Chapter 1
Prologue: Time Travel with Abel

Imagine an observer in the state beyond space and time from which one can watch the universe and human history unfold from the beginning to the end. Let us call him Abel. He takes us on a voyage through time and lends us his eyes and insight. This is what we see.

1.1 From the Big Bang to the Sun

A singularity out of nothing blows up in a glaring white. "This is *ENERGY* – the cosmic building stuff," Abel whispers as we watch in awe. "You see the beginning of space–time in the Big Bang 14 billion years ago. Right now the primordial content of the universe has a temperature of 10^{32} degrees."[1]

Space and time expand. The quark soup condenses out of the glittering radiation. Then quarks form protons and neutrons. These fuse into the first light elements: deuterium, helium, and lithium. "Now the universe is 100 seconds old, and its temperature is down to some billion degrees," Abel comments. The cosmos expands further. After 400,000 years matter and radiation decouple; space is filled by a multicolored glow: the cosmic background radiation and its fluctuations. A dark age follows for the next 600,000 years, when the first stars form and fuse the elements heavier than iron, such as copper, silver, and gold. Then stars and galaxies become visible. They proliferate and fill the universe with their shining glory, while it expands to size of over 100 billion light years. The cosmic background radiation has cooled down to a temperature just 2.725 degrees above absolute zero. Abel summarizes what we have seen:

[1]The Celsius (°C) temperature scale has its zero point at 273.15 degrees above the zero point of the absolute Kelvin (K) temperature scale.

R. Kümmel, *The Second Law of Economics: Energy, Entropy, and the Origins of Wealth*, The Frontiers Collection, DOI 10.1007/978-1-4419-9365-6_1,

"All matter has condensed out of energy, all changes are driven by energy conversion, and all structures originate from energy fluctuations, such as the ones you note in the slightly warmer and colder regions of the background radiation."

Before we rejoice about having the full cosmic vision, Abel cautions us: "You have just seen 5% of what the universe contains. The rest is 20% dark matter and 75% dark energy." He refuses to reveal more about dark matter and dark energy, stating that he is only allowed to show what is already part of human knowledge. When we ask him "What is human knowledge about energy?" he replies, "I'll just give you the grand tour. Details you may look up in the treatise I'll hand over to you at the end of our voyage."

Our vision zooms in on an average star at the fringe of a galactic spiral arm. Protuberances flicker on its surface, and flares of gleaming hot gases shoot up into the darkness of space. A distant blue planet encircles the radiating sphere.
"The fountain of life," Abel comments, and recites

> *"Splendid are you in the heavenly mountain of light,*
> *Living Sun, living since the Beginning,*
> *filling all the lands with your beauty.*
> *Great are you, shining in every country,*
> *embracing all the earth with your life-giving rays.*

This is how the Egyptian pharaoh Amenophis IV, who calls himself Echnaton, greets the Sun."

We dash toward the Sun. At its surface Abel announces: "The temperature is 5777 K. Let's go to the center. It is just 696,000 km away." Our space–time elevator speeds down past huge, swaying tubes in which gleaming hot gases are driven up by convection. After 200,000 km the tubes disappear, and there is just a glow. Then, farther down, we are surrounded by glorious gold. Abel tells us: "We are in the wedding saloon of the Sun's particles. It is the solar core with a radius of 140,000 km. Here, every second 600 million tons of hydrogen are fused into helium. The mass difference between the hydrogen and the fusion product helium is about four million tons. It is all converted into energy, at 15 million degrees. Watch out for protons and neutrons. They show up as red and black balls. You will also see red dots, the positrons. Photons, the quanta of light, will flash, and neutrinos will appear and vanish chimerically. Here we go."

Space teems with protons. Occasionally, two protons fuse into a black-red compound. "That's deuterium," Abel informs. "And did you see the positron and the neutrino escape?" Deuterium catches another proton. "Now we have helium-3." This happens many times. Each helium-3 compound chases after a partner of the same kind, and in most cases the two merge into a two proton–two neutron nucleus, emitting two protons. At each particle wedding, photons flash up. Like the neutrinos, the photons would like to dash away at the velocity of light. But they are absorbed immediately in the proton–neutron throng, then they are reemitted, reabsorbed, and in this catch-and-let-go game they diffuse away at a crawling pace.

"This has been going on for more than four billion years and should continue at least that long into the future. Four hydrogen nuclei – that's what the protons are – fuse into one helium-4 nucleus. In so doing, they generate two positrons, two neutrinos, and two photons. The photons are almost trapped in the extreme density of matter in the solar core, which is about 150 times the density of water. Therefore, they still need about a million years until they get out of the Sun and provide the Earth with light and warmth."

"People know the Sun's importance for life," Abel adds, "but only few realize that they are also children of long-gone stars."

Sensing our question, he explains: "In the Sun's atmosphere there are traces of heavy elements. These elements, quite common on Earth, can only be generated in fusion processes at temperatures much higher than those in the core of the Sun. Temperatures above 10^8 and 10^9 degrees occur in contracting stars, which have burned up all their hydrogen and fuse higher elements. These fusion processes produce energy, up to iron, ^{56}Fe. The fusion of elements heavier than iron consumes energy. Such elements are cobalt, nickel, copper, tin, silver, gold, lead, and uranium, the heaviest natural element in the periodic table. This energy may have been provided by novae and supernovae. Thus, the Sun, the Earth, and everything on Earth itself have been processed through the inside of at least one star."

We digest the feeling that most components of our bodies have been parts of dying, exploding stars. Then we move back in time by four billion years.

1.2 Light on Earth

The Sun is fainter than the one we know. The Earth is wrapped in a uniform gray layer of clouds. While we wonder how cold it may be down there, Abel tunes in: "Earth's surface temperature is about 85°C. It is so hot because of the greenhouse effect in an atmosphere that consists mainly of nitrogen, methane, water vapor, and up to 1,000 times more carbon dioxide than in the atmosphere you know." He explains that during the next 3.5 billion years most of this carbon dioxide will become dissolved in the oceans, where bacteria and algae will produce oxygen from it. The weathering of silicate rocks on the continents, followed by the deposition of carbonate sediments on the sea floor, will also remove carbon dioxide from the atmosphere/ocean reservoir. "This drastic decrease of carbon dioxide has reduced the greenhouse effect to a very convenient level. Between the two revolutions that decisively shape human history – the Neolithic revolution, with its beginning of farming and cattle breeding, and the Industrial Revolution, with its invention of the heat engine – it keeps the average surface temperature of the Earth at a comfortable $+15°C$. Without it you would have a deadly $-18°C$. And now lets move to the Cambrian, with its explosion of life forms, 530 million years before your time. Since then you can observe the forces that drive evolution."

The Earth has become the blue planet. Oceans surround land masses. Clouds sail through the thin shell of the atmosphere. In a first quick dash we ride the arrow of time through the ages of Earth. They are marked by the trilobites, the first fish and insects, the conquest of the land by plants and reptiles, the forests of giant ferns and shave-grass, the saurians, the conifer and deciduous forests, and the mammals. And during all that time the only inputs into the Earth system are energy, emitted by the Sun, cosmic radiation, and once in a while some rocks from outer space.

Solar energy activates life and fosters its growth. This also becomes dramatically patent by the mass extinctions of species we observe during periods when volcanic eruptions or dust, stirred up by the impact energy of huge meteorites, block much of the sunlight. The catastrophic disappearance of the dinosaurs 60 million years ago makes room for the mammals, which until then had barely survived in ecological niches. We also see how ionizing particles from solar or cosmic radiation, or terrestrial radioactive material, transfer energy to the genes of the living cell. This causes mutations that occasionally result in new species. “Got it?” Abel checks our understanding. “Energy conversion and genetic information processing drive the evolution of species.”

Contemplating the Sun and the Earth, we understand more deeply why the Sun has been revered as sacred throughout the ages. Abel quotes from Shakespeare’s Sonnet VII:

Lo! in the orient when the gracious light
Lifts up his burning head, each under eye
Doth homage to his new-appearing sight,
Serving with looks his sacred majesty;
And having climbed the steep-up heavenly hill,
Resembling strong youth in his middle age,
Yet mortal looks adore his beauty still,
Attending on his golden pilgrimage.

