# Chapter 2
# Resource and Technology

## 2.1 The Importance of Natural Resources

The standard economic theory states that natural resources are only one factor in economic activities, which can be easily substituted by other factors, and output can be augmented by increases in technology. The depletion of natural resources is of little concern since for neoclassical economists for technological advance and resource substitution will generally overcome the problems caused by depleted resources. The standard economic theory is taught in almost all universities worldwide. It has a great influence on public opinion.

To understand better the relation between resources and technology, we will examine regions where the resource base is very narrow so the impact of resource depletion can be assessed more clearly. Sunlight is the most universal resource to the world. Many other resources, such as fresh water and fertile land, are derived from abundant sunlight. We will examine population change in a mining town in the North, where solar energy, the most important and universal natural resource, is scarce. Suppose in one mining town, there are 10,000 residents, of which 20 % are miners or mining related service providers. The remaining 80 % are policemen, teachers, doctors, pastors, bakers, grocery store cashiers and other service providers. Can we conclude, from this figure, that only 2000 people in the town depend on the mining activities? Suppose, after some years, the mine is exhausted. Can new technologies provide additional job opportunities or at least support the non-mining population? Some historical examples will offer a hint. In its heyday of gold rush, Barkerville, in northern British Columbia, Canada had over 10,000 residents. It was once the largest town in the west of North America. Its population dwindled to zero when the gold mines were exhausted. This is not an isolated example. In almost all mining towns in the north, once mines are exhausted, the towns become ghost towns. Any region requires resources to support its residents.

When resource bases are narrow, it is easy to recognize natural resources as the ultimate source of all economic activities and technologies as means to utilize



J. Chen, *The Unity of Science and Economics*,
DOI 10.1007/978-1-4939-3466-9_2

resources. But often there are many different kinds of natural resources in the same place. People will move on to other natural resources after the depletion of one natural resource. For example, with the depletion of gold mines in California, people moved on to agriculture and other activities that require different kinds of resources, such as fertile soil, fresh water, sunlight, and petroleum. Some cities, such as New York, may not have large resource base themselves. But these cities provide service to large areas, even globally. It is the amount of resource they can control that determines the level of consumption of particular regions.

With the increasing volatility in commodity prices, more and more people are becoming aware of the importance of natural resources. However, the total cost of gasoline and other commodities is still small for most people. Output from resource industries is still only a small part of overall economic activity, even for major commodity producers, such as Canada. This gives an impression that natural resources constitute only a small part of overall economic activity. But this is really only a matter of definition. The transportation industry is not defined as a resource industry. However the manufacture and operation of vehicles, ships and planes are totally dependent on the availability of energy resources.

To better understand the extent of our dependence on natural resources, we will view our use of natural resources through the lens of thermodynamic theory.

## 2.2 Natural Resources: Diverse Forms and Unifying Principle

Most of the natural resources on the earth can be attributed to the temperature differential between the sun and the earth. The surface temperature of the sun is 6000 K while the surface temperature of the earth is around 300 K. The high temperature solar surface emits sunlight, which carries high quality energy. The earth receives high quality solar energy and emits low quality waste as infrared light energy. This temperature differential is what drives most things, including living organisms, on the earth. Intuitively, this temperature differential is like the in water levels at a hydro dam, which drives turbines to produce electricity.

Part of solar energy is captured by plants through photosynthesis and converted into chemical energy, which can be stored for a longer period of time than photons. The chemical energy stored in plants can be released to work for plants when and where it is needed to maintain various life activities of the plants, including photosynthesis process. Animals, by eating plants, obtain some of the chemical energy stored in plants. Almost all of the energy sources in the food web on the earth ultimately come from solar energy.

Fresh water is so common that we often take it for granted. In many places, its economic value is very low. However, fresh water is vital for our survival. Fresh water is also very scarce compared with salty water. It comprises only 3 % of all water. The rest, 97 %, is salt water. Salt water has lower free energy level than fresh water. Hence, salt water is stable and in chemical equilibrium, while fresh water is unstable and in a non-equilibrium state. The non-equilibrium state is maintained by solar energy. Solar energy distills salt water into vapor and returns fresh water to the earth, and especially the higher elevation areas, in the form of rain or snow. Since fresh water has higher free energy, the intake of fresh water instead of salt water saves living organisms a lot of energy. That is why areas with abundant fresh water have higher levels of biomass density than areas with little fresh water, such as deserts and oceans, where water is salty. Most cities are located by rivers or lakes, where fresh water is abundant. Fresh water is another gift from the sun.

Water will flow from high to low places due to gravity. Without solar energy enabling water vapor to escape the pull of gravity, all water would remain at low elevations. Clouds would not form and rain would not fall. The whole earth would be a desert. Rivers would not flow. Rivers are vital to human life. Most early civilizations originated by the riverside. Rivers formed the major channels of transportation before the age of cheap fossil fuels. With rivers comes hydro power, which is the only renewable natural resource that generates significant amount of electricity for human society.

Today, most energy needs of human society are provided by fossil fuels. We often call our civilization the fossil fuel civilization. Coal, oil and most of the natural gas are from ancient biological deposits. These biological deposits, which were formed over millions of years, were transformed for use by human societies over the last several hundred years. The abundant use of fossil fuels is the foundation of economic prosperity for many people the world over.

More detailed and systematic discussion about natural resources can be found from the standard references, such as Hall et al. (1986) and Ricklefs (2001). While the forms of natural resources are diverse, most natural resources can be classified into two classes. The first class includes low entropy sources, more popularly understood as energy sources. The second class includes raw materials that can be used as building blocks to harness energy sources for our use. The second class includes most metals. Many resources belong to both classes. Wood can be used as cooking fuels or building material. Petroleum can be processed into vehicle fuels or vehicle parts. Proteins, fats and carbohydrates can be used as energy sources or as building blocks for organisms.

