Rachel Carson Center Perspectives

How to cite:

Zachmann, Karin. "Energy Regimes, Foodways, and the Efficiency of the Human Engine." In: "Energy Transitions in History," edited by Richard W. Unger, *RCC Perspectives* 2013, no. 2, 59–67.

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Rachel Carson Center for Environment and Society
Leopoldstrasse 11a, 80802 Munich, GERMANY

ISSN 2190-8087

SPONSORED BY THE

Federal Ministry of Education and Research

Deutsches Museum

LMU Ludwig-Maximilians-Universität München

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Energy Regimes, Foodways, and the Efficiency of the Human Engine

This essay explores connections between energy regime changes and nutrition, as well as the impact of such changes on nutritional knowledge and food policies in the nineteenth and twentieth centuries. At the core of this second part is the thermodynamic revolution, which led to a new conception of the human body and thus a new paradigm of nutritional physiology. Whereas nutrients had previously been viewed in a hierarchy, with some more important than others, the new paradigm considered them interchangeable based on the first law of thermodynamics (heat and energy are equivalent and neither lost nor gained within a system). In the latter part of the twentieth century, with the advent of the information age, a new concept of nutrition emerged, with information instead of energy being seen as critical for understanding the physiology of nutrition. While these concepts shaped food policies, they did not necessarily change production policies; practice did not align with theory. Instead, since the mid-nineteenth century, the hierarchy of nutrients concept (with protein at the top) has been enthroned while the development of industrialized livestock production has decisively reoriented Western foodways towards a diet centered on animal calories. This misalignment of theory and practice indicates how energy regimes, the state of food and nutrition, and strategies of production and consumption in food and agriculture are interconnected in manifold but not always straightforward ways.

Food is the most important fuel for the human body. In traditional energy regimes it is the main source of power. Humans can use their energy output to master other forms of energy. The more successfully they do so, the more they control their environment and achieve goals not strictly related to animal existence.

For most of human history, humans relied on wild plants and on animals that had converted solar energy into carbohydrates, lipids, and proteins, and thus into chemical energy that served as fuel for the human body. The range of human activity was limited by the resources that happened to be available in nature. They could live only where their needs did not surpass nature's reproductive capacity. To overcome this, humans had to learn how to control and increase the supply of plants and animals or had to discover new sources of energy. These two problems were solved by the Agricultural and the Industrial Revolutions respectively.

The Agricultural Revolution was the process whereby humans learned to control, increase, and improve the supply of plants and animals at their disposal. Paradoxically, with the transition from the hunter-gatherer society to an agrarian society, the nutritional condition of humans deteriorated, as revealed in decreased body heights (Sieferle 1997, 73–4). As humans developed greater control over their food supply, the population density increased because a given area of land could provide food for more people. At the same time, however, the quality of the food deteriorated. There was a decrease in meat, in the percentage of fresh foods over stored, preserved, and processed foods, and in variety. There were also frequent shortages of proteins, vitamins, and minerals. However, a return to the nutritionally richer hunter-gatherer society was impossible, because agrarian society led to population growth.

Part of the development of societies was the establishment of foodways. The term was coined by anthropologists, who define foodways as "a culture's primary form of nutritional sustenance. … Each foodway relies upon one particular food source as the foundation for one's meal. For the Japanese it is rice, for the Mexicans it is maize, for large parts of Africa it is yam, for the Masai of East Africa it is blood drained from the vein of cattle and for the Americans it is meat" (Willard 2002, 116). For Europeans it was grain.

The cultural dimension of foodways becomes obvious in local cuisines. Through the selection, preparation, and cooking of food, a cuisine transforms nutritional raw materials from a natural to a cultural state. Food chains, foodways, and cuisines are closely connected. For centuries, food chains were organized on a predominantly regional basis so that the geographical and climatic context in which people lived as well as their regional culture determined their foodways. Imported food products, such as spices, sugar cane, coffee, or cocoa, remained luxury goods until the eve of the Industrial Revolution and thus did not challenge the regional determination of foodways—as long as the foreign products did not become domestic products.