1.2.1 As Life Goes

Our vision zooms in on the nanoworld of the living cell. We enter the interior of an algal cell. “Watch the process of photosynthesis,” Abel recommends.

We see the pulsating green compound of chlorophyll in the center of the cell. Flashes of incident photons dance over its surface. The compound pumps currents of yellow electrons along conducting chains. Red hydrogen and blue oxygen atoms flow out of the watery envelops of the chains. Brown adenosine triphosphate boxes, bearing the letters ATP, are also emitted and move into a dark reaction chamber. A gray gas of carbon dioxide molecules flows into this chamber and mixes with hydrogen. Varying its color several times, the mixture reaches the ATP boxes and reacts with them seethingly. White sugar ribbons emanate and slide toward the border of the cell. There, new cells separate and float away through blue oxygen molecules that bubble out of the wall of the cell.

Our guide comments: “In nature’s sugar plant, chlorophyll converts the energy of the photons into work performed by electric currents that flow along molecular chains and produce adenosine triphosphate. ATP serves all living species as *the* universal energy currency. It is transported to places where work has to be performed. There, ATP gives off the energy from the Sun stored in it and produces sugar and new cells. Summing this up quantitatively, we note that, via the chlorophyll of the living cell, sunlight converts six water and six carbon dioxide molecules into six oxygen molecules and one sugar molecule. This breeds new cells. And now observe the complementary part of the life cycle: the conversion of sugar into work. It’s called respiration.”

We see an Amano shrimp devouring algae. Inside its translucent body, algae fragments merge with blue oxygen balls, which enter from the surrounding water. Brown ATP boxes emanate from the merger zone, accompanied by an undulating glimmer. The ATP boxes dissolve, their energy is transferred to the legs, which begin to move, and the shrimp crawls away, emitting gray carbon dioxide and red-blue water molecules.

Abel continues: “Here you see how the sugar of the devoured algal cell is burned with oxygen so that the moving shrimp’s legs can do work. Again the whole process operates via the conversion of the solar-generated chemical energy of sugar into the chemical energy of adenosine triphosphate. This ATP acts as a sort of battery. As in photosynthesis, this battery delivers energy to those parts of the cell where work must be performed by discharging itself. To be more precise: during the combustion of food, one molecule of sugar combines with six molecules of oxygen to become six molecules of water plus six molecules of carbon dioxide plus adenosine triphosphate. The undulating glimmer you have noticed is caused by waves of waste heat into which, unfortunately, a certain part of valuable energy must always be converted. The same processes occur in the predators that feed on the shrimps, and in all other plants and animals.”

Abel illustrates the cycle of life by a picture [1]: “The controlled process of the biological energy cycle can be depicted by the running of a series of water mills driving generators which charge batteries.... When photosynthesis is compared to a solar-driven pump used to bring ‘water’ to an elevated level, respiration can be represented as the stepwise downfall of the ‘water’ which drives the ‘water mills’ charging the ‘ATP batteries.’ The batteries then can be transported to sites where work has to be done; when properly connected, they can be ‘discharged’ by the hydrolysis reaction when work is performed.”

Then we are shown how the giant stores of fossil fuels are formed from the products of photosynthesis.

In the Carboniferous and the Permian, about 300 million years before the present, huge forests grow in warm, swampy freshwater regions. When the trees in these forests die, they fall onto the swampy ground and are buried by the debris of the following years. Many generations of plants form layers of dead vegetation, which, in turn, are overlaid by sediments of nonorganic material washed down into the low-lying swamps from surrounding higher ground. Thus, the dead biomass, sealed off from the oxygen of the air, cannot rot away, and a good part of the energy stored in it is conserved, when it is squeezed and transformed into peat. As more layers of sediment pile up upon the organic deposits and these sink further down, coming under increased heat and pressure, they are further transformed, first into lignite (brown coal), then (hard) coal, and finally anthracite. Later, in the Tertiary era, which lasts between 64 million years and one million years before the present, we note the second peak of coal formation, when the large deposits of lignite are formed. We also observe the production of oil and natural gas from the remains of plants and animals, especially plankton. These remains are laid down mainly in coastal regions near or under salt water and are eventually sealed off by sediments that build up to form new layers of rock. Over millions of years, in reduction reactions with hydrogen sulfide (H_2S) and with bacterial support, they undergo chemical changes similar to those that produce coal, and become the liquid and gaseous stores of solar energy [2].

1.2.2 Fire and Grain

Abel takes us to the Quaternary, less than a million years before the present. Huge ice masses spread from the north and south poles over the northern and southern parts of the continents, and glaciers creep from high mountains into plains. When it gets warmer, the ice recedes and the land greens, then it gets colder again, and the ice comes back. The average surface temperature of Earth varies rapidly by several degrees Celsius.

In this harsh environment the first humans roam the fields and forests as collectors of plants and their fruit and live on a daily energy budget of about 2 kWh. Then they take up hunting. Although physically much weaker than their prey, such as mammoths, and competing predators, such as bears and tigers, they prevail thanks to the use of tools made from stone and wood.

A huge leap forward in the art of survival is made by the taming of fire, roughly half a million years before the present. We watch the bold leader of a horde grab the fire with a dry branch from the flames that engulf a tree ignited by lightning. The members of his horde begin to guard and nourish the fire. Quickly its domination spreads to other hordes. People learn more and more how to use the energy liberated by the oxidation of carbon and hydrogen in wood for warming their caves, defense against wild animals, cooking plants, roasting meat, and the preparation of weapons such as fire-hardened yew-tree spears. By then, the average energy consumption is 6 kWh per person per day.

Abel reminds us of Greek mythology: "Prometheus stole the fire from Olympus, the residence of the gods, and brought it to the humans on Earth. Zeus, the king of the gods, punished him cruelly for this deed, which gave humans so much power and saved them from doom." To be sure that we really understand the paramount achievement of prehistoric man, he adds Goethe's reference to Prometheus:

Kindle the Fire! Fire's on top.
Greatest the deed of stealing it.
He who lightened it,
he who made friends with it
hammered and rounded crowns for Man's head,

and quotes from Schiller's "Song of the Bell":

Power of fire, how beneficial
if carefully guarded and harnessed by man.
Whatever he forms, and what he creates,
he owes it to you, o gift of the gods.

We arrive at the dawn of human civilization in the Fertile Crescent between the Euphrates-Tigris and the Nile. Twelve thousand to 10,000 years before the present, the average temperature of Earth rises by more than 4°C and stays nearly constant after that. Still, small fluctuations occur but hardly exceed more than 1°C. After the much stronger fluctuations of the ice ages, advanced humans live for the first time in a nearly stable, warm climate. Photosynthetic biomass production occurs in bountiful, predictable cycles. In this new environment, which feels like paradise compared with the living conditions of the preceding ice age, *Homo sapiens* triggers the "Neolithic revolution": Men and women invent farming and cattle breeding. Instead of just collecting and hunting what grows and lives in grasslands, forests, and waters, humans expand their harvesting of solar energy systematically, and to an extent that grows with the area of the agriculturally utilized land.

"Look at Eve, how she did it," Abel suggests.

We see a woman who collects the seeds of grass. She separates out especially big grains and stores them for times of drought. After a number of fertile years, when the grain store overflows, she throws out the grains from the oldest harvest into the backyard of her house on the bank of the broad river. The next spring, grass plants with bigger-than-average grains of seeds grow in the backyard. The woman gets an inkling of a totally new opportunity of food provision. She sows more of the big-grain seeds and selects again the biggest grains from the blades that grow out of them. After a number of cycles of sowing, harvesting, and selecting, the woman has a field close to her house from which she gets more grain food than from the huge area of the savannah she used to roam when collecting ordinary grass. Meanwhile, her male companion continues hunting, watching her efforts with quite some suspicion. When she finally asks him to help her dig up some more ground in order to expand the area of big-seed cultivation, he first protests full of indignation. After all, he is a hunter and grain care is women's business. But his wife, seductively beautiful in her enthusiasm about her discovery, convinces him to do what he had always considered as something out of question. He joins her in digging and planting and harvesting the new fruit of knowledge. Together they cultivate the special seeds into what finally becomes wheat.

