A Lesson from Past Energy Crises

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After dealing with the very recent history of Moore's law in the previous issue of *IEEE Industrial Electronics Magazine,* I will jump far back into the past for this issue, taking the opportunity given by a present-world economic event. The recent collapse in oil prices to around US$30/barrel, after it soared in 2008 to peak at US$140/barrel, was welcomed by drivers, airlines, and transportation companies, but it is not beneficial from all points of view. The collapse causes major stresses in the financial world and weakens the awareness of the finiteness of fossil reserves and of the need for switching to renewable nonpolluting resources. Prospects such as these are not new. Nevertheless, despite the warnings launched decades ago by the models developed by several groups, starting with the System Dynamics Group of Jay Forrester at Massachusetts Institute of Technology (1971) and by the Club of Rome with the Meadows' Report (1972) [1], the industrialized world has long delayed realizing the weakness of its dependence on nonrenewable resources and, more generally, on the limited availability of raw materials. The extraordinary industrial development in the United States during the two postwar periods depended, to a major extent, on the wide availability of oil at a very low cost, after geological exploration in the 1930s revealed immense oil fields in Asia (e.g., the Persian Gulf, Iran, etc.). The European choice of coal, formalized early after World War II with the institution of the European Coal and Steel Community (ECSC), pointed to a less valuable, although important, energy source. More recently, the new strong Eastern economies, notably those of China and India, have resulted a dramatic rise in oil demand that called for a keener evaluation of the limits of existing reserves. During the last few years, several governments have undertaken steady policies in support of technological research for the replacement of fossil fuels and the reduction of pollution. These plans have a central role in the European Union (EU) Horizon 2020 program, with the objective of covering 20% of energy demand by means of renewable sources and reducing pollution by 20% from the 1990 level by 2020. The U.S. Department of Energy under the Obama administration conceived a US$15 billion per year plan to develop renewable sources for reducing emissions by 80% by 2050. We are confident that these measures will be timely and appropriate because we rely positively on the human ability to find new solutions capable of promoting progress. Nevertheless, such evolution should not necessarily be taken for granted. In fact, the depletion of energy resources and raw materials is not a specific problem of postindustrial economies. Similar circumstances occurred several times in the past and successful solutions were not always found.

I will revisit some of such cases, focusing on a material that has strongly influenced the history of civilizations: wood. For thousands of years, it was the raw material of choice for structural use in mechanics, construction, shipbuilding, and furniture, inter alia, and at the same time, the only thermal energy source available on a large scale, directly or as charcoal [2]. Wood is exhaustible in the short term, but under favorable conditions, a forest can regenerate within a few centuries, comparable to the typical duration of emergence, establishment, and decline of civilizations. Thus, in the same region, it could happen that wood recreates its abundance, ensuring conditions for the development of a new civilization, after it had been exhausted by a previous one. Sometimes, humans have been able to adopt rules for the controlled exploitation of wood, balancing the capacity for self-regeneration of forests. In other cases, they have found alternative solutions, possibly initially as fallbacks that over time may have produced extraordinarily fruitful developments. However, at other times, the uncontrolled exploitation has led to such levels of deficiency as to trigger even a real collapse [3].

Looking back through human history, we can find clues of resource shortage and depletion since very ancient times. At the beginning of the third millennium before the common era (BCE), the mountain slopes of the Near East were covered with vast forests of cedars. There, early deforestation was caused by the massive timber needs of the earliest civilizations, whose prosperity was highly dependent on wood, as both a structural material and a thermal energy source for metallurgy and the production of bricks, tiles, ceramics, and lime [4]. The first Sumerian civilization of the Mesopotamian region collapsed in the 28th century BCE after being struck by a disastrous flood, still evidenced by muddy deposits some meters deep. The earliest surviving poem, the *Epic of Gilgamesh*, narrates a flood, identified with the biblical flood [5]. It also describes how Gilgamesh, a king of the Sumerian Uruk, went to cut down a forest of cedars to build his palace, and in doing so, defied the protector god and was later punished by the other gods with the loss of immortality. The *Epic* was put into writing around the seventh century BCE on earlier Sumerian fragments; after the oral tradition over the centuries had transformed historical facts into myths. Thus, the episode has been interpreted as the narration, reworked in the myth, of the rupture of ecological equilibrium caused by excessive deforestation with serious and irreversible consequences and triggered by exceptionally intense torrential rain in a then-tropical-climate region. Centuries later, the Code of Hammurabi (ca. 1770 BCE), the first comprehensive legal body, was put into written form by the king of the Amorite empire in Mesopotamia [6]. One of the rules established penalties for the unauthorized felling of trees, a clear sign of the attention to a scarce resource. Later, in the eighth century BCE, the Assyrians organized a large river expedition to Anatolia and the Zagros Mountains for gathering wood, and it was so memorable that it deserved celebration in the impressive bas-reliefs of the imperial palace of Sargon II in Khorsabad, Mesopotamia.

