11

When Will We Run Out of Oil? Never!

> If I say they behave like particles I give the wrong impression; also if I say they behave like waves. They behave in their own inimitable way, which technically could be called a quantum mechanical way. They behave in a way that is like nothing that you have ever seen before. Your experience with things that you have seen before is incomplete.
>
> (*Richard Feynman*, The Character of Physical Law, *1994*)

> The so-called theories of Einstein are merely the ravings of a mind polluted with liberal, democratic nonsense which is utterly unacceptable to German men of science.
>
> (*Dr. Walter Gross, Nazi Germany's official exponent of "Nordic Science," in Cerf and Navasky 1984*)

> The theory of a relativistic universe is the hostile work of the agents of fascism. It is the revolting propaganda of a moribund, counter-revolutionary ideology.
>
> (Astronomical Journal of the Soviet Union, *in Cerf and Navasky 1984*)

> What will we do when the pumps run dry?
>
> (*Paul and Anne Ehrlich*, The End of Affluence)

Energy, the Master Resource

Energy is the master resource, because energy enables us to convert one material into another. As natural scientists continue to learn more about the transformation of materials from one form to another with the aid of energy, energy will be even more important. Therefore, if the cost of usable energy is low enough, all other important resources can be made plentiful, as H. E. Goeller and A. M. Weinberg showed.[1]

For example, low energy costs would enable people to create enormous quantities of useful land. The cost of energy is the prime reason that water desalination now is too expensive for general use; reduction in energy cost would make water desalination feasible, and irrigated farming would follow in many areas that are now deserts. And if energy were much cheaper, it would be feasible to transport sweet water from areas of surplus to arid areas far away. Another example: If energy costs were low enough, all kinds of raw materials could be mined from the sea.

On the other hand, if there were to be an absolute shortage of energy—that

is, if there were no oil in the tanks, no natural gas in the pipelines, no coal to load onto the railroad cars—then the entire economy would come to a halt. Or if energy were available but only at a very high price, we would produce much smaller amounts of most consumer goods and services.

The question before us is: What is the prospect for oil scarcity and energy prices? Here is the summary—at the beginning rather than at the end of the chapter to provide guideposts for your foray into the intellectual jungle of arguments about energy.

1. Energy is the most important of natural resources because
   a. the creation of other natural resources requires energy; and
   b. with enough energy all other resources can be created.
2. The most reliable method of forecasting the future cost and scarcity of energy is to extrapolate the historical trends of energy costs, for reasons given in chapters 1 and 2.
3. The history of energy economics shows that, in spite of troubling fears in each era of running out of whichever source of energy was important at that time, energy has grown progressively less scarce, as shown by long-run falling energy prices.
4. The cause of the increasing plenty in the supply of energy has been the development of improved extraction processes and the discovery of new sources and new types of energy.
5. These new developments have not been fortuitous, but rather have been induced by increased demand caused in part by rising population.
6. For the very long run, there is nothing meaningfully "finite" about our world that inevitably will cause energy, or even oil in particular, to grow more scarce and costly. Theoretically, the cost of energy could go either up or down in the very long run. But the trends point to a lower cost.
7. Forecasts based on technical analyses are less persuasive than historical extrapolations of cost trends. Furthermore, the technical forecasts of future energy supplies differ markedly among themselves.
8. A sure way to err in forecasting future supplies is to look at current "known reserves" of oil, coal, and other fossil fuels.
9. An appropriate technical forecast would be based on engineering estimates of the amounts of additional energy that will be produced at various price levels, and on predictions of new discoveries and technological advances that will come about as a result of various energy prices.
10. Some technical forecasters believe that even very much higher prices will produce only small increases in our energy supply, and even those only slowly. Others believe that at only slightly higher prices vast additional supplies will be forthcoming, and very quickly.
11. Causes of the disagreements among technical forecasters are differences in
    a. scientific data cited,
    b. assessments of political forces,
    c. ideology,

d. belief or nonbelief in "finiteness" as an element of the situation, and
e. vividness of scientific imagination.

12. The disagreement among technical forecasters makes the economic extrapolation of decreasing historical costs even more compelling.

Now let's fill in this outline.

Because energy plays so central a role, it is most important that we think clearly about the way energy is found and used. This is the common view:

> Money in the bank, oil in the ground.
> Easily spent, less easily found.
> The faster they're spent, the sooner they run out.
> And that's what the Energy Crisis is about.[2]

But this jingle omits the key forces that completely alter the outcome. We shall see that, with energy just as with other raw materials, a fuller analysis produces an entirely different outlook than does this simplistic Malthusian projection.

The analysis of the supply of mineral resources in chapters 1–3 identified four factors as being important: (1) the increasing cost of extraction as more of the resource is used, if all other conditions remain the same; (2) the tendency of engineers to develop improved methods of extracting the resource in response to the rising price of the resource; (3) the propensity for scientists and businesspeople to discover substitutes—such as solar or nuclear power as substitutes for coal or oil—in response to increasing demand; and (4) the increased use of recycled material.

The supply of energy is analogous to the supply of other "extracted" raw materials with the exception of the fourth factor above. Minerals such as iron and aluminum can be recycled, whereas coal and oil are "burned up." Of course this distinction is not perfectly clear-cut; quarried marble is cut irreversibly and cannot be recycled by melting, as copper can. Yet even cut marble can be used again and again, whereas energy sources cannot.

The practical implication of being "used up" as opposed to being recyclable is that an increased rate of energy use would make the price of energy sources rise sharply, whereas an increased use of iron would not affect iron prices so much because iron could be drawn from previously used stocks such as dumps of old autos. This may seem to make the energy future look grim. But before we proceed to the analysis itself, it is instructive to see how energy "shortages" have frightened even the most intelligent of analysts for centuries.

