Substantia
An International Journal of the History of Chemistry

Firenze University Press
www.fupress.com/substantia

Editorial

Sustainability and Energy
Knowledge of the Past is Critical for our Future

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Citation: S. C. Rasmussen (2019) Sustainability and Energy. Knowledge of the Past is Critical for our Future. *Substantia* 3(2) Suppl. 1: 9-11. doi: 10.13128/Substantia-691

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Competing Interests: The Author(s) declare(s) no conflict of interest.

Sustainability and Energy – two fundamental topics that are key to the past, and future, of humanity. Of these two, however, energy has long been the primary focus and the contribution of sustainability has been a secondary concern. Our preoccupation with energy via chemical means can be traced back to the initial taming of fire, dating to at least 500,000 BCE[1]. By 300,000 BCE, mankind was beginning to use fire to cook their food and, by 100,000 BCE, the use of fire as a source of heat and light had become well-established, permanently changing the future of humanity[2]. Throughout these time periods, mankind was dependent on carbon as the singular source of fuel for energy production via combustion. As the carbon sources consisted of wood and other plant matter, this earliest energy technology could at least be viewed as renewable. As such, it could be considered sustainable, providing that the consumption of wood and plant matter did not outpace the regrowth of new trees and plants to take their place.

Of course, as civilizations developed and population centers grew, the desire for more effective fuels grew. By the first millennium BCE, coal had emerged as a more concentrated fuel for combustion, with Theophrastus (c. 371–287 BCE) referring to the use of coal as fuel in his geological treatise *On stones*[3]. During the 18th century it was found that coal could also be used to produce a combustible gaseous product, known as *coal gas*, via its destructive distillation. This gas went on to become the initial fuel for gas lighting. Methane, originally known as either *firedamp* or *marsh gas*, was also first studied in the 18th century and was later determined to be the primary component of coal gas[4]. In the modern day, methane from natural deposits is

[1] S. C. Rasmussen in *Chemical Technology in Antiquity* (Ed.: S. C. Rasmussen), ACS Symposium Series 1211, American Chemical Society, Washington, D.C., **2015**, p. 7.
[2] R. Shahack-Grossa, F. Bernab, P. Karkanasc, C. Lemorinid, A. Gophere, R. Barkaie, *J. Archaeol. Sci.* **2014**, *44*, 12.
[3] E. R. Caley, J. F. C. Richards. *Theophrastus On Stones. Introduction, Greek Text, English Translation, and Commentary*. The Ohio State University, Columbus, OH, **1956**, p.48.
[4] S. C. Rasmussen. *Acetylene and Its Polymers. 150+ Years of History.* Springer Briefs in Molecular Science: History of Chemistry, Springer, Heidelberg, **2018**, pp. 5-6.

more commonly known as natural gas, which can also contain some higher alkanes and small amounts of other gaseous impurities. The discovery of other hydrocarbon gases such as ethylene and acetylene then followed in the 19th century, although coal gas still remained the primary gaseous fuel for applications such as lighting until the large-scale production of acetylene from calcium carbide at the end of the 19th century[5].

During this same time period, another commonly used fuel was whale oil, particularly for use as a lamp oil for lighting. The demand for whale oil was high during the 18th century and reached its peak in the 19th century. It was only with the development of the petroleum industry that the use of whale oils declined considerably as it was replaced by cheaper and more effective fuels. Although descriptions of the distillation of crude oil by Islamic philosophers date back to the 9th century[6], the modern history of petroleum began with the development of kerosene by Abraham Gesner (1797-1864) in 1846[7]. Even though kerosene was first produced from coal, it was soon found that it could be produced more easily from petroleum. Other products were also isolated during the fractional distillation of kerosene from petroleum, but these initially found little use. It wasn't until the invention of the automobile in the late 19th century that one of these products, gasoline or petrol, was recognized as a valuable fuel. By 1916, the production of gasoline grew to surpass that of kerosene and petroleum fuels rapidly became the primary source of energy throughout the industrialized world.

While we were able to view the early use of wood for combustion as sustainable, at least under specific limiting factors, the same cannot be said for these later carbon fuels. Coal, natural gas, and petroleum are all fossil fuels resulting from the anaerobic decomposition of organic matter. While initially abundant, the natural deposits of these materials are thought to have taken millions of years to accumulate and cannot be replenished within a reasonable timeframe. Whale oil, too, is anything but sustainable and the hunting of whales for this fuel is said to have nearly brought about their extinction.

