Robert U. Ayres

THE HISTORY AND FUTURE OF TECHNOLOGY

Can Technology Save Humanity from Extinction?

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Preface

I arrived on this Earth at the moment (in geologic time) when petroleum—to power ships, cars, trucks, and aircraft—became "black gold." Those who found it also gained political and economic power, and simultaneously defined the ultimate limit to economic growth ("peak oil"). Yet, at almost the same moment (in geologic time) I have lived through the years when the "splitting the atom" seemed to offer a viable long-term future energy supply, combined with an existential threat to human survival. Is the asteroid belt a reminder of what some earlier "civilization" did with nuclear power?

I was never a prospector for oil, or gold, but I was personally involved in the last atmospheric test of a thermonuclear H-bomb by the USA (summer 1962) and the Cuban missile crisis that followed. For personal reasons not suitable for publication here, that experience has left a scar. Let me say only that, for logical technical reasons, I am strongly opposed to the spread of uranium-based nuclear power technology (because of its by-product, plutonium). A viable alternative nuclear technology based on thorium is possible, but is not being developed with any degree of vigor.

In my lifetime, thanks in part to the discovery of massive quantities of petroleum under the sea or attached to shale, that we can burn (and broil us all), and in part to nuclear technology, we humans have become capable of destroying our planetary home. I mean that literally. Will we drive our cars unthinkingly over the cliff, like lemmings, or will some still newer technology—like artificial intelligence—come to the rescue?

For many reasons, as others have noted before me, any history of technology—or the history of machines—is unavoidably tinged by personal experiences of the author. This being so, there is also a temptation to sermonize, presenting particular technologies—or technology all at once—as the great

benefactor of humanity, or its fatal disease. I am not immune to the temptation. Beware! Having said that, I should also say that this book is a kind of summary of my personal intellectual life. So, who am I and how did I come to write this?

I was in high school when the Atomic Bomb destroyed Hiroshima, then Nagasaki, and ended the Second World War in the Pacific. The human cost didn't trouble me much; the war itself had killed millions, and an invasion of Japan—which everybody expected—promised to kill many more, including a lot of American soldiers. Ethical concerns about nuclear weapons came later. At the time I was fascinated by the physics. This led me to the University of Chicago, where scientific refugee Enrico Fermi (and his team) built the first nuclear reactor under the grandstand of the football stadium. Eight years and three universities later, I received a PhD in mathematical physics from Kings College, at the University of London. That was in 1958. The next 4 years I spent doing odd jobs as a postdoctoral researcher in several places, employed but unguided.

In 1962, I was reaching the end of my road as a theoretical physicist without an interesting problem to solve. By some coincidence, I was offered a temporary job as a scientific observer/jack-of-all-trades, during the upcoming atmospheric test of Edward Teller's new "H-bomb." The test was at Johnson Island, in the South Pacific. I "observed" it from a great distance, using black boxes to detect electromagnetic pulses (EMPs). I never "saw" any of the test explosions with my eyes, either in person or on my equipment. I arrived back home in New York, just as the Cuban Missile Crisis was starting. For 2 weeks in October, New Yorkers became aware that there were a number of nuclear--armed missiles, sitting in Cuba that were aimed at us. Much of the world blamed the USA for starting the crisis, by accusing the Russians of secretly putting nuclear missiles in Cuba, without any actual evidence of the fact. President Kennedy finally showed fuzzy photographs from a high-flying spy plane and announced an embargo of Cuba. If the Russians tried to break the embargo would it be war? This confrontation went on until Adlai Stevenson made his famous "I'll wait until Hell freezes over" speech at the UN. It was extremely scary. The crisis ended, by negotiation, thanks to the willingness of both Kennedy and Khrushchev to overrule their more belligerent advisors. It was a close call.

But my trip to the nuclear test in the South Pacific somehow made me an "expert" in nuclear weapons effects. That mythical expertise got me hired by the Hudson Institute, a "think tank", recently created by Herman Kahn – the famous (or infamous) - author of "On Thermonuclear War" (Kahn 1960). I was hired to answer the question: Could human civilization actually survive a

global nuclear war, such as the one that almost happened, taking into account environmental and ecological consequences? Being entirely ignorant of the subject, I took the job. Three years later I wrote a 3-volume Report for the US Department of Defense, on the environmental consequences of global nuclear war still exists, somewhere.

