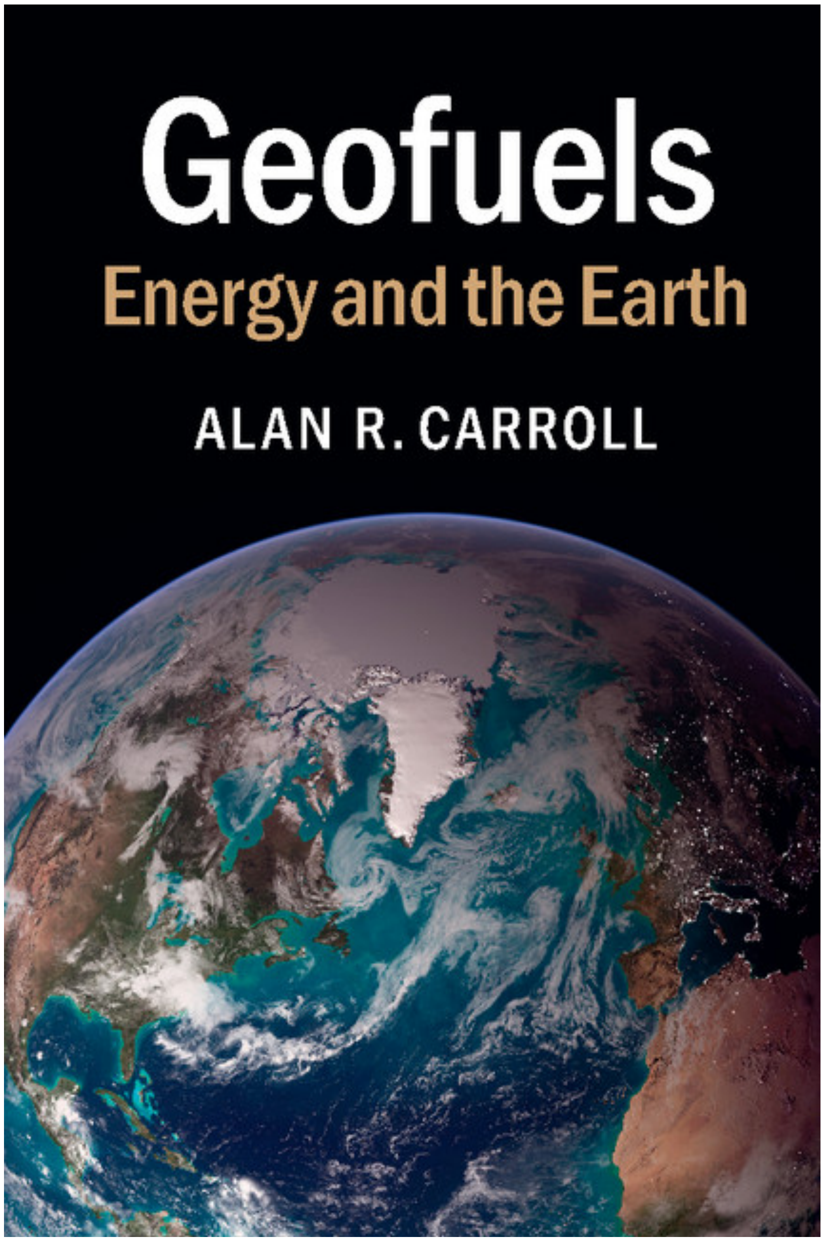
Introduction – excerpts from "Geofuels: Energy and the Earth" by Alan Carroll



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Energy and the Earth

Save the Planet! This slogan has been often repeated, and with good reason. The world we live on seems to be under heavy assault on numerous fronts, ranging from biological extinctions to potential shortages of key natural resources. Energy use and its consequences currently rank among the most pressing of these concerns, and not surprisingly are among the most hotly debated and divisive issues of the day. Our use of fossil fuels lies at the heart of the debate, largely because fossil fuels supply the vast majority of our current energy use (~86 percent in the United States). It has also become increasingly clear that emissions from the burning of fossil fuels are altering the composition of the atmosphere, carrying the potential for catastrophic climate change.