The English Coal Scare

In 1865, W. Stanley Jevons, one of the nineteenth century's greatest social scientists, wrote a careful, comprehensive book proving that the growth of

England's industry must soon grind to a halt due to exhaustion of England's coal. "It will appear that there is no reasonable prospect of any relief from a future want of the main agent of industry," he wrote. "We cannot long continue our present rate of progress. The first check for our growing prosperity, however, must render our population excessive."[3] Figure 11-1 reproduces the frontispiece from Jevons's book, "showing the impossibility of a long continuance of progress." And Jevons's investigation proved to him that there was no chance that oil would eventually solve England's problem.

What happened? Because of the perceived future need for coal and because of the potential profit in meeting that need, prospectors searched out new deposits of coal, inventors discovered better ways to get coal out of the earth, and transportation engineers developed cheaper ways to move the coal.

This happened in the United States, too. At present, the proven U.S. reserves of coal are enough to supply a level of use far higher than the present consumption for many hundreds or thousands of years. And in some countries the use of coal must even be subsidized because though the labor cost per unit of coal output has been falling,[4] the cost of other fuels has dropped even more. This suggests that not enough coal was mined in the past, rather than that the future was unfairly exploited in earlier years. As to Jevons's poor old England, this is its present energy situation: "Though Britain may reach energy self-sufficiency late this year or early next, with its huge reserves of North Sea oil and gas lasting well into the next century, the country is moving ahead with an ambitious program to develop its even more plentiful coal reserves."[5]

The Long-Running Running-Out-of-Oil Drama

Just as with coal, running out of oil has long been a nightmare, as this brief history shows:

> 1885, U.S. Geological Survey: "Little or no chance for oil in California."
> 1891, U.S. Geological Survey: Same prophecy by USGS for Kansas and Texas as in 1885 for California.
> 1914, U.S. Bureau of Mines: Total future production limit of 5.7 billion barrels, perhaps ten-year supply.
> 1939, Department of the Interior: Reserves to last only thirteen years.
> 1951, Department of the Interior, Oil and Gas Division: Reserves to last thirteen years.[6]

The fact that the gloomy official prophesies of the past have regularly been proven false does not prove that every future gloomy forecast about oil will be wrong. And forecasts can be overoptimistic, too. But this history does show that expert forecasts often have been far too pessimistic. We therefore should

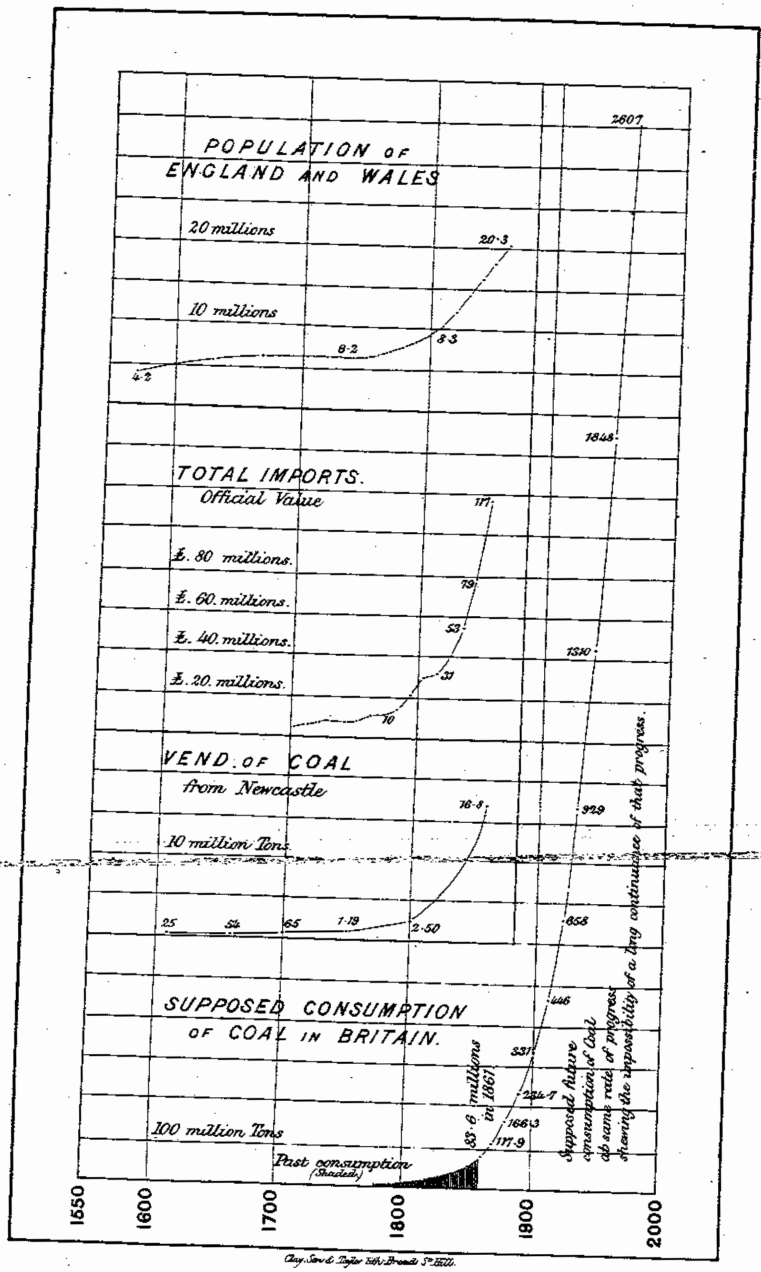

Figure 11-1. Jevons's View of Coal and of England's Future, as of 1865

not simply take such forecasts at face value, because of the bad record as well as because they are founded on an unsound method of proven reserves, as discussed in chapter 2.