My report didn't try to answer the question "yes" or "no." It did collect and present a lot of information related to the subject. Apparently, the existence of that report made me an environmental/ecological expert. It got me a job offer from another new "Think Tank" called "Resources for the Future Inc." (RFF). This group had been created by the Ford Foundation to assess future needs and availabilities of natural resources, such as fossil fuels and other minerals, by the USA. In 1966 RFF had received a grant from Rockefeller Foundation to start a new research program focused on the physical and biological environment *as a natural resource*.

They offered me the job of running that program. It was a fascinating idea. But I felt utterly incompetent to undertake it, especially as RFF was a nest of economists and I had no training in economics. Instead, they gave me a grant to write a book on a topic of my choice. I chose alternatives to the "Internal Combustion Engine," another subject I knew nothing about when I started. That was when a few people started to worry about the environmental effects of automobile exhaust ("smog"). I thought that the best alternative would be a newly designed external combustion (steam) engine. I also looked at the possibilities for battery-powered electric cars. Unfortunately, the lithium-ion battery hadn't been invented yet. The book was published (in 1972) by RFF.

After leaving RFF in 1968, I joined another nuclear physicist, Theodor B. Taylor. He was a former A-bomb designer from Los Alamos and leader of "Project Orion" at Gulf General Atomic Corp. (You can look it up in Wikipedia.) With finance from another nuclear company, EG&G Inc., we started a consultancy in Washington DC with the grandiose name "International Research and Technology Corporation" (IR&T). Our purpose was to undertake studies on various topics for the government. Ted Taylor specialized in topics related to nuclear weapons proliferation and nuclear power ("atoms for peace"). I specialized in transportation, environmental pollution, and alternatives to the internal combustion engine.

IR&T survived for a few years but did not grow huge. After a few years Ted Taylor moved to Princeton to pursue an energy storage idea. I took over, as boss and chief rainmaker, but learned that I am no good at it. I have no marketing talents. So, IR&T was absorbed into another larger company. I was "self-employed" for a couple of years. In 1979 I moved to the (relatively) new Department of Engineering and Public Policy at Carnegie-Mellon University,

in Pittsburgh. There I hung out until 1992, except for 2 years (1988–1989) at the International Institute for Applied Systems Analysis (IIASA), in Austria. Then I moved to INSEAD in France where I created a Center for the Management of Environmental Resources (CMER). During all of the years since 1970, at IR&T (with other colleagues), at Carnegie-Mellon University, at IIASA, and at INSEAD, I spent a lot of my time thinking and writing about what has come to be called "industrial metabolism" or "industrial ecology."

What I have learned, in a few words, is that technology is both our greatest hope and our greatest threat, while economics is the framework within which most actions outside the family take place? Looking around me in my old age, I see that most of the important things that happen, and the things that make them happen, are not closely related to physics or ecology, but are related to technology, culture, economics, and politics. There are a lot of histories of technology out there, mostly focused on interesting discoveries, inventions, and their inventors. My intention, in this book, is to focus on technology as a change agent in society. With rare exceptions, technology is developed—evolves—in response to societal needs that have evolutionary roots. I see technological change as an important element of human (biological) evolution, not as a separate phenomenon.

Five years ago, I wrote a report for UN Environment Program (UNEP), describing a hypothetical MBA course based on business proposals with significant environmental implications. The idea was to induce profit-oriented MBA students to teach themselves about the critical issues of sustainability, while making a lot of money. The report was finished and submitted to the UNEP, but for several reasons nothing was done about it and the main sponsor of the idea, within UNEP, was subsequently promoted and transferred to a different job in another part of the UN. He now lives in Bangkok, Thailand.

Three years ago, I wrote a book "Energy, Complexity and Wealth" covering some of the same material that was in that UNEP Report (Ayres 2016). In fact, I have borrowed from both the Report and the subsequent book quite extensively in this book. I can only hope that the additions and improvements are enough to justify a modest degree of auto-plagiarism.

Having said these things, I promise to try to abide by Melvin Kranzberg's First Law "Technology is neither positive, negative nor neutral"; I would add a lemma: "Technology is everywhere."

Fontainebleau, France Robert U. Ayres

Acknowledgments

A lot of what I have learned about the history of technology before the middle of the twentieth century came from the 5-volume Oxford University Press series edited by Charles Singer, E.J. Holmyard, A.R. Hall, and Trevor L. Williams, published in 1956, and the two volume "supplement" edited by Melvin Kranzberg and Carroll W. Pursell. Jr. published (also by Oxford) in 1967. I have made an editorial decision not to cite the individual chapter authors of those books every time I could have because it would add significantly to the academic weight of this one, without adding much information that non-academic readers will care about.