So how did we get to this point? We live in a world made possible by the use of fossil fuels, but it was not always so. Prior to the 19th century virtually all energy was “green” energy, mostly derived from standing biomass in the form of agricultural crops and native vegetation. This biomass could be burned directly for warmth or fed to animals and humans to produce mechanical power (the horse still represents the reference point for some power measurements today!). Most people worked in the fields, went to sleep when it got dark, and rarely traveled far from their homes. This lifestyle may have been dull, but the boredom generally did not last very long. Average life expectancy at birth was far lower than today, estimated at forty years or less. Famine and pestilence were ever-present threats, and few means were available to combat them.

Dramatic change began with the Industrial Revolution, during the late eighteenth to early nineteenth centuries. The initial rise of machines was powered largely by coal, which fueled steam engines. The origins of the Industrial Revolution are undoubtedly complex, but it clearly occurred most rapidly in countries possessing rich supplies of coal (most notably Britain, Germany, and the United States). Coal conveys significant advantages over earlier biomass fuels: It has a higher energy density, its availability is not limited by arable land surface area or growing season, and it can be mined relatively cheaply. The technology originally built around coal was also responsible for the large-scale commercialization of crude oil; for example, a steam engine was used to drill the first modern oil well in the United States (operated by Edwin Drake in Titusville, Pennsylvania, 1859). Although oil and natural gas have since taken over much of the position once occupied by coal, coal-fired steam turbines continue to supply a major share of our electricity.

Today we tend to take for granted that we will always be warm and well fed. We enjoy the luxury of free time, because most farmwork and other heavy labor is done using machines. We barely think about the ease of traveling tens or hundreds of miles by automobile and cannot easily imagine living without this ability. Average people can safely and cheaply travel to another continent for a week's vacation. The same journey would have cost their not-so-distant ancestors many months in travel time, a large part (if not all) of their wealth, and possibly even their lives. Average life expectancy in the United States nearly doubled during the 20th century, and world population nearly quadrupled. These increases were unprecedented in human history, and coincided with a tenfold increase in gross domestic product per capita in industrialized countries. During the same period the use of fossil fuels increased by a factor of nearly 8. To a large extent these recent transformations were all powered by the unprecedented bounty of fossil fuels.

It is highly doubtful that most people would want to return to the living conditions of the 18th century, even it were possible for the current population to do so. We are therefore confronted with a very challenging problem: How can we sustain the historically unprecedented level of energy consumption of the past century and thereby continue to enjoy its benefits? Equally important, how can we extend these same benefits to the billions of people who presently consume energy at a far lower rate than those in the United States and other highly developed countries? In the past few decades it has become apparent that the "energy problem" also encompasses another distinctly different but equally important question: how to avoid or remediate the unwanted consequences of large-scale energy use. Climate changes related to the burning of fossil fuels currently loom as the most serious example of the latter. However, it is only prudent to assume that any form of energy production will incur its own unique environmental costs, especially when scaled to the present magnitude of fossil fuel use.

Before we can even hope to conquer the energy problem we need to understand it better. The Earth itself can help in this regard. The past geological evolution of the Earth has directly influenced the present and future availability of *all* energy resources, in one way or another. This connection is obvious for fossil fuels, nuclear, and geothermal energy, all of which exploit the tremendous natural leverage of geologic time. In contrast, renewable systems rely solely on contemporary energy fluxes, which are very large in their own right. The evolution of the Earth has literally set the stage for their use, however, by shaping the geography of practical renewable energy. It has also predetermined the availability of nonrenewable Earth resources that are required to obtain renewable energy. This dependency on the geologic history of the Earth places intrinsic limitations on all energy systems. Note that these limitations are not static, but instead evolve continuously through time. Three overarching principles govern the changing relationships among humans, energy, and Earth resources, as described in the following sections.

Quality, not quantity

Our voracious energy appetite has stimulated spirited debate over the ultimate quantities available from different sources, motivated by concerns that supplies might eventually fall short of demand. In a gross sense this concern is misplaced, however. For example, the total amount of solar power reaching the Earth exceeds current human power consumption by a factor of more than 10,000. The total amount of energy stored in organic matter buried in the Earth's crust is on the order of five thousand times greater than the presently recognized magnitude of fossil fuels. Various other energy systems hold similarly mind-boggling surpluses. The Earth clearly has plenty of energy. What matters therefore is not quantity, but quality. Energy quality can be defined in many ways; in the present context it represents the relative potential for doing useful work, at a minimal cost.

