of resources are able to choose whether the rate of resource consumption will follow a pattern similar to curve A or curve B of Figure 5-9. If they choose a usage rate similar to curve A, the total length of time for which they have the use of the resource is t_a. If they choose curve B, the corresponding time is t_b. In both cases the total area under the usage curve is equal to Q_T.

This simplified formulation of unidirectional resource flow assumes no recycling. Since institutional, technological, and economic factors today are such that most processed raw material comes from virgin sources, the use of recycled resources is not explicitly a part of the model structure. However, recycling can be enacted as a policy variable at any time in a model run; its effects on the sector behavior are described in section 5.6.

The representation of nonrenewable resources by a single level ignores the distinction between an unknown resource underground that has not been discovered and a proven reserve that has been located but has not been extracted and processed. The level of resources in the world model must then represent the sum of unknown resources and proven reserves that can be tapped for use at some finite cost, including discovery, extraction, processing, and distribution costs.

Increasing Costs of Obtaining Resources

The world model assumes that the cost of obtaining the next unit of resources must eventually rise as more resources are extracted from the earth. As stated earlier, the fundamental postulate of the nonrenewable resource sector is that resources are present in finite supply and are distributed widely in grade and location. If it is assumed that the best grades and the nearest locations are utilized first, then they will normally be used in an order of ascending cost, creating an identifiable "resource conversion path" (Figure 5-10). The horizontal portions of the path indicate periods

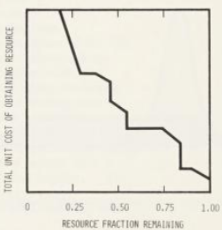

Figure 5-10 Resource conversion path
Source: Adapted from Barnett and Morse 1963.

in which output grows with no increase in unit costs; the vertical portions represent periods in which costs must increase before output can continue to grow.

For the purposes of this model, it is assumed only that resource costs tend to rise in the long run as the fraction of resources remaining decreases. One might expect periods of decreasing costs due to new low-cost reserve discoveries or technological breakthroughs. Short-term commodity price cycles may also decrease price briefly, but the overall long-run tendency is toward increasing costs with a decreasing nonrenewable resource fraction remaining. The long-run relationship is based on the physical characteristics of mineral distribution, whereas short-term variations are due to local or transient changes in distribution or extraction economics. The world model is based only on the long-term physical relationship.

In terms of the entropy analysis described earlier, the assumption of increasing costs stems from the fact that resources exist in widely varied entropy states, and man tends to process the low-entropy resources first. This implies that the amount of energy necessary to convert a resource to processed raw material increases as higher-entropy resources are mined.

As shown earlier, however, energy at present is a minor fraction of resource extraction costs, the major cost or input being industrial capital—the amount of capital goods necessary to process a given grade of raw material. The industrial capital stock consists of all the buildings and machines that are used in the construction of new buildings and machines and in the production of anything else that is a manufactured physical good. The capital stock also includes the mining equipment, pipelines, railroad cars, and smelters used to locate, extract, process, and distribute nonrenewable resources.

Thus the capital stock can be visualized as consisting of two fractions—the fraction required to obtain the raw materials (mineral and fossil fuel resources), and the fraction required to convert the raw materials into usable industrial output. As nonrenewable resource stocks are depleted, the efficiency of resource extraction goes down, forcing producers to allocate more capital to obtaining resources. As lower-quality ores are mined and new deposits must be sought in increasingly inaccessible places, a larger fraction of total industrial capital must be diverted from production to the exploration, extraction, and processing of nonrenewable resources. As stated by the Paley Commission on Materials Policy in 1952, "exhaustion is not waking up to find the cupboard is bare, but the need to devote constantly increasing efforts to acquiring each pound of materials from natural resources which are dwindling both in quality and quantity . . . " (Materials Policy Commission 1952). The reallocation of capital to resource extraction raises the fraction of total capital allocated to obtaining resources as illustrated in Figure 5-11. If it is not offset by technological improvements in the efficiency of capital, the reallocation of capital manifests itself as rising monetary costs of nonrenewable resources.

The Function of Technology in the Resource Sector

As shown in the section on time trends (5.2), the cost per resource unit has not in fact increased but has stayed relatively constant, or has even declined. As stated by