Six Chemists on Energy, Population, and the Environment

William B. Jensen

Department of Chemistry, University of Cincinnati
Cincinnati, OH 45221-0172

I first became interested in the questions of available energy supply, population growth, and environmental pollution in the 1970s while still a graduate student at the University of Wisconsin. These three topics (figure 1) are, of course, intimately interconnected via what I call "the master equation," which postulates that the average potential economic well-being (*EWB*) of an individual in a given society is measured by the available energy flow or power (*P*) available to that society, minus the energy costs of pollution (*P'*) abatement, divided by the population (*P"*) of the society among whom the available energy must be divided (1):

$$\text{Economic Well Being} = \frac{\text{(available power – pollution costs)}}{\text{population}}$$

or more symbolically:

$$EWB = (P - P'')/P'$$

To use a simplified industrial metaphor, these three topics roughly correspond to the concepts of production (available energy generation), demand (population), and the tax on doing business (pollution abatement).

The 1960s and 1970s also saw the publication of a large number of books dealing with these three questions. These included not only advanced monographs

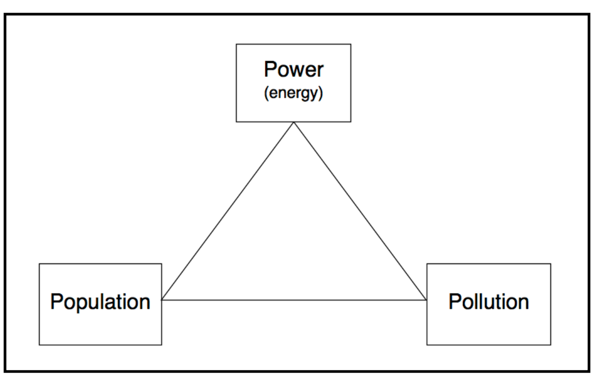
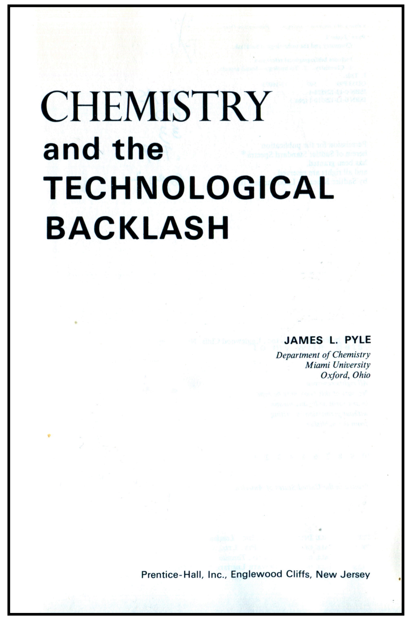


Figure 1. The triad of available energy production or power generation, population growth, and environmental pollution.


CHEMISTRY
and the
TECHNOLOGICAL
BACKLASH

JAMES L. PYLE
Department of Chemistry
Miami University
Oxford, Ohio

Prentice-Hall, Inc., Englewood Cliffs, New Jersey

Figure 2. Title page of a typical chemistry textbook from the 1970s that attempted to cash in on the sudden surge of interest in the questions of energy production, overpopulation, and environmental pollution.

and popular accounts for the general public, but also college-level textbooks in such fields as engineering (2), ecology (3), physics (4) and even chemistry (5), which attempted to cash in on the public's sudden interest in these questions. Unhappily, the latter textbooks (figure 2), in particular, often – though one hopes unintentionally – left students with the impression that chemists and chemistry were the villains responsible for most of our collective woes, a view which persists to this day, especially among more extreme ecological fanatics.

This is, of course, a vast oversimplification of a complex situation, and over the years I gradually discovered that chemists, far from being the universal purveyors of ecological evil they had been made out to be, had in fact made some significant contributions to our understanding of these questions. In what follows I will briefly outline some of these contributions using

Figure 3. William Stanley Jevons (1835-1882)

the examples of six chemists from the past, three of whom were winners of the Nobel Prize in Chemistry, and two of whom would eventually leave the field of chemistry in order to pursue other interests. All six illustrate that knowledgeable chemists have always been aware of the challenges of dwindling energy resources, the dangers of overpopulation, and the ongoing tragedy of environmental degradation.

No. 1. William Stanley Jevons on the Coal Question

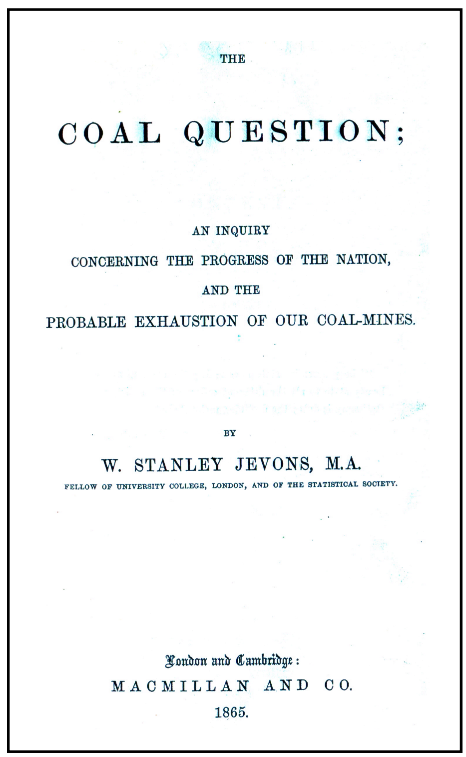
William Stanley Jevons (figure 3) was born on 01 September 1835 in Liverpool, England, the ninth of eleven children of Thomas Jevons, an iron merchant, and Mary Anne Roscoe (6). He obtained his chemical training at University College London under Thomas Graham. During this period he also roomed with his older cousin, Henry Enfield Roscoe, who would go on to become an eminent British chemist, Principal of Owens College in Manchester, and later Vice-Chancellor of the University of London.