The Long-Run History of Energy Supplies

The statistical history of energy supplies is a rise in plenty rather than in scarcity. As was discussed at length in chapter 1, the relevant measures are the production costs of energy as measured in time and money, and the price to the consumer. Figures 11-2, 11-3, and 11-4 show the historical data for coal, oil, and electricity. Because chapter 1 discussed the relationship of such cost and price data to the concepts of scarcity and availability, that discussion need not be repeated here. Suffice it to say that the appropriate interpretation of these data is that they show an unambiguous trend toward lower cost and greater availability of energy.*

The price of oil fell because of technological advance, of course. The price of a barrel (42 gallons) fell from $4 to thirty-five cents in 1862 because of the innovation of drilling, begun in Pennsylvania in 1859. And the price of a gallon of kerosene fell from fifty-eight cents to twenty-six cents between 1865 and 1870 because of improvements in refining and transportation, many of them by John D. Rockefeller. This meant that the middle class could afford oil lamps at night; earlier, only the rich could afford whale oil and candles, and all others were unable to enjoy the benefits of light.[7]

The price history of *electricity* is particularly revealing because it indicates the price to the consumer, at home or at work. That is, the price of electricity is closer to the price of the *service* we get from energy than are the prices of coal and oil, which are raw materials. And as discussed in chapter 3, the costs of the services matter more than the costs of the raw materials themselves.

The ratio of the price of electricity to the average wage in manufacturing (fig. 11-4) shows that the quantity of electricity bought with an hour's wages has steadily increased. Because each year an hour's work has bought more rather than less electricity, this measure suggests that energy has become ever less troublesome in the economy over the recorded period, no matter what the price of energy in current dollars.

In short, the trends in energy costs and scarcity have been downward over the entire period for which we have data. And such trends are usually the most reliable bases for forecasts. From these data we may conclude with consider-

* An interesting and revealing incident in which Ehrlich et al. asserted that the trend had changed before 1970, but their judgment was based on a single observation which turned out to be a typographical error, is discussed briefly in the Epilogue, and at more length in Simon (1990), selection 3, or in Simon (1980b).

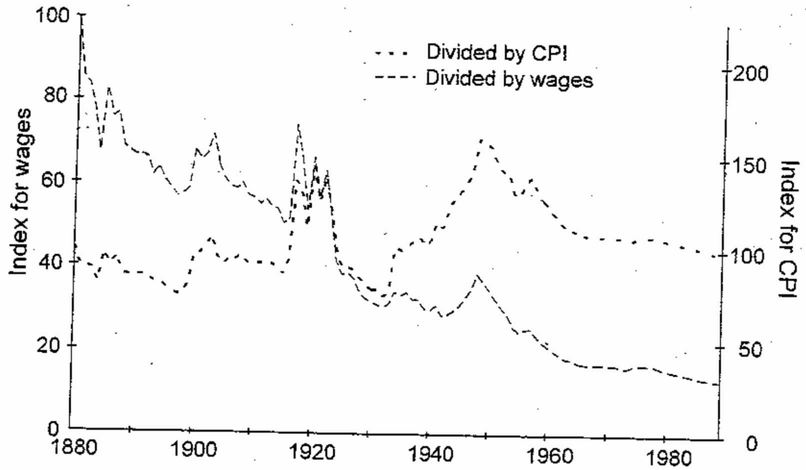

Figure 11-2. The Price of Coal Relative to the Consumer Price Index and Wages in the United States

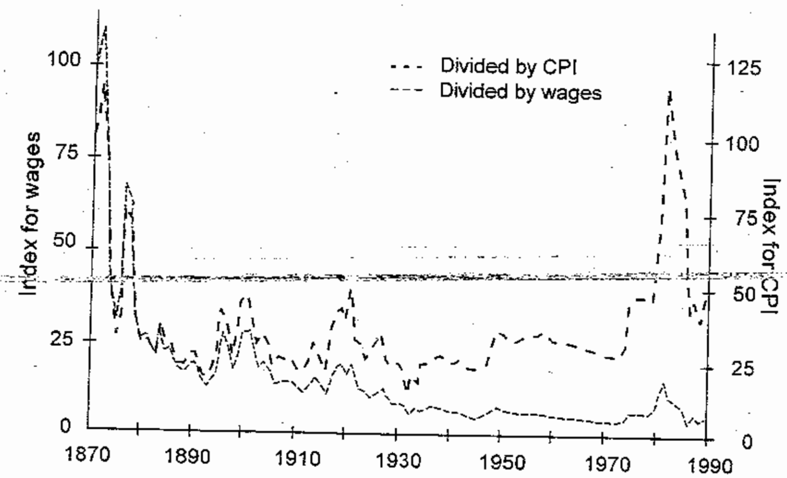

Figure 11-3. The Price of Oil Relative to the Consumer Price Index and Wages in the United States

able confidence that energy will be less costly and more available in the future than in the past.