## 2.3 Living Systems: Positive Return Technologies of Utilizing Resources

Resources are low entropy sources, or materials providing a gradient to the environment. But to utilize resources, it requires structures to harness entropy flows. These structures will be called technologies. We will look at the Periodic Table to see what kinds of chemical elements are good raw materials for building up structures to harness entropy flows.

**Table 2.1** The first three row of the periodic table, minus the chemically inactive noble gases

| H | | | | | | |
|---|---|---|---|---|---|---|
| Li | Be | B | C | N | O | F |
| Na | Mg | Al | Si | P | S | Cl |

Table 2.1 shows the first three rows of the Periodic Table without the column for noble gases, which are chemically inactive. Carbon is the first element of the fourth column (the center column of the Periodic Table). Carbon is the lightest of a group of elements that are largely chemically neutral and have four valence bonds. The chemical neutrality and large number of valence bonds makes it easy for carbon to link with many different atoms to form large molecules. Large molecules are essential for the preservation of life. They help to withstand random dissipation (Schrodinger 1944). Large molecules are also essential for performing complex and various tasks. This is why carbon, and carbon alone, is the backbone of life (Atkins 1997). The chemical neutrality of carbon and its four valence electrons makes it easy to combine with and detach from other atoms and to build complex structures. The stable and weak bond of carbon is ideal for storing and releasing energy. This is why carbon is an essential part of any carrier of organic energy, including natural gas and petroleum. Hydrogen is the smallest and the lightest element. That is why hydrogen is a low cost carrier of energy and building block of an organic system.

In order for a technology to last, it must be able to utilize energy resources to make another copy of itself before it wears out. Living systems are technologies that last. Carbon and hydrogen atoms are natural raw materials that make up living systems. Since the buildup of living systems embodies energy resources, living systems themselves become the resources that can be used by other living systems. Animals eat plants, other animals, fungi and bacteria. Bacteria eat plants, animals and other bacteria. Viruses eat bacteria, plants and animals. Human beings and many bacteria also consume fossil fuels, which are transformed from the dead bodies of living systems.

The greatest amount of energy can be accessed by the earth is solar energy. The earliest organisms that developed the structure for photosynthesis were probably bacteria. These bacteria utilized solar energy to build up structures with carbon, hydrogen and other kinds of atoms. Bacteria obtained carbon atoms from carbon dioxide. Initially, bacteria obtained hydrogen from hydrogen sulfide ($H_2S$) via photosynthesis. Compared with water ($H_2O$), the chemical bond in hydrogen sulfide is weak. From Table 2.1, both oxygen and sulfur are at the sixth column of the periodic table. Their chemical properties are similar. But sulfur is one row lower than oxygen. It takes less effort, or lower fixed cost, to get hydrogen from hydrogen sulfide. "However, when hydrogen is removed from hydrogen sulfide in the interior of a bacterium, the excrement is sulfur. Sulfur, being a solid, does not waft away, so the colony of organisms has to develop a mode of survival based on a gradually accumulating mound of its own sewage" (Atkins 1997, p. 22). Eventually, organisms developed techniques to break the strong bond in water to get hydrogen.

Oxygen is a byproduct of this technology. Since oxygen is a gas, the pollution does not accumulate locally. It spread out globally. Another advantage of obtaining hydrogen from water is the abundance of water. With water as a raw material in photosynthesis, living systems spread all over the earth.

Oxygen molecules, the waste product from photosynthesis, are highly energetic. This energy destroyed many early living systems and rusts many materials. Eventually, some organisms evolved the structure to harness the energy from oxygen. These organisms used antioxidant technology to reduce the destructive power of the energy from oxygen to tolerable levels. Animals, whose active lifestyle require substantial energy consumption, evolved to take advantage of the abundant atmospheric oxygen. All materials with a gradient against the environment have the capacity to destroy. Only after we develop technologies to harness the gradient of these materials and contain their destructive power to manageable levels, do these materials become resources.

The amount of solar energy available to early photosynthetic bacteria was almost infinite. Those bacteria multiplied quickly. Over time, photosynthetic organisms came to cover most parts of the world. Photosynthesis is probably the most important technology organisms have ever developed. It transforms the vast amount of light energy, which is difficult to store, into chemical energy, which is easy to store. Since the invention of photosynthesis, almost all living organisms have come to derive energy available to them from solar energy, directly or indirectly.

If a technology helps an organism to earn a positive return on resource utilization, the technology will be duplicated and spread out. However, not all technologies developed by organisms are able to provide a non-negative return consistently. Most genetic mutations or innovations are harmful. Even among those mutations where new species are established, over 99.9 % of the species eventually went extinct. Technology and innovation do not guarantee prosperity and safety to any biological species or human societies that adopt them.

A technology is not only expensive to develop but also expensive to maintain. Some fish living in dark underground caves become blind because functional eyes are expensive to maintain. When eyes are no more useful, these structures degenerate. Similarly, the sense of smell of human beings is highly degenerated from that possessed by our ancestors. Walking upright increases our dependence on vision and reduce our dependence on our sense of smell. As a result, smell is under less selection pressure and degenerates. A technology will be developed and maintained if its return on investment is positive during that period. Otherwise, the technology or its host will degenerate.

With the multiplication of organisms, came competition for limited resources. Individual organisms defend themselves or are consumed by other organisms. There are two main strategies, forming social groups to increase the power of the group or enhancing individual power. Social sciences are generally viewed as being exclusively concerned with humanity. But almost all organisms form social groups (Trivers 1985; Willey et al. 2011). Bacteria can live alone. They often thrive better in groups. Most organisms need to develop effective means communicating or coordinating with other organisms. Social biology was developed to study these problems. Studying the social behaviors of other species has provided valuable insights into human behavior. Some single cell organisms evolved into multi-celled organisms. Multi-celled organisms are larger than a single celled organism. An individual multi-cell organism can grow into a collection of many trillion cells. Large animals can often overpower small animals and control more resources. But multi-cell organisms also need to communicate and coordinate among different cells inside their own body, very much like different individuals in a society need to communicate and coordinate with each other. Social and natural sciences need to understand very similar problems.