Having said that, I need to confess that my single most important source of historical data about people and technology in recent years has been the many anonymous authors of Wikipedia. I think it is fair to conjecture that many of them have also used earlier sources, such as the academic tomes mentioned above. If I could do so I would regard Wikipedia as a "co-author" of this book. I have been careful to edit and rewrite, where necessary, to avoid actual plagiarism. I have tried to give credit for invention and innovation where it is due, and not where popular history assigns it.

I have been interested in the history of technology, from various perspectives, for more than 50 years. My first published book was *Hyper cryogenics* with Felix Kaufmann (1965), my second was *Technological Forecasting and Long-Range Planning* (1969), and my third was *Alternatives to the Internal Combustion Engine* with Richard McKenna (1972). I cannot possibly remember which of many individual colleagues and contacts who gave me specific information or pointed me towards it. What I can do is to list the people with whom I have had memorable conversations that were not about economics, Marlowe, opera, politics, or Shakespeare. (I have another list of those.)

This list is alphabetical because most of it comes from my correspondence file. Brad Allenby, Julian Allwood, Serge Antoine, Kenneth Arrow, Brian Arthur, Nick Ashford, Tom Astebro, Bob Aten, Robert Axtell, Ed Ayres, Eugene Ayres, Leslie Wentz Ayres Christian Azar, Jeroen van den Bergh, Michael Braungart, Eric Britton, Harvey Brooks, Lester Brown, Peter Brown, Tom (and Sean) Casten, Marv Cetron, Cutler Cleveland, Joe and Vary Coates, Bill Clark, James Cummings-Saxton, Joel Darmstadter, David Devlin, Roman Dobrinski, Tiago Domingos, Rod Eggert, Nina Eisenmenger, Ike Ezekoya, Marina Fischer-Kowalski, Paolo Frankl, Jeffrey Funk, Murray Gell-Mann, Gael Girard, John Gowdy, Tom Graedel, Arnulf Grubler, Charles A.S. Hall, Nassim Haramein, Rob Hoffman, Leen Hordijk, Bill Hornyak, Ed and Carly Hudson, Erika Izakson, Herman Kahn, Jean-Marc Jancovici, Erich Jansch, Astrid Kander, Felix Kaufmann, Irv and Peg Kay, Yoichi Kaya, Michael Jefferson, Allen V. Kneese, Andrei Krasovski, Arkady Kryazhimski, Reiner Kuemmel, Steve Keen, Ashok Khosla, Carey King, Paul Kleindorfer, Jean Laherrere, John (Skip) Laitner, Bob Lamson, Tom Lee, Reid Lifset, Dietmar Lindenberg, Hal Linstone, Amory Lovins, Ralph (Skip) Luken, Leonard Lynn, Katalin Martinas, Andrea Masini, Richard McKenna, Fran McMichael, Dennis Meadows, David Meggysy, Gerhard Mensch, Steve Miller, John Molburg, Granger Morgan, Shunsuke Mori, Indira Nair, Neboysa Nakicenovic, Marc Narkus-Kramer, Vicki Norbert-Bohm, Michael Olenick, Robert Pestel, Philippe Pichat, Laura Talens Piero, the Plant family (Harry, Ethan, Isaac, and Matthew), Jukka-Pekka Ranta, Paul Raskin, Van Kirk Reeves, Lee Remmers, Robert Repetto, Ron Ridker, Sam Rod, Don Rogich, Pradeep and Kalpana Rohatgi, Adam Rose, Edward S. Rubin, Tom Saaty, Devendra Sahal, Warren Sanderson, Manalur Sandilya, Ian Schindler, Friedrich (Bio) Schmidt-Bleek, Uwe Schulte, Andre Serrenho, Adele Shapanka, Stanislas Shmelev Gerald Silverberg, Udo Simonis, Vaclav Smil, Robert Socolow, Marvin Sirbu, Lars Sjosted, Thomas Sterner, Mitchell J. Small, Wilbur Steger, Martin Stern, William Stigliani, Joel Tarr, Ted Taylor, Yuri Tchijov, Valerie Thomas, John S. Toll, Richard Tredgold, Antonio and Alicia Valero, Genevieve Verbrugge, Gara Villalba, Vlasios Voudouris, Ingo Walter, Ben Warr, Luk van Wassenhove, Ludo van der Heyden, David Wasdell, Ernst von Weizsaecker, Chihiro Watanabe, Peter Wentz, Roland Widgery, Eric Williams, Phil Wyatt, Lan Xue, Ming Xu, Huseyin Yilmaz, Ehud Zuscovich. I have forgotten quite a few, I'm sure, to all of whom I hereby apologize and blame encroaching old age.