The reason that the cost of energy has declined in the long run is the fundamental process of (1) increased demand due to the growth of population and income, which raises prices and hence constitutes opportunity to entrepreneurs and inventors; (2) the search for new ways of supplying the demand for

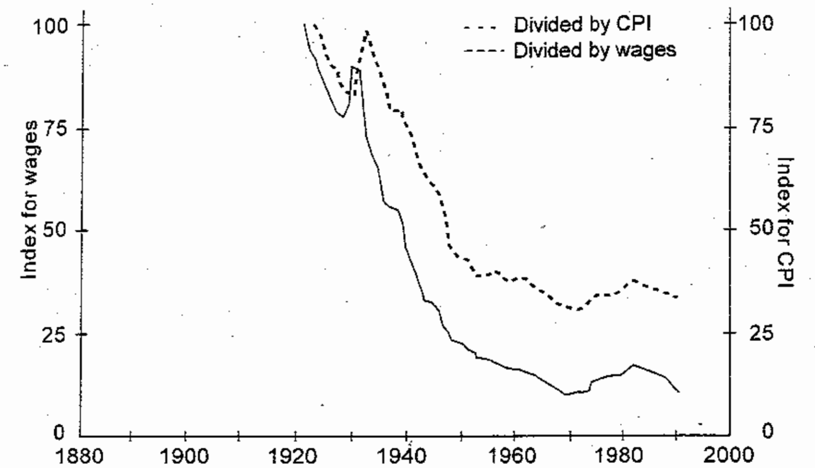

Figure 11-4. The Price of Electricity Relative to the Consumer Price Index and Wages in the United States

energy; (3) the eventual discovery of methods which leave us better off than if the original problem had not appeared.

An early illustration of the process: In 300 B.C.E., so much wood was being used for metal smelting that the Roman Senate limited mining. (Using the coercive power of government, instead of the creative power of the market, is a very old idea.)[8] Almost two millennia later, in England, the shortage of wood for use as charcoal in the casting of iron became so acute—it was affecting the building of naval ships—that in 1588 Parliament passed a law against cutting trees for coke in iron making, and then banned the building of new foundries in 1580.[9] Though the use of coal in place of charcoal had been known, there were technical difficulties—impurities that affected the quality of the iron. This time, the wood shortage exerted pressure that led to the development of coal as well as blowing machines to be used in smelting, a keystone in the upcoming Industrial Revolution.

Jumping Off the Eiffel Tower

You may object that extrapolating a future from past trends of greater and greater abundance is like extrapolating—just before you hit the ground—that a jump from the top of the Eiffel Tower is an exhilarating experience. Please notice, however, that for a jump from the tower we have advance knowledge that there would be a sudden discontinuity when reaching the ground. In the case of energy and natural resources, there is no persuasive advance evidence for a negative discontinuity; rather, the evidence points toward positive discontinuities—nuclear fusion, solar energy, and discoveries of energy sources that we now cannot conceive of. Historical evidence further teaches us that such worries about discontinuities have usually generated the very economic pressures that have opened new frontiers. Hence, there is no solid reason to think that we are about to hit the ground after an energy jump as if from an Eiffel Tower. More likely, we are in a rocket on the ground that has only been warming up until now and will take off sometime soon.

More appropriate than the Eiffel Tower analogy is this joke: Sam falls from a building he is working on, but luckily has hold of a safety rope. Inexplicably he lets go of the rope and hits the ground with a thud. Upon regaining consciousness he is asked: "Why did you let go of the rope?" "Ah," he says, "it was going to break anyway." Analogously, letting go of all the ropes that support the advance of civilization—for example, turning our backs on the best potential sources of energy—is the advice we now receive from energy doomsters and conservationists.

The Theory of Future Energy Supplies

Turning now from trends to theory, we shall consider our energy future in two theoretical contexts: (1) with income and population remaining much as they are now, (2) with different rates of income growth than now. (The case of different rates of population growth than now will be discussed in chapter 28.) It would be neatest to discuss the United States separately from the world as a whole, but for convenience we shall go back and forth. (The longer the time horizon, the more the discussion refers to the world as a whole rather than just to the United States or the industrialized countries.)

The analysis of energy resembles the analysis of natural resources and food, but energy has special twists that require separate discussion. With these two exceptions, everything said earlier about natural resources applies to energy: (1) On the negative side, energy cannot easily be recycled. (But energy can come much closer to being recycled than one ordinarily thinks. For example, because the fuel supply on warships is very limited, heat from the boilers is passed around water pipes to extract additional calories as it goes up the smokestack.) (2) On the positive side, our energy supplies clearly are not bounded by the Earth. The sun has been the ultimate source of all energy other than nuclear. Therefore, though we cannot recycle energy as we can recycle minerals, our supply of energy is clearly not limited by the Earth's present contents, and hence it is not "finite" in any sense at all—not even in the nonoperational sense.

Furthermore, humanity burned wood for thousands of years before arriving at coal, burned coal about three hundred years before developing oil, and burned oil about seventy years before inventing nuclear fission. Is it reasonable and prudent to assume that sometime in the next seven billion years—or

even seven hundred or seventy years—humanity will not arrive at a cheaper and cleaner and more environmentally benign substitute for fission energy?

But let us turn to a horizon relevant for social decisions—the next five, twenty-five, one hundred, perhaps two hundred years. And let us confine ourselves to the practical question of what is likely to happen to the cost of energy relative to other goods, and in proportion to our total output.

The Bogeyman of Diminishing Returns Again

First let us dispose of the "law of diminishing returns" with respect to energy. Here is how Barry Commoner uses this idea:

> [T]he law of diminishing returns [is] the major reason why the United States has turned to foreign sources for most of its oil. Each barrel [of oil] drawn from the earth causes the next one to be more difficult to obtain. The economic consequence is that it causes the cost to increase continuously.[10]

Another environmentalist explains her version of the "law of diminishing returns" with respect to oil:

> We must now extract our raw materials from ever more degraded and inaccessible deposits. This means that ever more of our society's precious investment capital must be diverted to this process and less is available for consumption and real growth. Fifty years ago, getting oil required little more than sticking a pipe in the ground. Now we must invest several billion dollars to open up the Alaska oilfields to deliver the same product. *Economists, if they understood this process as well as physical scientists*, might call it the declining productivity of capital [law of diminishing returns].[11]

All these quotes are just plain wrong; it costs less today to get oil from the ground in prime sources than it cost fifty years ago to get it from the ground in prime sources. (The second afternote to chapter 3 explains how there is no "law" of diminishing returns in general, and hence why this line of thinking is fallacious.)