Toward the end of Jevons' second year at University College, Graham received a request from the newly established Mint in Sydney, Australia, asking him to recommend a chemist for the post of assayer. Graham first recommended Henry Roscoe, but Roscoe was planning to leave for Germany to complete his doctoral degree under Robert Bunsen, and so he, with the further urging of Jevons' father, convinced his younger cousin to take the job instead.

Jevons arrived in Sydney in 1855 at age 20. However, not only did his work as an assayer prove to be repetitious and boring, it also left him with a great deal of spare time, which he filled by reading books on philosophy and economics. Having finally decided that a career as a chemist was not for him, Jevons resigned his position in 1859 and returned to England, where he pursued his new interests by completing B.A. and M.A. degrees at University College, followed by his appointment in 1866 as Professor of Logic and Political Economy at Owens College in Manchester, where his cousin Henry was then serving as Professor of Chemistry. This was followed by his appointment as Professor of Political Economy at University College London in 1876, from which he resigned in 1881, and his untimely death on 13 August 1882 at age 46 as the result of a swimming accident.

Jevons was a prolific writer and, despite an active career of only two decades, would author at least 15 books on the subjects of logic and economics, including a well known volume on the philosophy of science (7). At present he is widely considered to be the founding father of the subject of mathematical economics (6). Of greatest interest to us, however, is his fourth book (figure 4), first published in 1865 under the title of *The Coal Question,* and whose focus was well described by its subtitle, *An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of our Coal Mines* (8).

As indicated in his Introduction, Jevons was fully aware that it was energy, of which coal was the major



THE

COAL QUESTION;

AN INQUIRY
CONCERNING THE PROGRESS OF THE NATION,
AND THE
PROBABLE EXHAUSTION OF OUR COAL-MINES.

BY

W. STANLEY JEVONS, M.A.
FELLOW OF UNIVERSITY COLLEGE, LONDON, AND OF THE STATISTICAL SOCIETY.

London and Cambridge:
MACMILLAN AND CO.
1865.

Figure 4. Title page of the first edition (1865) of Jevons' book on the coal question.

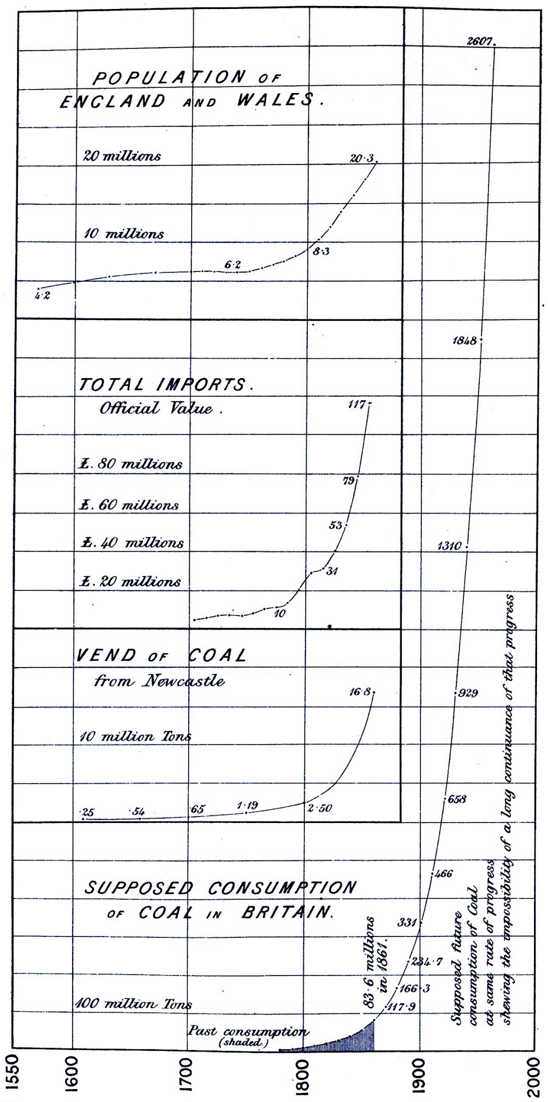


Figure 5. Frontispiece to Jevons' book showing graphs of population growth, imports, the sale of coal, and projected coal consumption extrapolated to 1970.

source, that was the true driving force of modern civilization (8):

Coal in truth stands not beside, but entirely above, all other commodities. It is the material source of the energy of the country — the universal aid — the factor in everything we do. With coal almost any feat is possible or easy; without it we are thrown back into the laborious poverty of earlier times.