## 2.4 Human Technologies and Human Societies

Technologies in human societies are generally understood as tools. These tools exist outside our bodies. The making of tools is not constrained by our body's physical and chemical environment. For example, iron smelting requires a temperature over 1000°, which is much higher than our body temperature. Aluminum smelting requires strong electric currents that would kill us instantly. However, all biological and human technologies are bound by the same economic principle. If a technology generates a positive return in a biological system, it will be developed and maintained. If not, it will decline. Since different technologies require different social structures and bring in different amounts of resources, technical structures and social structures become closely intertwined with each other.

We study past events to estimate the possible patterns in the future and to guide our actions today. The events that greatly affected the lives of people in the past, such as the Industrial Revolution, the Great Depression in 1920s, oil crisis in 1970s and the recent Great Recession, have especially strong grip on the minds of the public. The interpretation of these events greatly influences the public's vision about the future and the policies adopted by governments. In the following, we examine the most general increases over time in humanity's abilities to exploit energy and hence other resources, with a greater efforts to examine more recent events.

### *2.4.1 The Use of Fire and Cooking*

What is the most important activity that separates human beings from other animals? Different people have different answers. From an energy perspective, we might say the use of fire and cooking distinguishes humans from other animals (Wrangham 2009). Cooking kills most of the pathogens in food. Consequently our body doesn't have to spend as much energy on our immune systems. Cooking, by breaking down large organic molecules, predigests food before it is consumed and by breaking down cell walls allows access to much more food. Our body doesn't have to spend as much energy on our digestive systems. The energy saving can be used to nourish other important systems, such as our brain. Human beings can supply more energy to brains for more complex functions. Cooking reduces the risk of infectious disease. It enables human beings to live in higher density, which stimulates the need for better communication. Language, culture and religion flourished to bind people together. Cooking, by using fire regularly, makes us familiar with a chemical process of high energy intensity. This would become crucial in the development of future technologies. It seems no other activity has the same level of impact as cooking and the use of fire to influence the evolution of human beings and human societies.

### *2.4.2 High Resource Density, Sedentary Lifestyle and Agriculture*

Most researchers suggest that sedentary lifestyle followed the advent of agriculture. But it could precede agriculture. Some places have very high concentration of resources. Several times we travelled along Highway 16 toward Prince Rupert, British Columbia. We would pass by a canyon at a place called Morristown. In salmon spawning season, large amount of salmon waited just below the canyon, preparing to jump over the rapids to reach their final spawning destinations. Anyone can use a net to scoop up a fish from the river. The salmon are so abundant that local people are able to live a sedentary life around the canyon year around. They depend on salmon instead of agriculture. Some people could live sedentary lifestyles before the development of agriculture. But in general, it provided an incentive to practice agriculture, which requires intensive work in the fields for prolonged periods. So it could be sedentary lifestyle lead to agriculture, instead of the other way around.

While sedentary lifestyle may precede agriculture, large scale sedentary lifestyle followed the invention of agriculture. Agriculture is the growing of a few selected crops with active exclusion of most competing plants. Crops are mainly selected for their nutrition value to humans and not their competitiveness in the fields. They are usually not very competitive. The growth of crops requires intensive human intervention to remove weeds growing in the same fields. Crops, due to their high resource density, become the favored food source for microbes, other animals and other people. Farmers have to remain vigilant against other animals and other people. The increase of resource density always increases the potential of wars against microbes, other animals and other people. Since agriculture produces higher energy yield than hunting and gathering, it can support higher human density. Gradually, farming communities replaced hunting and gathering communities in many places of the world. High human density comes with complex society with many hierarchies.

### 2.4.3 Bronze Age, Iron Age and the Dark Age

Making bronze tools requires special smelting technology. The advent of the Bronze Age was a significant step in the mastery of using energy resources. The melting point of bronze is 232 °C while the melting point of iron is 1535 °C. It is much more difficult to smelt iron than to smelt bronze. The technology of making iron is developed much later than the technology of making bronze. Iron is much harder than bronze. Weapons made from iron are more powerful than weapons made from bronze. Iron tools can be used to cut down trees, from which charcoal is made. Charcoal is used to smelt iron. More charcoal led to more iron and more iron led to more charcoal. This positive feedback greatly increased the output of energy and iron equipment, such as swords and plows. Swords enabled iron making people to expand their territories. Plows enabled iron making people to get more nutrients from deep soil, thus enhancing crop yields and increasing population density. The arrival of the Iron Age generated the greatest burst of military, economic and cultural activity in human history to that point. However, the amount of iron production was ultimately constrained by the availability of trees around iron mines to provide fuel for the smelting process. A sharp increase in iron production in a place quickly deforested the surrounding area, which limited the scale of iron output throughout most of the Iron Age. Indeed, deforestation and soil erosion often turned once prosperous civilizations into desolate areas. A Dark Age, which consumed fewer resources, followed the Iron Age.

### 2.4.4 Coal, Iron and the Industrial Revolution

The Industrial Revolution has been interpreted in many ways. Here we offer another interpretation from the interaction between resource and technology, not necessarily inconsistent with other interpretations. Shortly before 1750, a technology of iron making with coal was invented in England. Mining and transportation of coal requires considerable iron made equipment. Since the beginning of the Iron Age, iron was smelted using charcoal, which is made from wood. Before 1750, the need for charcoal in iron making deforested most of England (Jevons 1865). The limit to the supply of charcoal limited the supply of iron, which limited the supply of coal. After the invention of iron smelting by means of coke, derived from coal, it replaced charcoal as the main fuel in iron making. Coal is much more abundant than wood and coal has much higher energy density than wood. More coal led to more iron and more iron led to more coal. The positive feedback between the output of coal and iron, the most important energy source and the most important material of the Iron Age, enabled human beings to grow tremendously in number and in prosperity. This was the essence of the Industrial Revolution. Jevons was very aware of the importance of this invention. In *The Coal Question*, he described it in great detail.

