

ALTERNATIVE ENERGY CHALLENGES

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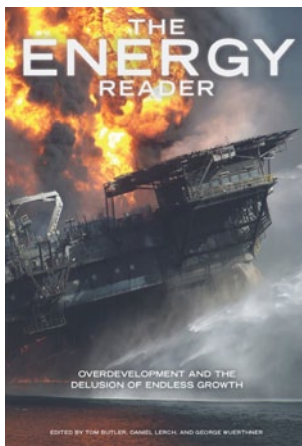


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High oil prices, concerns over energy security, and the threat of climate change have all stimulated investment in the development of alternatives to conventional oil. “Alternative energy” generally falls into two categories:

- Substitutes for existing petroleum liquids (ethanol, biodiesel, biobutanol, dimethyl ether, coal-to-liquids, tar sands, oil shale), both from biomass and fossil feedstocks; and
- Alternatives for generating and storing electric power (wind, solar photovoltaics, solar thermal, tidal, biomass, fuel cells, batteries).

The technology pathways to these alternatives vary widely, from distillation and gasification to bioreactors of algae and high-tech manufacturing of photon-absorbing silicon panels. Many are considered “green” or “clean” although some, such as coal-to-liquids and tar sands, are “dirtier” than the petroleum they are replacing. Others, such as biofuels, have concomitant environmental impacts that offset potential carbon savings.

Unlike conventional fossil fuels, where nature provided energy over millions of years to convert biomass into energy-dense solids, liquids, and gases—requiring only extraction and transportation technology for us to mobilize them—alternative energy depends heavily on

engineered equipment and infrastructure for capture or conversion, essentially making it a high-tech manufacturing process. However, the full supply chain for alternative energy, from raw materials to manufacturing, is still very dependent on fossil fuel energy for mining, transport, and materials production. Alternative energy faces the challenge of how to supplant a fossil fuel–based supply chain with one driven by alternative energy forms themselves in order to break their reliance on a fossil fuel foundation.

The public discussion about alternative energy is often reduced to an assessment of its monetary costs versus those of traditional fossil fuels, often in comparison to their carbon footprints. This kind of reductionism to a simple monetary metric obscures the complex issues surrounding the potential viability, scalability, feasibility, and suitability of pursuing specific alternative technology paths. Although money is necessary to develop alternative energy, money is simply a token for mobilizing a range of resources used to produce energy. At the level of physical requirements, assessing the potential for alternative energy development becomes much more complex since it involves issues of end-use energy requirements, resource use trade-offs (including water and land), and material scarcity.

Similarly, it is often assumed that alternative energy will seamlessly substitute for the oil, gas, or coal it

is designed to supplant—but this is rarely the case. Integrating alternatives into our current energy system will require enormous investment in both new equipment and infrastructure—along with the resources required for their manufacture—at a time when capital to make such investments has become harder to secure. This raises the question of the suitability of moving toward an alternative energy future with an assumption that the structure of our current large-scale, centralized energy system should be maintained. Since alternative energy resources vary greatly by location, it may be necessary to consider different forms of energy for different localities.

Assessing the promise of alternative energy is complex and multi-faceted; the discussion is complicated by political biases, ignorance of basic science, and a lack of appreciation of the magnitude of the problem facing societies accustomed to inexpensive fossil energy as the era of abundance concludes. While not a comprehensive listing, the key challenges of alternative energy include:

SCALABILITY AND TIMING

For the promise of an alternative energy source to be achieved, it must be supplied in the time frame needed, in the volume needed, and at a reasonable cost. Many alternatives have been successfully demonstrated at the small scale (algae-based diesel, cellulosic ethanol, biobutanol, thin-film solar), but demonstration scale does not provide an indication of the potential for large-scale production. Similarly, because alternative energy relies on engineering, manufacturing, and construction of equipment and manufacturing processes for its production, output grows in a step-wise function only as new capacity comes online, which in turn is reliant on timely procurement of the input energy and other required input materials. This difference between “production” of alternative energy and “extraction” of fossil fuels can result in marked constraints on the ability to increase the production of an alternative energy source as it is needed.

COMMERCIALIZATION

Closely related to the issue of scalability and timing is commercialization, or the question of how far away a proposed alternative energy source stands from being fully commercialized. Often, newspaper reports of a scientific laboratory breakthrough are accompanied by suggestions that such a breakthrough represents a possible “solution” to our energy challenges. In reality, the average time frame between laboratory demonstration of feasibility and large-scale commercialization is from twenty to twenty-five years. Processes need to be perfected and optimized, patents developed, demonstration tests performed, pilot plants built and evaluated, environmental impacts assessed, and engineering, design, siting, financing, economic, and other studies undertaken.