IN ANCIENT ROME, WOOD FUELED METALLURGY AND THE KILNS THAT BAKED BRICKS, TILES, AND POTTERY; MELTED GLASS; AND PRODUCED LIME AND CEMENT.

Many archaeological clues suggest that iron forging, developed by the Hittites in the 13th century BCE, was induced by the scarcity of tin in their realm, a metal needed to smelt bronze, that was then a strategic resource of those civilizations. Iron emerged as a substitute, and for a long time was inferior to bronze [Vickers hardness (HV) of iron was 30–80 HV against 60–258 HV for bronze], but later, when forging techniques were perfected, it overcame and led to more advanced civilizations. Forging iron, however, required great quantities of wood, and the expansion of the new metal caused more deforestation. At the same time, the marine timber trade across long distances was boosted, contributing to the fortune of the Phoenicians, who held the cedar forests of Lebanon. They are mentioned by Homer, Pliny, and in the *Bible*, which tells that King Solomon of Israel asked the king of Tyre for a supply of cedar logs to build his great temple in Jerusalem. Those cedars were also pivotal in building the long Phoenician ships used for trading, the earliest provided with a keel for better sailing [7].

The collapse of the Minoans in the 15th century BCE has also been related to the massive deforestation of the island of Crete, still evident today. The archaic Greeks who emerged afterward found wood to be very important as a raw material for the construction of the fleet and as fuel for smelting metals that they traded intensively, such as copper of Cyprus and silver of the mines of Laurium, Attica [8]. Several classical authors, including Plato, Eratosthenes, and Pliny, wrote of the deforestation carried out by the Greeks, describing how those regions, which appear barren even today, were originally densely forested. Wood shortage, which forced importation from the Magna Graecia of southern Italy and from the Balkans, constituted a major concomitant techno-economic factor in the decline of classical Greece in the fourth century BCE.

The Romans, the most technologically advanced Western civilization of the ancient world, were well aware of the key importance of wood. Pliny wrote about trees in two books of his *Naturalis Historia* (79 AD), pointing out their importance: "…trees and forests were the supreme gift bestowed… on man…." Referring to the forests of Germany, he added, "…In the northern region is the vast expanse of the Hercynian oak forest, untouched by time and coeval with the world, surpassing all wonders for his almost immortal fate…," evidently conscious of the difference with the already affected condition of southern Europe. After the conquest of Greece in 167 BCE, the Romans forbade Macedonians from cutting down trees; at the beginning of the second century AD, Adrian enacted laws for the preservation of the remaining cedar forests of the Near East, declaring them imperial demesne.

Wood was the irreplaceable raw material for constructing war and workshop machinery, war and trade watercraft, and the scaffolds and ribs needed for erecting their magnificent buildings enriched with vaults and arches. Virtually the only source of thermal energy, it was essential in metallurgy and the steel industry, which were so important to the power of the empire [9]. Just to give a figure, the annual production of iron in the whole empire, exceeding 8.2×10^4 t, required 2.4×10^6 t of wood growing in 1.9×10^4 km^2 of land. In addition, copper, lead, silver, and gold were intensively smelted. Wood fueled the kilns that baked bricks, tiles, and pottery; melted glass; and produced lime and cement. One such kiln could require 2,600 t of fuel per year. Wood was indispensable for heating the waters of the thermal spas, which were fundamental civic institutions and required the seamless delivery of fuel.

Wood was also needed for heating the hypocaust, a sophisticated conditioning system of patrician houses, consisting of hot air distributed in the subfloor (Figure 1) and capable of a level of comfort unmatched until the 20th century. Therefore, a huge supply of wood was assured by systematic deforestation of large and increasingly distant territories and its transport across long distances, even by sea, rising in cost during the mid and late empire. The Mediterranean islands suffered widespread deforestation to the point that iron ore from major mines of Elba Island had to be transported to the mainland to be smelted.

