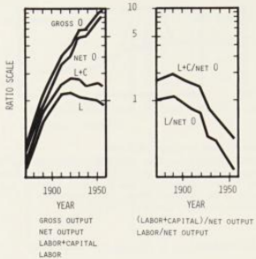

Figure 5-4 U.S. minerals: output, labor and capital inputs, and cost per unit of product, 1870–1957
Source: Adapted from Barnett and Morse 1963, p. 160.

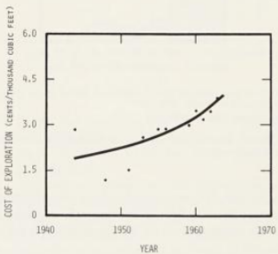

Figure 5-5 Cost of exploration in the natural gas industry, 1944–1963
Source: Data from Naill 1973.

5.3 BASIC CONCEPTS

The Fundamental Postulate

The fundamental postulate of the nonrenewable resource sector was that resources are present on the earth in finite supply and are distributed widely in grade and in location. Furthermore, it was assumed that this finite stock of resources is not destroyed when used but instead is dispersed geographically or changed chemically (for example, the rusting of iron or the combustion of fossil fuels). Figure 5-6 summarizes these concepts in DYNAMO flow notation, representing the flow of nonrenewable resources through the world economy from unknown virgin resources to useful products and finally to pollution.

The finite stock of virgin resources is discovered at a rate that depends on existing exploration technologies and the amount of capital invested in exploration. After discovery, these resources are classified as proven reserves. The reserves are then extracted from their original location and refined into processed raw material, which is then made into products that are eventually discarded to become solid waste. Solid waste can be either recycled and converted back to processed raw material or disregarded, in which case it eventually disintegrates or disperses to such an extent that profitable recycling is impossible. The dispersed or degraded resource is termed a pollutant.

The finiteness, or nonrenewability, of resources is represented in Figure 5-6 by the lack of any exogenous material sources feeding into the system. Furthermore, no material is actually destroyed (except in fission and fusion processes); no material leaves the system shown in Figure 5-6. Resources may exist at any time in any of the six forms shown in the figure, but the total amount of resources in the world system is a conserved quantity.

The flow of resources through the world economy can also be viewed by considering the different entropy states associated with each of the material levels. Figure 5-7 gives a hypothetical quantitative example of the changes in entropy states associated with this flow. The resource is usable as processed raw material when it is in its highest concentration or lowest entropy state ($S=1$). The resource's entropy tends to increase through dispersion or chemical conversion as the resource is processed into materials in use ($S=3$). When a material is discarded, its entropy state is increased as solid waste ($S=10$) and increased even more as a pollutant ($S=1{,}000$).

To convert a material into its most usable form (processed raw material), its entropy must be decreased. According to the second law of thermodynamics, that cannot be accomplished without adding energy to the resource system. The conversion of proven reserves to processed raw material "costs" something—in this simplified case ΔE_1 energy units. Similarly, the conversion of solid waste to processed raw material costs ΔE_2 energy units. If only energy costs were associated with resource processing, recycling would occur when ΔE_2 is less than ΔE_1; if ΔE_2 is greater than ΔE_1, virgin resources would be utilized. Finally, the difference between a pollutant