CHAPTER ONE

Will Resources Be Exhausted?—"Infinite" Supply of Finite Resources

Varied versions of resource exhaustion have come into being amid people's inevitable concern about resource deficiency and even the possibility of exhaustion given the nonrenewability of natural resources and a dramatic increase in both human population and resource consumption. Future global population growth and consumption growth per person, on the whole, are bound to aggravate resource constraints. However, there exist many checking and balancing factors. At the supply level, the proven reserves of conventional resources are increasing continuously and alternative resources have promising prospects with sizable potentials of unconventional resources and resources that have yet to be explored. At the demand level, demand is unlikely to multiply incessantly due to the slowing down of population growth, improved resource utilization, and an increase in substitution and recycling.

The supply of resources, from the perspective of market, is determined not by whether there is enough supply but by whether there is enough demand. To put it another way, supply is determined by effective demand. Therefore, resource development prospects are contingent on man's demand instead of supply. Resource shortage faced by the international community is more of an economic, political, and regional demand-dominated market shortage than resource exhaustion. The solution rests in each country developing economy, committing themselves to enhancing management, perfecting market, improving efficiency, and deepening cooperation. In addition, unnecessary panic about resource exhaustion and resource wars should be alleviated, and mistakes with regard to domestic regulations and resource allocation need to be averted.

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THE AGE-LONG VIEW OF "RESOURCE EXHAUSTION"

For several centuries, resource shortage has been plaguing human society, warning people of a dire possibility that human activities will use up resources on the earth. Ever since the beginning of the 20th century, with the surge in the world's demand for energy and resources and a substantial rise in prices, the issue of whether energy and resources are on the verge of exhaustion once again arouses worldwide attention. Constantly appearing in the media and research, such terms as oil doomsday, energy collapse, and resource exhaustion have become very popular. Meanwhile, the increasingly prominent issue of climate change and the world population having exceeded 7 billion have complicated the interplay between resources, population, and the environment, intensifying people's deep concern about resource exhaustion.

The view of "resource exhaustion" is of a long history. As early as the year of 1798, the 32-year-old British economist and demographer Thomas Malthus, in his work entitled "An Essay on the Principle of Population, as It Affects the Future Improvement of Society," pointed out that population growth would surpass the earth's ability to provide for subsistence resources and thus society was unsustainable. He argued that population multiplied geometrically while food multiplied only arithmetically and human population far surpassed the amount of subsistence materials provided by the earth for human survival. According to him, man could not escape this law of nature. Malthus, the first man to have issued the resource exhaustion disaster alert, emphasized that not only the finiteness of resources but also scarcity of economy was an absolute reality.

In 1968, the American entomologist Paul R. Ehrlich at Stanford University published a book entitled *The Population Bomb*, in which he asserted that in light of population explosion, resources would be depleted and man would eventually starve. He argued that the baby boom in the 1960s would continue until the widespread famine in the world sets in. He emphasized that no matter what emergency plans were to be taken, hundreds of millions of people would starve to death in the 1970s and 1980s and mass starvation were inevitable. However, in 1974, he gave a renewed prediction, saying that human beings would enter the era of resource deprivation before the year of 1985; many nonrenewable minerals would be depleted; man's destructive consumption of mineral resources would result in catastrophic consequences.

In 1972, the Club of Rome published *The Limits to Growth* written by Prof. Dennis Meadows and others from Massachusetts Institute of Technology in America. Through the analysis of the five factors of population growth, food shortage, nonrenewable resource depletion, environment pollution, and energy consumption, the authors concluded that population growth was bound to lead to more demand for food; it was inevitable that industrialization would result in the depletion of nonrenewable resources and the worsened pollution; sooner or later the human society would reach a critical level of crisis because these growth were all exponential in nature. If measures were not taken, they claimed, those nonrenewable resources like land and energy would be used up in less than 100 years, resulting in consequences like irrevocable recession in man's social and economic systems, man's ever-worsening living environment, food shortage, a burgeoning increase in death rate, and the inevitable end of human society.

In 2001, Michael T. Clare published the book entitled *Resource War*, points out that the global demand for many key materials is growing at an unsustainable rate, but the supply of certain substances around the world is very limited. The world is likely to face a significant shortage of conventional oil from the second or third decade of the 21st century. By the mid-21st century, the total water use of mankind will reach 100% of the water supply available, and this will cause serious problems of shortage in some areas [1]. In 2008, Clare published another book *Petroleum Politics*, and he illustrates the upcoming resource crisis in a whole chapter, emphasizing that although the previous shortage of resources have been eased, the nature of shortage at this time is different from that in the past. The consumption of energy and key resources and the demand for them have reached an unprecedented stage, and existing reserves are greatly declining with many resources depleting at the same time [2].

The Coming Energy Collapse, written by Stephen Leeb and others, also highlights that the plight of humans is not just a shortage of oil but the intensified shortage of all commodities. There is an interdependent relationship among metals, minerals, energy, and water, and the effort to obtain a certain kind of resource is often at the expense of other resources. The shortage of various resources appears simultaneously and those resources mutually restricted, thus forming a vicious cycle, and this will ultimately exert a devastative effect on human civilization. The authors argue that mankind suffers a great insufficiency to meet the greedy demand of global growth, and if oil consumption is maintained at about 31 billion barrels a year, then oil will be depleted by 2040. In accordance with the current consumption rate, we will run out of antimony, indium, lead, silver, tantalum, tin, and uranium in 4–20 years. Chromium, copper, and zinc will be depleted within 40 years; the depletion of nickel and platinum will be followed [3].

In 2008, the World Wildlife Fund launched "Report of the Earth's Vitality," asserting that the global natural resources were consumed at a fast rate, and three-fourth of the global population were living in the countries where resources were being excessively consumed and the rate of the consumption exceeded the level of environmental regeneration. The report argues that reckless consumption of "natural assets" would endanger the future of the world and bring about ecological shocks, including the increasing costs of food, water, and energy. If humans continue to consume resources from the earth at the current rate, humans will need resources equivalent to the supply of two earths to maintain their current lifestyles by the mid of 2030s.