Despite their efficiency in producing food, agrarian societies remained societies of scarcity as their energy supply depended on the fiercely contested availability and usage of space. Space was necessary to create food energy from fields, to grow fodder for the draft animals that provided mechanical energy, and to grow forests for thermal energy. Intensifying the usage of space was the main way to increase the supply of energy. Fostering innovations in agriculture and forestry was a central concern for early modern states. That their success remained limited is obvious, since our early modern ancestors experienced famines several times within the course of their lives.

The Industrial Revolution went hand in hand with the transition to the fossil fuel energy regime. The new energy regime gave rise to new technologies that enabled mankind to harness energy sources that had been unattainable before. The great transformation in social and economic organization, however, was not accompanied by equally significant improvements in living conditions. On the contrary, economic historians observed common people's declining biological standard of living in both Europe and North America. In the century of the great transition Robert Fogel observed "decades of sharp decline in height and life expectancy, some of which occurred during eras of undeniably vigorous economic growth" (Fogel 2004, 29).

Thus, early industrialization was characterized by a restricted food supply. The lowest strata of society had been too weak for work. "At the end of the eighteenth century British agriculture, even when supplemented by imports, was simply not productive enough to provide more than 80 percent of the potential labor force with enough calories to sustain regular manual labour. . . . Begging and homelessness were reduced to exceedingly low levels, by nineteenth century standards, only when the bottom fifth of the population acquired enough calories to permit regular work" (Fogel 2004, 42).

It is in this stage of transition, when the availability of new power sources suddenly increased the scope of human activities but potential manpower suffered from an insufficient energy input, that national food supplies and the efficiency of diets became subjects of scientific concern.

With the spread of steam engines, the shackles of the traditional energy regime loosened. The diffusion of steam power evoked hopes of an age of unlimited growth and progress. The observation that it was heat that enabled the working of machines transformed the steam engine into a model for everything. Using the steam engine as an analogy of the universe meant advancing the principles of thermodynamics as the basic framework to understand the workings of the natural as well as the man-made world. An important breakthrough toward this goal was fostered by the simultaneous yet independent measuring of the mechanical equivalent of heat (Joule's equivalent) by the German doctor Robert Mayer and the British brewer and gentleman of science

James Prescott Joule. This measure allowed a quantitative understanding of the relations between natural forces. Concretely, this equivalence made it possible to compare energy transformations in machines as well as in organic and inorganic nature (Neswald 2006, 133). Nutritional physiologists' preoccupations became closely connected to the world of engineers.

Robert Mayer's main interest was in explaining the metabolism of animals. Equipped with the mechanical equivalent of heat and with the law of conservation of energy, Mayer was the first to replace the chemical concept of metabolism with a thermodynamic one. The chemical theory of metabolism explained the motion of muscles as the combustion of muscle material. Thus, every motion of the muscles destroyed their own substance, which then had to be regenerated by vital forces. Robert Mayer argued against this idea as early as 1845, stating that, like steam engines, muscles obtain their fuel from the outside. Thus both the muscle and the steam engine were perceived as machines that transform chemical energy into heat and mechanical energy—that is, into work (Neswald 2006, 133–43).

The concept of metabolism as a transformation of forms of energy did not gain ground until the last third of the nineteenth century. Until then, a chemical understanding of metabolism prevailed, based on a biochemical concept of food as a compound of three nutrients: carbohydrates, lipids, and proteins. The German chemist Justus Liebig was one of the most famous advocates of a chemical understanding of metabolism. Based on his explorations of meat, Liebig determined a hierarchy of nutrients with proteins at the top. His student Pettenkofer, together with an entrepreneurial engineer, put the concept into practice, establishing the Liebig Meat Extract Company in Uruguay. The hierarchically framed nutrient paradigm, however, threatened political stability because it required increasing the percentage of meat in working class diets. Since meat was the most expensive foodstuff, championing the chemical paradigm as the foundation of food politics would have aggravated the already tense and conflict-ridden social situation in the early to mid-nineteenth century (Tanner 1999, 89-120).