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Part I

Before the Industrial Revolution

1

Introduction

In 1979, Isaac Asimov published his last major work: "A Choice of Catastrophes: The Disasters that Threaten Our World" (Asimov, 1979 #219). It was on my library shelf and, given the title of this book, I thought I should reread what he wrote 40 years ago. Asimov started with a reminder that the word "catastrophe" from Greek, meant "to turn upside down," at the end of a Greek play, whether tragedy or comedy. In his book, he considers five possible ways in which human life might end. The first of his typology was about how the universe itself might end, a trillion years from now. The second group was about how the solar system might end, e.g., due to the death of the sun from old age or being too close to a supernova explosion. The third class was about how the Earth might become uninhabitable, e.g., by glaciation, crustal shift, asteroid collision, or demagnetization.

This book is mostly about Asimov's fourth and fifth classes of catastrophes. The fourth class was about how human life on the Earth might become impossible, leaving other forms of life, but without us. The fifth class is about possible endings for what we call civilization, viz. condemning our descendants to a primitive life—solitary, poor, nasty, brutish, and short—for an indefinite period. Nuclear war or new diseases worse than COVID-19 could be catastrophes of the fourth kind. Overpopulation, famine, the next ice age, peak oil, the ozone layer, cloning, malignant artificial intelligence, and toxic industrial pollution would be in the fifth class.

Curiously, climate warming and rising sea levels were not on Asimov's list, published in 1979. Things he worried about, like running out of oil, no longer worry us, while things he did not think about, like the accumulation of

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greenhouse gases in the atmosphere, are almost upon us. My point is that—as many have pointed out—forecasting is difficult, especially about the future.

Should I start this book by defining technology? Some readers may feel the need but I do not feel a strong compulsion to do it. Usually, a change in technology follows a discovery or an invention, and we know it when we see it. However, a case came up in the late stages of writing this book that gave me pause. I had to decide whether the use of money is a technology. It is a social system, for sure. There are technological components to the money system: coins, checks, credit cards, bar codes, banks, traveler's checks, cash registers, cash machines, even cryptocurrencies. But money is more than that. It is also a measure of wealth, a unit of value, a medium of exchange, and an incentive to work. Is it technology? I finally decided (admittedly arbitrarily) that it is not.

Another puzzle: Near the end of the eighteenth century, Thomas Malthus wrote an essay about the misfit between the "power of population" and the "power of Earth to produce subsistence for man" (Malthus, 1798 [1946] #3300). Why did Malthus, and most of his critics (including Karl Marx) fail to see what seems too obvious in retrospect? I mean that substituting machines (powered by steam, later by electricity) for human muscles could increase productivity by factors of hundreds, even thousands? Why did they not see that this increase in productivity, increasing the size of the pie, could make everybody better off, not only the capitalists?

It is commonplace now, to say that technology drives the growth of material well-being—the global economic system—not to mention being a carrier of culture. Optimists think that the Industrial Revolution, especially the power of steam (and electricity), has proved that Malthus was wrong. An influential group of anti-Malthusian economists, exemplified by Julian Simon, has argued forcefully that the contest is over that "technology" will be our savior (Simon, 1977 #4641) (Simon, 1980 #4643). I also question that conclusion.

The real societal problem back in Malthus' time was essentially the same as the problem today, viz. inequality and maldistribution, not lack of production per se. A different problem confronts us now: The size of the pie may be approaching limits. Julian Simon et al may be wrong. For several decades, in the most industrialized countries, the rich have been increasing their *share* of the global pie at the expense of the rest of us. And the solution to that problem—if there is any solution—must be political, not technological. At the beginning of industrial revolution (c. 1750), India and China were as industrialized as Britain. By 1900, India's level of industrialization was only 1% of the level in Britain (Ashton, 1949 #216) p. 129. What are we missing today that future historians will think was obvious?

For decades, I have worked on the interfaces between science, technology, material flows, and—finally—economic theory again. A question that arises again and again is this: How much of our current malaise is caused by technological change? And how much does our future depend on developing new technologies to undo or counteract the old ones?

