

The Dilemmas of Energy: Essential energy services and potentially fatal risks

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Abstract. During their evolution, humans have made three energy transitions, each marked by the adoption of new ways of procuring energy with attendant changes in lifestyle. Modern civilization arose in the Third Energy Transition, and its major sources of energy come from coal, oil, gas, uranium, and hydropower. Unfortunately, despite its incalculable benefits, the Third Transition can't provide sustainable energy services for the indefinite future. Climate change is the most serious problem. Criteria and standards for each of the currently available, nine primary energy sources indicate the potential feasibility of replacing most or all uses of coal, oil, gas, and uranium with hydropower, solar, wind, biomass, and geothermal. This is the Fourth Energy Transition, promotion of which is strongly supported by considerations of sustainability.

Human life as we know it today is dependent on energy services. If these services were lost, most people would suffer and many would die. To establish a firm base of knowledge about energy, new methods of analysis are needed compared to methods used in the past. I will briefly indicate some of these methods.

1. Energy Transitions

During human evolution, humans have embraced four energy transitions, events based on mastering a new form of energy supply. The First Energy Transition was based on fire and firewood to cook food and provide light, heat, and protection from predators. This Transition probably happened about one million years ago during the evolution of *Homo habilis* to *Homo erectus*. Modern humans, *Homo sapiens*, are dependent upon cooked food. The Second Energy Transition occurred when *H. sapiens* domesticated plants and animals to stabilize and increase the supply of food energy. Agrarian civilization developed, about 10,000 years ago. The Third Energy Transition stemmed from substituting coal for firewood as a source of heat. This Transition began about 1550, and has since moved around the world. Modern civilization replaced agrarian civilization. The Fourth Energy Transition has barely begun, and it arose because of severe problems caused by the energy sources developed during the Third Transition, especially by coal, oil, gas, and uranium. The Fourth Transition has the potential to replace these four energy sources — possibly completely — with renewable energy and energy efficiency.

The Third Transition began in England in the 1500s when England, like all other countries, relied on firewood for its major external source of energy for cooking, heating, lighting, making metals and ceramics, and many other purposes. By the 1500s, however, the English population had risen to over



three million people, and the increased population had cleared forests for agriculture and reduced firewood supply by extensive harvests of woodland.

Coal was readily available at shallow depths, and people began to substitute coal for shrinking supplies of firewood. By 1700, the population had reached five million, and coal was commonly used for brewing, distilling, bricks, tiles, glass, pottery, nails, cutlery, salt, sugar, soap, brass, and copper. Moreover, the amount of heat available from coal far surpassed the amount available from firewood, and England began a spurt of unprecedented economic growth. This was the first step of the Third Energy Transition.

Step 2 of the Transition began in 1712 with the successful development of Thomas Newcomen's "atmospheric engine." This machine turned the heat of burning coal into physical motion that could pump water from coal mines. By the early 1700s, coal mines were deep enough to collect water that had to be removed. Newcomen's engine accelerated production of more coal.

Abraham Darby successfully used coal to make coke to replace charcoal for smelting iron ore in 1708 – 1709, and, combined with Newcomen's engine, created a mutually reinforcing cycle: more coal → more iron → more steam engines → more coal, and so forth. England's economy and military power grew rapidly.

Step 3 of the Third Transition began in the late 1700s and early 1800s. Inventors developed steam engines that could power ships and railroad trains. Thus, the heat of coal made mechanical motion, and the motion in turn increased mobility on the seas and the land. No longer was the speed of transport dependent upon fickle winds or the speed of a horse. People began to move themselves and their goods over landscapes and oceans far faster and more cheaply than had ever been done before. The pace of economic growth increased, and in the 1800s the inventions that had begun in England began to spread to other parts of the world.

In addition to coal, people also began to use deposits of oil and gas in addition to coal. Together, coal, oil, and gas comprised what are now called the "fossil fuels," and the combustion of these materials supply 81 percent of the heat energy used worldwide. In the 1940s and 1950s, scientists identified heat from fission of uranium, and nuclear power joined fossil fuels to make the "mineral fuels," which supply 86 percent of the world's heat energy (2015) [2]. I have called these mineral fuels the "big-four fuels" of the Third Energy Transition.

Step 4 of the Third Transition came in 1882, when Thomas Edison and Henry Rogers successfully turned the heat of burning coal and the energy of falling water, respectively, into motion to turn an electric generator. "Thermal electricity" and "hydroelectricity," both initially developed in the United States, augmented the Third Energy Transition by making energy that was easily transported long distances and could produce heat, light, motion, mobility, and telecommunications. Uranium supplemented thermal electricity and hydroelectricity after 1954, when the Union of Soviet Socialist Republics first turned the heat of fission into electricity.

Not only did the big-four fuels, plus hydroelectricity, spread, the amounts of energy deployed to provide energy services rose exponentially during the 20th century. In 1900, all of humanity used the energy equivalent to about 1000 million tons of oil per year, and by 2000, this amount had exceeded 14,000 million tons of oil per year. During the same time, the human population grew from about 1.6 billion to 6.1 billion and today stands at about 7.6 billion [3]. Support of today's population would be impossible without energy services.

Benefits of the Third Energy Transition have been incalculable. It is more accurate to say the Third Transition created "modern civilization," which replaced the "agrarian civilization" that arose from the Second Energy Transition. Agriculture did not disappear, but machines and energy sources replaced the muscle power of people and animals. By 2000, modern civilization occupied most of the globe, and only tiny, isolated pockets of people in remote places lived lives of the First and Second Energy Transitions.