### 2.4.5 The Age of Oil: The Great Depression, Oil Crises, and the Great Recession

Since the beginning of the Industrial Revolution, the global economy has been growing steadily, most of the time. There have been several slowdowns, such as the Great Depression, the oil crisis in the 1970s and the recent Great Recession. There are many interpretations of the causes of the Great Depression. Very often, it was attributed to structural weaknesses in various economic sectors and policy mistakes by various government agencies. From the energy and technology perspective, the transformation from a coal-based economy, centered on railways, to an oil-based economy, centered on cars and trucks, was partly responsible for the Great Depression. Since hydrogen content of oil is higher than that of coal, oil is a higher quality energy source than coal. In the decade of the 1920s, the number of cars increased tremendously. But the supply of oil had been quite limited. Cars were regarded as a supplement but not replacement to the railroad economy. However around the end of 1920s and the early 1930s, many gigantic oilfields were discovered over a short period of time due to the development of better exploration methods (Deffeyes 2001). It became very clear that the petroleum and car economy would replace the coal and railroad economy. A large part of the railroad economy fell apart immediately upon this realization. But it took time for the car economy to grow enough to replace the railroad economy. The structures of the railway centered economy were very different from that of the highway centered economy. Areas around the train station were often prime real estate and the center of most economic activity in a city in the railway centered economy. In many cities, the street where the train station locates is called the first avenue. However, in a highway centered economy, shopping areas are relocated to malls and residential areas are moved to suburbs. The shift of economic gravity devastated the downtown areas in most cities. Many once prosperous towns built on railways became ghost towns when highways bypassed them.

The discovery of the giant oil fields around 1930 happened over a short period of time. The adjustment was very sudden and painful. The Great Depression was unavoidable, regardless of government policies. Yet the abundance of oil, a higher quality energy source than coal, also set the stage of economic boom after the Second World War, when highways and gas stations were built in many parts of the world. The tremendous growth of the petroleum and car based economy greatly increased the consumption of petroleum. In 1956, M. King Hubbert proposed oil output in US and in the world would eventually peak and decline. Around 1970, many people became concerned by the increasing consumption of resources. A representative work at that time was *The Limits to Growth* published in 1972. In 1970, US oil production peaked. In 1971, the US government stopped converting US dollar to gold at the fixed rate of 35 dollars per ounce, thus delinking the value of dollar to gold, a major commodity. After that, the value of the US dollar depreciated sharply against gold. This put heavy pressure on the price of other commodities, such as petroleum (Galbraith 2008). In 1973, the oil price increased substantially due to the collective action of major oil exporting countries. This increase in oil prices generated a deep recession in many oil importing countries, including most wealthy countries. In 1979, events around Iranian Revolution generated another sharp spike in oil prices, causing another deep and prolonged recession in 1981–1982.

By the 1980s, most wealthy countries that experienced economic recession regained economic growth. The standard explanation is that these countries were able to overcome high oil price with proper economic policies. Hence good economic policy can overcome resource scarcity. However, if we understand human society as a biological system, we will observe that in most wealthy countries, where resource consumption is high, fertility rates dropped below replacement rate after 1973, the year of high oil price. This shows that the biological rate of return has turned negative. However, the drop in the fertility rate temporarily reduced the investment cost of raising the next generation. This generated temporary economic growth for several decades. Eventually, negative biological return will lead to negative monetary return in a society.

Another adjustment for wealthy countries was to move manufacturing activities to poor countries where ordinary people have minimal political power. This greatly reduced the energy consumption in production and in processing waste pollution. This also greatly reduced the salary paid to workers. Lower salary means less consumption of resources. By moving manufacturing to poor countries, the energy consumption is greatly reduced.

In the 1970s, the global oil output was still rapidly growing and the average physical cost of oil production was low. But the control of price setting of oil gradually shifted from major oil consuming countries to oil producing countries. This caused major economic recessions and negative biological return in most wealthy countries. By the end of 1990s, with the rapid depletion of easy to extract oil, the average cost of oil steadily increased. In a now classic paper titled The End of Cheap Oil, Campbell and Laherrere (1998), after carefully examining the oil exploration and production data, concluded "What our society does face, and soon, is the end of the abundant and cheap oil on which all industrial nations depend."

When their paper was published in 1998, oil prices were in the low teens. Since then, the price of oil, as well as other major commodities, has increased substantially. If we had recognized the fundamental importance of resources to the overall economy, we would have stopped the measures to stimulate economy after the burst of the internet bubble in 2000. However, the authorities were convinced that the economic recession in 1973 was caused by improper policy response to high oil prices instead of the high oil price itself. They believed that they had mastered the proper policy response now and were not worried about the steady increase in oil prices. That is why the authorities were unprepared when the financial crisis broke out in 2007 and 2008, although the prices of major commodities had been increasing for some time.

According to neoclassical economic theories, recessions are short term interruptions from long term economic growth. After each recession, economic growth will eventually resume. But from a biological and resource perspective, and from the perspective of heterodox political economy long term economic growth is not assured. It has been for several decades that the biological rate of return has been negative in most wealthy countries. With the demographic structure of inverse pyramid, economic activity will eventually decline. High resource cost makes it more difficult to maintain both high living standard and non negative biological return.

The resource and technology based interpretation provides a simple and consistent interpretation of the major events in human history. There are many other interpretations. Financial crises are often blamed on human greed. This is certainly true. But humans are always greedy, before and after financial crises. Financial crises are often blamed on bad monetary policies, keeping interest rate too low for too long. But in a system with abundant resources, a low interest rate policy only has mild impact to generate inflation. Financial crises are often blamed on wide spread fraud. This is certainly the case in the recent Great Recession. But why is fraud so systematically practiced this time? This is because in an environment with increasing resource cost, fraud becomes the only viable way to generate a high rate of return systematically, still expected by the public who are accustomed to the good old days of abundant resources (Chen and Galbraith 2012b).