The limited availability of wood made prices soar, and strict laws were enacted to counter the poor quality of bricks, due to hasty firing (good firing needed 1 kg of firewood for brick). The need of energy per capita in the Roman Empire was approximately 3,800 kWh per year (9,000 kcal per day), including wood for fire and heat, food for humans, and fodder for animals (which together were the main source of mechanical energy, whereas watermills, although important in terms of technological development, contributed less than 1%). This figure was about twice the energy need before civilization and decreased with the fall of the western Roman Empire, only being attained again at the beginning of the modern age. The crisis that hit the late empire leading to its collapse in the fifth century was not only economic, political, and military but also related to energy. After the fall, the depopulation of cities, the strong demographic decline, and the feudal economy allowed the mainland to recover its forests in the span of a few centuries, but not the Mediterranean islands, most of which remained definitely deprived of high vegetation as they now still are [10].

Various exotic civilizations fell in the early centuries of the second millennium AD; several conjectures ascribe their rapid decline to the depletion of the same resources that had enabled their expansion. The Maya of Central America collapsed during the ninth through the tenth century AD because of overpopulation and depletion of natural resources caused by excessive agricultural exploitation, together with a long period of drought [11]. Similar causes are attributed to the decline of the Anasazi in the southwest United States in the 14th century and of the Khmer of Cambodia in about 1430 [12]. The Neolithic civilization of Rapa Nui (Easter Island; Figure 2) collapsed between the 15th and 16th centuries because of the irreversible exploitation of its forest resources after cutting down all the trees on the island, which produced a rupture of environmental equilibrium that was apparent to European explorers in the 18th century and still affects its life today [13].

Following the late medieval economic revival, the use of wood for thermal and structural purposes had already produced several deforestations in central Europe during the 12th–14th centuries, causing a marked increase in the price of timber. Various steel districts (Liege in 1190–1230, England in 1243, Arles in 1345) began to use coal for iron making, but with limited success, because although it could smelt iron ores, it produced a low-quality cast iron, brittle because of its high carbon and sulfur contents [14]. In China, the conversion to coal in iron smelting began earlier on similar grounds, and in the 11th century, under the Song Empire, it was already successfully used in the production of good steel; such was the advancement of Chinese technology of that time [15].

VENICE SUFFERED FROM COMPETITION OF THE TRADES ON THE OCEANIC ROUTES AND ALSO FROM THE INCREASING DIFFICULTY IN FINDING TIMBER FOR ITS FLEET.

The economic revival following 1,000 AD involved a restart in large deforestation in southern Europe as well. The maritime republics were among the largest consumers of wood, particularly needed to create impressive fleets to ferry the Crusader armies to the Holy Land, in exchange of colossal gains. For the fourth crusade, Venice agreed to provide ships sufficient to transport 4,500 knights with their horses, 9,000 equerries, and 20,000 foot soldiers as well as 50 escorting galleys, negotiating for them the exorbitant sum of 85,000 silver imperial marks. The price of wood skyrocketed. When, in 1420, Filippo Brunelleschi faced the construction of

FIGURE 1 – The hypocaust of a Roman villa from the third century AD. The subfloor for hot-air heating is clearly visible (neighborhood of Yerveran, Armenia).

FIGURE 2 – Easter Island. Nowadays mostly barren after the complete deforestation of the 15th and 16th centuries, this led to a complete collapse of the Rapa Nui civilization. (Courtesy of Assunta Caruso.)

FIGURE 3 – The shortage of wood induced Filippo Brunelleschi to invent revolutionary techniques to build the magnificent and still unmatched masonry dome of the Florence Cathedral in 1420. (Courtesy of Pino Grasso.)

the extraordinary dome of Santa Maria del Fiore in Florence (Figure 3), the largest ever built in masonry (43 m in diameter and 60 m high), he would use a colossal quantity of timber to build the dome with the traditional scaffolds and forms, producing prohibitive costs even for the standards of the wealthy city [16]. He solved the problem by designing the revolutionary double shell with a herringbone brick pattern, capable of transferring the weight of the freshly laid bricks to the nearest vertical ribs, thus self-sustaining during construction. After having been the most powerful maritime republic and richest city-state of Europe, in the 16th century, the Venetian Republic was becoming exhausted in its clash with the Ottoman Empire. The Republic suffered from competition of the trades on the oceanic routes and also from the increasing difficulty in finding timber for its fleet. In 1548, the Council of Ten proclaimed the pine forest in the near Alps to be a republic property for the production of oars for galleys, establishing death sentences for unauthorized felling. Such had become the value of wood for the shipyard. Nevertheless, by about 1590, they were forced to import entire ship hulls from Scandinavia.