In one sense, this book is simply a recapitulation of human history, where technology plays an important, but largely invisible role in determining what happened (or did not happen) at every stage. It provides both capability and constraint. We have started modifying nature itself and doing so in ways that threaten our long-term survival as a species. So, the book is an attempt to clarify, point by point, the factors motivating invention, the limits of invention and the new problems created by invention.

This book is probably my last (and hopefully best) effort to explain the past and forecast the future of our civilization from the standpoint of technology. The reality is complex, but I think there are some major themes worthy of elaboration. One is the cross-fertilization—call it feedback—from technology to technology. Changing sources of useful energy (technically, exergy) from firewood to charcoal, then coal, whale oil, rock oil and natural gas, kerosene, town gas, to hydroelectricity, nuclear electricity, photovoltaics, and renewables are one constant. Candle light to LEDs illustrates this aspect. The history of medicine, from miasma to germs, from antiseptics to antibiotics to vaccines and monoclonal antibodies is another illustration. The so-called analog to digital revolution leading to artificial intelligence may be another theme. Are there more?

2

Fire and Water: Technologies Extending Nature

Abstract This chapter is about how our ancestors came down from the trees, learned to walk (and run) on two limbs, leaving the other two free for grasping tools and (later) for actions requiring dexterity. Living in groups, on the ground, created a need for verbal communication, which required more brainpower and bigger brains. The preservation of fire from natural sources led to a technology for the making of fire and then to more uses of fire, not only for warmth in winter, but also to make pottery and, with that, cook foods that were otherwise inedible. The use of seeds for food was the key to agriculture and (later) animal husbandry and thence to water management and irrigation. The need for mobility led to the wheel and the ship.

2.1 Bipedalism: Down from the Trees

When Charles Darwin proposed his theory of evolution by natural selection (Darwin 1859), the differences between humans and other animals appeared to be so great that most people, especially religious leaders, could not imagine any gradual evolutionary path from our hominin ancestors to us. For that reason, among others, Darwin's theory was rejected by many religious authorities in favor of a theory of "special creation," symbolized (in the Judeo--Christian part of the world) by the Biblical story of Adam and Eve. However, now that we know a lot more about human history, the evolutionary path is no longer so hard to imagine.

Most of the research on the "missing link" prior to the 1960s was focused on studying anatomical differences between various living species of 2-legged

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species (*hominins*), attempting to identify the nearest "sister species" of apes to humans and to infer the most likely appearance of the "last common ancestor" (LCA) of humans and other apes. Research covered anatomical features related to "knuckle-walking" on all fours, wrists suited to swinging under tree branches, opposable thumbs suited for grasping; finger dexterity, the thickness of tooth enamel, the flexibility of knees and feet, and the presence or absence of *oestrus* (absent in humans and Orangutans, present in all other mammals).

Today, there is much more information about our genetic history. Textbooks in anthropology now usually start with the emergence of the genus *Homo*, and the species *Australopithecus*, six or seven million years ago. They lived mainly in Africa; they walked on two legs but could probably climb trees. They had small brains 380–430 cc in volume. Two or three million years ago *Homo habilis*, a physically smaller species with a larger brain (600 cc) emerged. Then came *Homo erectus*, about two million years ago. These apes spread over much of South Asia, including China. Their brains were around 1000 cc in volume, a major increase over Australopithecus, or *habilis*. A scenario to explain the evolution of these anatomical and physiological differences has also emerged. It is that climate change in Africa was responsible for forcing forest-dwelling hominins well equipped for climbing and living in or near trees, like the Sumatran Orangutans of today, to come down from their trees and learn to live part-time—later full-time—on the ground.

To survive, they had to organize themselves into communities (tribes) to hunt and for defense against large predators with much better physical equipment. They lived in organized communities and used their hands for tasks other than locomotion. They learned how to capture and control fire of natural origin (lightning strikes). The larger brains facilitated the development of proto-language.

One of the most interesting, and controversial, theories of human evolution is that *proto* humans learned to run long distances for purposes of "persistence hunting" (Heinrich, 2002 #8539) (Bramble and Liberman 2004) (Liebenberg, 2008 #8540). Several of the anatomical changes of our bodies are consistent with this theory and difficult to explain otherwise. They include hairlessness, cardio-vascular efficiency and ankle and pelvis modifications. As persistent hunters they learned to out-run faster four-legged animals by exhausting them. This mode of hunting is still practiced today in two locations, the Kalahari Desert and the Copper Canyon in Mexico. Improved cardio-vascular efficiency seems to have led to longer lifetimes. Longer lifetimes also enabled longer gestation periods for children.

