

a consequence of the uneven geographical distribution of production and reserves. Currently, China is the dominant world source (over 95 percent) of the rare-earth element neodymium, a key input in the production of permanent magnets used in hybrid-vehicle motors and windmill turbines. In 2009, the Chinese government announced restrictions on the export of rare earths, ostensibly to encourage investment within China of industries using the metals. Whether for the rare earths themselves or for final products made from them, import dependency in the face of such a high concentration of production would do little to alleviate energy security concerns now seen in terms of import dependency on the Middle East for oil.

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.

5. INTERMITTENCY

Modern societies expect that electrons will flow when a switch is flipped, that gas will flow when a knob is turned, and that liquids 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 and wind power, in contrast, produce only intermittently as the wind blows or the sun shines, and even biomass-based fuels depend on seasonal harvests of crops. Integration of 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.

One indication of intermittency challenges in electric power generation is the capacity factor, or the average percentage of time in a year that a power plant is producing at full rated capacity. As shown in Table 2, photovoltaic systems produce at full capacity only 12 to 19 percent of the time over the course of a year, compared to an average of 30 percent for wind systems. In contrast, a coal-thermal plant will typically run at full capacity 70 to 90 percent of the time, while nuclear power operates at over a 90 percent capacity factor in the United States.

Our current electricity system is dominated by large baseload coal-and nuclear-power generation. The integration of intermittent energy forms such as solar and wind is increasingly seen as a matter of expanding transmission capacity and grid interconnections to extend the area over which these variations are felt, as well as implementing more complex operations controls. This approach in effect relies on strengthening and expanding the large centralized energy production and

TABLE 2 Common Capacity Factors for Power Generation

GENERATION TYPE	CAPACITY FACTOR
Photovoltaics	12–19%
Thermal solar	~15%
Thermal solar with storage	70–75%
Wind	20–40%
Hydropower	30–80%
Geo thermal	70–90%
Nuclear power	60–100%
Natural gas combined cycle (non-peaker)	~60%
Coal thermal	70–90%

Sources: Renewable Energy Research Laboratory, University of Massachusetts at Amherst, *Wind Power: Capacity Factor, Intermittency*; National Renewable Energy Laboratory, *Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts*, NREL/SR-550-34440 (Golden, CO: NREL, 2003).