Here we need to remind ourselves that, when Jevons was writing, coal was the only major fossil fuel in use, since the widespread use of oil and natural gas still lay in the future. And, of course, the same is equally true of other major energy sources such as hydroelectric and nuclear energy. Thus to write about an impending future coal crisis in 1865 was equivalent to writing about an impending future energy crisis and, to the best of my knowledge, Jevons' book was the first to deal with this question. In pursuit of this goal he would discuss, using numerical data whenever possible, the geology of coal, its geographical distribution, its mining, its most important industrial uses, possible energy alternatives, and its consequences for technological innovation, population growth, and Great Britain's balance of trade.

By 1865 geologists were estimating that Great Britain had roughly 90 billion tons of coal reserves. Given that Jevons' data showed that coal consumption was accelerating at an annual rate of 3.5% and that the cost of mining coal must necessarily increase as one was forced to mine deeper and deeper deposits, he estimated that this reserve would become insufficient in just under a century, at which point production would peak, followed by a decline and by dire economic and social consequences (8):

Suppose our progress to be checked within a half a century ... how shortened and darkened will the prospects of the country appear, with mines already deep, fuel dear, and yet a high rate of consumption to keep up if we are not to retrograde.

One of the unique features of Jevons' analysis was his recognition of the importance of population growth, the second major factor in our master equation. Once again his data showed that the increased availability of energy per capita supplied by coal consumption had stimulated a corresponding rapid growth in population, as more and more children were able to survive to the age of reproduction. However, he went on to warn that, when the coal begins to run out, the country would no longer be able to support such a population, at least in the manner to which it will have become accustom (8):

But long-continued [population growth] in such a manner is altogether impossible – it must outstrip all physical conditions and bounds; and the longer it continues, the more severely must the ultimate check be felt.

Jevons summarized many of these trends in a series of graphs that appeared as the frontispiece to his book (figure 5). All of them show a period of rapid exponential growth starting slowly in the 18th century and anticipate the "hockey stick" graph made famous by Al Gore in his 2006 movie on carbon dioxide and global warming.

One of the chapters of greatest interest to the modern reader deals with Jevons' treatment of possible energy alternatives. Here he discussed the possible use of wind, water, tidal, biomass, geothermal, solar, and electrical energy sources, and though he felt that some of these would be useful on a small scale, none, in his opinion, would be able to supply the quantities of energy currently produced from coal. Even more astounding was his discussion of the possibility of using electrolytically generated hydrogen as an alternative fuel, though in the end he felt that its low energy density as a gas made this impractical.

He also discussed the question of whether Britain could postpone its ultimate energy fate by banning the export of coal, by heavily taxing its use, and by increasing the efficiency of its steam engines. With respect to the latter tactic, however, Jevons' analysis showed that increased efficiency tended to stimulate increased demand and to further accelerate the rate of consumption, rather than the reverse – a result known as "Jevons' Paradox" (8):

It is wholly a confusion to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is true ... Whatever conduces to increase the efficiency of coal, and to diminish the cost of its use, tends to augment the value of the steam-engine, and to enlarge the field of its operations.

In the end Jevons did not have a very optimistic future prognosis for Great Britain, feeling that it had to choose between purposely slowing its rate of growth so as to enjoy a more prolonged, but less spectacular, period of prosperity, or allowing things to progress unrestrained, leading to a shorter, but more glorious, burst of progress (8):

We have to make the momentous choice between brief greatness and longer continued mediocrity.

No. 2. Svante Arrhenius on Global Warming

Svante Arrhenius (figure 6) was born on 19 February 1859 in Vik, Sweden, the second of two sons of Svante Gustaf Arrhenius, a land surveyor, and Carolina Thunberg (9). His chemical training was obtained at the University of Uppsala and at the Physical Institute of the Swedish Academy of Sciences in Stockholm. His best known contribution to chemistry – the theory of ionic dissociation – was the subject of his 1884 doctoral thesis. Considered controversial by his professors, the thesis was given only a third-level pass. However Arrhenius mailed copies to several renowned chemists and physicists, who took a far more favorable view of the work, which would eventually form the basis of his 1903 Nobel Prize in Chemistry.

Figure 6. Svante Arrhenius (1859-1927)

Following his graduation, Arrhenius obtained a travel grant from the Swedish Academy of Sciences that allowed him to study abroad in the laboratories of Ostwald, Kohlrausch, Boltzmann and van't Hoff. In 1891 he was appointed as Lecturer in Physics at the *Stockholms Högskola*, followed by promotion to full professor in 1896. In 1905 he was appointed head of the newly founded Nobel Institute for Physical Chemistry, where he remained until his death on 02 October 1927 at age 68.

Arrhenius' principal biographer, Elisabeth Crawford, has noted that his scientific work falls into three distinct periods (9). The first period, from 1884-1890, dealt with physical chemistry and included not only his theory of ionic dissociation and his well-known ionic acid-base definitions, but his equally famous equation relating the temperature dependence of reaction rates to the concept of activation energy. The second period, from 1895-1900, dealt with cosmic physics, and the third and last period, from 1901-1907, with immunochemistry. It was during the second period, when he was serving as a Lecturer in Physics, that he first developed a correlation between the carbon dioxide content of the atmosphere and the surface temperature of the earth.