SUBSTITUTABILITY

Ideally, an alternative energy form would integrate directly into the current energy system as a “drop-in” substitute for an existing form without requiring further infrastructure changes. This is rarely the case, and the lack of substitutability is particularly pronounced in the case of electric vehicles. Although it is possible to generate the needed electricity from wind or solar power, the prerequisites to achieving this are extensive. Electric car proliferation at a meaningful scale would require extensive infrastructure changes including retooling factories to produce the vehicles, developing a large-scale battery industry and recharging facilities, building a maintenance and spare parts industry, integrating “smart grid” monitoring and control software and equipment, and of course, constructing additional generation and transmission capacity. All of this is costly.

The development of wind and solar power electricity also requires additional infrastructure; wind and solar electricity must be generated where the best resources exist, which is often far from population centers. Thus extensive investment in transmission infrastructure to bring it to consumption centers is required. Today, ethanol can be blended with gasoline and used directly, but its propensity to absorb water and its high oxygen content make it unsuitable for transport in existing pipeline

systems,¹ and an alternative pipeline system to enable its widespread use would be materially and financially intensive. While alternative energy forms may provide the same energy services as another form, they rarely substitute directly, and these additional material costs need to be considered.

MATERIAL INPUT REQUIREMENTS

The key input to an alternative energy process is not money, but resources and energy; the type and volume of the resources and energy needed may in turn limit the scalability and affect the cost and feasibility of an alternative. This is particularly notable in processes that rely on advanced technologies manufactured with rare earth elements. Fuel cells, for example, require platinum, palladium, and rare earth elements. Solar photovoltaic technology requires gallium, and in some forms, indium. Advanced batteries rely on lithium. Even technology designed to save energy, such as LED or organic LED (OLED) lighting, requires the rare earths indium and gallium. Expressing the costs of alternative energy only in monetary terms obscures potential limits from the resource and energy inputs required. Successful deployment of a range of new energy technologies (and some nonenergy advanced technologies) would substantially raise demand for a range of metals beyond the level of world production today.

Alternative energy production is reliant not only on a range of resource inputs, but also on fossil fuels for the mining of raw materials, transport, manufacturing, construction, maintenance, and decommissioning. Currently, no alternative energy exists without fossil fuel inputs, and no alternative energy process can reproduce itself—that is, manufacture the equipment needed for its own production—without the use of fossil fuels. In this regard, alternative energy serves as a supplement to the fossil fuel base, and its input requirements may constrain its development in cases of either material or energy scarcity.

INTERMITTENCY

Modern societies expect that electrons will flow when a switch is flipped, that gas will flow when a knob is turned, and that liquid fuel will flow when the pump handle is squeezed. This system of continuous supply is possible because of our exploitation of large stores of fossil fuels, which are the result of millions of years of intermittent sunlight concentrated into a continuously extractable source of energy. Alternative energies such as solar or wind power produce only intermittently as the Sun shines or the wind blows, and even biomass-based fuels depend on seasonal harvests of crops. Integrating these energy forms into our current system creates challenges of balancing availability and demand, and it remains doubtful that these intermittent energy forms can provide a majority of our future energy needs in the same way that we expect energy to be available today.

The key to evening out the impact of intermittency is storage; that is, developing technologies and approaches that can store energy generated during periods of good wind and sun for use at other times. Many approaches have been proposed and tested, including compressed air storage, batteries, and the use of molten salts in solar thermal plants. The major drawbacks of all these approaches include the losses involved in energy storage and release, and the limited energy density that these storage technologies can achieve.

ENERGY DENSITY

Energy density refers to the amount of energy that is contained in a unit of an energy form. It can be expressed in the amount of energy per unit of mass (weight), or in the amount of energy per unit of volume. Energy density has greatly influenced our choice of fuels. The conversion to the use of coal in the seventeenth and eighteenth centuries was welcomed because coal provided twice as much energy as wood for the same weight of material. Similarly, the shift from coal to petroleum-powered ships in the early twentieth century was driven by the fact that petroleum possesses nearly twice the energy density of coal, allowing ships to go farther without having to stop for refueling.

Even when used in a motor vehicle's inefficient internal combustion engine, a kilogram of highly energy-dense gasoline—about six cups—allows us to move 3,000 pounds of metal roughly 11 miles.