In contrast to the chemical concept (which was partly replaced rather than abandoned), the thermodynamic interpretation of metabolism provided ideas for the improvement of diets without challenging the social system. According to the thermodynamic paradigm, it was not the nutritional but the caloric content of foods that determined the quality of diets. Thus, food improvement was achieved by balancing calories and costs within available budgets. To reach this conclusion, nutritional physiologists had further refined the comparison of the human body to the steam engine. In the 1860s, this equation was already common knowledge in physiology. Adolf Fick, a German physiologist, actually spelled out the equation in his *Compendium der Physiologie des Menschen mit Einschluss der Entwicklungsgeschichte* (1860). He argued that it made perfect sense to compare the energy principles of the body with those of the steam engine (Neswald 2006, 363).

Displaying a similar mindset to that of the engineers who strove to improve the efficiency of the steam engine, physiologists tackled the task of how to increase the efficiency of the human engine. Two fields of physiology emerged: ergonomics dealt with the output of human engines and thus with the capacity of bodies to do work, as well as with the most appropriate or efficient application, while nutritional sciences studied the input of the human engine in order to determine the caloric content and the combustion efficiency of food.

To determine the efficiency of the human engine, physiologists had to consider how much food/fuel the human engine required for work and for its basal metabolic rate. And they had to find out what kind of food provided the best combustion economy. This was meant to increase a nation's work capacity—and therefore economic growth—as well as to diminish an entropic waste of energy in food. Both were crucial aspects at the end of the nineteenth century, since the law of entropy fuelled nations' fears that they would struggle to survive within the increasingly fierce competition among imperial powers. In parallel, serious conflicts were triggered by the question of how to distribute the wealth of societies more fairly. Thus, the provision of food and improvement of diet ranked high on the political agenda in Germany.

Fully aware of the increasing importance of food and nutrition politically and socially, the influential nutritional scientist Max Rubner positioned and advanced the science of nutritional physiology (*Volksernährungslehre*) as part of social hygiene. He rooted nutritional physiology in the thermodynamic paradigm. The core aim of his nutrition program was to determine the relative caloric value or the specific dynamic effect of various foods. Just as the power and efficiency of the steam engine depended on the quality of the coal burned, physiologists assumed that there was an optimal fuel for the human engine. Rubner conducted experiments to explore the effect of staple foods on the production of heat. High-protein food produced the most heat, which Rubner interpreted as the result of digestion. Therefore, the chemical caloric value did not correspond to the organism's energetic use value because bodies need to invest various amounts of energy to digest different foods. As the effort linked to protein digestion was especially high, Rubner concluded that meat was not an especially efficient food. Meat could be useful to stimulate the unstable digestion of intellectuals but the optimal fuel for manual workers was the potato. Therefore, Rubner categorically fought against the "meat cult" that was prominent at the turn of the twentieth century (Neswald 2006, 373f).

This "meat cult" was not just a cultural attitude; it corresponded to changed consumption patterns. Industrial meat production took off in the second half of the nineteenth century when fossil-fuelled transport systems began to restructure the world food market. New methods of livestock production and highly mechanized slaughterhouses changed the systems of meat provision and led to a gradual but noticeable increase in meat consumption. This increase was interrupted by both world wars but meat consumption accelerated after each war and resulted in a new foodway during the second half of the twentieth century. This foodway was and is characterized by a dominance of animal calories and processed food. As was already the case at the turn of the last century, meat consumption is criticized today. Now, though, the argument is different. Today, industrial livestock production is perceived as the second biggest cause of climate change (surpassed only by the energy consumption of buildings) because of its low land use efficiency and the high emission of greenhouse gases. At the turn of the last century, however, the polemic against meat was not concerned with the overall energy efficiency of meat production but with the efficiency of its digestion in the human engine. The thermodynamic school of nutrition criticized meat as an inefficient and even dangerous food but could not stop meat producers from conquering a food market based on the transition towards a high-energy agriculture. The meat producers in turn could justify their activities by appealing to the long lasting belief in the hierarchy of nutrients.

