tract mineral raw materials from their place in the earth's crust, is on the threshold of a revolutionary advance. The increasingly successful application of rock-tunnel boring machines, such as the one shown in figure 3, represents the beginning of a breakthrough in excavation technology as important as the introduction of explosives to replace human toil in tunneling for minerals during the middle ages. We can look forward to an era of rapid change in mining as new science, new machines, and new engineering techniques are developed that will permit economic production of the increasing amounts of minerals the Nation must obtain from deposits that are becoming harder to find, deeper in the earth and lower in quality.

The usefulness of this new rapid-excavation technology will, of course, go far beyond mining. Indeed, its broad applicability to the many and varied problems of a technological society is a consideration that makes the effort to improve it potentially so rewarding. Increasing population, attended by profligate use of the land surface in the past and by growing congestion in the present, is resulting in a demand to go underground with the utilities and facilities vital to a complex society, wherever it is economically feasible to do so. Figure 4 shows the nature and geographical distribution of some of the problem areas in the United States that are causing increasing national concern. Some of the major problems are water supply, sewage, mining, urban mass transportation, mass intercity high-speed ground transportation, and highways through mountainous and urban areas. Only very limited use is being made of the earth's subsurface to alleviate these problems, because current technology is inadequate. An improved technology that would permit faster, cheaper, more efficient development of the earth's subsurface would be a significant contribution.

Almost all of the service functions shown in figure 4 now require at least some subsurface excavation. As the population of the United States grows and becomes increasingly urbanized, this requirement obviously will accelerate. An estimate of the current and the projected annual rate of expenditure over a 15-year period for subsurface excavation is illustrated in figure 5. In 1967, an estimated $½ billion will be spent for tunneling, and by 1982 the annual rate will increase fivefold to $2.5 billion. These estimates are probably conservative, because they are based solely on projected needs in these problem areas derived from space considerations alone. In other words, if present population and urbanization trends continue, this is the amount of subsurface excavation that will have to be done, regardless of the cost. Obviously, if the cost could be reduced sufficiently, the amount that would be done would increase because more of the smaller cities could afford subway transit systems. Furthermore some of the bold new concepts for utilization of the subsurface would then become feasible. An example is the dramatic plan proposed by the North American Water and Power Alliance to reverse the flow of several sub-arctic rivers and redistribute their waters in the western United States, Canada, and Mexico. This project, which would make extensive use of tunnels, would bring new life through irrigation to 90,000 square miles of arid land, help flush pollution from the continent's waterways, and generate enormous amounts of electric power. Other ambitious plans have been proposed to solve vehicular traffic and parking in some large cities. For example, a Rand Corporation study showed that an efficient private vehicular commuter system for Los Angeles would require 1,000 lane-miles of tunneling exclusive of parking facilities. Chicago would require 1,300 lane-miles.

The minimum amount of subsurface excavation that will be required will represent a sizable public investment. As shown in figure 6, it is estimated that during the next 15 years the tunneling required for all purposes, excluding defense needs, will cost at least $20 billion. This will be the cost if the technology advances only at the normal rate that can be expected without Government action. However, by an aggressive, well structured research and development program, it is confidently believed that the cost can be reduced substantially, probably by as much as 50 percent within the next ten years. Halving the cost of underground construction then would result in a saving to the taxpayer of between $8 and 12 billion in the cost of construction of just these minimum facilities.

The benefit to the public would, of course, go much further than the monetary savings. Increasingly valuable land surface would be saved for other purposes. The quality of our environment would be improved. Needed public utilities could be put into service much more quickly.

The need for subsurface excavation technology is not new. Since prehistoric times, man has gone underground for minerals. The caveman probably did some