"But Adam is never quite happy with having traded free hunting for tilling the soil. He thinks that he has lost paradise," Abel concludes this vision.

Other people pick up the art of farming. Subsequent generations learn how to domesticate animals. In our privileged view provided by Abel, we see and understand the geographic advantage in food production enjoyed by the inhabitants of the Eurasian land mass and northern Africa over the humans who live in sub-Saharan Africa and the Americas: In Eurasia there are many more domesticable wild plants and animals than on other continents. Domesticated mammals such as sheep, goats, pigs, oxen, cows, donkeys, horses, and camels provide meat, milk, leather, and manure, and they also provide muscle power for plowing the fields, the transportation of goods, and rapid military attack. These animals and domesticated birds such as chicken, geese, ducks, and turkeys convert the chemical energy of plants into high-quality food and physical work for the benefit of man. Furthermore, agricultural innovations diffuse much more easily along Eurasia's east–west axis than along Africa's and America's north–south axes, occupied by geographic and climatic obstacles. "Around those axes turned the fortunes of history" [3].

Our guide adds: "Whereas the food energy harvested per hectare per year by hunters and gatherers is only about 1 kWh, it amounts to more than 3,000 kWh for Indian wheat farmers, and nearly 80,000 kWh in Chinese intensive farming [4]. The energetic yields of agricultural technologies are the foundation of the preindustrial high civilizations around the Mediterranean, in Asia, northern Europe, and southern America. A time-compressed view of the energetics of these civilizations is the next part of the tour I have to offer."

1.3 Ancient Empires

The early agricultural societies unfold. Seven thousand years before the present they produce food surpluses that can satisfy an energy demand of 14 kWh per person per day. This liberates some of their members for specialization in crafts such as pottery, and the working of wood, stone, and metal. Craftsmen join the peasants. On these pillars rest the first agrarian high civilizations that rise about 5,000 years before the present. They develop an urban business sector, pronounced social strata, trade, art, and writing. Thus, farmers and craftsmen provide the energetic and technological means that empower the ancient empires of East and Southwest Asia, Egypt, Greece, and Rome.

In the agrarian societies economic and political power is with the land owners, because they are the ones who control the energy derived from the direct and indirect products of photosynthesis. In Latin, the original expression for cattle property, *pecunia*, assumes the meaning of "money" and "wealth." The land-owning nobility accumulates far-reaching political power. Feudalism becomes the dominating political system of the agrarian societies. It gains strength with the increasing energy demand of these societies, as they advance technologically, commercially, and militarily. In medieval western Europe, about AD 1400, the energy demand per person per day is 30 kWh. Despite their impressive cultural achievements, the agrarian civilizations are handicapped in their development by the limitations of the forces that can be derived from muscle power and by the low efficiencies of energy conversion in humans and animals. Inclined planes, pulley blocks, windmills, and water mills give some, but only limited help to surmount the biological barriers.

Abel explains: "The tractive power of a horse is about 14% of its body weight and amounts to about 80 kiloponds.[2] For deep plowing one needs 120–170 kiloponds, and for mowing 80–100 kiloponds. The average performance of a horse is 600–700 W, and a donkey provides 400 W. Thus, a winch, normally powered by four donkeys in order to provide mechanical work, has a performance of less than 2,000 W. A horse can perform work of 3–6 kWh/day, and for this it needs fodder with an energy content of roughly 30 kWh. Thus, its energetic efficiency is between 10% and 20%. The energetic limits of cross-country transportation are fixed by the need of a horse to eat one cartload of fodder per week. Therefore, it does not make sense to use a horse and wagon for the transportation of feed for more than a week. The energetic efficiencies of man and horse are similar. However, the average performance of man is only between 50 and 100 W, at most one seventh of the horse performance" [4].

With this information we understand the sad fate of peasants and slaves we observe during the 5,000 years between the first Sumerian, Babylonian, and Egyptian empires and the nineteenth century. Whenever huge armies invade a country in campaigns that last much longer than a week, they have to confiscate the food for soldiers, horses, and draft animals from the peasants of that country. Thus, in times of war, peasants are often robbed of all they have. The alternative to starvation is for the peasants themselves to join the armies.

Although humans are physically much weaker than oxen and horses, the combination of their muscle power with the skills of the human hand and the creativity of the brain is indispensable for all the sophisticated tasks involved in the construction of the pyramids, palaces, temples, and castles that inspire awe in many generations. Furthermore, the members of the nobility feel entitled to a lifestyle that corresponds to the splendor of the buildings they populate. Since it is energetically impossible for the few members of the nobility to provide the means for their luxurious lives themselves, they need huge armies of slaves, serfs, and bondsmen, deprived of rights, who labor for them in quarries, on construction sites, and most important of all, in the cultivation of land. When the apostle Paul writes his letter to Philemon on behalf of the slave Onesimus, about 25% of the population of the Roman Empire are slaves.

> Slavery, and its modification socage, was the prerequisite of the impressive cultural achievements of agrarian societies. The glory of the few rose from the misery of the many.

Our vision zooms in on a narrow strip of land between the Lebanon mountains in the north, the Red Sea in the south, the Mediterranean in the west, and the desert

[2]The technical force unit "one kilopond" is the force (weight) exerted on a mass of 1 kg by the gravitational field of Earth. It is equal to 9.81 N.

in the east. Abel comments: "The Bible's first book of Kings describes the painful transition from a primitive society of free farmers and cattle breeders to feudalism with its magnificence and compulsory labor."

We see Solomon, the first real king of Israel. His two predecessors, David and Saul, had laid the ground for kingship. But warring against each other and external enemies, they could not yet unfold court life. But Solomon does that lavishly. He builds a temple for the Lord and a palace for himself from huge, valuable stones and cedar wood. To get these materials he establishes socage in all of Israel. Many thousands of men have to take turns laboring in the quarries and the Lebanon mountains. Then Solomon dies after a life of splendor and power remembered throughout the ages. His son Rehoboam is to succeed him. All of Israel comes to Rehoboam and asks him to alleviate their statute labor. He refuses and even promises more of it. The people rebel. Only the tribe of Judah stays with Rehoboam. The rest of Israel elects another king. The empire of Solomon breaks apart into a northern and a southern kingdom, Israel and Judah. Weakened by disunity they are destroyed: first Israel by the Assyrians and then Judah by the Babylonians.

Abel takes us to the Louvre in Paris and guides us to a pillar, covered by cuneiform characters: "When more and more economic and political power accumulated in the hands of those who owned the land, people realized that societies must control power by laws and justice. Wise emperors ordered and ardent prophets demanded protection of the weak. Look at the translation of the inscription on Hammurabi's Stele, excavated in 1901–1902 in Susa." We read the solemn words in which the Babylonian emperor Hammurabi (1793–1750 BC) pronounces the reign of the law: "That I make justice visible in the country, that I exterminate the villains and wicked ones, so that the strong one does not deprive the weak one of his rights, and the land be bright." The extensive body of laws concludes with: "To provide justice for widows and orphans I wrote my delicious words into this monument." Then Abel recites words from the first chapter of the Jewish prophet Isaiah, written 1,000 years later: "So speaks the Lord: I am fed up with your burned offerings. Don't sacrifice meaningless gifts anymore. I do not listen to your prayers anymore, because your hands are stained with blood. Support the suppressed, help orphans to their right, carry on the lawsuit of the widow."