Although the thermodynamic paradigm of nutrition did not replace the nutrients or chemical paradigm entirely, the energetic concept dominated food issues well into the second half of the twentieth century. This concept was based on the first law of thermodynamics: the conservation and transformation of energy. The idea reduced the value of food to caloric content and asserted the material interchangeability of foodstuffs. The energetic concept was also informed by the second thermodynamic principle of entropy, which increased popular awareness of energy loss in the process of digestion. As the thermodynamic paradigm aimed at the efficiency of the human engine, it was most appropriate for economies of scarcity.

The war economies of the twentieth century fostered the application of the human engine concept with regard to food rationing. National Socialism took a pioneering role when it established a rationing system that defined caloric needs with regard to bodily work requirements, gender, and age. The League of Nations distinguished this "German-Type-Rationing" from an "Anglo-American Type," which based wartime food rationing on social criteria.

Nazi Germany not only based its wartime food rationing system on the concept of the human engine but also used it as an instrument of the racist policy of annihilation through hunger. Nutritional physiologists contributed to this policy with large-scale experiments that sought to determine the minimal rations needed to keep the concentration camp inmates and forced-labor workforce deployable (Heim 2003).

From the 1950s, in all developed countries, material conditions and scientific concepts of nutrition changed. The food sector rapidly expanded after the years of scarcity during the war and the transition to an era of mass consumption started with a widespread desire for overeating. The new regime was called the gluttony or binge wave. Agriculture boosted these new eating habits as it experienced a tremendous productivity increase. In Germany, the number of people one farmer could feed increased from 10 in 1949 to 133 in 2006. According to Vaclav Smil, the average energy inputs per cultivated hectare increased more than eighty-fold between 1900 and 1990, with the most dramatic increase taking place in the second half of the twentieth century (Smil 1994, image 191). Simultaneous with the increase in food supply due to enormous productivity gains, the food needs in rich countries changed due to a restructuring of work requirements. As machines took on more of the physically demanding work, calorie requirements for laborers decreased. The most pressing nutritional problems thus became overeating or unbalanced diets. In this context, the thermodynamic paradigm of nutrition, which was based on the concept of the human engine, became obsolete. It was replaced by a cybernetic body concept that focused not on the energetic content of nutrients but on the effects of active ingredients in food such as vitamins, trace elements, and special acids or enzymes. Like information effect feedback and adaption in systems, micronutrients influence the processing of food in the human body. The effects of micronutrients become visible when they are lacking, as in the case of scurvy, pellagra, or rickets. The gradual replacement of the thermodynamic concept of nutrition was a product of new knowledge of genetics and reproduction. The new understanding of vitamins as so-called micronutrients fostered the spread of the cybernetic body concept in nutritional physiology.

The demise of the thermodynamic concept of nutrition at the beginning of the second half of the twentieth century thus reveals the complex relationship between energy regimes, foodways, and concepts of food and nutrition. With the suddenly rising supply of crude oil and natural gas and new, politically-motivated consumption regimes, energy consumption took a remarkable leap. Pfister (1996) described it as the "1950s syndrome." This change was also felt in agriculture and the provision of food, with rising energy inputs in food production and, in its wake, a growing supply of high-energy food, especially animal protein. In this context, the foodways of the Western world changed, as meat gradually became the new staple food. With an abundant energy supply at hand for physiological needs, however, nutritionists initially lost interest in the energy content of foods. The consequences of these developments can be observed in rising body height and increased longevity but also in the remarkable growth of the body mass index of Western populations.

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