Around 350,000 years ago, Anthropologists postulate that *Homo sapiens*, *H. neanderthalensis*, *H. denisova*, *H. floresiensis,* and possibly others split off of the *Homo erectus* mainstream. These species—our competitors—had larger brains, up to 1450 cc. Leaping forward to 70,000 years ago, our species and the others were omnivorous hunter-gatherers. They lived in kinship bands, in or near forests, consuming fruits, nuts, edible fungi, eggs, rodents, rabbits, and other small animals that could be caught in traps. They also ate meat from occasional hunts of large animals such as wild pigs, deer, wild sheep, cattle, and even mastodons. Finally, and most important, they ate seed grains, beans, and roots that had to be cooked to be edible.

Around 12,000 years ago, the glaciers were melting, and forests were growing on the newly exposed hills. Game was plentiful, and hunter-gatherers, including the ancestors of *H. sapiens*, were well-fed. But as the glaciers retreated, the climate became drier, and the forests were replaced by scrub and grasslands. This forced the hominins to choose between two options: to become peripatetic nomads moving from oasis to oasis (with cattle or sheep) or to build defensible settlements near a permanent source of water, plant crops, and domesticate other animals. Water was crucial. We cannot live more than a few hours without it. The hominins who chose permanent settlements created agriculture. I discuss that option later in this chapter.

Hunting in groups, as well as defense, necessitated improved communication, using breath control and tongue movements as well as voice box control. These changes facilitated teaching, as well as communication and forward planning. Thinking ahead for immediate survival purposes also eventually forced our ancestors to expect, and fear, bodily death while believing in some sort of life after death. This led to the social practices of burial of the dead and respect for (or worship of) ancestors. The cerebral demands of verbal communication favored larger brains—the cerebral cortex—into the primary competitive advantage for our species. The brains of *Homo sapiens* now average 1.3 kg in weight, which is three times larger than the brains of our nearest surviving hominin relatives (Chimpanzees), with which we share 98% of our genes.[1] Yet the 2% of our genes we do not share with chimps separate us in important ways from all other animals.

[1] Our last competitor species, *Homo neanderthalensis*, had even bigger brains (and skulls) than we do. This may have turned out to be a lethal disadvantage, causing excessive risk to females giving birth, or to babies born too small for optimum survivability.

2.2 Pottery, Cooking, and Mobility

Before cooking there had to be pottery. Scientists used to think pottery was invented after people started farming and began living in permanent villages. Over the last decade, however, scientists have unearthed pots and other containers in East Asia that are older than farming. The most ancient pieces of clay pots, found in Xianrendong Cave (China), are 19,000–20,000 years old, from the ice age. However, people in the Middle East were making simple clay pots 14,500 years ago. Fat was relatively rare in foods available to them. So cooking would have been important, since heat releases more energy from meat and starchy plants like potatoes. What the cave dwellers cooked is unknown, but ancient clam and snail shells littered the Chinese cave where the oldest pottery was found. Those cave dwellers might have boiled animal bones to extract grease and marrow, to extract the fat. It is thought that the cave dwellers might also have used the pots to brew alcohol.

Use of yeast for making bread has an ancient history. Yeast microbes are probably one of the earliest domesticated organisms. Yeast is a single-celled living organism in the fungus domain, although it was not known to be alive until the nineteenth century. There are more than 1500 species of yeast known to mankind. Out of all the different varieties of yeast *Saccharomyces cerevisiae* is used in baking bread, making wine, and brewing beer since ages. This fungus is called the Bakers Yeast or Brewer's Yeast.

Yeast feeds on sugar and releases carbon dioxide and ethanol as its by--products. The carbon dioxide helps bread rise, makes them soft and fluffier, contributes to the flavor, and provides texture.

Archeologists digging in Egyptian ruins found early grinding stones and baking chambers for yeast-raised bread, as well as drawings of 4000-year-old bakeries and breweries. In 1680, Dutch naturalist Anton van Leeuwenhoek (1632–1723) first microscopically observed yeast, but at the time did not consider them to be living organisms (Fig. 2.1).

Richard Wrangham has postulated that cooking came much earlier. In fact, he theorized that cooking made the increase in human brain size since *H. erectus*, during the last 1.5 million years. He claims that evidence of cooking is unambiguous. (I am skeptical, because there is no evidence of pottery—needed for cooking—anywhere near that old.) His argument is inferential that *H. sapiens* brain uses up to 25% of the food energy consumed by the 75 kg human body. A larger brain requires more food. Therefore, *H. erectus* must have found more food to support the bigger brain.