We move in time to ancient Greece. There, as reported by Homer's *Iliad*, one slave is worth four oxen. Slaves of that worth are treated well and help sustain the glory of Greek culture until the Romans take over. The Roman wars of conquest during the second and first centuries BC produce huge armies of prisoners of war that are thrown on the slave market. The price of slaves decreases and their treatment deteriorates. Slave insurrections such as those of Spartacus (73–71 BC) are the result. In new large estates of agrobusiness great masses of slaves produce food at much lower cost than the free peasants with small or medium-sized land property can do. These peasants' civic virtues, productivity, and military strength are the roots from which the Roman Republic rose to power. But small peasants cannot compete, neither with mass production by slaves nor with the imported cereals that inundate the Roman market thanks to the globalization of trade in the Roman Empire. Ruined economically, they migrate to the city and become the Roman proletariat.

The noble big land owners and merchants manipulate them by *panem et circensis*. This sometimes works, and sometimes it does not. Civil wars between the troops of big agrobusiness and the forces of the poor masses shake society. The Roman Republic perishes, torn apart by its slave-generating victories. The Roman emperors take over and rule the world.

When the Roman Empire finally breaks down under the onslaught of barbarian Germanic tribes, civilizing them nevertheless during its agony, new feudal societies evolve in northern Europe. Again, initially free peasants become more and more dependent on big land owners. They suffer in bondage, until European feudalism is swept away by the French Revolution and the Industrial Revolution. Before that the Europeans reestablish slavery on a grand scale, to satisfy the luxury needs of the noble few, and provide wealth for the many who lack land in Europe and acquire it overseas.

Nearly ten million enslaved Africans are brought to the Americas between 1520 and 1850. This by far exceeds the number of European immigrants. Shortly before the outbreak of the American War of Independence, 192 British ships with a total carrying capacity of 47,000 humans participate in slave trade. Slavery in European–American civilization ends with the American War of Secession in 1861–1865. In this first modern war, the industrialized, abolitionist North States defeat the agrarian, feudal, slave-dependent southern Confederate States. Abel explains: "The northern unionist states can afford abolition economically, because they have a new army of slaves at their service: energy slaves."

While we wonder what is meant by "energy slaves," Abel suggests postponing a clarification until we have looked into preindustrial energy services *not* derived from muscle power.

1.4 Wind Power, Gunpowder, and Wood

We see sails on the sea. They belong to the ships of Tarshish which bring "gold, silver, ivory, apes, and guinea-fowls" to Solomon. They belong to Greek, Carthaginian, and Roman fleets that cruise the Mediterranean. They belong to Chinese and Arab vessels navigating along the shores of the Pacific Ocean and the Indian Ocean. Their sails catch the wind and transform its kinetic energy into the kinetic energy of the boats. Often galley-slaves provide additional power.

The sailing ships serve trade and war. Armed with guns, they become the instrument of Europe's rise to power.

Europe's global dominance between the sixteenth and the twentieth centuries is due to the ever more efficient maritime use of wind power by oceangoing sailing ships and the military use of gunpowder energy in firearms – and a Chinese folly in the fifteenth century.

The Chinese are the first to discover gunpowder. From the ninth century they use it in fireworks. But they do not succeed in casting guns that can withstand the sudden release of energy in a gunpowder explosion. About 500 years later, in the fourteenth century, Roger Bacon in England and Berthold Schwarz in Germany discover gunpowder too. Metallurgical progress in bronze and iron casting enables the Europeans to build guns that resist the high pressure of the explosion gases. Guns are the first weapons whose destructive impact does not depend on muscle power. Rather, they transform the chemical energy of gunpowder into the kinetic energy of bullets, cannonballs, and grenades. From the end of the fifteenth century, Portuguese, Spanish, English, Dutch, and French sailing ships with cannons and fire-armed soldiers carry the European conquerors to the Americas, Africa, Asia, and Australia. Much of the world is divided up into European colonies.

Abel takes us to the imperial court of medieval China: “In the early fifteenth century China is the world leader in technology. See how it misses its chance of beating Europe in colonizing the globe” [3].

A big, fat dignitary bows before the emperor. Then he straightens up and pronounces solemnly: “Son of the Heavens, let me summarize the proud achievements of your empire. Their glory shines even more brilliantly against the primitive technological background of the barbarian tribes in the realm of the sinking sun, with whom we have come in contact recently. The long list of our major technological firsts includes cast iron, the compass, gunpowder, paper, printing, and many others. And, may I add, the present administration of your faithful and humble civil servants has elevated China to world leadership in political power, navigation, and control of the seas. During the last few decades we have sent treasure fleets, each consisting of hundreds of ships up to 400 feet long and with total crews of up to 28,000, across the ocean as far as the coast of the black continent the barbarians call Africa. We trade the treasures of our ingenuity with the natural resources of distant countries. As a result, no one matches your majesty’s wealth.”

Abel adds: “And the Chinese did this decades before Colombus’s three small ships crossed the narrow Atlantic Ocean to the Americas’ east coast. Now you may be wondering: Why didn’t Chinese ships proceed around Africa’s southern cape westward and colonize Europe, before Vasco da Gama’s three ships rounded the Cape of Good Hope eastward and launched Europe’s colonization of East Asia? Why didn’t Chinese ships cross the Pacific to colonize the Americas’ west coast? Why, in brief, did China lose its technological lead to formerly so backward Europe? Watch a turning point in Chinese history.”

A slim, muscular man jumps up and shouts: “Wicked, corrupt eunuchs. You have wasted the empire’s resources. You have shielded the Son of the Heavens from the people. You don’t care about what is going on in the country. The treasure fleets, captained by the likes of you, serve most of all your personal wealth. This must not go on any longer. Your Highness,” he bows before the Emperor, “Your truly faithful servants will now save you and the country from these eunuch parasites.” At the shout of the last word the gates of the throne room burst open, warriors storm in and arrest the eunuch administration. The Emperor cannot help but hand power over to the eunuchs’ enemies.

Abel extends our vision: “That’s the end of China’s treasure fleets. Seven of those fleets had sailed from China between 1405 and 1433. Now they are suspended as a result of the power struggle between the two rivaling political factions at the Chinese court you just have witnessed. The eunuchs have been identified with sending and captaining the fleets. Their opponents, having gained the upper hand, reverse the eunuchs' maritime politics: the fleets are detained in the harbors, the shipyards are dismantled, and oceangoing shipping is forbidden altogether in imperial China. That one temporary decision becomes irreversible, because no shipyards remain to turn out ships that would prove the folly of that temporary decision, and to serve as a focus for rebuilding other shipyards. This sort of typical aberration of local politics can happen anywhere in the world and block social, political, or technological progress."

While we wonder how this fits with the general notion that technological progress will prevail one way or the other, Abel adds: "A lasting loss by a folly is much more likely in an isolated society than in societies interacting with each other. This is shown by another folly, this time the abandonment of guns by China's neighbor across the Yellow Sea. Here, cultural tradition finally abhors muscle power being beaten in warfare by the chemical energy of gunpowder. Let's go to Japan and watch its military development since the year 1543, when firearms first reach that country."

A Chinese cargo ship drops anchor in a Japanese harbor. Two Portuguese adventurers armed with harquebuses go ashore. They make big shows with their primitive guns. The Japanese are so impressed by the new weapon that they commence indigenous gun production, greatly improving gun technology. By 1600 they own more and better guns than any other country.

But there are factors working against the acceptance of firearms in Japan. The country has a numerous warrior class, the samurai, for whom swords rate as class symbols, and works of art, and means for subjugating the lower classes. Japanese warfare has previously involved single combats between samurai swordsmen. They stand in the open, make ritual speeches, and then take pride in fighting gracefully. Such behavior becomes lethal in the presence of peasant soldiers ungracefully blasting away with guns. In addition, guns are a foreign invention and grow to be despised, as do other things foreign in Japan after 1600. The samurai-controlled government begins by restricting gun production to a few cities, then introduces the requirement of a government license for producing a gun, then issues licenses only for guns produced for the use of the government, and finally reduces government orders for guns, until Japan is almost without functional guns. Only because Japan is a populous, isolated island can it get away with its rejection of the powerful new military technology. Its safety in isolation comes to an end in 1853, when the visit of Commodore Perry's US fleet bristling with cannons convinces Japan of its need to resume gun manufacture [3].