Inspired by the work of the Swedish geologist Arvid Högsbom, Arrhenius published a lengthy paper in 1896 attempting to show that past ice ages were due to decreases in the carbon dioxide content of the at-

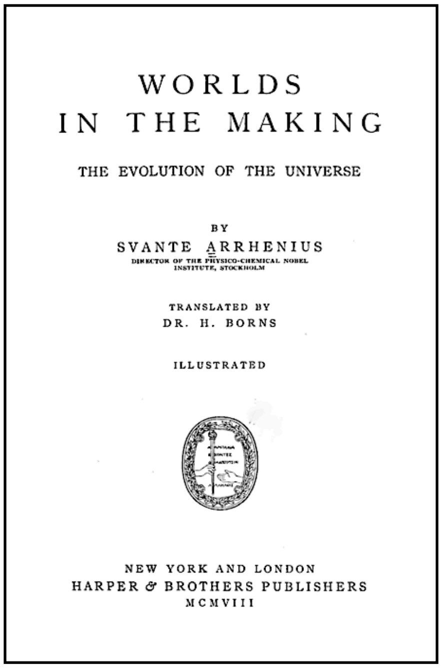

WORLDS
IN THE MAKING
THE EVOLUTION OF THE UNIVERSE
BY
SVANTE ARRHENIUS
DIRECTOR OF THE PHYSICO-CHEMICAL NOBEL INSTITUTE, STOCKHOLM
TRANSLATED BY
DR. H. BORNS
ILLUSTRATED
NEW YORK AND LONDON
HARPER & BROTHERS PUBLISHERS
MCMVIII

Figure 7. The 1908 English translation of Arrhenius' popular book on cosmic physics.

mosphere. This culminated in a large table showing the relationship at various latitudes between the change in temperature and the change in carbon dioxide content (10). No mention was made of possible future changes in temperature due to the impact of carbon dioxide generation from the burning of coal for purposes of industrial manufacturing and domestic heating.

This latter subject, however, had been briefly mentioned by Arrhenius earlier that year in a popular lecture (11), and repeated once again in a popular book on cosmic physics that was translated into English in 1908 (figure 7). But, far from viewing the gradual future warming of the earth, due to the burning of fossil fuels, as a tragedy, and ignorant of its possible consequences for changes in sea level and the ecological survival of many plants and animals, Arrhenius actually thought that such warming might have positive benefits (12):

We often hear lamentations that the coal stored up in the earth is wasted by the present generation without any thought of the future, and we are terrified by the awful destruction of life and property which has followed the volcanic eruptions of our days. We may find a kind of consolation in the consideration that here, as in every other case, there is good mixed with the evil. By the influence of the increasing percentage of carbonic acid in the atmosphere, we may hope to enjoy ages with more equable and better climates, especially as regards the colder regions of the earth, ages when the earth will bring forth much more abundant crops than at present, for the benefit of rapidly propagating mankind.

Thus Arrhenius himself did little to publicize the link between his theory and its possible future ecological consequences, and it would remain for others, more than a half century later, to begin the process of forging these connections, as detailed in the popular history of global warming by the American historian Gale Christianson (13).

As a final irony, it should be pointed out that Arrhenius's theory of the origin of the ice ages is no longer accepted and the current consensus attributes them instead to changes in the earth's orbit. Similarly, Arrhenius' own predictions about future warming were off by a factor of 10. In his popular lecture of 1896 he predicted that it would take roughly 3000 years for human activity to double the carbon dioxide content of the atmosphere, leading to a mean temperature increase of 6 C°. Current estimates are closer to 250 years.

No. 3. Leopold Pfaundler on Carrying Capacity

Leopold Pfaundler (figure 8) was born on 14 February 1839 in Innsbruck, Austria, the son of a local advocate and Professor of Law at the University of Innsbruck

Figure 8. Leopold Pfaundler (1839-1920)

(14). After attending the local Volkschule and Gymnasium, Pfaundler entered the University of Innsbruck in 1857, where he studied organic chemistry under Professor Heinrich Hlasiwetz, while also attending lectures in physics and mathematics. In 1859 his university studies were interrupted by military service in the Austro-Sardinian War, also known as the Second War of Italian Independence, followed in 1861 by a semester in Liebig's laboratory at the University of Munich and receipt of a doctorate from the University of Innsbruck.

Following three years as an assistant in Hlasiwetz's laboratory, Pfaundler, spent the years 1864-1865 in Paris studying physical chemistry, where he worked in the laboratories of Wurtz and Regnault, and also attended lectures by Deville and Berthelot. In 1866 he became a Privatdozent in physical chemistry at Innsbruck, though once again his academic career was interrupted by military service, this time in the Third War of Italian Independence of 1866. The following year he was appointed as Professor of Physics at Innsbruck. Here he remained until 1891, when he succeeded Ludwig Boltzmann as Professor of Physics at the University of Graz. In 1910 he became Professor Emeritus at Graz and was also ennobled by the Emperor, receiving the title of Pfaundler von Hadermur. He died in Graz on 16 May 1920 at age 81.

Pfaundler's fame as a chemist rests on a paper he published in 1867 in which he was the first to apply the newly emerging kinetic theory of gases to chemical equilibrium and reaction kinetics. In the course of this paper he also postulated the formation of a transient but critical collision complex between the various reactants which anticipated our modern concept of an activated complex.