## 2.5 On Inequality

When the water levels inside and outside of a hydro dam are unequal, electricity can be generated. When temperatures inside and outside of an engine are unequal, work can be generated. In popular terms, the inequality in gravitational potential, chemical potential, electric potential and other potentials is called energy. From thermodynamic theory, inequality in potential, or energy is the driving force in the nature. It is also a destructive force. We all need energy provided by oxygen. At the same time, our body produces many antioxidants to prevent oxygen from reacting with and destroying our tissues. Sugar is a vital energy our body needs. But too much sugar in our blood system, and in cells, will damage our health. When we cannot maintain a low level of sugar in our blood system, we get diabetes. Human societies depend very much on high energy input. But we carefully regulate the energy sources. “Playing with fire” is always considered dangerous. Whenever possible, systems with high gradient, or high inequality are carefully regulated. They are contained in isolated or remote places. Furnaces are usually located in basements. Electric generators are usually placed very far from residential areas.

In North America, electric voltage in residential areas is 110 V while in most other parts of the world, the electric voltage is 220 V. To carry the same amount of electric energy in a 110 V system requires much thicker wire than in a 220 V system. But when accidents occur, 110 V causes less shock than 220 V. In a system with abundant natural resources, such as North America, we often choose less resource efficient but safer options. In systems with scarce natural resources, we often choose more resource efficient but riskier options. There is a parallel in social systems. In a social system that controls more resource, its internal inequality is often low. But such system can utilize abundant resources as "energy slaves" (Nikiforuk 2012) or impose inequality on other weaker social systems. In a social system that controls less resource, its internal inequality is often high. In such system, efficiency is very high for the elites, the designers of the system. But such systems also have a higher probability of experiencing violent revolution. When factories are located in wealthy countries, much resource is used to control pollution. This lowers the ratio of output over resource input. But when factories are moved to poor countries, where local population has little political power, little resource is allocated to control pollution. This increases the ratio of output over resource input. Pollution is the reduction of chemical potential. Increasing pollution is the increase of inequality in chemical potential. By increasing inequality, the designers of the system gain higher efficiency and obtain cheaper products as a result.

It requires higher fixed cost to maintain a more unequal society. Dominant parties of a society do not necessarily hope to increase inequality all the time. When the British Empire was expanding rapidly in the 19th century, it abolished slavery, a more extreme form of inequality. By adopting less unequal social systems, Britain was able to maintain and expand a huge empire with relatively little cost and huge profit. The inequality of a system also depends on how long the dominant parties expect the system to last. When we go fishing, we hope to have some inequality over fish. We use a fishing line to hook fish. But if the general public is allowed to use fishing nets in rivers, lakes and oceans, fish population will decline rapidly in a very short period of time. For an unequal system to last, the level of inequality cannot be too extreme. This applies both in nature and in human societies. When the dominant parties expect the system to end soon, the inequality of the social system tends to increase so that dominant parties can extract more profits while the system lasts.

## 2.6 Carbon and Hydrogen as Energy Sources

Carbon and hydrogen are the main components of organism. They are also the main component of the energy sources in organisms and in fossil fuels. Most energy sources we encounter, from foods we eat to gasoline we use to power our cars, are mainly combinations of carbon and hydrogen atoms. Hydrogen is lighter and has much higher energy density than carbon. Hence hydrogen has lower cost of transportation than carbon. At the same time, hydrogen energy is more costly to produce. For animals, because of their mobile lifestyle, the cost of transportation is high. So animals store a lot of energy as fat, which has a high hydrogen content. Plants, because of their sedentary lifestyle, are more economical to use carbon energy directly. They contain little fat in their bodies, with the exception of seeds, which have high energy demand and need to be more mobile than the plants themselves. This pattern applies to human society as well. Automobiles and airplanes, as transportation tools, are highly mobile. Their energy supplies are petroleum products, such as gasoline, jet fuel and diesel, which contain high hydrogen content and are relatively light. Electricity generators are not mobile. The main energy input in electricity generation is coal, which is mainly carbon, heavy but cheap. The transportation of electric energy is to transport electrons, which are much lighter than atoms. So transporting electricity is a cheap way to transport energy. This is one reason electricity is universally used in most daily activities.

Among main energy resources, natural gas has the highest hydrogen content. That is why natural gas is preferred over coal as the energy source in home for cooking and heating. The last century can be thought as the transformation from carbon economy represented by coal to hydrogen economy represented by oil and natural gas. Therefore, people have moved toward a hydrogen economy long before official mandates from governments. This is also why natural gas and oil, which have much higher hydrogen content than coal, deplete much faster than coal. With the fast depletion of high quality (high hydrogen content) fossil fuel sources, can we create a man-made hydrogen economy?

Compared with coal, oil and natural gas burns more completely and emits fewer pollutants. In general, an energy source that reacts with the environment more easily will leave less harmful residue. At the same time, since clean energy reacts easily in the natural environment, it will be more difficult to preserve. This is why coal is much more abundant than oil and natural gas. In the end, we will have to rely on coal as our main energy supply after the depletion of oil and gas. The twenty-first century will become more a carbon economy instead of a hydrogen economy envisioned in some literature.

When the supply of high hydrogen content energy sources, such as oil and gas, are depleted, a man-made hydrogen energy can be produced from two possible sources. One is from renewable energy, such as solar, wind and biomass. We will discuss this option in a later section. The other is from low quality energy sources, such as coal. From the thermodynamic law, producing certain amount of high quality energy will require more low quality energy. Hence a hydrogen economy will produce more, not less pollution on the global level. The consequence of a hydrogen economy can be seen from an electricity economy. Electricity is a very clean form of energy at end use. Its cleanness enables average households to utilize a huge amount of energy without feeling its negative impact. But power plants are the largest consumer of coal and other energy sources.