We look across the seas and are fascinated by the proud, powerful ships under sail that race the oceans, transport goods and people, battle in fierce maritime combats between rivaling sea-faring nations, and tighten Europe's grip on the world.

Abel puts Turner's painting *The Fighting Temeraire* before our eyes (Fig. 1.1). "This painting comprises the end of the sailing ships' glory and the beginning of the greatest leap to power ever made by a civilization."

Fig. 1.1 *The Fighting Temeraire* by William Turner (1775–1851) [5]

The painting depicts a huge, pale, three-mast battleship with tied-up sails. A small, black tugboat, its chimney belching flames and smoke, tows her on the River Thames to her last berth to be broken up.

We know that the tugboat is powered by a coal-burning steam engine and understand that Turner's painting from 1839 heralds the dawn of the age of the fossil-fuel-powered heat engine and the end of the million-year period when humanity only thrived on the daily influx of solar energy and its storage in the living biomass.

"We should observe the use of fire more thoroughly than we have done so far," Abel suggests. "Before we watch its power unfold in the furnaces and heat engines of industry, let us see how fire and wood shape the technology and living conditions of preindustrial societies."

Scanning history, we note the following. Agrarian society obtains heat essentially from wood. Peat and coal are burned to a much smaller extent. There is no technology to transform this heat into mechanical work. Rotatory motions are generated only by wind, water, and animal and human labor – energy forms not permanently available and not very reliable. The corresponding machines such as winches, windmills and water mills are limited in size and power by the small pressure resistance of the universal raw material wood and its intense abrasion. Greater use of iron is frustrated by the high energy cost of iron ore smelting. Iron is very expensive because of technological and resource constraints, which limit the size of blast furnaces. The larger the blast furnace, the larger the quantities of wood required per unit time, and thus the larger the distances over which wood from sustainable forestry has to be transported. Except for the case of timber rafting, long-distance transportation results in negative energy balances as soon as the draft animals consume more scarce biomass energy than is contained in the wood they move. Thus, it is more advantageous to produce iron in small, decentralized production units scattered around in the woods, always close to their energy source. The iron output of a small, charcoal-fired blast furnace in 1 year is less than that of a twentieth century steel mill in 1 day. From an economical point of view, this method of iron production is extremely expensive, although it has ecological advantages such as small emission quantities, which can be absorbed by (and damage only) the local ecosystems. Furthermore, the energy source is renewable – if used sparingly. But often the woods as the main source of energy and raw materials are overused and destroyed.

Around the Mediterranean the once lavish forests are cut down during antiquity to satisfy the timber demand of ship and home construction. North of the Alps, wood becomes scarce first regionally, e.g., close to the German cities of the fourteenth century, and then everywhere in western Europe during the eighteenth century. These wood and energy crises lead to the medieval administrative regulations of forest utilization close to the cities, and in the eighteenth century to the reforestation of wastelands and the development of the science of forestry with its principle of sustainability.

Deforestation is proceeding at an alarming pace in the developing countries of the twentieth and twenty-first centuries. These countries still satisfy about 10% of their energy needs by the burning of wood. However, wood is burned not only for energy purposes, but also, and quite often, just to get rid of the forests which contain the largest variety of living species on Earth. Estimates of carbon release from all forests range from 2 to 10 gigatons (Gt; 1 Gt is one billion tons) annually. This is a nonneglegible fraction of gross annual terrestrial carbon production of 120 Gt in the annual vegetational cycle from carbon to carbon dioxide to carbon, where the total carbon content in all terrestrial biomass is 560 Gt, with 80% in the trees [6]. Most of the tropical rain forests are destroyed to clear land for small-scale farming colonization and accumulate pasture for large agroindustrial cattle ranches; in addition, there is the demand of international timber dealers.

In the northern countries the importance of wood as fuel declines. In 1850 there are 23.2 million US citizens, who, by the burning of wood, consume 76 kWh per capita per day; after peaking at 52 kWh per capita per day for 50.1 million citizens in 1880, US wood energy consumption steadily declines to 3.6 kWh per capita per day for 179 million citizens, until in 1960 it starts to rise again [7, 8]. During the same period, the share of wood energy in total US energy consumption declines from 90% in 1850 to about 50% in 1890, when it is surpassed by the share of coal, and reaches less than 5% by the middle of the twentieth century [9], when oil, coal, and gas have become the principal energy carriers. In Great Britain and continental Europe the switch from wood fuel to fossil fuel occurs much earlier than in the USA. From 1850 to 1950 coal commands a bigger than 90% share of British energy use, use of wood having almost completely disappeared by 1870 [9]. The cause of coal's rise to dominance is the Industrial Revolution.

1.5 Industrial Revolution

"1776 is a magic year. It is one of those years, when things mature, when creativity, hard work, and crises lead to breakthroughs that stir society on a new course," Abel states. "See what happens in 1776:
The first steam engines of James Watt are installed and are working in commercial enterprises. They trigger the Industrial Revolution.
The Wealth of Nations is published by Adam Smith. This book lays the foundation for economic science.
The Declaration of Independence is approved on July 4 by the Second Continental Congress in Philadelphia. It starts the history of the USA with the noble words:
'We hold these truths to be self-evident, that all men are created equal, that they are endowed, by their Creator, with certain unalienable Rights, that among these are Life, Liberty, and the pursuit of Happiness.'

The first German translation of the Declaration of Independence is published 4 days later by the printing press of Steiner & Cist of Philadelphia.

> The human rights, as proclaimed by the Declaration of Independence, and market economics, as established by *The Wealth of Nations*, would not have become ruling principles of free societies had not steam engines and more advanced heat engines provided the energy services that create the preconditions for freedom from toil.

One may quantify these energy services by the number of 'energy slaves' in an economy. This number is given by the average amount of energy fed per day into the energy conversion devices of the economy divided by the human daily work-calorie requirement of 2,500 kcal (equivalent to 2.9 kWh) for a very heavy workload. In this sense, an energy slave, via an energy-conversion device, does physical work that is numerically equivalent to that of a hard-laboring human. Dividing the number of energy slaves by the number of people in the economy yields the number of energy slaves per capita. The number of energy slaves at the service of a person has increased in time from one, 100,000 years ago, to roughly ten in medieval western Europe, to between 40 and 100 in modern Europe and North America. And, of course, modern energy slaves work much more efficiently than medieval ones. It is also interesting that Jefferson's original draft of the Declaration of Independence included a denunciation of the slave trade, which was later edited out by Congress. Only after industrialization had provided enough energy slaves could the noble words of the Declaration of Independence be finally put into practice – albeit not without the sufferings of the Civil War."

With this comment on energy and society Abel takes us to Glasgow in the year 1765. We see a 29-year-old Scottish instrument maker wandering across Glasgow Green. His name is James Watt. He is in deep thought: "Two years before I was given the job of repairing a model Newcomen steam pump for the University of Glasgow and realized the great inefficiency of this engine. But compared with muscle-powered pumps, Thomas Newcomen's engine represents tremendous technical progress. Even the first example from 1711 was able to replace a team of 500 horses that had powered a wheel to pump out a mine. In over 50 years few detailed changes have been made to the basic design. Seventy-five of these engines can now be found at mines all over England. Coal is dearly needed, because wood has become scarce. But following the seams of coal down into the Earth, the mines get flooded by water. Getting that water out of the mines is vital for exploiting the only available substitute for wood fuel. But Newcomen's pump consumes too much of the coal it unearths." Suddenly he takes a leap: "A separate condensing chamber for the steam could save much fuel! That's it!" This idea gets James Watt started on the scheme for an improved steam pump. Soon he has a working model.

Watt meets Mathew Boulton, a dynamic entrepreneur, and tells him about his ideas for improving Newcomen's engine. Boulton agrees to fund development of a test engine and becomes his business partner. For a while, progress is frustratingly slow and Watt repeatedly almost gives up on the project. But Boulton always succeeds in convincing him to continue.