The consequence of low energy density is that larger amounts of material or resources are needed to provide the same amount of energy as a denser material or fuel. Many alternative energies and storage technologies are characterized by low energy densities, and their deployment will result in higher levels of resource consumption. Lithium ion batteries—the focus of current research for electric vehicles—can contain only 0.5 megajoules per kilogram (MJ/kg) of battery compared to 46 MJ/kg for gasoline. Advances in battery technology are being announced regularly, but they all come up against the theoretical limit of energy density in batteries of only 3 MJ/kg.

ENERGY RETURN ON INVESTMENT

The complexity of our economy and society is a function of the amount of net energy we have available. “Net energy” is, simply, the amount of energy remaining after we consume energy to produce energy. Consuming energy to produce energy is unavoidable, but only that which is not consumed to produce energy is available to sustain our industrial, transport, residential, commercial, agricultural, and military activities. The ratio of the amount of energy we put into energy production and the amount of energy we produce is called “energy return on investment” (EROI). EROI can be very high (e.g. 100:1, or 100 units of energy produced for every one unit used to produce it—an “energy source”), or low (0.8:1, or only 0.8 units of energy produced for every one unit used in production—an “energy sink”). Society requires energy sources, not energy sinks, and the magnitude of EROI for an energy source is a key indicator of its contribution to maintenance of social and economic complexity.

Net energy availability has varied tremendously over time and in different societies. In the last advanced societies that relied only on solar power (sun, water power, biomass, and the animals that depended on biomass)

in the seventeenth and early eighteenth centuries, the amount of net energy available was low and dependent largely on the food surpluses provided by farmers. At that time, only 10 to 15 percent of the population was *not* involved in energy production. As extraction of coal, oil, and natural gas increased in the nineteenth and twentieth centuries, society was increasingly able to substitute the energy from fossil fuels for manual or animal labor, thereby freeing an even larger proportion of society from direct involvement in energy production. In 1870, 70 percent of the U.S. population was farmers; today the figure is less than 2 percent, and every aspect of agricultural production now relies heavily on petroleum or natural gas. The same is true in other energy sectors: Currently, less than 0.5 percent of the U.S. labor force (about 710,000 people) is directly involved in coal mining, oil and gas extraction, petroleum refining, pipeline transport, and power generation, transmission, and distribution.

The challenge of a transition to alternative energy, then, is whether such energy surpluses can be sustained, and thus whether the type of social and economic specialization we enjoy today can be maintained. Indeed, one study estimates that the minimum EROI for the maintenance of industrial society is 5:1, suggesting that no more than 20 percent of social and economic resources can be dedicated to the production of energy without undermining the structure of industrial society.² In general, most alternative energy sources have low EROI values. A high EROI is not sufficient to ensure that the structure of modern society and economies can be maintained, but it is a prerequisite.

CONCLUSION

Alternative energy forms are crucial for a global transition away from fossil fuels, despite the myriad challenges of their development, scaling, and integration. In face of the peaking of global oil production—to be followed by peaks in natural gas and coal extraction—and of the need to reverse trajectory in carbon emissions, alternative energy sources will need to form the backbone of a future energy system.

That system, however, will not be a facsimile of the system we have today based on continuous uninterrupted supply growing to meet whatever demand is placed on it. As we move away from the energy bounty provided by fossil fuels, we will become increasingly reliant on tapping the current flow of energy from the Sun (wind, solar) and on new energy manufacturing processes that will require ever-larger consumption of resources (bio-fuels, other manufactured liquids, batteries). What kind of society we can build on this foundation is unclear, but it will most likely require us to pay more attention to controls on energy demand to accommodate the limitations of our future energy supply. Moreover, the modern focus on centralized production and distribution may be hard to maintain, since local conditions will become increasingly important in determining the feasibility of alternative energy production.

ENDNOTES

- 1 John Whims, *Pipeline Considerations for Ethanol*, Kansas State University Department of Agricultural Economics (Manhattan, KS: Kansas State University, August 2002), http://www.agmrc.org/media/cms/ksupipelineethl_8BA5CDF1FD179.pdf.
- 2 Charles A.S. Hall, Robert Powers, and William Schoenberg, "Peak Oil, EROI, Investments and the Economy in an Uncertain Future," in *Biofuels, Solar and Wind as Renewable Energy Systems: Benefits and Risks*, ed. David Pimentel (New York: Springer, 2008), 109-132.