A parallel understanding can be made from the separation of residential and industrial areas. The separation makes residential areas cleaner, but adds the extra pollution from transportation as people now need to commute between residential areas and work areas. The longer the distance between residential and industrial or commercial areas, the cleaner the residential areas are. But the total pollution will be higher because the extra pollution caused by transportation will be higher. At the country level, trade allows heavily polluted industries to be moved to poor countries where general population has little political power. While the rich countries enjoy cleaner environment, total pollution on the earth will increase because of the added transportation and communication costs. The concept of ecological footprint, which represents the consumption level of each country, provides a better measurement to the burden of human society to the environment (Wackernagel and Rees 1995). On a global basis our ecological footprint exceeds biocapacity, a situation that cannot be maintained indefinitely.

The prevailing wisdom on energy consumption is that hydrogen based energy should be promoted and the carbon based energy should be suppressed. However, hydrogen based energy is scarce and has already been depleted at fast pace because of their high quality. A further restriction on carbon as an energy source will accelerate the depletion of high quality energy sources and leave future generations in a worse shape. In a more sensible strategy of energy consumption, different energy sources should be utilized in different ways according to the differing physical and chemical properties of hydrogen and carbon. Natural gas, with the highest hydrogen content among carbohydrate fuels, is the cleanest. It can be used as fuels in densely populated residential areas. Gasoline, being a liquid and high energy density fuel because of its high hydrogen content, can be primarily used as transportation fuel, where energy supply has to be carried on vehicles. Coal, being largely carbon, is heavy, abundant and hence cheap. It can be economically used to generate electricity. Utility companies are large companies that can afford to make high fixed cost investment. Since power plants use large amount of fuel, they are in the best position to use expensive equipment to reduce the pollution from coal burning. Before the large price increase of oil during oil crisis in 1970s, many power plants used oil as fuels. But after that most power plants use coal as fuel (Dargay and Gately 2010).

## 2.7 Some Patterns in Energy Economics

Almost all the energy sources on the earth ultimately come from the sun. However, not all living organisms use solar energy directly. Several factors determine the pattern of energy use. The first important factor is energy density. Solar energy is vast. But the net return from transforming light energy into chemical energy, which organisms can store and transport easily for their further use, is low. Plants, whose sedentary lifestyle requires low level of energy consumption, can effectively utilize solar energy directly through photosynthesis. Most animals, whose mobile lifestyle requires high level of energy input, could not support themselves through photosynthesis internally. Instead, some animals consume plants, which store high density chemical energy transformed from solar energy over a period of time. Other animals eat plant eating animals. Fossil fuels, which are further concentration of biomass in large scale, provide much higher energy density than biomass. The consumption of high energy density fossil fuels is the foundation of economic prosperity enjoyed by human societies in the last several hundred years.

The second factor of energy economics is the relation between the ease of storage and the ease of use. Electricity, which is very easy to use, is very difficult to store. The energy of biomass and fossil fuels are stored in the form of chemical energy, which is less easy to use compared with electricity, is easier to store. Nuclear energy, which requires very expensive system to harness, can be preserved for billions of years. This fundamental tradeoff is determined by the potential well of an energy source. The deeper the potential well, the easier to store the energy and the harder to use it. This is why attempts to reduce the storage cost of some easy to use energy sources, such as electricity, seem so elusive. On the other hand, it is often difficult for easy to store energy, such as fat, to be used easily. That is why it is so difficult for people to lose fat in their body. It is also difficult to achieve high energy density for easy to use energy sources, which react easily due to low potential well. Electricity is easier to use than gasoline. But the energy density in battery, a form of chemical energy, is generally low. For example, the energy density of lead battery is $0.16 * 10^6$ J/kg while the energy density of gasoline is $44* 10^6$ J/kg (Edgerton 1982, p. 74). Great progress has been made to increase energy density of batteries by utilizing smaller atoms, such as lithium. However, potential for further increase of energy density of batteries significantly is limited by the physical properties of electric energy. This is why progresses to develop electric cars that can drive similar distance to gasoline cars without recharging have been slow, although electric cars have a long history.

The third factor of energy economics is the efficiency of energy use and the total consumption of energy. Many people have advocated the increase of efficiency as a way of reduce energy consumption. Will the increase of efficiency reduce overall resource consumption? Jevons made the following observation more than one hundred years ago.

> It is credibly stated, too, that a manufacturer often spends no more in fuel where it is dear than where it is cheap. But persons will commit a great oversight here if they overlook the cost of improved and complicated engine, is higher than that of a simple one. The question is one of capital against current expenditure. … It is wholly a confusion of ideas to suppose that the economic use of fuel is equivalent to the diminished consumption. The very contrary is the truth. As a rule, new modes of economy will lead to an increase of consumption according to a principle recognized in many parallel instances. (Jevons 1965 (1865), p. xxxv and p. 140)

Put it in another way, the improvement of technology is to achieve lower variable cost at the expense of higher fixed cost. Since it takes larger output for higher fixed cost systems to breakeven, to earn a positive return for higher fixed cost systems, the total use of energy has to be higher than before. That is, technology advancement in energy efficiency will increase the total energy consumption. Jevons' statement has stood the test of time. Indeed, the total consumption of energy has kept growing, almost uninterrupted decades after decades, in the last several centuries, along with the continuous efficiency gain of the energy conversion (Inhaber 1997; Smil 2003; Hall 2004).