Watt finally gets access to some of the best iron workers in the world. The difficulty of manufacturing a large cylinder with a tightly fitting piston is solved by John Wilkinson, who had developed precision boring techniques for cannon making. Finally, in 1776, the first engines are installed and working in commercial enterprises. These first engines are used as pumps and produce only reciprocating motion. Orders begin to pour in and for the next 5 years Watt is very busy installing more engines, mostly in Cornwall for pumping water out of mines.

The improvement of the steam pump is dramatic: Watt's design uses about 75% less fuel than a similar Newcomen engine. Since the changes are fairly limited, Boulton and Watt license the idea to existing Newcomen engine owners, taking a share of the fuel cost saved by their improvement.

Smoothing the movement of the piston by injecting steam alternately on the two sides of the piston, and adding the sun and planet gear system to transform reciprocating motion in rotary power, Watt develops the pumping steam engine into the multipurpose steam engine. This engine becomes the main driver of the Industrial Revolution.

But there are also social forces that drive the revolutionary change of production and living. The traditional social fabric of the village ruptures, people abandon the countryside en masse and flock to the cities for a living. In the beginning city life is miserable for the newcomers. Manual labor in the small craft shops and factories with primitive machines is extremely hard. The working day has 14–16 hours, and people die early. But the huge surplus of cheap labor continues to exist and becomes another factor for the beginning industrial expansion. Furthermore, England comes under severe economic and political strain. First, because of the loss of its American colonies and, later, because of the continental blockade during the Napoleonic wars. Crises contribute to stimulating innovations.

Abel displays the acceleration of innovations [10]: Watt's multipurpose steam engine becomes operational for industrial applications in 1786, together with Cartwright's loom. An improved weaving machine follows in 1803, and in 1825 the automated Selfaktor spinning machine enters production. The mechanized textile industry grows rapidly, in conjunction with coal and iron industries. Blast furnaces burn no longer charcoal, but coke. This opens up new ways of using coal, e.g., in the form of coal gas, and the chemistry of iron is developed. English coal production, which in 1780 is a mere 6.4 million tons, grows to 21 million tons in 1826 and 44 million tons in 1846. The increasing demand for fuel results not only from the expansion of the textile industry and other manufacturing enterprises, but also to a large extent from the rapidly growing railroad system, which revolutionizes the early industrial era. In 1803 the first locomotive is built for coal mines and in 1829 the first train pulled by steam engines runs between Manchester and Liverpool.

Iron and more iron is needed. The puddle process (1784) makes possible the production of pig iron, which can be forged and rolled. English iron production grows from 68,000 tons in 1788 to 500,000 tons in 1825 and then jumps to one million tons in 1835, two million tons in 1848, and three million tons in 1855. The many branches of mechanical engineering emerge. New building materials are found: Roman cement in 1796, Portland cement in 1824. Coal and iron are the catalysts of the industrial transformation of England.

The appearance of cities changes drastically. Factory chimneys rise above church towers and belch huge, dark clouds of smoke. Charles Dickens writes in *A Christmas Carol* of 1843: "…candles were flaring in the windows …like ruddy smears upon the palpable brown air." Soot covers buildings and plants. Air pollution causes pneumonia and heart diseases. Occasional smog catastrophes claim many lives in London.

From England the Industrial Revolution leaps to the continent. There, it first catches on in France. In French industry the number of steam engines increases from 625 in 1830 to 5,200 in 1848 and 26,146 in 1870. The railroad system grows slowly between 1832 and 1851 to 3,541 km and then expands rapidly to nearly 18,000 km by 1870. Compared with industrial growth in England, industrial growth in France is restrained during the first half of the nineteenth century, despite France having rich coal and iron reserves. One reason is that high customs barriers protect French heavy industry from international competition. As a result, French blast furnaces are fired by wood and charcoal until the middle of the century. The wood for this backward technology is provided at good profit by the big landowners who have recaptured their prerevolutionary forest properties and are in a strong political alliance with the masters of heavy industry. "This folly is similar to the Chinese abandoning of seafaring and the Japanese banning of firearms," Abel comments. "But since France is anything but isolated, the folly lasts for a much shorter time."

Germany is a latecomer. The Thirty Years' War (1618–1648) and its aftermath had shattered the country into more than 300 states, ruled by absolute monarchs and bishops, who often wastefully and sometimes ridiculously tried to imitate the French *Roi Soleil*. The transformation of the feudal agrarian economy into a system of capitalistic dependencies is way behind that in England. Feudal structures survive into the twentieth century. When this country with its broken national identity finally starts to organize its economic and scientific powers after the formation of the German customs union in 1830 and the recuperation of political unity in 1871, and belatedly but vigorously joins her neighbors on the path of industrial expansion, it shows the typical behavior of the insecure latecomer, which causes Churchill to remark: “The Germans are either at your feet or at your throat.”

Germany’s way into the industrial era is facilitated by a nearly inexhaustible supply of coal and rich reserves of iron ore. However, initially the growth of the coal and iron economy is tardy, and the accompanying industrial dynamics only slowly gains momentum. In the state of Prussia, coal output increases gradually from 1.1 million to hardly four million tons between 1825 and 1848, whereas England produces 44 million tons in 1846, and the number of steam engines in manufacturing grows from 419 in 1837 to 1,444 in 1849. Machine and vehicle production have not yet conquered the internal market. There are 245 locomotives operating in 1842, of which only 38 have been built in German factories, the rest are imported. German production of pig iron grows from 100,000 tons in 1837 to just less than 230,000 tons in 1847. But after this slow start the industrial economy begins to boom in the second half of the century: coal production leaps from 11.3 million tons in 1857 to 21.8 million tons in 1865 and climbs to 109 million tons in 1900, whereas the output of iron increases to 500,000 tons in 1860 and 1.8 million tons in 1876. The railroad network expands from 549 km in 1840 to 6,044 km in 1850 and 19,575 km in 1870; it reaches a length of 61,148 km in 1910. The Industrial Revolution accelerates with technical progress, which brings improved iron and steel production processes (Bessemer converter, 1856, Siemens–Martin process, 1864), electrical engineering (in 1866 Werner von Siemens develops the electricity generator and the electric motor), telecommunications, chemical industry, and individual mobility (in 1888 Carl Benz builds the first automobile powered by a petrol engine, and in 1897 Rudolf Diesel has the first engine running that bears his name). The Industrial Revolution is accompanied by a rapid population increase due to gradually improving living conditions and medical progress: Ignaz Semmelweis’s discovery of the septic and contagious nature of puerperal fever (1847), Joseph Lister’s antiseptic wound treatment, and vaccinations against the principal contagious diseases initiate and accelerate the drastic reduction of mortality in industrialized countries. The concomitant decline of the birth rate prevents an even greater population increase.

The Industrial Revolution sweeps over to North America, where the USA grows to become the dominating industrial giant of the twentieth century, and to Japan. Since then, all countries have striven for industrialization.

Abel summarizes the fundamental energetic steps in human history:

> “Universal history can be subdivided into three parts. Each part is characterized by a certain energy system. This energy system establishes the general framework, within which the structures of society, economy, and culture form.

Thus, energy is not just one factor acting among many. Rather, it is possible, in principle, to determine the formal basic structures of a society from the pertaining energetic system conditions" [4].

Becoming a bit more specific he adds: "Humans lived as hunters and gatherers on the solar energy stored in naturally growing biomass for 90% of the time of their existence, that is until the Neolithic revolution. The social structure is that of the horde. For 98% of the time of civilized life, that is between the Neolithic revolution and the Industrial Revolution, people continued to live on the daily influx of solar energy, using naturally growing *and* cultivated biomass, wind power, and water power. Peasants and craftsmen were the pillars of society, whose structure changed from tribal to feudal. The last 2% of civilized life, the years since the Industrial Revolution, has been determined by the combustion of fossil fuels in heat engines. Since then, in addition to the daily influx of solar energy, people have to their avail the giant stores of fossil fuels accumulated on Earth by the Sun over more than 200 million years. They have already used one third of that in 200 years. Now they are turning to the nuclear fuels on Earth and in the Sun. The social structures that have emerged for industrial societies are either democratic or authoritarian. In the battle between democratic and authoritarian societies, democracy seems to emerge as the winner. About 35 countries are considered as full (or only somewhat flawed) democracies by some standards.[3] Among them are the seven industrial countries Canada, France, Germany, Italy, Japan, the UK, and the USA, which have about 11% of the world population and generated more than 64% of global domestic product in 2006."

