distribution model that has characterized the fossil-fuel era, but may not necessarily be suitable for a future of renewable energy generation.

The key to evening out the impact of intermittency is storage; that is, the development of 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.

6. 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. In everyday life, it is common to consider energy density when considering food choices. Food labeling in the United States requires that both numbers needed for calculating energy density be provided: the number of food calories per serving and the weight or volume of the serving (expressed in-grams or liters, respectively). Potatoes, for example, have an energy density of 200 food calories per 100 grams, or, expressed in units common in energy discussions, 8.4 megajoules[8] (MJ) per kilogram (about 2.2 pounds). Cheese is more energy dense than potatoes, containing about 13 MJ per kilogram.

Energy density has also influenced our choice of fuels. Aside from alleviating a growing wood shortage, 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 6 cups—allows us to move 3,000 pounds of metal about 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. As shown in Figure 1, the main alternatives under development to supplant gasoline use in cars are dramatically lower in energy density than gasoline itself. Lithium-ion batteries—the focus of current research for electric vehicles—contain only 0.5 MJ per kilogram of battery compared to 46 MJ per kilogram for gasoline. Advances in battery technology are being announced regularly, but they all come up against the theoretical limit of battery density of only 3 MJ per kilogram. Low energy density will present a significant challenge

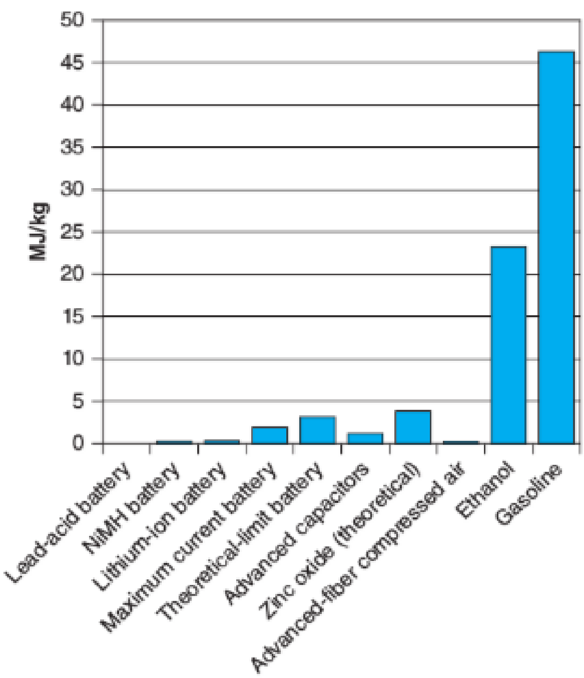

FIGURE 1 Comparison of energy densities.

Source: Kurt Zenz House and Alex Johnson, "The Limits of Energy Storage Technology," *Bulletin of the Atomic Scientists* Web edition, January 20, 2009, http://www.thebulletin.org/web-edition/columnists/kurt-zenz-house/the-limits-of-energy-storage-technology.