GLOBAL ENERGY RESOURCES

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Current global energy consumption is 4.1×10^{20} J annually, which is equivalent to an instantaneous yearly-averaged consumption rate of 13×10^{12} W [13 trillion watts, or 13 terawatts (TW)]. Projected population and economic growth will more than double this global energy consumption rate by the mid-21st century and more than triple the rate by 2100, even with aggressive conservation efforts. Hence, to contribute significantly to global primary energy supply, a prospective resource has to be capable of providing at least 1-10 TW of power for an extended period of time.

The threat of climate change imposes a second requirement on prospective energy resources: they must produce energy without the emission of additional greenhouse gases. Stabilization of atmospheric CO_2 levels at even twice their preanthropogenic value will require daunting amounts of carbon-neutral energy by mid-century. The needed levels are in excess of 10 TW, increasing after 2050 to support economic growth for an expanding population.

The three prominent options to meet this demand for carbon-neutral energy are fossil fuel use in conjunction with carbon sequestration, nuclear power, and solar power. The challenge for carbon sequestration is finding secure storage for the 25 billion metric tons of CO_2 produced annually on Earth. At atmospheric pressure, this yearly global emission of CO_2 would occupy 12,500 km^3, equal to the volume of Lake Superior; it is 600 times the amount of CO_2 injected every year into oil wells to spur production, 100 times the amount of natural gas the industry draws in and out of geologic storage in the United States each year to smooth seasonal demand, and 20,000 times the amount of CO_2 stored annually in Norway's Sleipner reservoir. Beyond finding storage volume, carbon sequestration also must prevent leakage. A 1% leak rate would nullify the sequestration effort in a century, far too short a time to have lasting impact on climate change. Although many scientists are optimistic, the success of carbon sequestration on the required scale for sufficiently long times has not yet been demonstrated.

Nuclear power is a second conceptually viable option. Producing 10 TW of nuclear power would require construction of a new one-gigawatt-electric (1-GW_e) nuclear fission plant somewhere in the world every other day for the next 50 years. Once that level of deployment was reached, the terrestrial uranium resource base would be exhausted in 10 years. The required fuel would then have to be mined from seawater (requiring the equivalent of 10 Niagara Falls), or else breeder reactor technology would have to be developed and disseminated to countries wishing to meet their additional energy demand in this way.

The third option is to exploit renewable energy sources, of which solar energy is by far the most prominent. United Nations (U.N.) estimates indicate that the remaining global, practically exploitable hydroelectric resource is less than 0.5 TW. The cumulative energy in all the tides and ocean currents in the world amounts to less than 2 TW. The total geothermal energy at the surface of the Earth, integrated over all the land area of the continents, is 12 TW, of which only a small fraction could be practically extracted. The total amount of globally extractable wind power has been estimated by the IPCC and others to be 2-4 TW_e. For comparison, the solar constant at the top of the atmosphere is 170,000 TW, of which, on average, 120,000 TW strikes the Earth (the remainder being scattered by the atmosphere and clouds). It is clear that solar energy can be exploited on the needed scale to meet global energy demand in a carbon-neutral fashion without significantly affecting the solar resource.

Solar energy is diffuse and intermittent, so effective storage and distribution are critical to matching supply with demand. The solar resource has been well established, and the mean yearly insolation values are well documented. At a typical latitude for the United States, a net 10% efficient solar energy “farm” covering 1.6% of the U.S. land area would meet the country’s entire domestic energy needs; indeed, just 0.16% of the land on Earth would supply 20 TW of power globally. For calibration purposes, the required U.S. land area is about 10 times the area of all single-family residential rooftops and is comparable with the land area covered by the nation’s federally numbered highways. The amount of energy produced by these boxes is equal to that produced by 20,000 1-GWe nuclear fission plants. This many plants would need to be constructed to meet global demands for carbon-neutral energy by the mid-21st century if carbon sequestration were to prove technically nonviable and if solar energy were not developed.