Figure 2.1 displays the total primary energy consumption worldwide from 1965 to 2012, a period of rapid technology progress. During this period, energy consumption grew steadily, with only two brief interruptions. From 1979 to 1982, a period of Iranian Revolution, oil price jumped from 13.60 US dollars per barrel in 1978 to 35.69 in 1980, causing serious recession in industrial world. The drop of

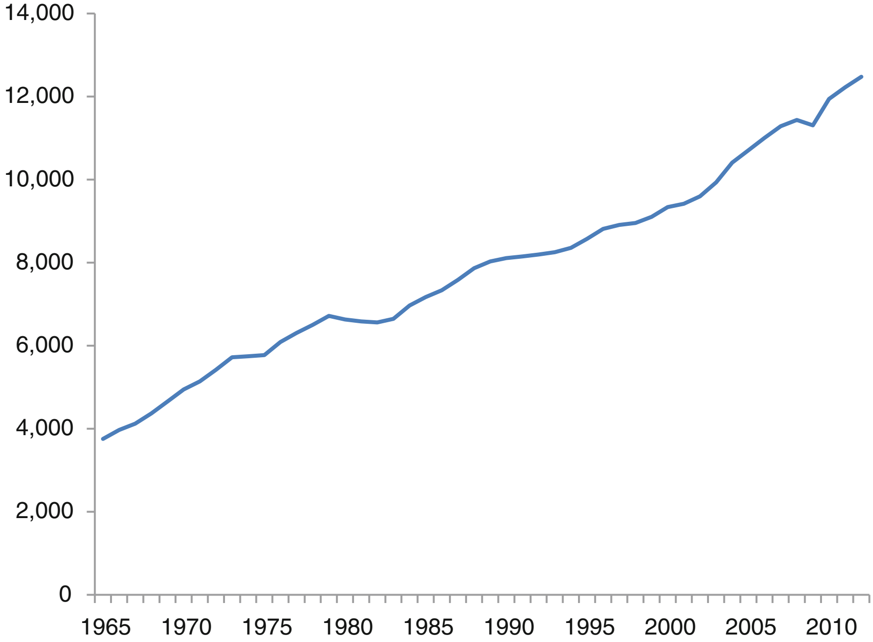


**Fig. 2.1** Global energy consumption (Million ton oil equivalent) from 1965 to 2012. *Source* BP

energy consumption from 1979 to 1982 was due to sharp jump in oil price and the ensuing contraction of economic activities, not due to technology progress. Another brief period of interruption is year 2009. In 2008, oil price rose sharply, reaching 147 dollars per barrel at its peak. The ensuing Great Recession diminished the capacity for energy consumption. But the decline of energy consumption only last for one year.

We may also examine energy consumption of individual innovations such as hybrid cars. Hybrid cars need two engine systems, such as an internal combustion engine and electronic motor. Hence their production requires more resource and energy input. If the owners of hybrid cars drive very little, the total energy cost of a hybrid car is actually higher than a conventional car due to the high resource consumption in manufacturing hybrid cars. Only when the owners of hybrid cars drive extensively, hybrid cars become more economical than conventional cars. Hence the use of more efficient cars will encourage, indeed enforce, the high consumption of energy. It should also be noted that hybrid cars, equipped with two engines, are heavier than conventional cars of the same class. Hence hybrid cars will be less fuel efficient in highway driving where frequent stop and acceleration is not required. In the end, hybrid cars, because of their high resource consumption in production and hence high prices, will become a symbol of status, just like SUV at present time.

## 2.8 On the Concept of Renewable Energy

The deepening public concern about the long-term availability of fossil fuels has promoted governments worldwide to adopt policies to subsidize research and production of renewable energy. To understand the effectiveness of these policies, we need to clarify the concept of renewable energy.

Almost all life forms depend on solar energy directly or indirectly for billions of years. So the use of renewable energy is not a new adventure. Instead, it has been practiced for billions of years by all life forms.

Almost all of the energy sources are renewable to some degree. Fossil fuels are generally considered to be non-renewable because of the time, heat, and pressure needed to transform carbohydrates into hydrocarbons. They are produced every day in various geological structures, however the rate of production of fossil fuels is much lower than the rate of consumption. A resource is renewable when its consumption rate is lower or equal to its regeneration rate. Otherwise it is not renewable. Hence, the concept of renewable resource is intrinsically linked to the level of consumption of that resource. For example, many supposed renewable resources, such as fishery, collapsed when consumption levels became higher than regeneration. This will clarify a lot of confusions around renewable resources.

Corn is supposedly an important part of renewable energy industry. Pimentel and Patzek (2005) reviewed the past research works on the production of ethanol from corn and found the following results.

1. The total energy input to produce a liter of ethanol is higher than the energy value of a liter of ethanol. Thus there is a net energy loss in ethanol production from corn.
2. Producing ethanol from corn causes major air, water pollution and degraded environmental system.
3. There are over 3 billion people in the world are malnourished. Expanding ethanol production, which divert corn needed to feed people, raises serious ethical issues.

Despite the fact that ethanol production from corn is not a renewable energy, it pollutes environment and raise serious ethical issues, government subsidy on bio-energy has been expanding rapidly over time. Why is that? There could be several reasons.

1. Because of government subsidy, companies participating bio-energy production have been very profitable (Pimentel and Patzek 2005). Hence they will lobby hard for this type of subsidy.
2. The term "renewable resources" provides a psychological satisfaction for the general public. People can continue their grand lifestyle that requires high level of resource consumption while still feel morally superior because they invest on renewable resources, which are supposedly to be beneficial to future generations.

3. Governments are eager to be seen as doing "something" for the environment. Spending money on environment related issues projects a positive image. Government actions are generally channeled into directions with maximum political support and minimum political resistance. This means that government policies often benefit the current generation at the expense of future generations, who are not here to vote and lobby. This is true even for government policies that are supposed to benefit future generations.