Among the theories of resources depletion, the shortage of energy was of greatest concern in the book *Coal Problem*, published by the British economist Stanley Jevons. In this book, he predicts that the shortage of energy, the collapse of industry, and the recession of nations would appear in the future and those problems are hard be solved [4]. In 1881, William Thomson, one of the greatest scientists of the 19th century, warns that Britain's energy base is very weak and the disaster is imminent. In the report, he demonstrates the glorious era of the United Kingdom is coming to an end due to the fact that "underground coal" was going to "dry up," and the only hope for energy is windmill or fan, which would rise again in some form [5].

Shortly after the oil industry was born, scientists, politicians, and energy analysts prophesied that oil depletion would come soon. In 1885, the Pennsylvania State Bureau of Geology argues that the crazy performance of the oil is a temporary phenomenon and will soon disappear—now young people witness this phenomenon will naturally come to an end [6]. During World War I, the United States made sensational arguments about impending dry up of oil from time to time. The US Senate initiated an investigation in 1916, claiming optimistically that oil was likely to be depleted in 25 years. In 1919, the US Geological Survey predicted that oil in the United States would run out in 9 years [7]. In 1939, the US Department of the Interior predicted that the global oil supply would be completely depleted in 13 years.

During World War II, Harold Ickes, the US wartime oil administrator, published a popular article *Oil Exhaustion*, pointing out that if there was a third world war, this Field war must be an oil war because in the United States, there would be no oil in the future. Since then, oil shortage phobia reached its peak from 1943 to 1945. In 1949, the US Department of State announced that the United States would face the oil shortage within 20 years, and there was no option except for the import from the Middle East. In 1951, the Ministry of the Interior amended the previous forecast and proposed that global oil would be exhausted in the next 13 years [8].

In 1956, Hubbert proposed the bell-shaped curve, predicting that US oil production would peak in the 1960s or early 1970s, while the actual US oil production did fall from a historical record in 1970. The success of the Hubbert's bell-shaped curve lies in the popularity of the concept "resource depletion" in the 1970s. In 1972, the Club of Rome released the report *The Limits to Growth*, which further prophesied that the world's oil and natural gas would be exhausted by 1992 and 1993, respectively. In 1978, Hubbert predicted that the children born in 1965 would witness the depletion of the world's oil in their lifetime, and that mankind would enter the "no-growth era." At that time, many people believed that it was difficult for oil reserves to meet the sustained growth of consumption, and the world's oil industry would come to a halt by the end of the 20th century or the beginning of the 21st century.

Throughout the 20th century, there were at least three rounds of arguments on oil exhaustion: the first round began in the World War I period, and came to an end with a lot of oil flooding the market in 1930; the second round started from the World War II, and with the oil production gradually overdone a few years later, depletion theory was gradually denied and completely overturned in the late 1960s; the third round began in the early 1970s, reaching its peak with experience of two oil crisis, and finally came to an abrupt end in 1986 with the dramatic plummet of oil prices [9].

By the end of the 20th century and the beginning of the 21st century, although the world's oil and gas resources did not run out of schedule, the sharp rise in oil prices caused a new panic on global energy shortage, especially with the popularity of the peak oil theory. The peak oil theory argues that the oil production has been close to or has reached its peak, and has begun or is about to appear unstoppable downward trend. An oil peak theorist even warned that the consequences of oil depletion would include war, hunger, recession, and perhaps even the extinction of modern humans. The initial prediction is that the peak of oil production will come before and after Thanksgiving in 2005; then, it is predicted that insurmountable gap between supply and demand will come around in 2007; and then, it has been pushed to 2011. Then, some people propose that oil peak would be very likely to appear before 2010 [10].

After years of sustained economic growth, there is a growing anxiety about the shortage of resources such as oil in China, especially when China has transformed itself from oil exporting country into oil importing country in 1993. Many analysts have pointed out that the world is about to face the shortage of resources and energy, especially oil shortage. For example, the book *Oil and National Security*, published in 2001, once states that oil is a natural resource with limited reserve and increasing depletion, so the golden age for oil production will come to an end (before or after 2010) due to the fact that most of the oil field production is declining. The depletion of conventional oil resources is the grim reality facing the whole world [11]. The author of *The Resource Conspiracy* argues that under the condition of limited resources, people are speeding into an era with the shortage of resources. In terms with mineral resources, oil and natural gas will be exhausted in decades, even if an optimistic estimate will not exceed 100 years. According to the current mining, consumption rate and the world's proven reserves, gold will reach the exhaustion period in 15 years, silver in 20 years, copper in 30 years, and nickel in 50 years. Except for iron ores, the mineral resources supporting modern society and lifestyle will be exhausted in the 21st century [12].

At the same time, many foreign researches on the depletion of resources were introduced into the domestic research. Partly due to China's unique energies and resources insecurity, or the consideration of marketing strategies, the lack of resources to some extent has been generalized or exaggerated, thus leading to the impending end of the world because of the depletion of energies and resources.

The shortage of resources around the world varies, and the depletion theorists are manifested by various views due to the different perspectives. But in general, they emphasize the resources restriction on economic growth or the limit of economic growth due to the limited resources. Dennis Meadows claims that the essence of the problem results from the earth, where the resources are limited and mankind has always craved for infinite development. American economist Stephen Leeb points out that developing countries are climbing higher in the ladder of the economic development with the continuous consumption of precious and limited resources. Global economic growth cannot continue indefinitely, and one day the resources will be completely depleted [13]. Chinese scholar Xue Ping affirms that the contradiction between population and natural resources is a basic contradiction of human social production activities, mainly manifested in the contradiction between the limited supply of resources and the infinite demand of human beings [14].