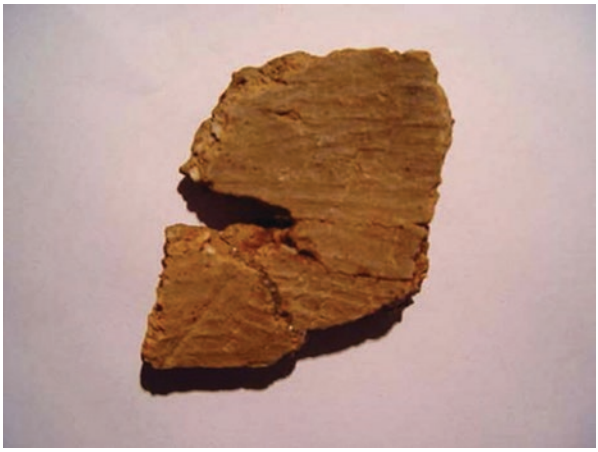

Fig. 2.1 A pottery fragment from a Chinese cave. (Phys.org)

It is true that a given primary food source enables a given body to support a larger brain, with cooking, than without cooking. Cooking makes some indigestible foods digestible and increases the efficiency of the digestion process. That makes food gathering more efficient and makes more energy available for other activities. Gareth Wyn Jones argues that cooking was a major energy revolution (Jones, 2019 #8603). However, he does not explain how cooking was accomplished without pottery.

Quite possibly the most important single accomplishment of *Homo sapiens* was that they not only learned how to capture, preserve, and utilize fires of natural origin. They learned how to make fire. Animals never did that. There is evidence of controlled use of fire in China *by H. erectus*, up to a million years ago, before the "official" appearance of *Homo sapiens*. The dates are highly uncertain, as is the picture below (Fig. 2.2).

Our proto-human ancestors probably started by conserving fire from natural sources, such as brush fires started by lightning. The defensive value of a fire for a group of bipedal animals with small children to defend was obvious. Predatory animals from wolves to bears to wildcats of all kinds feared fire. The fire's other benefits, such as warmth in cold weather, the ability to harden spear tips, to make clay pots and to cook otherwise inedible foods, multiplied its value. Most of those innovations belong to prehistory. Much later (only during the last 5000 years) was heat from fire used (in primitive furnaces) to make bricks or ceramics or to smelt metals.

Sometime in prehistory, primitive hominins learned to make fire from frictional heat. This probably happened during the last million years. It must

Fig. 2.2 Homo erectus; diorama in the National Museum of Mongolia. (Copyright free Ulaanbaatar (sculptor anon))

have corresponded to the period when proto-humans migrated out of Africa into subtropical and temperate regions where seasonal temperatures vary significantly. The first invention needed for humans to be able to use fire consistently and safely is a "fire starter." The simplest method used by *Homo erectus* is shown in Fig. 2.2, using the motion of the hands to create the necessary friction in the indentation.

The "bow drill" (Fig. 2.3) is quite a bit more sophisticated. It was probably invented about the time of the invention of the projectile weapon we know as the bow and arrow. Instead of projecting an arrow, the cord is wrapped around it and used to twirl the arrow with its point in an indentation in a piece of dry wood. The friction from the twirling creates enough heat to start a fire in dry grass.

2.3 Keeping the Dark at Bay

God said "Let there be light!" and there was light. For God's people, living on Earth it was not so easy. To the people of Sumer 10,000 years BCE, light was everything good. Light was the gift of God, to mankind. Night is for predators and prowlers. Daytime is safe. Night is dangerous, Even now, "light vs. dark" carries enormous symbolic weight.