Basic thermodynamic considerations dictate that highly concentrated energy sources can be exploited more efficiently than more diffuse ones and therefore represent higher quality. The primary reason that fossil fuels have proven so revolutionary is that they naturally concentrate sunlight, a diffuse resource. This process of natural concentration has occurred partly in time, through the accumulation of solar energy over many millions of years. It has also occurred in space, through the localized enrichment of combustible organic deposits. Other nonrenewable resources have experienced comparable processes of natural concentration. For example, minable uranium ores contain at least one part uranium per thousand by weight, a natural enrichment of 5 million times compared to uranium's average terrestrial abundance.

Geothermal energy developments have generally focused on areas where the temperature of near-surface rocks has been greatly increased by the localized ascent of hot magma.

Renewable energy resources also depend heavily on natural concentration. Hydroelectric dams provide perhaps the most striking example of this. They work by focusing the gravitational energy of precipitation falling across an enormous catchment area, into a single narrow river course. It is no accident that hydroelectric was the first large-scale renewable energy system to be developed, and it remains important today. Wind turbines also exploit natural concentration; they are most productive where near-surface winds naturally blow at velocities greater than average, such as ridge tops, unobstructed plains, or windy stretches of coastline.

Bioenergy represents something of a unique case in that it does not initially appear to benefit from any natural amplification; for example, the conversion of raw feedstocks into concentrated liquid fuel must be accomplished artificially in a refinery. However, the soils needed to grow those feedstocks contain nutrients that have been naturally concentrated over long periods, within a thin surface layer above their parent rocks. Artificial fertilizers needed to replace these nutrients result mostly from naturally concentrated, geologic deposits.

Naturally concentrated, high-quality energy resources represent only a tiny part of the Earth's total energy endowment, a principle commonly expressed through the metaphor of the resource pyramid. The volume of the pyramid represents the Earth's total endowment of a particular resource, whereas concentrated, high-quality resources are represented by the tip. Exponentially increasing amounts of energy can be had by digging deeper into the pyramid, but that energy is obtained at ever-increasing costs. The important question is not the size of the pyramid, but how far down we can afford to dig. We will run out of money long before we run out of energy.

This same basic logic applies equally well to both nonrenewable and renewable resources. For example, the magnitude of concentrated power that may be theoretically obtained from hydroelectric dams or wind turbines is a minuscule fraction of the total energy contained in raindrops or the wind. The useful potential of renewable energy depends on prevailing technology and on energy prices, but generally speaking the highest-quality, most naturally concentrated resources are among the first to be exploited. At some point the continued growth of renewable energy output will depend on exploiting lower-quality natural resources. Assuming no change in the underlying technology of these systems, the cost per unit of energy obtained might be expected to increase.

Technology changes reality

All predictions are by necessity rooted in present reality, for the simple reason that we cannot really know what the future. However, if the recent past is any guide we can be reasonably certain that the future will include change, and that new technologies will fundamentally alter our perception of the available energy resources.

Prior to the 1850s crude oil was largely a geological curiosity, used for such miscellaneous purposes as road paving, the formulation of patent medicines, or the caulking of wooden ships. Its potential value as an energy source was largely unknown, and known reserves of crude oil were practically nonexistent compared to those today. Since then the technologies for finding, extracting, refining, and utilizing crude oil and natural gas have advanced continuously. Our perceptions of the economic magnitude of these resources have grown apace. Most recently, the application of horizontal drilling and hydraulic fracturing has allowed us to extract large amounts of oil and gas from rocks that most geologists believed to be impervious to such efforts as recently as the 1990s. These efforts have created large new reserves of Cenothermic fossil fuels, which previously did not exist.