Pfaunder had many interests besides chemistry. He had a significant reputation as a photographer of alpine scenery, was an early enthusiast of the Japanese game of *Go*, and an advocate of a simplified universal language called *Ido*. In 1902 he published a lengthy article in the *Deutsche Revue* entitled, in translation, "The World Economy in the Light of Physics," in which he made the first reasonable estimates of the carrying capacity of the earth (15).

Carrying capacity refers to the maximum population that a given geographical area can support and must take into account the nutritional energy requirements per human, and the total free energy flow available to the region in question, whether for agricultural or industrial purposes. Attempting to apply these criteria to the planet as a whole also requires estimating what percentage of the land area is suitable for food production, and the average agricultural output per capita with and without extraneous energy supplements, such as tractors, fertilizers, etc.

Pfaundler was not the first to estimate the earth's carrying capacity, but he was among the first to base his estimate on an energy analysis. He concluded that land suitable for food production could support an average of five people per hectare, thus establishing a lower limit of 11 billion people for the sustainable carrying capacity of the entire planet. Estimates made since Pfaundler have varied widely, some being lower and others higher than his estimate (16). As of 2016 the current world population stands at 7.5 billion.

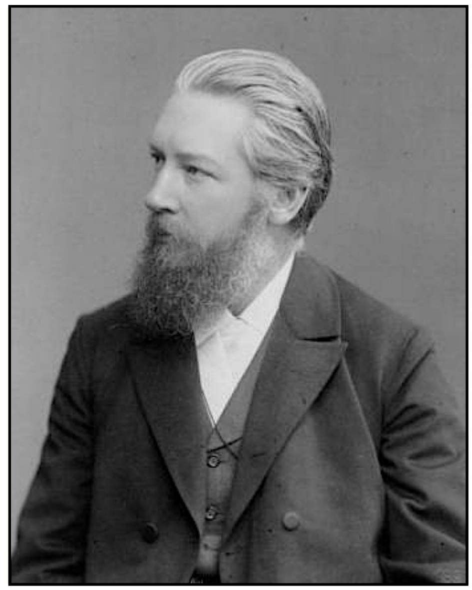
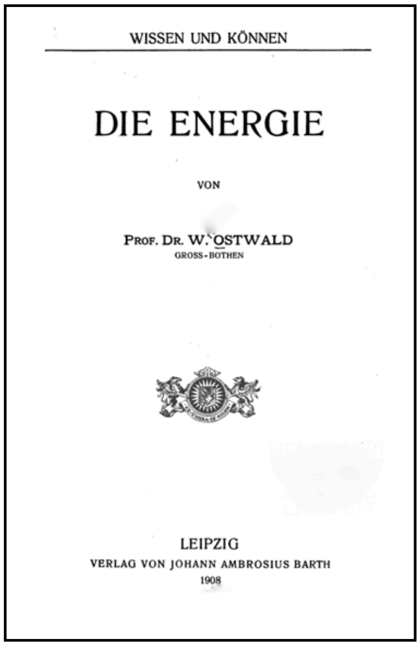


Figure 9. Wilhelm Ostwald
(1853-1932)

No. 4. Wilhelm Ostwald on Energy and Culture

Friedrich Wilhelm Ostwald (figure 9) was born on 02 September 1853 in Riga, Latvia, the second of three sons of Gottfried Ostwald, a master-cooper, and Elisabeth Leuckel (17). Both parents were native Germans. His chemical training was obtained at the University of Dorpat (now Tartu) in Estonia, from which he received his doctorate degree in 1878 for work done under the supervision of Carl Schmidt.

Ostwald served as Professor of Chemistry at the Riga Polytechnicum until 1887, when he was appointed Professor of Physical Chemistry at the University of Leipzig, where he remained until his early retirement in 1906 at age 53. This move to Germany was due not only to recognition of his published research record but also to his monumental multivolume treatise, *Lehrbuch der allgemeine Chemie*, published between 1885 and 1887, and his founding, with van't Hoff as coeditor, of the *Zeitschrift für physikalische*


WISSEN UND KÖNNEN

DIE ENERGIE

VON

PROF. DR. W. OSTWALD
GROSS-BOTHEN

LEIPZIG
VERLAG VON JOHANN AMBROSIUS BARTH
1908

Figure 10. The title page of Ostwald's 1908 popular account of energy and its uses.

Chemie in 1887. For these reasons Ostwald is widely regarded by historians of chemistry as the founding father of the modern discipline of physical chemistry.

In 1909 Ostwald was awarded the Nobel Prize in Chemistry for his work on the theory of catalysis in which he clearly differentiated between the kinetic and thermodynamic aspects of chemical reactions. His name is also associated with the "Ostwald Process" for the catalytic oxidation of ammonia to nitric acid, which would later play a key role in the development of the Haber-Bosch process for nitrogen fixation. In retirement he became involved in several movements dedicated to the scientific reorganization of science and society, as well as doing fundamental work on the classification of colors.

A prolific writer, it has been estimated that, during the course of his life, Ostwald authored 45 books, 500 articles, 5000 book reviews, and 10,000 letters. Though his early textbooks on chemistry were quite popular and were widely translated, his later writings on philosophical and social issues are available only in German. He died on 04 April 1932 in Leipzig at age 78.