To put it bluntly, almost all people now alive depend upon the energy services of the Third Energy Transition for their comfort, safety, prosperity, and survival. No other options exist: humanity must have the benefits of energy sources or literally billions of people will suffer and die. Only sustainable energy services can preserve modern civilization.

If no problems with the Third Energy Transition existed, then energy would not be a subject of interest. Unfortunately, multiple, serious problems have arisen, and these problems threaten the sustainability of energy services. We turn next to these problems.

2. The Third Energy Transition is not Sustainable

Four challenges have arisen in the Third Energy Transition: climate change, geopolitical tensions, and health and environmental consequences of using the big-four energy sources, plus depletion of the mineral deposits of the big-four. Climate change is by far the most serious and imminent of these four challenges, and it is a global problem. The other three tend to be local or regional problems, and I won't discuss them here.

Briefly summarized, climate change results primarily from the production and release to the atmosphere of carbon dioxide (CO₂) a combustion product of coal, oil, and gas. CO₂ is a greenhouse gas that alters the radiation balance of the earth by absorbing and retaining on earth heat that would otherwise leave the earth as infrared radiation. Historically for the past 800,000 years, the concentration of CO₂ in the atmosphere has varied between about 280 parts per million (ppm) and 300 ppm. The Third Energy Transition has released enough CO₂ to increase its concentration to over 400 ppm. This extra CO₂ has warmed the atmosphere and the oceans by about 1°C in 2016 compared to 1951–1980 [4].

Levels of CO₂ are now at unprecedented, high levels compared to the entire time that modern humans, *Homo sapiens*, have existed (about 300,000 years) and to the time that humans have engaged in agriculture (about 10,000 years). CO₂ levels are still increasing, and the Intergovernmental Panel on Climate Change estimates that humans have injected about 500 billion tons of CO₂ into the atmosphere. If future injections put an additional 500 billion tons of CO₂ into the atmosphere, the predicted temperature increases will be about 2°C, an increase that most scientists believe may disrupt agriculture, cause extreme weather, and disrupt other processes [5].

Future damages from climate change risk being horrendous, but already evidence has accumulated showing damages of USD 1.1×10^{12} from extreme weather events in the United States since 1980 [6]. These include heat waves, droughts, and severe rain storms. Sea-levels have risen threatening coastal areas world-wide, and the ocean has become more acidic due to dissolved CO₂, a threat to aquatic species. Arctic ice has declined, which is likely to produce a positive feedback to further temperature increases. In addition, a wide range of theories and models produces results highly consistent with the already observed events, strongly suggesting that climate change poses existential risks to modern civilization across the earth.

3. Analysis of Sustainability of Energy Services

To meet the needs of the present without compromising the ability of the future to meet their needs. This is the guiding principle of sustainability identified in *Our Common Future*, published in 1986 by the World Commission on Environment and Development. It directs those who are alive now not to use the earth's resources in ways that diminish the ability of future generations to meet their own needs. Often the principle of sustainability is shortened to the "3 E's:" economy, environment, and equity. Managing earth's resources must pay attention to each factor to find sustainable ways of supporting the lives of present and future generation.

Further guiding principles of sustainability analysis comes from the following questions, with my brief answers. Issues of science and technology must be considered in sustainability analysis, but they are not sufficient by themselves to complete the analysis. Ethics, morals, and values also must be included, which makes sustainability analysis a difficult — but necessary — process.

- What is to be sustained? (Energy services)
- Over what area? (Every country)
- Over what time? (Forever)
- At what cost? (Reasonable)
- For whose benefit? (Present and future generations)
- Who pays? (Fairness and equity guide division of costs)

Democracy and rule of law must play a central role in decision-making about energy to find sustainable ways forward. For universities, this means that students must have opportunities to develop general energy literacy so that they understand why the Third Energy Transition, despite its benefits, is not sustainable and must give way to the Fourth Energy Transition and sustainable energy services. Universities must also educate and train the scientists and engineers as well as social-cultural-economic-political experts who have deep knowledge of energy technologies.

The most important task in building sustainable energy services focuses on which of nine primary energy sources are best suited to provide sustainable energy services. Once the sources compatible with sustainable services have been selected, then the technological and social infrastructure needed can be constructed. The big-four energy sources (coal, oil, gas, and uranium) cannot provide sustainable energy services. The five sources that can — if used with proper safeguards — are hydropower, solar, wind, biomass, and geothermal energy.

The conclusion that renewable energy sources can provide sustainable energy services stemmed from developing criteria and standards to assess each of the nine primary energy sources. The results of the analysis divide the criteria into “Traditional Criteria” used in building the Third Energy Transition, and “New Criteria for Sustainability” that assess the ability of each of the nine sources to provide sustainable energy services.

Each of the nine sources is assessed by each criterion with an ordinal, qualitative variable in which +++ means exceptional strength on a criterion and --- means exceptional and fatal weakness on a criterion. Intermediate values, ranked from strong to weak are ++, +, -, and --. The details of the analysis are published elsewhere, but the general pattern is clear: the big-four fuels have their greatest strength based on traditional criteria, and the five renewable energy sources are strongest on the criteria for sustainability [7]. Renewable energy has mixed but adequate strength on the traditional criteria, but the big-four fuels have predominantly fatal weaknesses on the criteria for sustainability. It's important to note that energy efficiency scores strongly on both traditional and sustainability criteria.

Sustainability assessment indicates that achieving sustainable energy services requires directing new investments in energy to favour — as much as possible — the Fourth Energy Transition, in which renewable energy and energy efficiency replace the big-four fuels of the Third Transition. Barriers and challenges to this change will arise, but the problems identified with the Third Transition, especially climate change, make the changes imperative for the sake of current and future generations.

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