In brief, there is no compelling theoretical reason why we should eventually run out of energy, or even why energy should be more scarce and costly in the future than it is now.

The Best—and Worst—Ways to Forecast Future Energy Availability

The best way to forecast price trends is to study past price trends, if data are available and if there is no reason to believe that the future will be sharply different from the past. (The reasoning that supports this point of view is set forth at length in chapter 2.)

For energy there are plenty of past price data available, as we have seen in figures 11-2, 11-3, and 11-4. And there is no convincing reason to believe that the future will break completely from the past. Therefore, extrapolation of the trends in those figures is the most reasonable method of forecasting the future of energy supplies and costs, on the assumption that price has been close to cost in the past and will continue to be so in the future. This method of economic forecasting envisions progressively lower energy costs and less scarcity.

Geologists and engineers, however, rely on technical rather than price-trend data in their forecasts of energy supplies. Because their forecasts have had so much influence on public affairs, we must analyze their methods and meanings.

We must first dispose of the preposterous but commonly accepted notion that the energy situation can be predicted with the aid of "known reserves." This notion is an example of the use of misleading numbers simply because they are the only numbers available. We briefly considered the uselessness of this concept of "reserves" in chapter 2 with respect to mineral resources. Now let us discuss it with respect to oil.

"Known reserves" means the total amount of oil in areas that have been prospected thoroughly, quantities that geologists are quite sure of. Individuals, firms, and governments create known reserves by searching for promising drilling areas long in advance of the moment when wells might be drilled—far enough ahead to allow preparation time, but not so far ahead that the investment in prospecting costs will not obtain a satisfactory return. The key idea here is that it costs money to produce information about known reserves. The quantity of known reserves at any moment tells us more about the expected profitability of oil wells than it does about the amount of oil in the ground. And the higher the cost of exploration, the lower will be the known reserves that it pays to create.

"Known reserves" are much like the food we put into our cupboards at home. We stock enough groceries for a few weeks or days—not so much that we will be carrying a heavy unneeded inventory that bulges the cupboard and ties up an unnecessary amount of money in groceries, and not so little that we may run out if an unexpected event—a guest or a blizzard—should descend upon us. The amount of food in our cupboards tells little or nothing about the scarcity of food in our communities, because as a rule it does not reveal how much food is available in the retail stores. Similarly, the oil in the "cupboard"—the quantity of known reserves—tells us nothing about the quantities of oil that can be obtained in the long run at various extraction costs.

This explains why the quantity of known reserves, as if by a miracle of coincidence, stays just a step ahead of demand, as seen in figure 11-5. An elderly man commented to me in the 1970s that, according to the news stories about known reserves, "we've been just about to run out of oil ever since I've

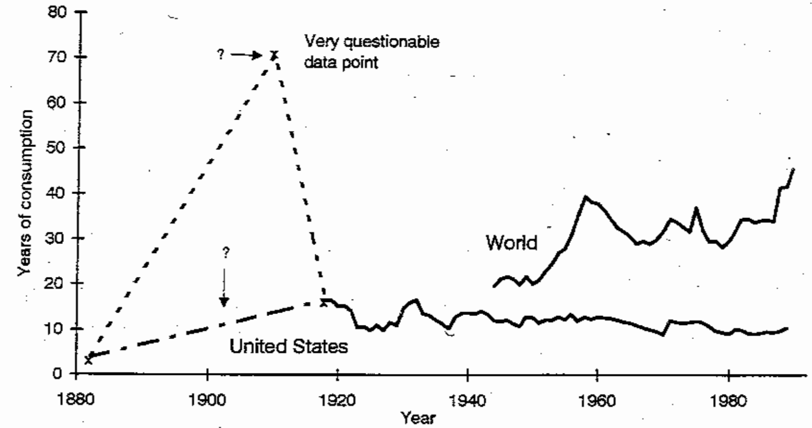

Figure 11-5. Crude Oil, United States and World Known Reserves/Annual Production

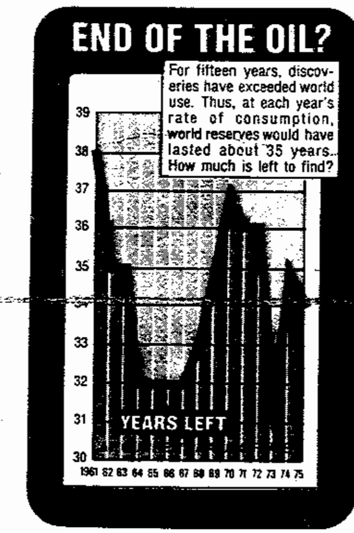

Figure 11-6. The Confusion of the Proven-Reserves Concept

been a boy." Yet most discussions of the oil and energy situation—among laymen and also among the most respected journalists—still focus on known reserves. Figure 11-6, taken from *Newsweek*, is typical. The graph apparently shows that the world's proven reserves have been declining, leading to the rhetorical threat above the picture "End of the oil? . . . How much is left to find?"