Early in his career Ostwald became aware of the importance of thermodynamics, which he eventually generalized into what he called the science of "energetics." Initially this was applied to purely chemical questions and an attempt to displace the atomic theory, which Ostwald considered as unsubstantiated speculation, with a purely phenomenological chemistry based on the phase rule. After his retirement, however, he began broadening the scope of its application to include the subjects of psychology and sociology.

In 1908 he published a popular book on energy (figure 10) and its various applications for the general public in which he included brief chapters on energy and psychology and energy and sociology (18). The next year he expanded upon the latter subject in a booklet (figure 11) entitled, in translation, *The Energetic Foundations of the Science of Culture* (19). Ostwald used the word "culture" to denote the sum of all activities, however mundane, that occurred within a given society and not just *haute culture,* such as the creation of famous oil paintings or great operas. The majority of these activities were, in his opinion, shaped by the available energy flows accessible to society and were, in many cases, designed, either consciously or unconsciously, to help maintain that flow.

He also illustrated his argument by briefly sketching the historical evolution of various societies as they gained access to ever greater amounts of available energy flow and learned how to both control and modify those flows. Thus, beginning with the primitive club, and proceeding through such devices as the spear, knife, and bow and arrow, primitive mankind learned how to redirect and concentrate muscle power. This was followed by the discovery of how to control fire, the use of draft animals, human slaves, wind and water power and, finally in the 18th century, by the invention of the steam engine which allowed mankind to tap the earth's reserves of fossil fuels.

Every increase in available energy flow stimu-


Philosophisch-soziologische Bücherei
Band XVI

Energetische Grundlagen der Kulturwissenschaft

Von

WILHELM OSTWALD

Leipzig 1909 • Verlag von
Dr. Werner Klinkhardt

Figure 11. The title page of Ostwald's 1909 booklet on energetic foundations of sociology.

lated a corresponding increase in human population and led, in turn, to ever larger and more complex societies. Referring to the unidirectional flow of energy, postulated by the second law of thermodynamics, from high potential available energy into isothermal waste energy, the American science writer, Edwin Slossen, rather aptly summarized Ostwald's major premise with the catchy phrase:

The rise of civilization is coupled to the fall of energy.

Ostwald was rather appalled at the low efficiency of most known means for capturing and interconverting various forms of energy. Thus green plants utilize between only 0.1% and 2% of the incoming solar energy and steam engines between only 5% and 25% of the thermal energy generated in their boilers. The rest was allowed to degrade into unused isothermal waste heat. Rather he hoped that the future would bring the development of highly efficient photovoltaic cells that would allow mankind to tap the incoming light of the sun at high efficiencies and thereby free civilization from its dependency on finite fossil fuels and inefficient heat engines.

In keeping with this, Ostwald soon came to believe that the superiority of any given society was a function of the efficiency of its energy conversion devices, an idea that he extended not just to a society's existing energy technology but also to many other realms of social activity (18):

The economic coefficient [i.e. efficiency] of energy transformation is thus, finally, the general yardstick against which all human affairs should be measured.

Thus, for example, he was an advocate, like Pfaundler, of an auxiliary universal language, since he believed that the necessity of translating books and papers from one language to another was an unnecessary waste of energy, and, for the same reason, he advocated the elimination of Latin and Greek from the school curriculum.

Indeed, in later writings, this obsession with the efficient use of energy led Ostwald to formulate – in imitation of Kant's "categorical imperative" in the field of ethics – what he referred to as the "energetic imperative." This read (20):

Vergeude kein energie, verwerte sie.

which translates as "waste no energy, utilize it." Later writers have renamed this the "thermodynamic imperative."

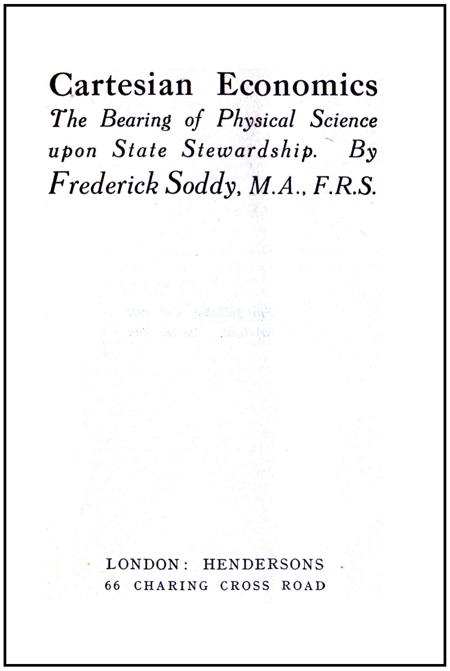
As some of Oswald's critics were quick to point out, many of his ideas on energy and culture were sketched out in very general terms and often failed to provide supporting details and data. In the case of sociology, in particular, it was not until 1955 that this detail was finally provided in the form of the classic textbook, *Energy and Society*, by the American sociologist Fred Cottrell (21).

Figure 12. Frederick Soddy
(1877-1956)

No. 5. Frederick Soddy on Energy and Economics

Frederick Soddy was born on 02 September 1877 in Eastbourne, England, the youngest of four sons of Benjamin Soddy, a corn merchant, and Hannah Green (22). His chemical training was obtained at University College of Wales in Aberystwyth and at Oxford University. In 1900, after two years of postgraduate research at Oxford, Soddy was appointed as a Demonstrator in Chemistry at McGill University in Canada, where he collaborated with the newly appointed Professor of Physics, Ernest Rutherford, in establishing that radioactivity was the result of the transmutation of one element into another – work that would lead to a Nobel Prize for Rutherford in 1908.

