CHAPTER SEVEN

Expert Estimates of Oil-Reserves and the Transformation of "Petroknowledge" in the Western World from the 1950s to the 1970s

Rüdiger Graf

Introduction

In November 1977, the West German Körber Foundation organized its 58th conference that brought together German and international politicians, journalists, economists, social scientists, and energy experts to debate the energy crisis. After a presentation by the European Commissioner for Energy, Klaus M. Meyer-Abich, a professor of philosophy of the natural sciences, predicted there would be sufficient energy from fossil fuels until the mid 1980s. Meyer-Abich argued further that after the year 2000, all energy problems would be solved by inexhaustible sources of nuclear fusion and solar energy. Before 2000, however, he expected a serious energy problem for industrialized countries.[1] Although this now sounds like a ridiculous prediction, none of the experts present at the conference questioned his claim. On the contrary, Walter J. Levy, an eminent U.S. oil expert who had worked for several U.S. government agencies, supported Meyer-Abich's view, arguing that the industrialized countries might face a serious energy problem between 1985 and 1990 when there would be a shortage of oil, coal, atomic, and solar energy.[2]

Meyer-Abich's prediction is one example of many similarly false expert predictions of energy reserves. The history of energy prognoses, and of the future availability of oil in particular, is one of fantastic failures.[3] Despite the economic and political importance of oil and the enormous intellectual and financial resources spent on oil exploration and prediction, expert opinions after 1945 differed widely and most predictions failed.[4] Yet it is too easy to ridicule the mistakes of past experts using the knowledge of later generations, particularly because today we are not in a fundamentally better position: Prophets of an impending "peak oil" exist alongside those who rely on the infinite availability of oil. At least one of these groups must be fundamentally wrong.[5] In the following chapter, I will assume a different perspective by asking why historical oil prognoses were surprisingly unsuccessful. What was specific about the "unknowns" surrounding the future availability of oil that made it so difficult to predict its development or to foresee impending crises? Which different groups of experts produced estimates of oil reserves and how did their discursive hegemony change over time? Thus, the chapter ties into current debates concerning the status of knowledge and insecurity in modern societies as they become increasingly oriented towards the future.[6]

While the question may sound abstract and theoretical it can only be answered historically by looking at the reasons for falsified hypotheses about the future of oil. In order to do this, I will adopt and modify the concept of "petroknowledge" that has been coined by the political scientist Timothy Mitchell as a description of postwar Keynesian economics.[7] Unlike Mitchell, I use the term in a broader sense, signifying the various systems of expert knowledge that surrounded the oil economy in the twentieth century. There were three main groups of experts producing petroknowledge: petroleum geologists and engineers, energy economists, and political scientists. Dealing with the future availability of oil from different scientific and practical backgrounds, they produced heterogeneous bodies of petroknowledge that changed over time. Depending on their scientific backgrounds, the experts' concepts of what a reserve was and how it had to be calculated varied significantly. Each group knew different things about oil and, for each, different aspects of the oil question were unknown. While certain unknowns stood in the focus of their specific research interest, each group of experts neglected other aspects of the oil question in producing a certain body of knowledge, and had blind spots that remained unknown throughout the research process.

The following paper deals with the various forms of petroknowledge produced by Western experts and their complex interactions. It will not provide a comprehensive account of all knowledge claims concerning petroleum but will focus the perspective on the United States and the period leading up to the first oil crisis of 1973–74. Above all, I will try to elaborate the characteristic elements of three different approaches towards the issue stemming from heterogeneous scientific backgrounds. First, I will concentrate on the concrete physical assessments of oil reserves made by petroleum geologists and engineers. In the years leading up to the first oil crisis, economists and political scientists increasingly challenged their predictions. In the second and the third part of this paper, I will analyze how and why new forms of expert economic and political knowledge became more important for the prediction of the availability of oil. Finally, I will argue that the achievements of petroleum engineering and geology increased the importance of oil for Western industrialized countries but simultaneously eroded the dominant position of engineers and geologists in predicting and managing oil reserves. This self-marginalization via success became apparent and was further catalyzed in the so-called oil crisis from 1973 to 1974.