The idea of extracting energy from the nucleus of an atom would have been unthinkable prior to the very last years of the 19th century, and unworkable until the middle of the 20th. It has since become commonplace, and the main limitations on nuclear energy are now imposed by public policy and the availability of investment capital, rather than technology. Renewable energy technologies have also advanced markedly since the mid-18th century, primarily as an outgrowth of the invention and refinement of practical dynamos that can convert the motion of water and wind directly into electricity. The transformation of sunlight directly into electricity without the use of dynamos was impossible prior to the invention of the first practical solar photovoltaic cell, developed at Bell Labs in 1954. Solar collectors employing this technology are now cheaply available at any local hardware store, and the cost of manufacturing them continues to drop.

Similar innovations can reasonably be expected to continue in the future. Fossil fuel extraction technologies are evolving rapidly, and several different approaches to mitigating their atmospheric impact are also being explored. Technologies for solar collection and storage are also advancing rapidly, as is the quest for commercial biofuel production from celluosic feedstocks. Other known opportunities for advancement include biofuels produced using cellulosic feedstocks or algae, offshore wind development, expanded use of geothermal energy, and nuclear fusion. Technologies for transmitting, storing, and conserving energy are also improving. It is difficult to predict which innovations will bear the most fruit, but it seems inevitable that new energy supplies *will* be made available.

There is no free lunch

All potential energy sources present implicit trade-offs between the benefits they provide and their various environmental, financial, or social costs. This is perhaps most obvious for fossil fuels. Elevated atmospheric CO_2 concentration was first proposed to cause atmospheric warming by the geologist Thomas Crowder Chamberlin in 1899, in an effort to explain the coming and going of ice ages. The realization that human activities could alter this balance dawned much later, long after fossil fuels had become our dominant energy source. It is now plainly understood that the unprecedented rise in global prosperity associated with fossil fuel combustion had a steep environmental price. Emissions of CO_2 have already altered the greenhouse gas composition of the atmosphere, and climate scientists expect that resultant environmental degradations will continue for centuries. This knowledge has served to heighten public awareness of the full costs of energy consumption, an important step toward positive change. However, it can also lead to the illogical conclusion that if fossil fuels are bad, then any alternative must by definition be good (or at least better).

What's missing from this view is the realization that all of the alternatives have costs of their own, and that those costs will inevitably scale up in size according to the amount of fossil fuel consumption that is displaced. Hydroelectric and nuclear are currently the leading alternatives to fossil fuels, and not surprisingly they also tend to attract the most attention to their downsides. Biofuels are also drawing increasing amounts of criticism, in part because of the large energy investments required to produce ethanol from corn. Even if produced from cellulosic feedstocks, it seems unlikely that biofuels seem can ever approach the energy return ratios of Mesothermic fossil fuels. Furthermore, biofuel production will always hold the potential to compete with food production, since both require the same supporting geologic resources. As bad as the effects of global warming may become over the next century, famine and malnutrition are by nature more immediate problems.

Renewables such as wind, solar, and geothermal have made more modest contributions to date and generally appear more environmentally benign. Perhaps they are, but until they grow significantly in scale it is hard to know for sure. One hundred years ago no one dreamed that the combustion of fossil fuels might result in the melting of polar ice. Substantially increased use of solar, wind, wave, or geothermal energy also appears likely to require massive new investments in infrastructure, both for primary collection and for secondary transmission and storage. The need to make such investments in order to sustain our growing energy use will likely make a direct impact on the world economy.

In the end the only truly “green” energy strategy is to use less of it. This will not be so easy to do, however, because energy use is closely associated with wealth. Most of us in the developed world probably do not want to return to the horse-and-buggy lifestyles experienced by our ancestors only a few generations ago. Since we cannot escape the negative consequences of our own energy consumption, we will be forced instead to choose the consequences we deem least damaging.

Final Thoughts

If the Earth could speak, it would probably express bemused surprise at our concern for its safety. It has, after all, survived for 4.54 *billion* years so far and will most likely continue to circle the Sun for at least a few more billion years. The Earth has survived many previous crises, the history of which is literally carved in stone. It has been repeatedly pummeled by meteorite impacts, wracked by earthquakes and volcanic explosions, and baked or frozen during countless climatic fluctuations. It has witnessed the diversity of living organisms rise, fall, and rise again in new forms, dozens of times. Through all of this the Earth itself has proven quite durable. It is of course not really the planet that needs salvation, but ourselves.