On returning to England in 1902, Soddy entered into a collaboration with Sir William Ramsay that demonstrated that helium was a by-product of certain kinds of radioactive decay. In 1904 he was appointed Lecturer in Physical Chemistry and Radioactivity at the University of Glasgow, where he and his students mapped the radioactive decay series for alpha particle emission, discovered the element protactinium, and formulated the concept of isotopes, for which Soddy was given the 1921 Nobel Prize in Chemistry. In 1914



Cartesian Economics
The Bearing of Physical Science upon State Stewardship. By
Frederick Soddy, M.A., F.R.S.

LONDON: HENDERSONS
66 CHARING CROSS ROAD

Figure 13. The title page of Soddy's 1922 booklet on energy and economics.

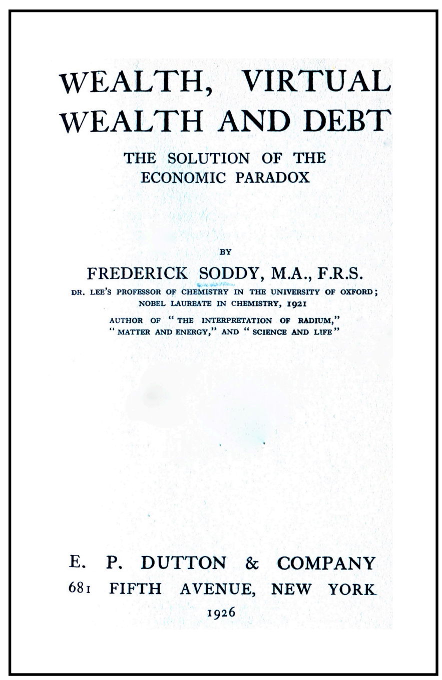
he was appointed Professor of Chemistry at the University of Aberdeen, and in 1919 as Lee's Professor of Chemistry at Oxford, where he remained until his early retirement in 1937 at age 60. He died on 22 September 1956 in Brighton, England, at age 79.

In 1912 Soddy published a small popular book entitled *Matter and Energy* in which he outlined the importance of energy for society, warned of the prospect of a future energy crisis if we continued to be dependent on fossil fuels, and broadly hinted at the future possibility of the practical application of nuclear energy (23). A decade later, heavily influenced by World War I and the subsequent economic depression in Great Britain, Soddy began to turn his thoughts to the relationship between energy and economics, and especially to the relationship between energy and money. The result was a small booklet published in 1922, entitled *Cartesian Economics* (figure 13) (24), followed by a major book four years later, entitled *Wealth, Virtual Wealth, and Debt* (figure 14) (25). Yet a third book was published in 1933 (26), as well as several more pamphlets on the same subject.

In these writings Soddy argued that science had shown that the basis of economic prosperity was available energy flow, whether renewable energy from the sun or nonrenewable energy from fossil fuel deposits. When we purchased food or various goods and services, we were exchanging money for something that required the consumption of a certain quantity of available energy to produce, and this suggested, in the most abstract terms, that money was simply a symbolic token exchanged for a certain quantity of available energy. In short, available energy flowed through the economy unidirectionally as it was degraded from its initial high potential input sources into useless isothermal waste heat, while money circulated continuously as a counterflow in the opposite direction.

This suggested to Soddy that the amount of money in the economy should be regulated so as to vary with the available energy flow, thereby keeping its purchasing power as constant as possible and thus avoiding alike both potential inflation (too much money per unit of available energy flow) and potential depression (too little money per unit of available energy flow). This would require some type of national or international organization to monitor energy use and adjust the currency accordingly.

However, instead of this, Soddy found that bankers, governments, and economists had artificially tied the value of money, not to energy flow, but to meaningless material standards, such as the gold standard, and were constantly manipulating the money flow without regard to energy flow in an attempt to create wealth where none existed through such paper creations as loans, the issuing of interest bearing bonds, etc. This they referred to as the creation of wealth, when in fact it was the creation of debt, since it did nothing to stimulate increased energy flow, which was



WEALTH, VIRTUAL WEALTH AND DEBT
THE SOLUTION OF THE ECONOMIC PARADOX

BY
FREDERICK SODDY, M.A., F.R.S.
DR. LEE'S PROFESSOR OF CHEMISTRY IN THE UNIVERSITY OF OXFORD; NOBEL LAUREATE IN CHEMISTRY, 1921
AUTHOR OF "THE INTERPRETATION OF RADIUM," "MATTER AND ENERGY," AND "SCIENCE AND LIFE"

E. P. DUTTON & COMPANY
681 FIFTH AVENUE, NEW YORK
1926

Figure 14. The title page of Soddy's 1926 book on energy and economics.

Figure 15. Alfred J. Lotka
(1880-1949)

the only true source of wealth. Soddy was particularly opposed to the concept of compound interest which he viewed as a perpetual and undeserved drain upon society's future energy resources.