In the early 17th century, wood was still the fuel most widely used in England, but it had also become the strategic raw material for shipbuilding in a nation that was aiming for maritime expansion after defeating the Spanish Armada (of Philip II), whose construction had led to vast and irreversible deforestation in Spain. Ocean exploration and European colonial development were permitted by the availability of wood for the construction of Dutch, English, and French fleets. However, the strong demand caused an energy crisis in the 17th century, and England itself had to import wood from the Baltic, Scandinavia, and the colonies of North America. Britain's forests simply could not keep up with the demand for wood [17]. Such conditions promoted the use of coal, which was plentiful and easily accessible in England, although it allowed less-valuable combustion in metallurgy. For these same reasons, peat was exploited in The Netherlands. Toward the end of the century, coal mines had reached depths of 120 m, and water drainage with pumps driven by horses was affordable for iron mines but too expensive for a low-value material such as coal (a single mine could require a costly stable of 500 animals). It was the search for more economical solutions that led technicians such as Thomas Savery (who patented the steam pump dubbed Miner's Friend in 1698) and Thomas Newcomen (with his atmospheric engine of 1712; Figure 4) to conceive drainage machines powered by the pressure of steam cheaply produced with that same coal [18]. The coke process, invented by Abraham Darby in 1709 and exploited from 1735, allowed the use of coal in

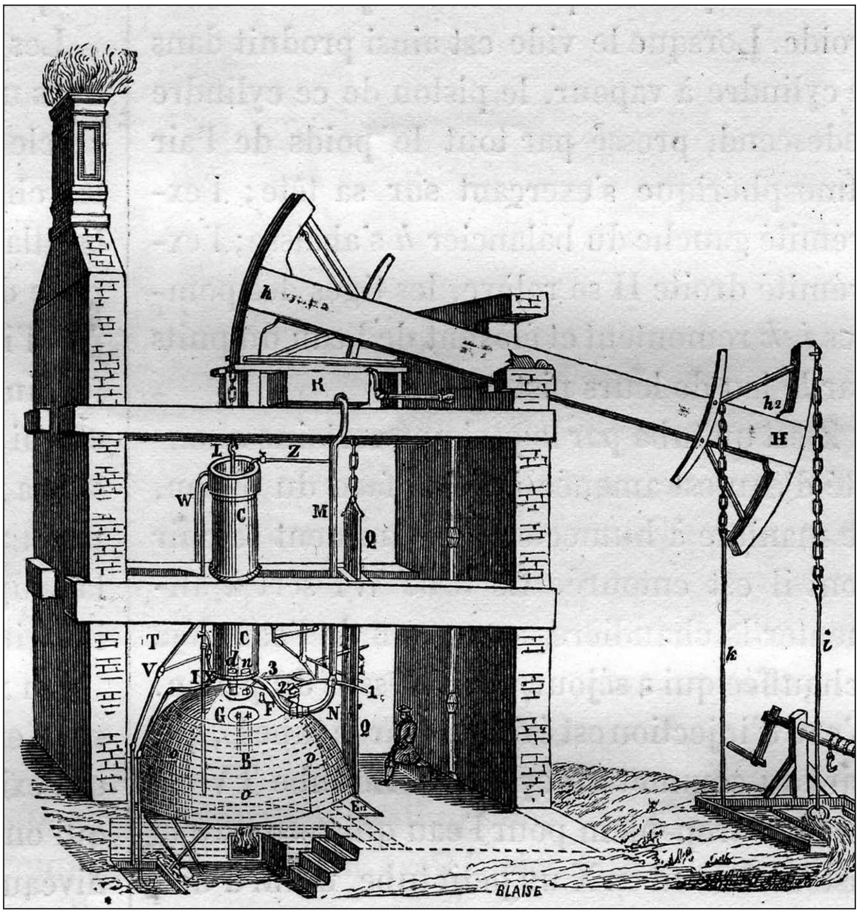

FIGURE 4 – Thomas Newcomen's atmospheric engine, the first effective steam engine, was invented in 1712 for drainage of water in coal quarries, marking the start of the massive coal use that powered the Industrial Revolution. (Courtesy of Wikimedia Commons.)

the production of good iron, starting the replacement of wood with coal as a fuel in iron metallurgy and with steel as a structural material [19]. Emerged as a less-valuable substitute for wood, coal with iron and the steam engine turned into the source that powered the Industrial Revolution, both in factories and for transportation. The increasingly intense use of fossil fuels (namely, coal, oil, and gas) has led to the present unparalleled standard of life and energy consumption per capita to up to 15,700 kWh per year (37,000 kcal per day, fourfold the need before the Industrial Revolution and 12-fold the human food energy need).