INFINITE SUPPLY FOR LIMITED RESOURCES

It is undeniable that the absolute reserves of certain resources on Earth are limited, but in a sense the amount of resources available to mankind is relatively infinite. At present, the main energies used by humans (including fuel wood, coal, oil, gas, etc.) are ultimately from solar energy. The scientific community generally believes that before the destruction of the earth, the sun will exist for billions of years. In this sense, the supply of solar energy is inexhaustible before the extinction of the earth and human beings, and furthermore, there are thousands of stars like the sun outside the planet of earth. In addition to fossil fuels and clean energy that humans have discovered and exploited on earth, there are a lot of renewable and potential energy sources, such as hydrogen, nuclear fusion, combustible ice (natural gas hydrate), and the like.

In a sense, in the limited period of human existence, there should be sufficient energy resources available, but the problem is how to transfer potential energy and relatively infinite solar energy into effective, convenient, and economical use of energy for humans. The fundamental problem faced by mankind in the supply of resources is not the question of whether absolute resources are adequate, but the question of how to deal with those resources more economically and efficiently. Thus the major challenges to be faced are technology and cost. Among the factors that determine technology and economic use, prices, investment, and politics will play a very important role.

From the perspective of the basic principles of economics, resource supply is fundamentally determined by effective demand. Market economy works in the format of supply driven by demand. Because there is market demand, especially the effective needs, enterprises will produce and supply products and services. If there is no demand for a product and service on the market, there is no return on the cost of providing such products and services, and the business is nonprofitable. After the demand begins to increase, enterprises will make many profits with higher market price due to the insufficient supply at the beginning phase of the market. Therefore, higher profits will attract more enterprises to provide products and services, and with the increase in supply, the market price will fall. In terms of resources and from a long-term and market perspective, whether human beings have sufficient energy and resource supply, to a certain extent, depends on whether human beings have sufficient effective demand, given the relative limits of population growth and resource requirements. The outlook of the resource development will ultimately depend on human resource demand rather than supply.

American economist Julian Simon is a typical resource optimist, who even opposes the use of the concept of "limited resources." He points out in the book *The Ultimate Resource* that "limited" is more of a concept and an assumption in the semantic and mathematical sense. As the points in a line can never be counted clearly, the service provided by natural resources for humans cannot be counted either, because resources are not limited in any reasonable sense. First of all, the rising demand for resources will lead to tight supply with rising prices in a short time. On the one hand, rising prices will reduce demand, and on the other hand, this will encourage companies to invest in more efficient mining technologies and find alternative resources to alleviate resource dilemmas. Second, the ultimate resource is the ever-increasing population. What a person has created in his whole life is always more than what he has consumed. As long as the population continues to grow, the prospects for human resources will be getting better and better [15].

Simon illustrates that there are many limitations to the assumption that the earth is limited and resources are limited. Human beings can neither know the number of natural resources and the amount of service those resources can ultimately provide nor determine where the boundaries of the relevant resources system lie. The search for resources by mankind goes ahead farther and farther. After other continents have been explored, the ocean will be then under detection. The metal deposits and other resources contained in the ocean exceed any storage we know about on land. Furthermore, humans have begun to explore the moon. If conventional energy prices go much higher, nonrenewable fossil fuels such as oil, coal, and natural gas could be replaced by energy services provided by solar, nuclear, and unconventional resources. He even analyzes that fossil fuels and nuclear fuels on earth are rather limited, so the concept of limited energy supply is purely nonsense [16].

Bob Peipi, the author of the book *Introduction to the Oil Economy*, argues that oil is indeed a depleted resource and a nonrenewable supply because of the disparity between the exploitation rate and the rate of natural regeneration. Now we are consuming it, but we will never run out of oil. For natural and economic reasons, we will never be able to dig out the last drop of oil. Economics does not allow the material to be consumed by the imagination of people through the formula of X divided by Y. Mankind has never been able to determine the exact amount of oil resources, and the best way is to economically develop the supply. To calculate the time required to exhaust resources through the annual consumption is meaningless. In terms of oil, the depletion point exists outside the limits of human imagination. The final supply should be a function of human imagination and knowledge, not a measurable physical quantity. We cannot accurately foresee the external boundaries of supply, nor can we make full use of known underground resources [17].

In the existing oil reserves, a considerable part of the resources cannot be obtained by conventional technical methods. If the price is raised high enough to make humans improve oil recovery technology, then part of the oil can be recovered. The total amount of oil that cannot be recovered through conventional methods reaches 300 billion barrels in the United States, 10 times more than the remaining proven oil reserves. In recent years, the successful exploration of shale and tight oil in the United States has further proved that with the advances in technology and the rise of energy prices, many unconventional resources can be converted into exploitable conventional energy resources. In a very realistic sense, mankind is just beginning to get the initial and cheapest part of the initial conventional oil resources. There is a certain amount of oil reserve, but compared with the idea of developing and exploiting oil efficiently, it is not a scarcity. There will be a good way to cope with oil depletion before the world runs out of it [18]. Science is accelerating, and more human resources are being discovered, and limited space can feed more people [19].

Rosser Roberts, a professor of economics at the University of Washington at St. Louis, asserts that as long as the price rises too high, people will no longer use oil, but instead use other alternatives. The rest of the oil will remain unexplored due to the high cost of exploration;

therefore, natural resources will never run out [20]. OPEC founder Sheikh Ahmed Zaki Yamani repeatedly points out that just as the end of the Stone Age is not derived from the lack of stones, the oil era will not come to an end because of oil depletion. Ideas, innovation, and technology will not end the oil age due to its full exhaustion by mankind. The end of the oil age may also occur before its full exploration. If oil prices continue to remain high, people will reduce oil consumption and speed up the search for alternative energy, thus the end of the oil era is not far away.

American economist Landsburg further points out that overcrowdedness is a spillover cost of population growth, and that the question of how many population the planet can carry is entirely wrong because the decision-making cannot be controlled by earth. We do not have to worry about how many population the earth can carry, but should think about if everyone gets as much wealth as you can, how many people can share the wealth on earth, and so to adjust the size of your family accordingly. Some people will ask if oil and other nonrenewable resources are exhausted, what should we do? This is another wrong question, because the subtext of this problem is that our energy consumption will bring costs to neighbors and not to ourselves [21].