During his lifetime Soddy's views on economics were met with derision and he was dismissed as a crank by most economists. At present many of his views have been accepted, often without acknowledgement, and they have now been incorporated into a school of economic thought known by its followers as "ecological economics" (27).

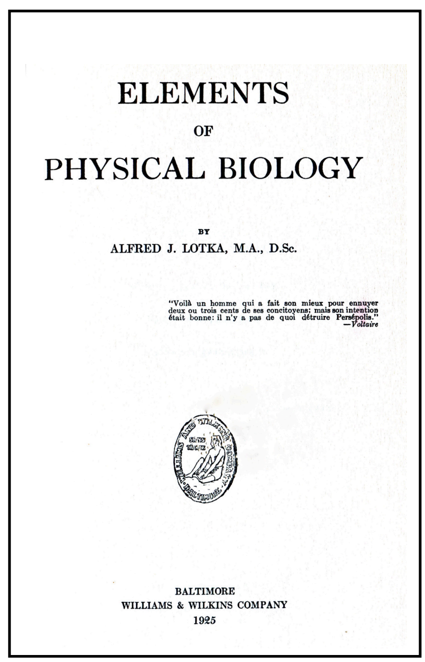
No. 6. Alfred Lotka on the World Engine

Alfred J. Lotka (figure 15) was born on 02 March 1880 in Lemburg, Austria (now Lvov, Ukraine), the son of Jacques Lotka and Marie Dobeley (28). Both parents were American citizens. Educated in Europe, he received his chemical training at the University of Birmingham, followed by a year of postgraduate study in Leipzig, where he was heavily influenced by Ostwald's program in energetics.

Returning to the United States in 1903, Lotka would hold a bewildering variety of jobs over the next two decades, including work as an industrial chemist, a patent examiner, a physicist with the US Bureau of Standards, an assistant editor at *Scientific American*, and a research fellow at Johns Hopkins. During this period he published numerous articles on the application of energetics and statistics to problems in physical chemistry, biology, evolution, and demographics, as well as picking up both a MS degree from Cornell University and an external doctoral degree from the University of Birmingham based on his published papers. Finally, in 1924, he obtained a position as a statistician for the Metropolitan Life Insurance Company, where he would remain until his retirement in 1947. He would die on 05 December 1949 in New York City at age 69.

In 1925 Lotka published his magnum opus, *Elements of Physical Biology* (figure 16) (29). In many ways this was a poor choice of title and something along the lines of *Ecological and Evolutionary Energetics* would have been closer to the mark. In this book Lotka attempted to trace the unidirectional flow of energy through the ecosystem and the various material cycles that it drove, such as the recirculation of water, carbon dioxide, nitrogen and phosphorus. But his central focus was the role of energy as a driving force in evolution. Adopting Boltzmann's observation that the struggle for existence was the struggle for free energy, Lotka arrived at what he called the "Law of Maximum Energy Flux," which stated that any species able to tap those portions of the available energy flux in nature that were currently wasted would not only have a reproductive and evolutionary advantage but would also accelerate the rate of available energy flow (29):

The general effect will be to increase the rate of energy flux through the system of organic nature, with a parallel increase in the total mass of the great world



ELEMENTS
OF
PHYSICAL BIOLOGY

BY
ALFRED J. LOTKA, M.A., D.Sc.

"Voilà un homme qui a fait son mieux pour ennuyer deux ou trois cents de ses concitoyens; mais son intention était bonne: il n'y a pas de quoi détruire Persépolis."
—*Voltaire*

BALTIMORE
WILLIAMS & WILKINS COMPANY
1925

Figure 16. The title page of Lotka's 1925 book on energy flow in biology and ecology.

transformer, of its rate of circulation, or both ... one is tempted to see in this one of those maximum laws which are so commonly found to be apt expressions of the course of nature.

The most obvious example of such as species was mankind itself, which, via its many technological advances, had tapped virtually all of Nature's available energy sources and whose ever-increasing population and demand for land was gradually pushing many other species to the edge of extinction.

Lotka's book would greatly influence the American ecologist, Howard T. Odum, who would write numerous books on energy and ecology in the 1970s based on the energy flow or flux concepts of Soddy and Lotka and heavily illustrated with explicit flow diagrams and a complex symbolism inspired by that used for electronic circuits (3, 30).

Summary

In summary, we see that significant contributions to the questions of energy use, population growth, and the energetics of ecology were made by chemists in the late 19th and early 20th century. Jevons was the first to detail the future consequences of fossil fuel depletion and to link it with the problem of unchecked population growth. Arrhenius was the first to establish a link between the carbon dioxide content of the atmosphere and the surface temperature of the earth. Pfaundler was among the first to apply an energy analysis to the problem of estimating the carrying capacity of the earth. Ostwald was the first to suggest that available energy was a determining factor in both the historical development and structure of human societies. Soddy was the the first to suggest that the realities of energy use required a significant reform of our economic system, and Lotka the first to attempt to comprehensively map its role in both biological evolution and the ecosystem.

Missing from these early contributions is any consideration of the problems of pollution, which seem to have first surfaced as a major public issue in the 1960s and 1970s. However, if one extends their historical survey forward to cover this period, it is once again easy enough to find significant contributions by chemists to this question, such as those of Mario Molina and F. Sherwood Rowland in uncovering the role of chlorofluorocarbons in ozone depletion (31).

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