Even more misleading is a graph of proven reserves in the United States alone, as in figure 11-7. As the United States turns to imports because they are

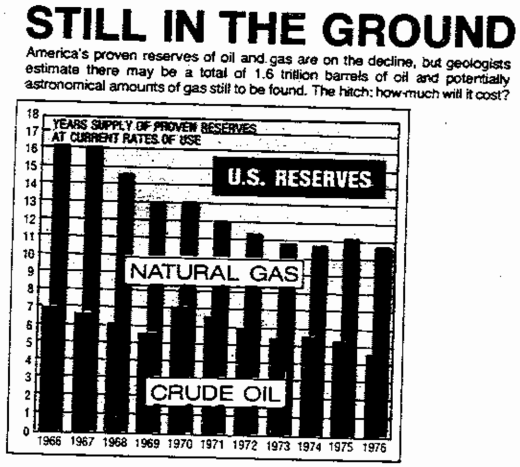

Figure 11-7. More Confusion

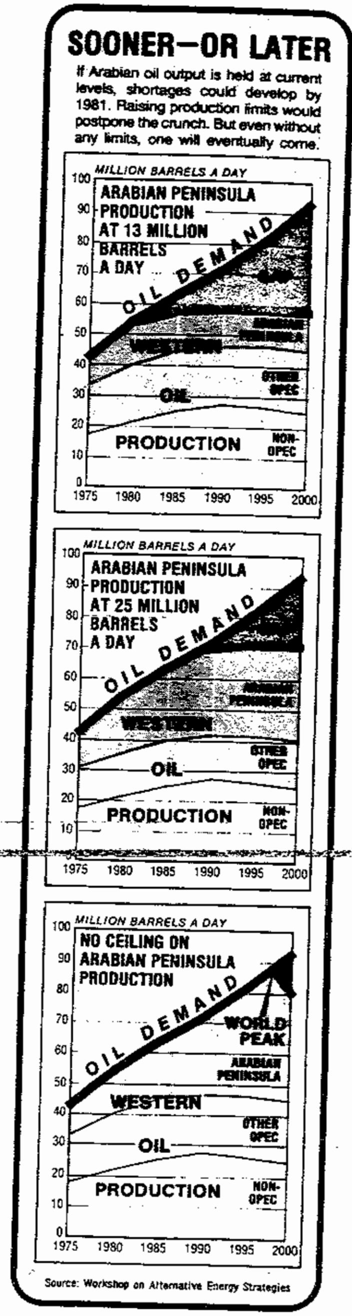

Figure 11-8. Another Form of Hokum

cheaper than the home product, its proven reserves inevitably will fall. If one were to draw a graph of U.S. proven reserves of aluminum or gold, they also would appear tiny. So what?

A more "sophisticated"—and even more misleading—approach is to project present growth in demand, assuming the price will remain constant, and then compare that projection to known reserves, thereby indicating that demand will apparently outstrip supply very soon. This approach may be seen in figure 11-8. Even assuming that the growth in demand at present prices is reasonably estimated—and this would be difficult to do well—all that such a calculation would show is that price must rise in order to lower the demand and raise the supply until demand and supply meet. This basic economic way of looking at supply and demand is totally missing from figure 11–8.

Equally misleading is the assumption underlying figure 11-8 that there will be no developments in oil production or in other energy sources that will make future energy costs lower than they would be with the present state of technological knowledge.

Better Technical Forecasting Methods

If one insists on making a technical forecast of the energy supply—even though such a forecast is likely to be inferior to extrapolations of past economic trends—how should it best be done? That is, how might one make a sound material-technical forecast for oil and energy in the near term—say over the next ten or twenty years? (See chapter 2 for a general discussion of material-technical forecasts of resource supply.)

During the next decade or two, increases in income and population in the United States and in the world may be assumed to be known. Therefore, they can be taken into account as data rather than treated as imponderables. In addition, forecasts of the production of energy in the near-term future utilize two other kinds of information: (1) engineering estimates of the cost of extracting fuel from such currently unexploited sources as shale oil and wind power with available technology, based on calculations of the engineering inputs required for each type of energy source; and (2) economic estimates of how many conventional new oil wells and coal mines and nuclear reactors will be developed at various prices higher and lower than the present energy prices, based on past data about the extent to which energy-producing firms respond to changes in market prices.

Engineering estimates must play the dominant role in forecasts of the place of nuclear energy, shale oil, solar power, wind power, and other energy sources for which there are considerable uncertainties about technical processes and costs due to a lack of experience with these sources. But where an energy source is currently being employed sufficiently to produce a large body of data about the process of extraction and about producer behavior; as is true of the fossil fuels, empirical economic estimates of supply response to price changes should have the dominant role. The best overall energy forecast, therefore, would be a blend of both the economic and engineering approaches.

There is great variety, however, in the estimates of engineers and scientists about the future costs of developing such energy sources as shale oil and nuclear power. Technologists also differ greatly in their guesses about the dangers to life from the various processes. And economists differ considerably in their estimates of the responsiveness of the energy industry to various price levels. For example, in 1977 the supply of natural gas became a very contentious political issue. These were some of the resulting supply estimates: (1) A predecessor agency of the Department of Energy, the Energy Research and Development Administration (ERDA), made three production estimates within three months, varying by a factor of three![12] President Carter offered an even lower estimate than the lowest of those three, that there was only "10 years supply . . . at 1974 technology and 1974 prices."[13] (2) The American Gas Association said that there is enough gas "to last between 1,000 and 2,500 years at current consumption." And the newspaper story continued that "Experts in ERDA have been trying to tell the White House [this] too."[14] The difference between this and the estimate in (1) above boggles the mind—ten years' supply versus a 1,000–2,500 years' supply! (3) A later "official" estimate, made in the midst of the congressional debate on energy in the same year 1977, by Dr. Vincent E. McKelvey, who was then director of the U.S. Geological Survey, was that "as much as . . . 3,000 to 4,000 times the amount of natural gas the United States will consume this year may be sealed in the geopressured zones underlying the Gulf Coast region."[15] But this estimate ran contrary to what the White House was saying, and within two months McKelvey was fired from his job as director—after six years as director and thirty-seven years at the Geological Survey, and after being nominated for the director's job by the National Academy of Sciences. As the *Wall Street Journal* put it, "Dr. McKelvey did not know enough to keep his mouth shut!"[16] Such enormous variation can arise simply as a result of political fiddling with the figures.