Sinopec researcher Zhang stresses that the history of human civilization has experienced different energy "stages." "Fire-wood era" is followed by "coal age" and then "oil era." However, the rise of each era does not mean the depletion of the previous main resource, instead due to the fact that the latter generation has produced one or several new energies, which are more efficient, more convenient, and more capable to promote social development. The "post-oil era" will not arrive because of oil depletion. It is an era with coexistence of a variety of clean and efficient energy, which are derived from a variety of basic energy and new energy in accordance with place and time [22].

HUGE POTENTIAL IN RESOURCES RESERVES

The global distribution of mineral resources is imbalanced in terms of either variety or geographic locations. It is estimated by the US Geological Survey that the earth contains a 610-year supply of potash, ensuring centuries more of fertilizer-making. Furthermore, the known iron—ore reserves are available for 590 years and copper for 136 years, with roughly a half in North America. Andrew Mackenzie, a geologist and BHP Billiton PLC's chief executive for nonferrous metals, claims that people think there are 10,000 more years of minerals left for civilization. Civilization will change, of course, and there will be different minerals involved, but 10,000 more years [23].

Chemical elements are present everywhere. The crust is about 3—30 miles thick, while only the first half-mile has been mined on most land masses. According to the chemists, if anyone was interested in sifting the oceans, they could recover 10 million tons of gold, worth over $500 trillion. Scott McLean, the chief executive of HTX Minerals Corp., a Sudbury, Ontario-based mining company, believes the earth's mineral bounty is immense, and it will continue to provide for millennia. J.E. Tilton, an economist at the Colorado School of Mines, estimates that at current rates of consumption the copper and iron found in the earth's crust would last 120 million years and 2.5 billion years, respectively [23].

In terms of oil and gas reserves, the world has not suffered the shortage as estimated in the 20th century, for the remaining proven reserves continue to increase, far beyond the production. The world's oil production between 1971 and 1996 was 80.64 billion tons, while newly increased proven reserves was 161 billion. The world's proven oil reserves have boosted from 72.94 billion tons in 1971 to 240.7 billion tons in 2016, with the reserve-to-production ratio (RPR) rising from 28.3 to 50.8 years. Since 1980, the world's remaining proven oil reserves have more than doubled, increasing by nearly 557.9 billion barrels only between 1992 and 2016. The world's remaining proven gas reserves have climbed from 92.7 trillion cubic meters in 1983 to 186.6 trillion cubic meters in 2016, with an increase of 63.1 trillion cubic meters from 1996 to 2016 [24].

There remain plenty of conventional oil and gas resources to be discovered in the world. Their average recovery degree is 80% and 60%, respectively, while the average rate of primary oil recovery in the world known fields is only about 15%, and that of secondary oil recovery is 30%, with 70% ~ 85% of the remaining oil unproduced. One hundred years ago, only 10% was considered "proven," but technological innovation should enable us to explore 35% of the reserves, an increase of 2.5 trillion barrels [25], in an economically feasible way. Middle East, Eastern Europe, and Africa contain three-fourth of global oil reserves, but only one-seventh of the world exploration drilling. Oil exploration activities are still too concentrated in North America [26]. Before the 1960s, it was widely believed that the world's conventional oil recoverable resources were 50 billion tons, while it went up to 458.2 billion tons in 2000 according to an estimate by the 16th World Petroleum Congress [27].

Daniel Yergin, vice chairman of IHS Inc., proposes that the world apparently did not exhaust its oil supply, and the digital oil field technology would make the world's oil reserves increase by 250 billion barrels, more than the total proven reserves in Iraq. Since the birth of the oil industry in the 19th century, the world has produced 1 trillion barrels of oil; according to the current analysis, the world has at least 5 trillion barrels of oil resources, 1.4 trillion barrels of which can be fully explored. Total liquid production has increased from less than 10 million barrels per day in 1946 to 98.32 million barrels per day in 2016. According to the current plan, the total capacity, which is greater than the total production, can rise from 92 million barrels per day in 2010 to 114 million barrels per day in 2030 [28].

The International Energy Agency (IEA) estimated that the global conventional natural gas recoverable resources are 471 trillion cubic meters, with 66 trillion cubic meters produced and 405 trillion cubic meters left. From 1987 to 2008, natural gas resources have increased by 87%, and it will continue to show "growth" trend with the passage of time. Overall, the global level of exploration and development of natural gas is still at the low side, only around 15%. Huge amount of resources is to be developed, and the amount of natural gas resources will gradually be converted into recoverable reserves with the technological progress and increasing proven degree. Therefore, the amount of natural gas resources can guarantee the stable supply of natural gas in a longer term [29].

The world also contains rich unconventional oil and gas resources. According to the theory of oil and gas generation, the oil and gas generated in the hydrocarbon rock formation will form conventional oil and gas reservoirs when being discharged, migrated, and enriched in a rock space with high porosity and permeability. And the oil and gas which are not discharged from the hydrocarbon rock formation become unconventional oil and gas, of which the gas retained in the coal is called coal-bed methane while the gas remained in the mud and shale is called shale gas. In addition, tight oil, oil shale, oil sands, and other oil and gas resources also belong to the unconventional oil and gas resources. It is estimated that the total amount of unconventional oil and gas resources, such as heavy oil, asphalt, tar sands and oil shale, coal-bed methane, tight sandstone natural gas, deep basin gas, and natural gas hydrate, is up to 40 trillion barrels (545.7 billion tons), more than 10 times the amount of conventional oil and gas resources. Based on the IEA statistics, the amount of world's unconventional natural gas resources is 922 trillion cubic meters, of which the compact sandstone gas is 210 trillion cubic meters, the coal-bed methane is 256 trillion cubic meters, and the shale gas is 456 trillion cubic meters [29].