Beyond carbon, the ability to obtain energy from other elements on the periodic table was not really an option until the beginning of the 19th century. It was in 1800 that energy via non-combustion methods was primarily introduced with the discovery of the Voltaic Pile (i.e. the first battery) by Alessandro Volta (1745-1827)[8]. Electricity via static generation had been previously known since the Roman era, but could only be stored in an early form of capacitor and could not be released or applied in a controlled fashion. It was Volta's invention of the battery that really began the electric age. Although Volta's initial battery utilized combinations such as copper and zinc, a variety of other metal combinations were also found to successfully generate current and modern battery technology now exhibits a plethora of chemical combinations. Other electrochemical variants of the classical battery followed, most notably the fuel cell introduced by William Grove (1811-1896) in 1839[9].

It was also in the 19th century that interest began to turn to the potential of electrical energy from light, beginning with the first report of photovoltaic effects by Edmond Becquerel (1820-1891) in 1839. Of course, mankind had always relied on the sun for both heat and light, but the possibility of harvesting electricity from sunlight ushered in the development of solar cells in the pursuit of solar energy. Although initial progress was slow, the first practical silicon solar cells were developed in 1954 by Bell Labs[10], which only further increased interest in this nascent technology. Since then, great advances have been made in the development of silicon solar cells, as well as the introduction of a wide variety of other solar cell devices, including the recent focus on solar cells from semiconducting organic materials in the last couple of decades.

Of course, another powerful source of energy in the form of uranium (specifically uranium-235) resulted as a consequence of the Manhattan Project during World War II. The first nuclear reactor was constructed in November 1942 by a group led by Enrico Fermi (1901-1954), with a self-sustaining nuclear reaction successfully demonstrated in December of the same year[11]. This was followed with the construction of an experimental breeder reactor in Idaho, which generated the first electricity from nuclear energy on December 20, 1951. The first commercial plant to generate electricity by nuclear energy was located in Shippingport, Pennsylvania and reached its full design power in 1957, after which the US nuclear power industry grew rapidly in the 1960s.

As can be seen from the discussion above, mankind's love-affair with energy is long and varied. This is

[5] S. C. Rasmussen. *Acetylene and Its Polymers. 150+ Years of History.* Springer Briefs in Molecular Science: History of Chemistry, Springer, Heidelberg, **2018**, pp. 30-35.
[6] R. J. Forbes. *Studies in Early Petroleum History*, E. J. Brill, Leiden, **1958**, pp. 149-150.
[7] A. Gesner. *A Practical Treatise on Coal, Petroleum, and Other Distilled Oils.* Bailliere Brothers, New York, **1861**, pp. 8-9
[8] A. Volta, *Philos. Trans. R. Soc. London* **1800**, *90*, 403.
[9] A. E. Becquerel, *C. R. Acad. Sci.* **1839**, *9*, 145.
[10] J. Perlin. *The Silicon Solar Cell Turns 50* (NREL Report No. BR-520-33947). National Renewable Energy Lab., Golden, CO, **2004**.
[11] U.S Department of Energy (DOE/NE-0088). *The History of Nuclear Energy*. Office of Nuclear Energy, Science and Technology, Washington DC.

especially true as the current discussion has been limited to those fuels and technologies based on chemical processes. As such, physical/mechanical energy technologies such as hydroelectric power and wind energy could also be added to those previously discussed. Still, considering the varied sources of energy at our disposal, the industrialized world still relies primarily on fossil fuels to meet its energy needs. This is especially concerning due to the finite nature of these fuels, as well as the toll our historic dependence on combustion technologies has inflicted upon the environment. While a hot-button topic within the general public, the vast majority of actively publishing climate scientists – ca. 97%[12] – agree that global warming and climate change are the result of such human activities[13]. Furthermore, if something is not done to change our energy habits, things will only get worse. In fact, it is believed that even if we completely stopped emitting greenhouse gases today, global warming would continue for at least several more decades, if not centuries. Still, it is believed that it is not be too late to avoid or limit some of the worst effects of climate change.

Due to these various factors, it is clear that future energy technologies must be both sustainable in practice and shift away from our current emphasis on combustion. At the same time, there are various factors that actively inhibit such paradigm shifts, be it economic, political, limits in current technology, or simple inertia. It is only with a clear knowledge of the past that we can completely understand how mankind came to the current cross-roads. At the same time, such knowledge can also highlight factors that prohibited the development of alternate technologies that might have served us better in the long run. Thus, to better serve the future, it is worthwhile to review the past in greater detail. It is with this viewpoint that I am proud to present the following special issue on *Sustainability and Energy* that highlights the histories of various energy technologies, particularly those that might provide potential paths forward to a better future. The fact that this issue is part of *Substantia*'s celebration of the *International Year of the Periodic Table* is also very fitting, as the various energy technologies discussed above have not been limited to any one element or periodic block, but have originated in chemistry based upon elements from across the periodic table.

[12] J. Cook, D. Nuccitelli, S. A. Green, M. Richardson, B. Winkler, R. Painting, R. Way, P. Jacobs, A. Skuce. *Environ. Res. Lett.* **2013**, *8*, 024024.
[13] N. Oreskes. *Science* **2004**, *306*, 1686.