1.6 Golden Age

We are in 1945. Soviet tanks roar toward Berlin. Allied bomber fleets unload their cargo on Dresden and Würzburg. Some Messerschmitt Me 262 jet fighters take off from remote German air fields and attack Flying Fortresses. The last U-boats launch their torpedoes at oil tankers and are sunk. Nazi Germany collapses. Trucks and trains transport concentration camp survivors and prisoners of war across Europe. Ships bring food from the Americas to fight hunger in devastated Europe. World War II continues in the Pacific theater. On August 6 a lone US aircraft, the B-29 Superfortress *Enola Gay*, drops the first atomic bomb on Hiroshima, destroying 80% of the city and killing 140,000 people. Four days later, Japan surrenders.

The vehicles of war and peace are propelled by fossil-fuel-powered heat engines: tanks, trucks, and submarines by diesel engines, aircraft by gasoline engines,

[3]The Economist Intelligence Unit's index of democracy, 2007.

jet fighters by gas turbines, ships by steam turbines, and locomotives by steam engines. Without heat engines the European wars of the twentieth century could not have gone global.

Modern heat engines serve peace even better than war. They put nature's resources and forces at the service of humans in quantities we realize by just looking at areas. The 800-MW steam turbine of a fossil-fuel-burning electric power station occupies an area of $44 \times 14 = 616\,\mathrm{m}^2$. A horse, which provides muscle power of about 0.7 kW, needs roughly $10{,}000\,\mathrm{m}^2$ of pasture. In total, 1.143 million horses provide the same power as the steam turbine. The total area of pasture they need is 11.43 billion square meters. This area is more than 18 million times larger than the area occupied by the steam turbine. Even if one includes the area required for mining and transportation of the steam turbine's fossil fuel, the power per area of the fossil energy system tremendously exceeds that of the horse system.

After 1945 a Golden Age begins for the industrial democracies. Peace reigns in Europe for a longer time than ever since the end of the Thirty Years' War – except for conflicts on the Balkans. With generous support from the USA, western Europe is rebuilt – first slowly, then at an accelerating pace. In 1951–1952 Belgium, the Federal Republic of Germany, France, Italy, Luxembourg, and The Netherlands form the *European Coal and Steel Community*. This grows into the *European Union* of 27 nations in 2007. Although coal is the energy carrier whose jointly administered power initially drives political unity, its importance decreases when cheap, abundant oil begins to flow from the wells in the Middle East and the Americas and drives the production of wealth in North America, western Europe, and Japan. Progress is slower in the eastern parts of Europe under the inefficient regime of "socialist" planned economies.

The communist party claims to know the course of history and economic evolution. Even at universities and in intellectual circles of western democracies, Marxists teach the inevitability of the collapse of capitalism and predict the global victory of communism. Their religious zeal is based on the belief that all wealth is created by labor, so the accumulation of private property is only possible by the exploitation and pauperization of the working masses. These masses will eventually revolt, establish the dictatorship of the proletariat, and then create the classless society where everybody receives according to his abilities and needs. But experience proves Marxism wrong.

In 1989 the Berlin Wall falls. The Iron Curtain comes down. People who had to live behind it accept the often painful transition from planned to market economies. Most of the former East European satellites of the Soviet Union eventually become members of the European Union.

Abel comments on the failure of the Marxist prophecy: "Marxism failed to realize that private wealth can be created by the exploitation of energy sources instead of the exploitation of people. Industrial democracies have demonstrated that so convincingly that it came to this other magic year, 1989. And thanks to the threat from the devastating energies stored in nuclear weapons the Cold War between the communist and the capitalist camps never grew hot.

An example for the big increase of material well-being in industrial democracies in one generation is the growth of the buying power of the work minute. This is the average working time of an industrial employee the remuneration of which can buy a given quantity of goods. For instance, in the Federal Republic of Germany the number of required work minutes decreased between the years 1958 and 2005 by factors of 2 for bread, 10 for butter, 6 for sugar, 4 for milk and beef, 2 for potatoes, 5 for beer, and 3 for gasoline. Thus, for most of the basic goods of everyday life, industrial workers have to work much less at the beginning of the twenty-first century than they had to during the middle of the twentieth century. They owe this to the growing support from energy slaves. In 1960 each West German had about 20 energy slaves and each US citizen had 60 energy slaves at his service, and these numbers grew to more than 45 and 90 by the end of the twentieth century. The energy slaves toil in furnaces, heat engines, and information processors. They take over hard and boring jobs so that people have to work less. Their services are much cheaper than those of human labor. Thus, goods become cheaper and can be afforded more easily by the average citizen. The situation is, of course, quite different in developing countries, where, on average, a person only commands six energy slaves."

Abel grabs behind himself and then stretches out his hands. Each hand carries a device. One is a triangle balancing on a point contact with a thin plate. Three metallic wires are connected to its upper base. The other device is a slab with three stripes on its top. One metallic wire contacts the center stripe, covered by a thin metal layer, and two other wires are connected to the two ditches between the three stripes. "Look at the transistor. The very first specimen of its kind was the point-contact transistor. Its all-important successor, however, is the field-effect transistor. The transistor has revolutionized information processing. In combination with heat engines it propels automation and liberates people from hard and boring work. Let's watch its birth, which triggered the second industrial revolution."

We move back to October 22, 1945, and enter the Bell Telephone Laboratories at Murray Hill, New Jersey. John Bardeen, who just has joined Bell Labs, Walter Brattain, and William Shockley begin the work that leads to the transistor [11].

A foreseeable energy crisis is one reason why some of the best brains in solid-state physics are dedicated to research into a substitute for the electronic vacuum tube. The vacuum tube can act as an amplifier of signals and as a valve. As an amplifier it is at the very heart of telecommunications. As a valve, which blocks electric currents or lets them pass, it is the device that can represent the basic elements of computing: 0 and 1. Unfortunately, the vacuum tube consumes so much energy that in the 1940s people were speculating when the rapidly growing number of radios and television sets in the USA would consume all electricity generated by the power stations in that country. Furthermore, the vacuum tube, consisting of metallic filament, grids and a plate within a glass mantle, is bulky, fragile, and expensive. The idea is to replace it by suitably tailored semiconductor compounds, where the flow of electrons can be modulated by electric fields in a similar way as in the vacuum tube.

Shockley asks Bardeen to look over a design that he had sketched in his notebook 6 months earlier for a silicon "field-effect" amplifier. An electric field is applied perpendicular to a thin slab of silicon; the field draws charges in the slab to its surface. In a thin sample, Shockley argues, the field should cause a substantial change in the number of available charge carriers. In this design the field would play the role the grid plays in a vacuum tube. But the design does not work in practice. By March 1946, Bardeen theorizes that a substantial number of the electrons close to the surface may be trapped in surface states and thus cannot contribute to conductivity. An experiment proves the existence of the surface states and also shows that charge carriers in thin films are less mobile than in bulk material. Now the group knows why Shockley's field-effect design failed. But during the next 18 months little progress is made toward a semiconductor device that can act as an electronic amplifier and valve. The "magic month" that culminates in the transistor begins in the middle of November 1947. Bardeen and Brattain work closely together on a new design, based on point contacts between metal tips and a germanium plate. The breakthrough comes when Brattain, at the suggestion of Bardeen, wraps a gold foil around the apex of a polystyrene triangle and slits it carefully open. With use of a spring, the triangle is pushed down on the germanium and by "wiggling it just right," it makes contact with both points of the two metallic lines, separated by about 0.004 cm. On December 16, 1947, this design is tried for the first time. Immediately it achieves substantial power and voltage amplification. The (point-contact) transistor is born. Later Bardeen jokes that his and Brattain's invention of the point-contact transistor slowed the development of the field-effect transistor by several years [11].