At present, the most unconventional oil and gas resources have not yet been developed for technical and economic reasons, except for Alberta heavy oil sands in Canada, Orinoco heavy oil in Venezuela, and shale gas, coal-bed methane, and tight sandstone gas in the United States. Global heavy oil, oil sands, and oil shale reserves surpass the global conventional oil reserves greatly. If oil prices can be maintained at least $80 a barrel (2007 dollars), the remaining global conventional and unconventional oil reserves have been 4.5 times the amount of oil that has been produced so far [30]. In the second half of the 21st century, unconventional natural gas will become an important source of natural gas supply. Since new millennium, unconventional natural gas production in the United States has grown at an average rate of 9% per year, from 156 billion cubic meters in 2001 to 543.6 billion cubic meters in 2014. Globally, from 2007 to 2030, unconventional natural gas production in the world will increase from 367 billion cubic meters to 629 billion cubic meters, which will account for 15% of the total natural gas supply [29].

In 2013, 2030 World Energy Outlook issued by British Petroleum (BP) made a forecast that the strong growth in unconventional oil and gas production would exert a significant impact on the global energy pattern, thereby changing expectations for major economies and influencing the trade balance. By then, the US energy production will reach 99% of domestic consumption. It also predicted that unconventional oil supply, such as dense oil, oil sands, and biofuels, would account for all the net growth in global production by 2020, and over 70% of the growth from 2020 to 2030. By 2030, 20% of the global energy supply increment will go to shale gas and dense oil. Daniel Yergin believed that by 2030, unconventional oil resources would account for one-third of the total oil production capacity, and with the technological progress, most unconventional oil will be collectively referred to as "conventional oil."

Compared with oil and natural gas, the world's coal enjoys huge reserves, larger amount, and wider distribution. According to the BP's statistics on the world's energy in 2017, the world's remaining recoverable coal reserves rises from 636.4 billion tons in 1978 to 1139.331 million tons at the end of 2016. In recent years, its RPR has declined from 200 years around the 1990s down to 153 years in 2016, mainly due to the substantial growth in consumption in emerging market countries and the relative stagnation of global coal exploration activities [24]. For the sake of environmental protection and efficiency, many countries gradually reduce coal consumption, or even give up coal exploration and production, leading to changeless proven reserves over the years. In addition to the remaining reserves, the amount of coal resources to be discovered is far more than that of oil and gas resources.

Great potential lies in a variety of alternative energy resources, which can be divided into several categories. The first category involves the energy or resources that contain relatively limited reserves, can be regenerated, and have formed a certain scale, such as wind, hydro power, geothermal, and bioenergy. The second category includes the energy or resources that contain huge reserves, pose difficulties in mining technology, and have not yet been developed in large scale, such as hydrogen, nuclear fusion, and combustible ice. The rational use of these resources will enable mankind to obtain "adequate fuel." Hydrogen accounts for 75% of the air mass. Water, fossil fuels, and all organisms contain hydrogen, without emitting carbon dioxide when being combusted [31]. The total amount of combustible ice in the world's oceans is about 1.8 trillion to 1.3 trillion cubic meters if converted into methane gas, equivalent to about twice the amount of known fossil energy reserves. The uranium required for nuclear fission is relatively limited, but there will be no resource constraints if the technology and cost problems can be solved properly. The third category embraces the energy or resources that contain relatively infinite reserves but require the improvement in the technology, cost, and efficiency. For example, the sun will exist longer than the earth, and the other stars in the universe can also play the same role as it. Thus the amount of solar energy resources is relatively infinite, while the restriction lies in the technology, cost, and large-scale application, especially the breakthroughs in energy storage and conversion technology. The forth category includes other possible and unknown energy or resources, such as the inorganic oil, the lunar energy, and other space energy.

Reserves of most metals or minerals are richer than those of fossil fuels. The prediction on how long the reserves can be available for human use is possible for such energy sources as oil, natural gas, coal, and uranium, while it is impossible for metals or minerals, as many metal deposits in the world still remain identified. Unlike oil, the earth is rich in iron, nickel, silver, and copper with immeasurable resource potential, far from being able to depict the "Hubbert curve." The iron and lead in the United States also showed more or less bell-shaped curves, but they did not run out. In 2007, the United States produced 52 million tons of iron and 120,000 tons of lead (refined), and their base reserves are 15 and 19 billion tons, respectively. In 2007, the US iron ore resources were estimated at 110 billion tons, and the world's 800 million tons. Based on the historical maximum yield data, the US resources can be available for 900 years, while the world for 400 years. The global lead reserves are estimated at 1.5 billion tons, which are enough to mine for more than 400 years according to the existing global production [32].

In 1970, Harrison Brown asserted that humanity would totally run out of copper by 2001, and that lead, zinc, tin, gold, and silver would all be gone by late 1980s [33]. In fact, the world's copper and other metals are not exhausted, for copper reserves are much more than his original estimates. Between 1950 and 2006, global copper accumulated production was more than 400 million tons, almost 4.5 times the global reserves estimated by the US Geological Survey in 1950, which then predicted in 2008 that there were still 550 million tons of copper reserves globally, six times the estimated value of 1950 [34]. In addition, the largest gold storage of the Earth's surface is in the ocean, with reserves of about 10 billion tons. There is currently no feasible way to extract submarine gold, which is simply a drop in the ocean compared with the reserves of space gold. However, no way is available to get that gold at present [35].

NON-ENDLESS DEMAND FOR RESOURCES

As the world's leading energy, wood is replaced by coal, which is then replaced by oil. It is not because of resource depletion but lack of demand. Some analysts pointed out that the future development of the world's long-term resources industry may be more subject to the lack of demand, rather than depletion of reserves. In terms of oil and gas, the amount of resources, proven reserves, and production are increasing with the world economy development and consumption demand growth.

Human development and utilization of oil will not fall into the embarrassing situation where the demand is strong and supply is exhausted. Conversely, influenced by such factors as cost and environment, the demand is likely to be suppressed and gradually shrinking before the oil reserves are far from exhaustion. For instance, recent decades have witnessed that many of the mineable coal resources have been abandoned due to the lack of demand. By the middle of the 21st century, some of the underground oil resources may suffer postponed development or even remain undeveloped due to the shrinking demand. Oil production is determined by the consumers' demand at a particular price, and in most cases, the declining production is attributed to the demand for a commodity rather than the depletion of resources [36].