As I have attempted to illustrate, for thousands of years, powerful civilizations have been menaced by shortages in energy sources and raw materials; often, the lack of foresight resulted in catastrophic epilogues. These pieces of evidence deserve to be taken into account if we want to avoid repeating the mistakes of the past. We must prudently avoid being so naive as to believe that such epilogues cannot be repeated. Often, the ingenuity of humanity has transformed those threats into opportunities for strong strides ahead in human development; we have become accustomed to the impressive achievements that technology can provide. However, we are also facing a formidable challenge regarding energy. Today, we are designing the passage to renewable energy sources, but the level of energy per capita that we need, with a world population heading to 10 billion in the next century, raises an unmatched challenge. Without a doubt, industrial electronics is to play a major part in switching the next energy transition.

References

[1] D. H. Meadows, *Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind*. New York: New American Library, 1977.

[2] J. Perlin, *A forest Journey: The Role of Wood in the Development of Civilization*. Cambridge MA: Harvard University Press, 1991.

[3] M. Williams, *Deforesting the Earth: From Prehistory to Global Crisis*. Chicago: University of Chicago Press, 2003.

[4] R. Meiggs, *Trees and Timber in the Ancient Mediterranean World*. Oxford, U.K.: Oxford University Press, 1982.

[5] S. Dalley, Ed., *Myths from Mesopotamia: Creation, the Flood, Gilgamesh, and Others*. Oxford, U.K.: Oxford University Press, 1998.

[6] M. Mieroop, *King Hammurabi of Babylon: A Biography*. Cambridge, U.K.: Blackwell Publishers, 2004.

[7] L. Casson, *Ships and Seamanship in the Ancient World*. New York: The Johns Hopkins University Press, 1995.

[8] J. F. Healy, *Mining and Metallurgy in the Greek and Roman World*. London: Thames & Hudson, 1978, pp. 141–152.

[9] P. Malanima, "Energy consumption in the Roman world," in *The Ancient Mediterranean Environment Between Science and History,* W. V. Harris, Ed. Leiden, Boston: Brill, 2013.

[10] W. V. Harris, "Defining and detecting Mediterranean deforestation, 800 BCE to 700 CE," in *The Ancient Mediterranean Environment Between Science and History,* W. V. Harris, Ed. Leiden, Boston: Brill, 2013.

[11] A. Demarest, P. M. Rice, and D. S. Rice, *The Terminal Classic in the Maya Lowlands: Collapse, Transition, and Transformation*. Boulder, CO: University Press of Colorado, 2004.

[12] C. Childs, *House of Rain: Tracking a Vanished Civilization Across the American Southwest*. London: Little, Brown and Company, 2007.

[13] T. L. Hunt, "Rethinking the fall of Easter Island," *Am. Sci.*, vol. 94, no. 5, pp. 412–419, Sept.–Oct. 2006.

[14] F. Tylecote, *A History of Metallurgy*, 2nd ed. Leeds, U.K.: Maney Publishing, 1992.

[15] J. Needham, *Science and Civilization in China, Vol. 4, Physics and Physical Technology, Pt. 2, Mechanical Engineering*. Taipei, Taiwan: Caves Books, 1986.

[16] R. King, *Brunelleschi's Dome: The Story of the Great Cathedral of Florence*. New York: Penguin, 2001.

[17] J. U. Nef, "An early energy crisis and its consequences," *Sci. Am.*, vol. 235, no. 5, pp. 140–151, Nov. 1977.

[18] H. Richard Leslie, *Power from Steam: A History of the Stationary Steam Engine*. Cambridge, U.K.: Cambridge University Press, 1993.

[19] J. E. Rehder, "The change from charcoal to coke in iron smelting," *J. Hist. Metallurgy*, vol. 21, no. 1, pp. 37–43, 1987.