The field-effect transistor, especially the silicon-based metal oxide semiconductor field-effect transistor becomes the workhorse of semiconductor electronics. The transistor first expels the vacuum tube from radios and television sets. In fact, "portable radio" and "transistor" become synonymous. Computers shrink in size and tremendously increase their computing power as transistors replace vacuum tubes. After the first landing on the Moon, one of the Apollo 11 crew says to Bardeen: "Without you I wouldn't have been there" [12].

The semiconductor industry becomes one of the principal driving forces of technological progress. Transistors decrease in size to micrometers and nanometers. Their density on a microchip approximately doubles every 18 months. This progress in integrated circuitry is given the name "Moore's law." The early information processors such as vacuum tubes and electromagnetic switches were too voluminous, and too energy- and material-consuming, to be integrated in very large numbers in the capital stock. But the tiny, energetically much more efficient transistor and progress in the miniaturization of information processors accelerate the pace of automation.

International trade and travel boom. Tariffs are lowered, or abolished altogether, by international agreements. After 1989 ideological barriers are no obstacle anymore. Highly automated container ships and wide-body jets with small crew, moved by cheap fuel and embedded in a system of sophisticated, computerized logistics, transport goods over long distances from cheap-labor production sites to high-wage consumer countries. Electromagnetic waves, propagating through cables or beamed from ground-based and satellite-based antennas, carry information services around the globe. Globalization, the worldwide division of labor, is established. Average-income citizens of the industrialized countries enjoy the beauty of the Blue Planet as tourists. At home they are offered a rich variety of goods from all over the world. Never in history have so many lived so well.

1.7 Outlook

Abel turns stern: "And this very success embodies the germ of self-destruction." Noting our bewilderment, he adds: "Industrial evolution has been driven by human creativity that has intensified energy conversion in furnaces and heat engines and combined it with information processing in machines. But all wealth production by energy slaves must face the problem that, unfortunately, energy slaves do not only consume and convert energy. They also excrete life-threatening substances such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), hydro carbons (C_mH_n), dust, radioactive waste, and climate-destabilizing carbon dioxide (CO_2). Global warming by emissions of infrared-active greenhouse gases, especially CO_2 from the combustion of fossil fuels, is likely to become a very serious problem. People in industrial countries have put a big burden on the fragile biosphere of Earth during their Golden Age.

You will need lots of creativity to relieve that burden, because, like all slaves, energy slaves make life comfortable and threaten the ones they serve. An irrefutable law of physics is behind all that. It says that energy conversion is coupled to entropy production, and entropy production is coupled to emissions of particles and heat. Large quantities of emissions change the molecular composition of and the energy flows through the biosphere. If these changes are so big and occur so rapidly that adaptation deficits of the living species and their societies develop, they are perceived as environmental pollution."

After having let us ponder energy conversion and entropy production for a while, Abel sums up:

> "Global society faces a threefold challenge: provide sufficient energy for the future, observe the biosphere's limited capacity of absorbing pollution, and prevent the growth of social tensions."

"Social tensions arise from the loss of decently paid jobs for common people. Energy slaves, toiling in heat engines and transistors, take away these jobs in the rich countries. In the poor countries, many of their citizens will find it increasingly difficult to escape poverty. Dwindling oil and gas resources and environmental constraints may prevent the developing countries from catching up with the rich countries in per capita income. Whether the battle for survival can be restricted to migration movements without armed conflicts is uncertain.

Geologists and petroleum engineers expect that sometime in the second decade of the twenty-first century global oil production will start to fall – for ever. "Peak Oil" is the name of this turning point. Already, for every barrel of oil discovered, three barrels are consumed [13]. The energy slaves are just too thirsty. Natural gas will not last much longer than oil. There is still plenty of dirty coal. But so far only the pollutants SO_2, NO_x, and dust are being removed from the flue gases of coal-fired power plants in the countries that can afford the technology and the additional energy. Theoretically, it also seems possible to remove the greenhouse gas CO_2 and store it underground. But the financial and energetic costs are quite high, and no one knows whether carbon capture and storage can ever be done on a significant scale.

To sum it up: If industrial evolution is restricted to the surface of Earth, the first half of the twenty-first century will become an unstable time of painful transitions. You'll need a lot of creativity to avoid a Dark Age after the Golden Age."

Abel pauses, sensing our bewilderment. Then he goes into economics: "Problems have begun to accumulate since 1989, this other year of freedom's victory. When capitalism lost its competitor 'socialism,' the protagonists and champions of capitalism also lost interest in sharing the wealth, produced by the energy slaves, with the general population. Gaining the upper hand in more and more market economies, especially in the new ones, they implemented the rules of the game established by the most powerful player, the USA. These rules are shaped by the belief that a market economy works best if only a minimum of regulations controls human greed in its strife for profit – never mind occasional market crashes. Thus, facilitated by automation, a growing share of production has been transferred to the shareholders and managers of the capital stock. They are the masters of the energy slaves toiling in the machines of the capital stock. As such they are endowed with economic and political power comparable to the power of the aristocratic landowners when the Roman Republic began its decline.

Look at the economics of automation and globalization. In the course of industrial progress, energy has become cheaper – except for occasional oil price shocks – and labor has become more expensive. Therefore, automation continues to take over routine jobs, even rather sophisticated ones in banking and trading. In addition, globalization exports jobs to countries were labor is cheap and taxes are low. Net income for the lower and middle classes stagnates or even decreases, whereas the income of the richest 10% of households increases steadily. Everywhere in the world the gap between rich and poor widens. The question is how long free, democratic societies can sustain that."

When we ask whether anything can be done about that, Abel answers: "There is a way to distribute the wealth created by the energy slaves more evenly and avoid disruptive social tensions: decrease the taxes and levies on labor substantially and increase the taxes on energy correspondingly. Such a tax system will stimulate employment and, in addition, energy conservation. Of course, to minimize problems in the competitiveness of energy-intensive industries, it should ideally be introduced in an internationally harmonized and gradual manner."

We remember the idea of an "ecological tax reform" and that this idea has been torpedoed so far by powerful special interest groups. We wonder,whether a stronger emphasis on the productive power of energy and the distribution of wealth would make it more acceptable to politicians and their electorate. But what about the problems of future energy scarcity and pollution?

Sensing our question, Abel makes his last remark: "Earth receives about 1.2×10^{17} W of solar radiation, which is the same as 33×10^9 kWh/s. This energy influx exceeds present world energy demand by a factor of roughly 10,000. You can collect solar power on a grand scale if you are willing to pay for the necessary investments. You can even overcome the limits to growth, which exist in all finite systems, by expanding the production system into space with the help of solar power satellites and space manufacturing facilities [14]. There is also the option of nuclear fission, which liberates the energy stored in thorium and uranium. There are inherently safe nuclear reactors, whose core cannot suffer a melt down. But you must solve the problem of radioactive waste disposal. And, eventually, the attempts to reproduce the solar fire in terrestrial fusion reactors may succeed.

Choosing your energy system you'll choose your road map to the future. Your choice will very much depend on how you assess financial and environmental risks. Risks concern the future, and since I am not entitled to show you the future, my tour ends here. I hope that you have got a feeling for the long way people had to go until they understood that heat, food, work, and light can be summed up by the concept of energy, and that motion, fire, wind, flowing water, coal, oil, gas, cereals, sunshine, and the masses of the lightest and the heaviest elements can provide energy services.

Understanding energy and its ugly sister entropy will be all important for future well-being and stability. This understanding must especially prevail in economic theory, because economists are in modern industrial societies what priests and theologians were in antiquity and during the Middle Ages. You can read more about this in the treatise I herewith hand over to you. Good luck and good bye."

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