Population growth is not infinite. One key theoretical hypothesis of resource depletion is the infinite growth in resources demand resulted from unlimited growth of population, while the panic of the infinite population are mostly derived from linear predictions. In the era where Malthus lived, the world's population was about 980 million, doubling every 25 years. Thus he believed that the world population would surmount 300 billion in 2009. In the 1970s and 1980s, the population was in the steep period of the S-shaped curve, and the fear of resource constraints was prevailing. People kept talking about "the world population explosion," warning that increasing world population would inevitably lead to world famine and resource shortages. When criticizing Simon and other resource optimists, Thomas Homer Dixon emphasized that the future would suffer scarce resource complications that had never occurred before, and the population size and growth were its key variables [37].

In fact, the population catastrophe as Malthus and Ehrlich have predicted did not happen. Population growth, just like the development of many other things, is not linear but fluctuating, with peaks and valleys. With the decline in the birth rate and growth rate of the world's population, the international communities in the recent years increasingly worry about the population aging and decline. In 2006, the United Nations expected the world average fertility rate to fall below the mortality rate by 2025. In July 2007, the British *Economist* suggested in an article that, the number of born children was not sufficient to sustain population stability in an increasing number of countries, and there were already 4 out of 9 people living in countries where fertility was lower than the mortality rate. The world population is still growing but it seems to be near the inflection point recently. Zlotnik, the Director of United Nations

Population Division, argues that the global population was moving in the direction of nonsurge as a whole, and by 2030 the world would achieve the replacement fertility rate. Demographers estimate that the global population will reach about 10 billion peak 50 years later.

In his book *The Next 50 Years of the Trend*, Alice Watson predicts that the global population would begin to decline around 2050. In November 2010, in his article "*Foreign Policy*," Philip Longman argues that too few rather than too much population has become the anxiety of demographers. As the birth rate continues to decline, the outlook for mankind will be that the rate of population decline will be as fast as its previous growth rate, even faster. The Russian population has fallen by more than 7 million in 1991. In November 2, 2011, Sanjeev Sanyal, the Deutsche Bank global strategist, points out in his article "Population Growth Stops" that our future world is faced with the problem of too few instead of too much population, and the world population is likely to reach the peak of 9 billion in the 2050s——half a century earlier than the general forecast, and then drop sharply. A research article published in British magazine *Nature* forecast that the likelihood of a population decline in 2070 was 50% globally. According to the United Nations, the world's population may be only half of the current population by 2150 [38].

Demand also has peaks. Generally speaking, resource depletion or pessimism tends to overestimate the consumption, while demand always keeps fluctuating in response to prices in the long run. In March 2010, Christopher Johnson claimed in his article that the peak of global oil demand may be coming soon, since the current world economy was in rapid growth while the growth in oil demand did not catch up. In fact, oil demand has peaked in Western developed countries, and this phenomenon is currently spreading to developing countries. Over the past decade, oil demand intensity (with oil demand growth divided by economic growth) has declined at an annual rate of 2%, with a trend to accelerate. Energy efficiency, environmental issues, and the continuous development of alternative energy are gradually reducing the world's demand for oil. According to the calculations of a Canadian analyst Ershi, the high point of per-capita oil consumption has appeared in 1973, and it has been declining slowly but steadily since then. In March 2010, the US per-capita consumption of oil and its derivatives was 2.28 gallons average daily, down more than 10% compared with 10 years ago [39].

Western developed countries are moving forward to the postindustrial society, where the energy demand is close to the peak with slowing-down growth rate. In 2006–16, the world's primary energy consumption increased from 11,667 million tons of oil equivalent to 13276.3 million tons of oil equivalent. But in OECD countries, the energy consumption is reduced from 5677.4 million tons of oil equivalent to 5529.1 million tons of oil equivalent. In the United States, 2331.6 million tons of oil equivalent fell to 2272.7 million tons of oil equivalent (2370.2 in 2007). Europe and Japan declined from 3023.5 and 520.4 million tons of oil equivalent to 2867.1 and 445.3 million tons of oil equivalent, respectively. Meanwhile, CO_2 emissions from OECD countries fell from 13.791 million tons in 2006 to 12.574 billion tons in 2016 [24].

Currently, population growth and economic growth in developing countries can still boost oil absolute consumption for a certain period of time. Some oil demand analysts, however, concluded that oil consumption would stop increasing in the following 15 years. Edward, an oil demand analyst of IEA, argues that the downward trend of oil demand intensity would continue to accelerate incessantly in the future, and "a structural change of oil demand market would become increasingly noticeable." Some developing countries controlled prices and granted subsidies, which might push up oil demand increase in a short term, claimed David, the head of Oil Industry Marketing Department of IEA, but in the long run, the decline at such a speed was inevitable. With many elements in mind, such as economic development, diversification of fuel sources, and alternative energy, oil demand intensity, I am afraid, would reduce at an annual rate of about 2.5% in the next 5 or 6 years [40].

The Institute of Energy Economics, Japan, projects that the average annual growth of global GDP would drop from 3% in 1998–2007 to 2.8% in 2008–35. The annual growth rate of global primary energy consumption would fall from 2% in 1980–2007 to 1.5% in 2008–35, while the same rate of Asia would fall from 4.6% in 1980–2007 to 2.5% in 2008–35. After reaching its culmination in 2003, the domestic demand for oil products in Japan would begin to enter the stage of persistent declination and was estimated to tumble further down to 180 million tons by 2030 [41].