A more recent sober estimate by the "International Gas Union Committee on World Gas Supply and Demand estimates that even by the year 2000, the static lifetime of world gas reserves will be 112 years"[17]—and that does not include future discoveries of gas, of course.

With respect to still-undeveloped sources such as shale oil and artificial gas, the variation in estimates is greater yet.

Why do estimates of supply response to price changes differ so widely? There are a host of reasons, including (a) vested interests—for example, the oil companies have a stake in low gas prices paid to gas suppliers so that fewer gas wells will be drilled and more oil will be sold, and hence they want lower estimates of the responsiveness of natural gas supplies to changes in price; in contrast, gas companies have a stake in higher (unregulated) prices, and hence want higher estimates of gas supply responsiveness; (b) basic beliefs about the "finiteness" of potential supplies and about the likelihood of the human imagination to respond to needs with new developments; (c) differences in the scientific imaginations of the engineers and geologists making the estimates; and (d) professional differences among engineers and among economists due to differences in technical approaches.

Every month, it seems, we read of new ways to get more energy. Item: Three-dimensional seismic exploration methods have produced large new oil discoveries at very low cost. In Nigeria and Oman, Shell "has found new oil reserves at costs of less than 10 cents a barrel."[18] Item: Lumps of methane hydrate on the ocean floor could constitute "a potential fuel reserve that may dwarf all the fossil fuel deposits on land combined."[19]

In my view, the data and theory continue to support a forecast made years ago by Herman Kahn and associates. "Energy costs as a whole are very likely to continue the historical downward trend indefinitely. . . . Except for temporary fluctuations caused by bad luck or poor management, the world need not worry about energy shortages or costs in the future."[20]

What about the Very Long Run?

Chapter 3 alluded to the increase in efficiency in energy use over the decades and centuries. An analysis by William Baumol mentioned there shows that such increases in efficiency have huge effects. The key idea is that an improvement in productivity not only reduces resource use in the present but, even more important, also increases the future services of the entire stock of unused resources. This alone could mean that the future supply will never run out.

This process may be seen in figure 11-9, where the amount of coal required to move a ton of freight by sea fell to about a tenth of its 1830 value by 1890. That is a greater proportion of increase in efficiency than was the increase in population over those years. The transition to oil represented an increase in economic efficiency (or it would not have taken place). And there is no reason why that process should not continue indefinitely, with ship surfaces getting smoother, and so on. Of course nuclear power can replace coal and oil entirely, which constitutes an increase in efficiency so great that it is beyond my powers to portray the entire process on a single graph based on physical units.

Much the same occurs with electricity in figure 11-9. A generator converts the heat from fuels or the power of falling water into electrical energy. One

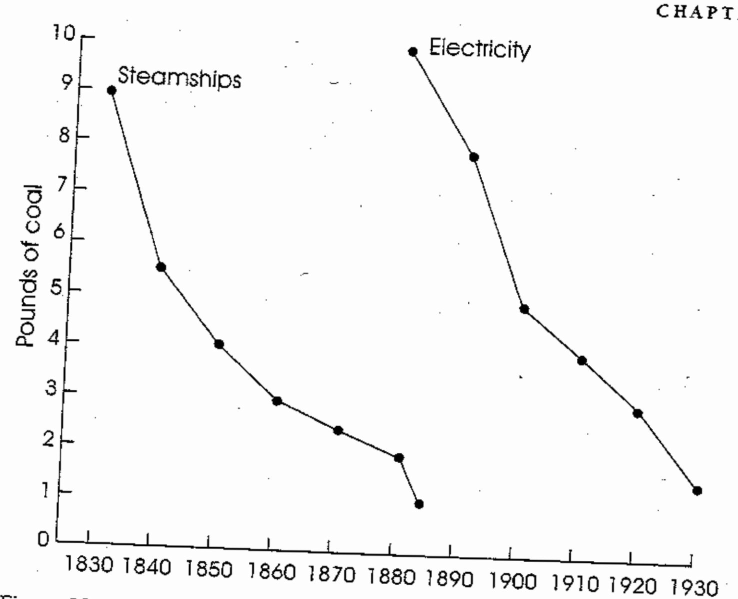

Figure 11-9. Energy Utilization over the Long Term, 1830–1930

cannot extract more energy from a generator than one puts in, but in addition to increasing efficiency in generation, there is increasing efficiency in end-use products such as refrigeration, heaters, and appliances.

The process is even more extraordinary with respect to the input of human energy (no matter how human energy is measured). A handful of humans can now move hundreds of thousands of tons of freight across an ocean in a single ship, many fewer people per ton than in centuries past. And measured in ton-miles per day, the increase in efficiency is even greater.

The Nonfiniteness of Oil

You may wonder whether "nonrenewable" energy resources such as oil, coal, and natural gas differ from the recyclable minerals in such a fashion that the nonfinite arguments in earlier chapters do not apply. Eventually we'll burn all the coal and oil that powered these impressive advances, you may be thinking. But our energy supply also is nonfinite, including oil as an important example. That was not a misprint. In chapter 3, I showed that it is necessary to say how one would count the amount of a resource if one is to meaningfully say that the resource is finite. Therefore, let's consider the following sequence of difficulties with respect to counting the amount of oil. As with other resources, careful thinking leads to the conclusion that the potential amount of oil—and even more, the amount of the services that we now get from oil—is not finite.