Like any other viable investment in life, viable investment in energy should yield positive rate of return. Estimates of energy return on investment (EROI) of many renewable energy resources have been produced by experts in different areas. But the origin of the idea, and most of the numbers, are attributable to Charles Hall. Sometimes these estimates are very high. For example, many estimations of energy return on investment of wind power is around 20 and some estimations of energy return on investment of solar panel is around 7. If the energy returns of these resources are really that high, the construction of these projects will spread like wild fire, even without any government subsidy. There will be no more problem of energy shortage because of the vast amount of solar energy. It is beyond my expertise to estimate the rate of return on each type of renewable energy resources. For more background information, please see Prieto and Hall (2013), Hall et al. (2014), Lambert et al. (2014). Instead, I will discuss some general economic principles that suggest the costs of most renewable energy programs have been seriously underestimated in some literature.

Living organisms, including human beings, generally utilize resources from easy to difficult, or in economic terms, from low fixed cost to high fixed cost, or from most accessible to least accessible For example, humans use wood, coal, oil and natural gas, in that order, because the fixed cost of using them increases in each case. Promising renewable energy sources have not been brought into market place because of their high fixed costs. These high fixed costs are heavily subsidized through tax dollar funded university and industry research. The development and maintenance of most renewable energy technology requires high level of technology expertise, which is developed through the expensive education system. While education is funded by general tax revenue, it mainly benefits high tech industries.

All proponents of alternative renewable energy acknowledge the high fixed cost inherent in these new energy resources and argue that scale economy will eventually bring down the average cost. There are several types of economies of scale in the resource industry. We will discuss them separately.

The first type of scale economy is in high-tech research. The expensive high tech research only pays off when it market size is large. For example, people have been harnessing wind power for many centuries. But only with light and strong new materials such as fiberglass, has generating electricity via wind power become feasible. Fiberglass, as a synthetic material made from petroleum, is a direct outgrowth from the fossil fuel industry. Indeed, most of metal based technologies are supported by the abundance of fossil fuels. When the fossil fuel becomes scarce, most modern industries, with their high fixed cost, may not have a sufficiently large scale to be viable. While the fixed costs in developing some renewable energy seem high today, they could be much higher in the future when fossil fuels become less abundant.

The second type of economy of scale is the use of large quantities of fossil fuel itself. For example, electrical transmission systems are very expensive to build and maintain. They become economically viable only when large amount of electricity, most of which is generated by fossil fuels, is being transmitted. It is the scale economy of fossil fuel generated electricity that supports the infrastructure that is also been used by alternative energy sources. If fossil fuels are excluded in electricity generation or depleted in the future, will the alternative energy sources be able to provide sufficient large market size to support the high cost electrical transmission system? This leads to the third type of scale economy: the scale of each type of renewable energy.

Hydro power, which generates 7 % of total electricity output worldwide, has already achieved substantial economy of scale. At certain locations, hydro power has the advantage of high energy density, just like fossil fuels. This is also why hydro power has achieved such a large scale. For other renewable energy resources, such as biomass, solar and wind, the energy density may not be very high and steady, which poses a physical limit on the reduction of cost.

The current biosphere is the result of more than three billion years of evolution. In the competition for survival, many different ways of utilizing resources more economically have been explored. The most discussed forms of renewable energy, such as solar, wind, and bio energy, have been around for billions of years and have been extensively explored by many species, including human beings. While it is difficult to rule out the possibility that human beings can develop new technologies that has significantly higher overall efficiency in energy use than other living organisms and our own ancestors, if research and development costs are included, the likelihood will be low. Human beings, like other dominant species, excel at controlling more resources, not at utilizing resources more efficiently (Colinvaux 1980). Furthermore, research activities themselves are very resource intensive and accelerate the depletion of natural resources. Hence government policies about future energy investment patterns should not rest on the assumption that technological progress will automatically substitute the demand for natural resources, as mainstream economic theory asserts (Samuelson and Nordhaus 1998, p. 328).

## 2.9 Concluding Remarks

Because of the importance of energy in our life, people have pursued the dream of convenient and cheap renewable energy since time immemorial. In the course of history, many people believe they have discovered an inexhaustible source of energy, such as battery, or invented one or another kind of perpetual motion machine. They think their discoveries or inventions can be put into practical use in large scale once necessary technical improvements can be made in the future.

However, more rigorous investigation leads to the development of thermodynamic theory, which rules out the possibility of a perpetual, or renewable energy source without external input.

In this chapter, I investigated further how physical environment enables and constrains living organisms and economic systems by integrating the economy of human society into the economy of nature. I explored the relation between natural resources and technology in human society. It helps us envision the future of human society in an environment of increasingly scarce and costly natural resources. The main results can be summarized as follows. First, the survival and prosperity of human society depends entirely on the availability of natural resources. Second, while the forms of natural resources are diverse, they can be understood from the unifying principle as low entropy sources. Third, to utilize natural resources, fixed structures are required, which consume resources themselves. Fourth, when certain structures can generate positive returns on the use of natural resources over an indefinite period of time, these structures are called living organisms. Fifth, it is the unique chemical properties of carbon that enables it to become the backbone of life. The major non-renewable resources that our industrial civilization builds on, such as coal, petroleum and natural gases, are generated from the remains of the living organisms. They all contain carbon.

Some practical implications emerge from our theoretical discussion. First, we prefer high quality resources over low quality resources. This is why we moved gradually from more carbon based fuels, such as coal, to less carbon based fuels, such as natural gas and petroleum. However, as high quality resources, such as conventional oil, are seriously depleted, human society will be forced to move back toward a carbon based economy from the current mixed carbon and hydrogen economy. This contradicts the often dreamed of hydrogen economy in the future. Second, increasing energy efficiency, which requires the increase of fixed cost, will increase total resource consumption. This was pointed out by Jevons more than a hundred years ago. Third, due to the levels of potential well, energy sources that are easy to use, such as electricity, are difficult to store. This is why it is so difficult to develop electric cars that can drive long distance without recharging.

Springer

http://www.springer.com/978-1-4939-3464-5

The Unity of Science and Economics
A New Foundation of Economic Theory
Chen, J.
2016, XVI, 136 p., Hardcover
ISBN: 978-1-4939-3464-5