In August, 2013, an article in *The Economist* points out that global hunger for oil was coming close to its peak. In developed countries, oil demand had reached the culmination and started to descend since 2005. In the author's opinion, even taking into account the needs of China and India, two technological revolutions were supposed to weaken the global demand for oil. On the one hand, shale gas revolution led by fracturing technique would promote the substitution of natural gas for oil. On the other hand, oil demand would be inevitably influenced by automotive technological reformation, improving fuel efficiency, and the extension of hybrid vehicles, electric vehicles, as well as natural gas vehicles. Citybank observed if the fuel efficiency of cars and trucks increased by an annual rate of 2.5%, it would be sufficient to curb oil demand. And the bank also made a bold prediction that the oil consumption would reach the culmination of 920 million barrels a day in the next few years. In December 2013, Edward L. Monser noted in an article of *Oil* that energy efficiency increase would reduce oil demand by 3.8 million barrels per day by 2020; natural gas may contribute to the reduction of gasoline and diesel consumption by at least 3.2 million barrels per day; and oil demand would not peak until 2020–2025 [42].

BROAD PROSPECT FOR RESOURCE SUBSTITUTION

Resource substitution has wide and broad prospects. The key problem in resource utilization lies in that we need the service provided by metallic and fossil fuels rather than metallic and fossil fuels per se. For example, the use of telephone wires boosted the increasing demand of copper, while with the communication demand achieved by optical fiber or mobile phones, copper demand has remarkably dropped down. Thus, what is needed is the communication service rather than copper [43]. Almost all types of mineral resources are involved in resource substitution, which is mainly manifested, in terms of energy, as substitution of efficient energy for inefficient energy, renewable energy for nonrenewable energy; in terms of non-energy, as incessant surge of new materials, substitution of nonmetallic materials and metallic-and-nonmetallic composite materials for metallic mineral products.

There have been substitutions, in varying degrees, for many resources utilized by human beings. The trend of resources demand has changed, following the changes of technologies, price, lifestyle, etc. In the early 20th century, the demand for carriage as a means of transportation finally ended up in the world. Then in just 10 years or so, automobiles became widely popular. Sperm oil used as fuel in the 1850s across the world was swiftly substituted by kerosene in the 1860s [44]. The application of

Internet transformed the communicative and interacting methods, for example, reduction of business trip, changes of information transmission, and logistics delivery means, which altered and decreased the demand for a certain resource. Mercury production peaked in 1970s, its price soaring skyward. The recognition that mercury would play havoc with human beings' immune, enzyme, gene, and nervous systems resulted in the replacement of zinc, nickel–cadmium, ceramics and organic compounds, etc., for mercury. Accordingly, mercury production and price diminished quickly in the world, finally ending up in complete shutdown in 1993 [45].

Economic cost motivates resource substitution significantly. Consumers and companies may take other measures in cases of raw materials deficiency and price rise. Some would burn wood for heating in order to reduce oil and gas consumption. Fuselages of Boeing 787 are made of graphite fiber compound materials and fiber glass, rather than aluminum products, which are not in use any longer. On the energy front, the reduction of natural gas price may induce the increase of natural gas power generation and the decrease of coal power generation. In 2009, the development of shale gas led to the price fall of natural gas in America, which reduced the coal-fired generating capacity by 11%, and increased the natural gas–fired generating capacity by almost 5%. Natural gas–fired generating capacity in Europe occupied 8%–10%. Price rise of oil or natural gas would partly bring on the substitution of oil and gas for coal.

Meanwhile, recycle ratio of resources climbs significantly. Nonferrous metals recycling becomes an independent industry in developed countries, while in developing countries, resource recycle is attracting attention with each passing day. Currently, recycled ores mainly include staple and common metals such as copper, iron, and aluminum. In 2000, the ratio of recycled steel consumption to raw steel amount reached 8.3%, ratio of recycled aluminum to raw aluminum 32.9% [46]. Normal circular economy has formed in iron, steel, aluminum, and zinc productions. Now, steel made from secondary raw materials and steel scrap accounts for half of the steel output in Germany. Each automobile on average is made from steel over 500 kg, almost half of which can be recycled, with the cost of recycled steel lower than that of steel smelt from iron ores. Gold price has always been persistently high in history, which forces human beings recycle it from time to time. Of note, 85% gold turns out to be recycled until now [35].

ESSENCE OF AND SOLUTION TO RESOURCE DEFICIENCY

In the long term, there will be ample energy and resources to support human beings' consumption demand. In this sense, resources will not really "exhaust." They are efficient, clean, and cheap resources that are comparatively short. Renewable energy is environment friendly and affluent, but it is less competitive on cost and efficiency terms. Although hydrogen prevails everywhere, it seldom exists independently in nature. The world is abundant in such unconventional resources as oil sands, heavy oil, oil shale, etc. But under present technological conditions, they would bring more serious environmental pollution if they were in use. In general, future energy and resources supply shall be more subject to such elements as technology, cost, and environmental protection than to the amount of resources. The problem of resource deficiency in human society may be represented either as economic deficiency due to insufficient effective demand or as political deficiency. It would be more represented as local and temporary market deficiency than nonresource deficiency or exhaustion. Various types of deficiency result from different causes. Therefore, subsequent countermeasures adopted are entirely different.

First and foremost comes economic deficiency. Resource deficiency that some countries or people are confronted with at present is primarily economic deficiency, represented as insufficient effective demand. Effective demand is defined as both the desire and the capability to purchase. Economic deficiency due to insufficient purchasing capability is highlighted in food and water resource front. In energy terms, it is mainly represented as energy poverty in some countries or groups. Nearly 800 million people around the world are in want of food supply. It is not that there is not adequate food, but these people do not have enough purchasing capability [47]. Countries with the lowest income per capita are the most likely to be threatened by famine, for instance, Angola, Somalia, Egypt, Ethiopia, Mozambique, Afghanistan, etc. The report of the United Nations Food and Agriculture Organization (UNFAO) assessed that 34 countries were in food emergency around the world, 26 of them locating in Africa [48]. Resource deficiency appears predominantly in developing countries with insufficient financial resources. One report of International Water Management Institute claimed that 1 billion people living in areas short of water were confronted with "economic lack of water." Africa is in the most urgent need of water. Among the 25 countries with the highest percentage of people to whom safe drinking water is not accessible, 19 are in Africa [49]. Economic deficiency is rooted in economic underdevelopment and poverty. Hence, economic development and elimination of poverty, among others, are the keys to the solution of economic deficiency.