The history of light touches virtually every technology today. But when the sun was not shining, the only practical source of light for human purposes was flame from a fire. Early lighting fuels consisted of olive oil, beeswax, fish oil,

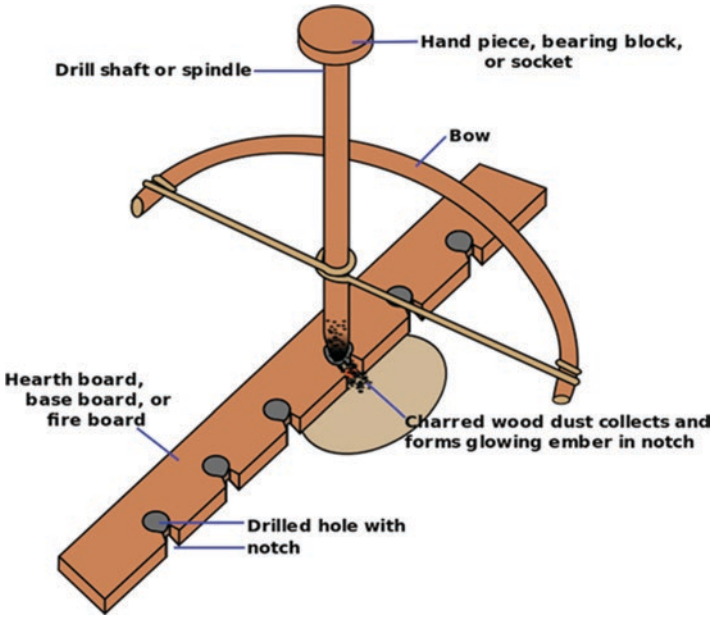

Fig. 2.3 Bow drill (modern version) as a fire starter. (Copyright free Model by Reddi, annotations by John Richfield)

whale oil, sesame oil, nut oil, and similar substances. These were the most commonly used fuels until the late eighteenth century.

The ancient Chinese of the Spring and Autumn period (771–476 BCE) made the first practical use of natural gas for lighting purposes around 500 BC where they used bamboo pipelines to transport and carry both brine and natural gas for many miles. Chinese records dating back to 300 AD note the use of natural gas in the home for light and heat via bamboo pipes to the dwellings. The mausoleum of Qin Shi Huang (259–210 BC) contained candles made from whale fat. The word zhú was used as candle during the Warring States period (403–221 BC); some excavated bronze wares from that era feature a pricket (spike) thought to hold a candle.

The Han Dynasty (202 BC–220 AD) Jizhupian dictionary of about 40 BC suggests that candles were being made of beeswax, while the Book of Jin (compiled in 648 AD) covering the Jin Dynasty (265–420) makes a solid reference to the beeswax candle in regards to its use by the statesman Zhou Yi (d. 322). An excavated earthenware bowl from the fourth century AD, located at the Luoyang Museum, has a hollowed socket where traces of wax were found. Generally, these Chinese candles were molded in paper tubes, using rolled rice

paper for the wick, and wax from an indigenous insect that was combined with seeds.

Wax from boiling cinnamon was used for temple candles in India. Yak butter was used for candles in Tibet. The early Greeks used candles to honor the goddess Artemis's birth on the 6th day of every lunar month.

Romans began making true dipped candles from tallow, beginning around 500 BCE. While oil lamps were the most widely used source of illumination in Roman Italy, candles were common and regularly given as gifts during Saturnalia. After the collapse of the Roman Empire, trading disruptions made olive oil, the most common fuel for oil lamps, unavailable throughout much of Europe. As a consequence, candles became more widely used. By contrast, in North Africa and the Middle East, candlemaking remained relatively unknown due to the availability of olive oil.

There is a fish called the eulachon or "candlefish," a type of smelt which is found in the Pacific Ocean from Oregon to Alaska. During the first century AD, indigenous people from this region used oil from this fish for illumination. A simple candle could be made by putting the dried fish on a forked stick and then lighting it.

The use of oil lamps and electric light is major part of the Industrial Revolution. I return to this later, in Chap. 15.

2.4 Pain, Anesthesia, and Surgery

Humans have been practicing various forms of pain management for thousands of years. Stone Age peoples, believing that pain and disease were punishments handed down by the gods, tried various techniques to banish the pain, such as presenting religious offerings and sacrificing animals. They also used rattles, gongs, and other noise-making devices to frighten malevolent spirits out of a person's body. Some Native American cultures sucked on pain pipes held against a person's skin to extract the pain or illness, while South Americans practiced trepanation—the cutting of holes in the head to alleviate pain. (This required both special skill and very sharp instruments for making the holes.)

Medicines derived from willow trees and other salicylate-rich plants have been part of pharmacopeia at least dating back to ancient Sumer. The Ebers Papyrus, an Egyptian medical text from ca. 1543 BCE, mentions use of willow and myrtle (another salicylate-rich plant) to treat fever and pain.

Willow bark preparations became a standard part of the *materia medica* of Western medicine beginning at least with the Greek physician Hippocrates in