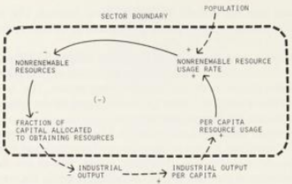

Figure 5-12 Causal-loop diagram of the nonrenewable resource sector

3. The tendency toward rising costs may be temporarily offset by advances in technology but, with the assumption of a finite resource supply, costs must ultimately rise as the stock of resources nears depletion.
4. The nonrenewable resource usage rate in any given year is the product of the total population and the per capita resource usage.
5. As the level of industrial output per capita increases, the per capita resource demand to support that industrialization also increases.

The causal-loop diagram describing the interrelationships among variables in the nonrenewable resource sector (Figure 5-12) shows that the sector is simply a single negative feedback loop. As nonrenewable resources near depletion, the fraction of capital that must be allocated to obtaining them eventually increases. For a given level of the capital stock, an increase in the fraction of capital allocated to obtaining resources implies a decrease in industrial output. Given a constant population, a reduction in industrial output reduces industrial output per capita directly. The reduced industrial output per capita leads to a lower per capita resource usage, which reduces the nonrenewable resource usage rate and leads to a slower depletion of nonrenewable resources, completing the negative feedback.

In the normal mode of operation of the model, both population and industrial capital grow exponentially. Under these growth conditions, even as capital is diverted to obtaining resources, industrial output may continue to rise—as long as the rate of growth of capital exceeds the rate of shift of capital from production to obtaining resources. Thus in a growing economy the economic consequences of resource depletion (shifting capital, leading to rising costs) may continue practically unnoticed for a long time.

However, if resources are depleted at an exponentially increasing rate, the cost of obtaining more resources will increase more rapidly. Therefore, the rate at which capital must be shifted (away from industrial production and toward obtaining the resources necessary to support that production) tends to increase and must eventually slow the rate of growth in industrial output as resources near depletion. The effect is at first imperceptible, for the reasons already noted, but becomes more significant as

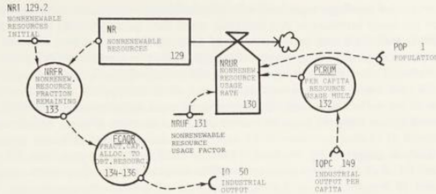

Figure 5-13 DYNAMO flow diagram of the nonrenewable resource sector

resource costs rise more quickly due to exponential depletion.

A DYNAMO flow diagram depicting the structure of the nonrenewable resource sector and its interaction with the rest of World3 is shown in Figure 5-13.

5.5 DESCRIPTION OF EQUATIONS

Nonrenewable Resources NR

```
NR.K=NR.J+(DT)(-NRUR.JK)                              129, L
NR=NRI                                                129.1, N
NRI=1E12                                              129.2, C
     NR     - NONRENEWABLE RESOURCES (RESOURCE UNITS)
     DT     - TIME INTERVAL BETWEEN CONSECUTIVE
                CALCULATIONS (YEARS)
     NRUR   - NONRENEWABLE RESOURCE USAGE RATE (RESOURCE
                UNITS/YEAR)
     NRI    - NONRENEWABLE RESOURCES INITIAL (RESOURCE
                UNITS)
```

Nonrenewable resources NR, the total stock of resources available for use at any given time, are defined as follows:

$$NR(t) = NRI - \int_0^t NRUR(t)\,dt \tag{5.2}$$

where NRI equals the initial amount of nonrenewable resources in the World3 system and NRUR equals the nonrenewable resource usage rate.

NR(t) at any given time is a positive quantity, for resources are never completely depleted; rather, their usage is curtailed by economic forces. The aggregation of all nonrenewable resources into a single level requires a clear definition of the role of nonrenewable resources. In the world model, nonrenewable resources NR were defined as the nonrenewable materials used in industrial production, for example, iron, lead, mercury, and copper, as well as the fossil fuels. Nonrenewable resources that are directly used in farming activities, such as phosphorous and potassium, were excluded from this analysis; but iron and other materials used to produce farm