclingtoday.com/article/china-bans-solid-waste-imports/*

*Sachs, Jeffrey D. (2015, September 25). The Age of Sustainable Development. Columbia University Press New York. pp.261-262.*

*Schons, Mary. (2011, January 21). Superfund. National Geographic. https://www.nationalgeographic.org/article/superfund/*

*Science Focus. (2019, March 1). Which Elements Are in Danger of Running Out? Science Focus Magazine. BBC. https://www.sciencefocus.com/science/which-elements-are-in-danger-of-running-out/*

*SCMP. (2017, September 25). Has Guiyu Finally Shaken Off the Title of World's E-Waste Capital (Video)? South China Morning Post (SCMP). https://www.youtube.com/watch?v=RJ6VX3pC02s&feature=youtu.be*

*SCMP. (2019, July 10). Southeast Asia Says No to Waste From the West (Video). South China Morning Post (SCMP). https://www.youtube.com/watch?v=JoofsCHeAt0&feature=emb_logo*

*Semuels, Alana. (2019, May 23). The World Has An E-Waste Problem. Time. https://time.com/5594380/world-electronic-waste-problem/*

*Senge, Peter. (2016, February 7). Systems Thinking in a Digital World (Video). https://www.youtube.com/watch?v=Zs3ML5ZJ_QY*

*Silberglitt, Richard. (2017, December 12). Critical Materials and U.S. Import Reliance. RAND Corporation. https://www.rand.org/content/dam/rand/pubs/testimonies/CT400/CT485/RAND_CT485.pdf*

*Smith, Brad. (2020, January 16). Microsoft Will Be Carbon Negative by 2030. Official Microsoft Blog. https://blogs.microsoft.com/blog/2020/01/16/microsoft-will-be-carbon-negative-by-2030/*

*State Council. (2016, December 25). State Council Public Release on Extended Producer Responsibility Plan and Implementation Notice (Chinese). The State Council of the PRC.* *http://www.gov.cn/zhengce/content/2017-01/03/content_5156043.htm*

*Tan, Quanyin. (2019). EPR For E-Waste Management in China. Tsinghua University.* *https://www.itu.int/en/ITU-D/Regional-Presence/AsiaPacific/SiteAssets/Pages/Events/2019/Policy-awareness-workshop-on-E-waste/China%20E-waste%20EPR.pdf*

*TCR. (2019, March 1). Inside Your Phone : The System on a Chip (SoC). Triangle Cellular Repair (TCR).* *https://www.mytcr.com/blog/inside-phone-system-chip-soc/*

*TechCrunch. (2017, September 19). Apple's Lisa Jackson on Protecting the Planet (Video). Disrupt SF 2017.* *https://www.youtube.com/watch?v=j3NAjXQ_9Tk*

*Than, Ker. (2018, January 17). Critical Minerals Scarcity Could Threaten Renewable Energy Future. Stanford Earth. School of Earth, Energy & Environmental Sciences.* *https://earth.stanford.edu/news/critical-minerals-scarcity-could-threaten-renewable-energy-future*

*The Economist. (2018, September 27). A Chinese ban on rubbish imports is shaking up the global junk trade. The Economist.* *https://www.economist.com/special-report/2018/09/27/a-chinese-ban-on-rubbish-imports-is-shaking-up-the-global-junk-trade*

*The Economist. (2020, September 17). The Great Disrupter. The Economist.* *https://www.economist.com/special-report/2020/09/17/the-great-disrupter*

*UCSD. (2020, June 13). The Great Learning (Bilingual). University of California San Diego (UCSD).* *https://pages.ucsd.edu/~dkjordan/chin/Koong/GreatLearning.html*

*UNEP. (2015, May 12). Illegally Traded and Dumped E-Waste Worth Up To $19 Billion Annually Poses Risks to Health, Deprives Countries of Resources, Says UNEP. The United Nations Environment Programme (UNEP).* *https://www.unenvironment.org/news-and-stories/press-release/illegally-traded-and-dumped-e-waste-worth-19-billion-annually-poses*

*UN University. (2017, December 14). E-Waste Rises 8% by Weight in 2 Years as Income Rise, Prices Fall. The United Nations University.* *https://unu.edu/media-relations/releases/ewaste-rises-8-percent-by-weight-in-2-years.html*

*USGS. (n.d.). Iron and Steel Scrap Statistics and Information. National Minerals Information Center. The United States Geological Survey (USGS).* *https://www.usgs.gov/centers/nmic/iron-and-steel-scrap-statistics-and-information?qt-science_support_page_related_con=0#qt-science_support_page_related_con*

*Vaute, Vianney. (2018, October 29). Recycling Is Not The Answer To The E-Waste Crisis. Forbes.* *https://www.forbes.com/sites/vianneyvaute/2018/10/29/recycling-is-not-the-answer-to-the-e-waste-crisis/#650aaccb7381*

*Vidal, John. (2013, December 14). Toxic "E-Waste" Dumped in Poor Nations, Says United Nations. The Guardian.* *https://www.theguardian.com/global-development/2013/dec/14/toxic-ewaste-illegal-dumping-developing-countries*

*Virginia Tech. (2014, January 22). Environmentally Friendly, Energy-Dense Sugar Battery Developed to Power the World's Gadgets. Virginia Tech University. https://vtnews.vt.edu/articles/2014/01/012213-cals-battery.html*

*Wagstaff, Keith. (2016, April 24). Old TVs Create Toxic Problem for Recycling Programs Across America. NBC NEWS. https://www.nbcnews.com/science/environment/old-tvs-create-toxic-problem-recycling-programs-across-america-n558701*

*Wang, Z., Zhang, B., and Guan, D. (2016, August 4). Take Responsibility For Electronic-Waste Disposal. Nature 536, 23-25. doi:10.1038/536023a. https://www.nature.com/news/take-responsibility-for-electronic-waste-disposal-1.20345*

*Wertz, Joe. (2017, October 11). EPA Vows To Speed Cleanup Of Toxic Superfund Sites Despite Funding Drop. NPR. https://www.npr.org/2017/10/11/554564288/epa-vows-to-speed-cleanup-of-toxic-superfund-sites-despite-funding-drop*

*Wilkinson, Ella. (2020, August 7). COVID-19 and The Problem of Electronic Waste. Bright Green. http://bright-green.org/2020/08/07/covid-19-and-the-problem-of-electronic-waste/*

*Wood, Johnny. (2019, July 1). The Chinese Megacity Is Building A Giant Waste-to-Energy Plant. World Economic Forum. https://www.weforum.org/agenda/2019/07/one-of-china-s-biggest-megacities-is-building-a-giant-waste-to-energy-plant/*

*Xu, Guangqing. (2005). Chinese Philosophy And Systems Thinking. L'Association Française de Science des Systèmes, France. http://www.afscet.asso.fr/resSystemica/Paris05/guangqing.pdf*

*Zhao, W., and Yang, J. (2018, May 19). An Effectiveness Assessment of China's WEEE Treatment Fund. International Journal of Environmental Research and Public Health. 2018 May. 15(5): 1028. https://doi.org/10.3390/ijerph15051028*