1. The oil potential of a particular well may be measured, and hence it is limited (though it is interesting and relevant that as we develop new ways of extracting hard-to-get oil, the economic capacity of a well increases). But the number of wells that will eventually produce oil, and in what quantities, is not known or measurable at present and probably never will be, and hence is not meaningfully finite.
2. Even if we unrealistically assume that the number of potential wells in the Earth might be surveyed completely and that we could arrive at a reasonable estimate of the oil that might be obtained with present technology (or even with technology that will be developed in the next one hundred years), we still would have to reckon the future possibilities of shale oil and tar sands—a difficult task.
3. But let us assume that we could reckon the oil potential of shale and tar sands. We would then have to reckon the conversion of coal to oil. That, too, might be done, but the measurement is becoming increasingly loose, and hence less "finite" and "limited."
4. Then there is the oil that we might produce, not from fossils, but from new crops—palm oil, soybean oil, and so on. Clearly, there is no meaningful limit to this source except the sun's energy (land and water are not limits—see chapters 6 and 10). The notion of finiteness is making ever less sense as we proceed.
5. If we allow for the substitution of nuclear and solar power for oil—and this makes sense because what we really want are the services of oil and not oil itself—the notion of a limit is even less meaningful.
6. Of course the sun may eventually run down. But even if our sun were not as vast as it is, there may well be other suns elsewhere.

The joke at the head of chapter 3 makes the point that whether there is an "ultimate" end to all this—that is, whether the energy supply really is "finite" after the sun and all the other planets have been exhausted—is a question so hypothetical that it should be compared with other metaphysical entertainments such as calculating the number of angels that can dance on the head of a pin. As long as we continue to draw energy from the sun, any conclusion about whether or not energy is "ultimately finite" has no bearing upon present policy decisions.

About energy from the sun: The assertion that our resources are ultimately finite seems most relevant to energy but yet is actually more misleading with respect to energy than with respect to other resources. When people say that mineral resources are "finite," they are invariably referring to the Earth as a bounded system—the "spaceship Earth" to which we are apparently confined just as astronauts are confined to their spaceship. But the main source of our energy even now is the sun, no matter how you think of the matter. This goes far beyond the fact that the sun was the prior source of the energy locked into the oil and coal we use. The sun is also the source of the energy in the food we eat, and in the trees that we use for many purposes.

In coming years, solar energy may be used to heat homes and water in many parts of the world. (As of 1965, much of Israel's hot water had been heated by solar devices for years, even when the price of oil was much lower than it is now, although I remember that the showers you got with this water were at best lukewarm unless you used a backup electrical system to boost the temperature.) If the prices of conventional energy supplies were to rise considerably higher than they now are, solar energy could be called on for much more of our needs, though this price rise seems unlikely given present technology. And even if the Earth were sometime to run out of sources of energy for nuclear processes—a prospect so distant that it is a waste of time to talk about it—there are energy sources on other planets. Hence, the notion that the supply of energy is finite because the Earth's fossil fuels or even its nuclear fuels are limited is sheer nonsense. And this discussion has omitted consideration of any energy sources still to be discovered.

Conclusions

Energy differs from other resources because it is "used up," and cannot be recycled. Energy apparently trends toward exhaustion. It seems impossible to keep using energy and still never begin to run out—that is, never reach a point of increasing scarcity. But the long-run trends in energy prices, together with the explanatory theory of induced innovation, promise continually decreasing scarcity and cost—just the opposite of popular opinion. At worst, the cost ceiling provided by nuclear power guarantees that the cost of electrical power cannot rise far above present energy costs, political obstacles aside.

The historical facts entirely contradict the commonsensical Malthusian theory that the more we use, the less there is left to use and hence the greater the scarcity. Through the centuries, the prices of energy—coal, oil, and electricity—have been decreasing rather than increasing, relative to the cost of labor and even relative to the price of consumer goods, just as with all other natural resources. And nuclear energy, which at present costs much the same as coal and oil,[21] guarantees an inexhaustible supply of energy at declining cost as technology improves.

In economic terms, this means that energy has been getting more available, rather than more scarce, as far back as we have data. This implies that the rate at which our stocks of resources increase, or the increasing efficiency of use over time, or a combination of the two forces, have overmatched the exhaustion of resources.

Another way to look at the matter: Energy has become less and less important as measured by its share of GNP. This is the same story as revealed by all other natural resources.

The reason that the prices of energy and other natural resources decline even as we use more is the advance of technology. Nevertheless, just as with land and copper, there are other forces at play which make it possible for us to have increasing amounts of the services we need even as we boost the demands we make upon the supplies of those resources.

One saving grace is improved techniques of use. Consider the steam engine, which when first invented operated at 1 percent efficiency. Engines nowadays operate perhaps thirty times more efficiently. That is, they use a thirtieth as much energy for the same result. The invention of the microwave oven immediately meant that only 10 percent as much energy was necessary to cook a meal as before.[22] When someone finds a way to increase the efficiency of using a resource, the discovery not only increases the efficiency of the energy we use this year, but it also increases the effective stocks resources that are known or are as yet undiscovered. And this process could continue for a long time, perhaps indefinitely.

Also important are increases in energy supply. We learn how to dig deeper, pump faster. And we invent new sources of energy—aside from coal, shale, oil, tar sands, and the like. We can also "grow" oil substitutes as long as there is sunlight to raise plants. (See chapter 6 on hydroponic farming using fresh water. And production of oil-seed crops that grow with salt water, which allows agriculture with irrigation of the desert, is now entering commercial development in Saudi Arabia.)[23] Also, nuclear fission power will be available at constant or declining costs practically forever.

After our sun runs out of energy, there may be nuclear fusion, or some other suns to take care of our needs. We've got seven billion years to discover solutions to the theoretical problems that we have only been able to cook up in the past few centuries of progress in physics. It's reasonable to expect the supply of energy to continue becoming more available and less scarce, forever.