Next is the political and institutional deficiency. Resource deficiency in some countries results from domestic political elements, especially ossifying mechanism and misleading policies. As to this type of deficiency, solutions lie in improving the management of the government and perfecting market mechanism. Many famines in the 21st century have nothing to do with climate- or weather-related natural disasters. It is the "frustrating government" that finally and fundamentally brings them forth. Although western countries donated food to Ethiopia during the 1984–85 poor harvest, the military government allocated a great amount of food to support the army. Millions of people may have died of hunger long before the military government was ousted [50]. In modern societies, it is unlikely that famines would occur in countries with political stability and market economy. In 1996, UNFAO admitted that 14 sub-Saharan African countries were in the state of food emergency. Ten dropped into food deficiency due to civil strife [51].

The third one is comparative or regional deficiency. There is much talk of global energy or resources crisis, which is either regional or comparative deficiency in nature. Real global deficiency or crisis is not so frequent. Even though two crises have been recognized by the international community, they are quite at odds with our imagination. One of the crises results from political supply disruption, which is oriented only to some countries. The other is "artificial crisis" due to scare, hoarding of stock and price control, such as long queues in American gas stations and toilet paper crisis in Japan, whereas oil supply deficiency is actually not very serious, even in those countries most severely sanctioned in America and Japan.

Oil embargo does not bring about oil deficiency in America, for crude oil is practically not in short. The US Department of Energy data show that compared with 1972, 370 million more barrels of crude oil were imported into America in 1973. And crude oil import peaked in 1974, 85 million more barrels than 1973. The truth behind 1973 embargo is that both the deficiency of motor fuel and long distance transportation of gas are caused by government intervention in the energy market. With adequate food supply in the world as a whole, local efficiency is mainly due to food distribution methods and low purchasing capability of some countries. Similarly, despite of the popular saying of global water crisis, the absolute amount of water is enough to meet the demand. In most cases, water deficiency may extend to problems of regional distribution and management, which need political solutions. Internationally, it is recommended to have further dialog and cooperation, while distribution and management of water resource are expected to be strengthened at home.

Then follows the supply disruption or deficiency due to either international or regional conflicts, such as two oil crises, conflicts between Russia and Ukraine over gas price. Owing to regional disputes or conflicts, resources are in short supply now and then in history. It is not rare, therefore, for resource-holding countries to employ resources as a weapon to strike resource consuming countries. However, with the development of globalization, resource-holding countries and consuming countries are increasingly depending on each other. There are few cases that exporters disrupt supply at its own initiative and take resource as a weapon. For many resource-holding countries, whose dependence on resources and focus on the safety of resources demand are not second to consuming countries, resource export income is the main pillar of their economy. Solutions to this type of deficiency are as follows: to strengthen the market competitiveness and comprehensive support capability and improve emergency response mechanism, such as the establishment of Strategic Petroleum Reserve System, to deepen international dialog and cooperation, and promote peaceful solutions to bilateral or regional disputes.

When it comes to using energy as a weapon, the most commonly cited is the conflict over gas between Russia and Ukraine as well as other countries. Russia is blamed for its utilizing energy export to exchange political interests. As to the energy relationship between Europe and Russia, Russia's dependency on Europe, on the aspect of export income of oil and gas, is stronger than Europe's dependency on Russia. Undeniably, Russia takes political concerns over several gas conflicts between Russia and Ukraine, as well as over the energy conflict resulting from 2014 Ukraine crisis. But it is essentially a kind of price conflict, in which Russia mainly aims at Ukraine rather than Europe. Russia–Ukraine energy conflict embodies both the political orientation of Russia and its increasing focus on economic and market factors. It also reflects that Russia attaches increasing importance to keeping pace with the international community.

The fifth one is demand-oriented market deficiency, mainly manifested as price rise. Since the early 21st century, high and volatile energy price is essentially equal to the demand-oriented price rise driven by strong growth in the global economy. The reason of the demand-oriented price rise this time is different from the price rise in the two oil crises. The former is due to anything but resources exhaustion, whereas the latter is chiefly brought about by supply disruption. From a global point of view, with the increasing development of international marketability and globalization of energy and resources, the relationship between resource price and economic growth is not like that in the past, which is purely symbolized as negative correlation. Price rise of resources is mainly driven by strong global economic growth. If global economy grew at a lower speed or declined owing to high prices, resource demand, which has a close relationship with global economic growth, would fall after rise. If global economy demonstrated strong enough upward momentum, effects caused by high oil price would be offset.

Generally speaking, human beings would not stop advancing because of one exhaustive resource. By means of scientific research, they will never fail to find out a substitution for the original resource. With the accelerating development of science, more exploitable resources will be discovered so that more people can be supported within a limited space. It is quite unlikely that resources across the world may be exhausted. Considering the limit to what we can do, we should make a wise choice to avoid unnecessary panic, take measures suitable for a given country to address various types of resources efficiency, vigorously develop the economy, attach great importance to the demand-side management, speed up the research and development of substitution resources, and accelerate the market-oriented reform. As far as one country is concerned, natural resources scarcity is not an ultimately serious problem. Without scarcity, economics would not have been created or developed. Similarly, without scarcity, tremendous creativeness would not have been brought about under the tremendous pressure of economic crisis. The fact that countries short of resources, for example, Japan and Singapore, and countries with affluent resources have fallen into "resource curse" indicates the unnecessary connections between the amount of natural resources and economic development. Social resources are the most important strategic resources, which influence economy significantly.

As far as the globe is concerned, resource supply deficiency does not refer to the exhaustion or scarcity of the resources but rather regional shortage of efficient, clean, and economic resources during a certain period of time. The main or fundamental reason lies in market failures caused by government intervention or management. If the market ran freely and fluently, there would be no fear of deficiency. The most terrible is the irrational behaviors driven by inefficiency and panic. Currently, we need to avoid the panic resulting from the assumption that oil would disappear or resources may be exhausted. Because it leads to either the clamor and delusion, like resource wars, resource contention, and so on, or domestic policy mistakes and improper resource allocation.

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