and a resource can be viewed as a matter of entropy: a pollutant is a discarded resource that is so dispersed geographically or so contaminated chemically that its recovery may not be technologically or economically feasible.

Although the amount of available energy appears to be a theoretical constraint on the usable resource base, energy costs at the present time contribute very little to the total cost of processing most resources. Figure 5-8 shows the percentage cost, based on 1966 data, of purchased electric power in the primary metal industries (AMM 1970). Only in the production of primary aluminum and electrometallurgical products is the energy cost of processing the raw material greater than 5 percent of the total processing cost. Most of the cost in current resource processing is actually material capital (for example, drilling rigs, processing plants, and distribution systems). Therefore, in the world model, the cost involved in converting resources to processed raw materials suitable for use was measured in terms of the fraction of industrial capital that must be allocated to obtain the resources required for the present level of industrial output. Energy costs might be added in an extension of this model, but the entire energy question would probably be best modeled separately, making a distinction between energy resources and material resources.

Primary Metal Industries	Cost of Purchased Power to Value of Shipment (percent)
Blast furnaces and steel mills	2.0
Electrometallurgical products	11.3
Steel wire drawing	1.0
Cold finishing of steel shapes	0.7
Steel pipe and tubes	0.8
Gray iron foundries	1.2
Malleable iron foundries	2.3
Steel foundries	2.7
Primary copper	0.8
Primary lead	0.3
Primary zinc	4.3
Primary aluminum	12.1
Primary nonferrous metals, other	3.7
Secondary nonferrous metals	0.3
Copper rolling and drawing	1.0
Aluminum rolling and drawing	1.0
Rolling and drawing, other	0.8
Nonferrous wire drawings, etc.	0.8
Aluminum castings	1.0
Brass, bronze, and copper castings	1.0
Nonferrous castings, other	1.3
Iron and steel forgings	0.9
Nonferrous forgings	1.3
Primary metal industries, other	2.1

Figure 5-8 Electric power cost in U.S. metal industries

Source: AMM 1970, p. 113. Reprinted with the permission of Metal Statistics, American Metal Market/Metalworking News (1970). Copyright © 1970, Fairchild Publications, Inc.

Level of Aggregation

In the resource sector of World3, a number of simplifying assumptions cause its structure to differ from that shown in Figure 5-6: unknown resources and proven reserves are aggregated into one level that decreases over time as resources are utilized by the industrial sector, and the three levels of processed raw material, material in use, and solid waste are omitted. Therefore, the direct connection between resource use and pollution is not modeled. Instead, pollution generation is modeled as a function of resource use.

If Q_T is the total world supply of nonrenewable resources, representing the sum of unknown and proven reserves, then the possible usage rate of virgin materials over time U(t) is limited by

$$\int_0^t U(t)\,dt \leq Q_T, \tag{5.1}$$

where U(t) may be measured in resource units per year.* The integral may be very much less than Q_T, since some part of Q_T may ultimately be uneconomic to use. This usage rate must both start and end at zero, taking some series of nonnegative values so that its integral is less than or equal to Q_T. The only physical constraint put on the usage rate is that expressed by equation (5.1). One can imagine two extreme possibilities for this curve of the usage rate as a function of time (Figure 5-9). The users

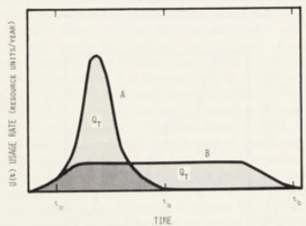

Figure 5-9 Possible usage rates of nonrenewable resources over time

*The following discussion is based on material in M. King Hubbert's "Energy Resources" in CRAM 1969. Hubbert develops his theory for fossil fuel resources, but the basic concepts are applicable to any nonrenewable resource.