Assessing Material Reserves: Petroleum Geology and Engineering

With the growing significance of oil for the industrialized economies during World War II and the postwar economic boom, predictions about the availability of oil reserves became increasingly important. The inaccessible underground locations, varying volumes, and worldwide distribution of petroleum reservoirs made their size difficult to estimate. Among the scientific experts producing knowledge about the future availability of oil, petroleum geologists were most concretely occupied with the reservoirs and reserves in a physical sense. They developed methods and tools in order to estimate the locations and sizes of oil fields around the globe. Since there is no way of certifying the existence of an oil field apart from drilling, they interacted closely with petroleum engineers.[8]

While the beginnings of petroleum engineering date back to the late nineteenth century, it evolved as an autonomous discipline alongside petroleum geology at the beginning of the twentieth century. In 1914, the American Institute of Mining and Metallurgical Engineers (AIME) established a Technical Committee on Petroleum and, roughly at the same time, Petroleum Engineering was introduced into the curriculum at several universities especially in the oil producing states.[9] The increasing demand for oil in the course of World War II led to a further professionalization of petroleum engineering, and reservoir engineering emerged from the war as an autonomous discipline.[10] From the 1950s onward, primarily specialized petroleum engineers (and not generally educated engineers as before), many of whom came from rural areas in the oil producing states and had fathers in the oil business, worked on the oil fields.[11] While in 1923 the Petroleum Division of the AIME had had only 900 members, membership had risen to 12,400 when it became the Society of Petroleum Engineers in 1957 and reached 18,034 in 1970.[12] Correspondingly, in 1917, 122 geologists founded the American Association of Petroleum Geologists, which attracted more than fifteen thousand members by the early 1970s.[13]

The knowledge of the petroleum geologists and engineers was necessary in order to estimate the future availability of oil for two reasons. First, they developed methods to assess the location and size of petroleum reservoirs and, second, their oil recovery techniques determined the total amount of oil ultimately recoverable from a particular reservoir, i.e., the reserve. In his 1953 handbook on *Petroleum Production Engineering*, Lester Charles Uren defined an oil and gas reservoir as "a body of porous and permeable rock containing oil and gas, through which fluids may move toward recovery openings under the pressures existing or that may be applied."[14] While there was no commonly accepted usage throughout the literature, "reserve" mostly denoted that part of a reservoir that could be produced in a profitable way under current—and sometimes also future—economic and technological conditions.[15] Vincent E. McKelvey, the chief geologist of the United States Geological Survey and its director from 1971 to 1977, argued that two elements were essential for the definition and distinction between resources and reserves. These were the "knowledge about the existence, quality, and magnitude of individual deposits" and "the feasibility of their recovery under existing prices and technology." The U.S. Geological Survey and the U.S. Bureau of Mines officially used his categorization by differentiating between "reserves" as "identified deposits presently producible at a profit" and "undiscovered and subeconomic material," i.e., resources.[16]

After 1945, textbooks for the education of future petroleum engineers described elaborate methods for finding oil reservoirs. According to Hewitt C. Dix, a geophysical consultant of the California Research Corporation and associate professor of geophysics at the California Institute of Technology, in the 1950s the exploration process consisted of nine steps: 1) library studies, 2) surface geology, 3) core drilling, 4) aerial mapping, 5) magnetometer surveys, 6) gravity surveys, 7) seismic reflection exploration, 8) seismic refraction, and 9) wildcat drilling.[17] Distinguishing only gravitational, magnetic, and seismic methods, in the introduction to his 1960 textbook *Petroleum Engineering*, Carl Gatlin concluded that the seismograph was "the most successful and widely applied geophysical tool in exploration history."[18] However, even with the use of the seismograph that started in the 1920s and had its first successes in the 1930s, it was hard to ascertain the existence of oil without drilling. As Gatlin argued, "the success percentage for technical methods has been relatively constant for the last 15 years at about 12.5 percent, or approximately one success per eight wildcats."[19] This rate remained stable during the 1960s and only slightly improved afterwards.[20] Yet, due to technical improvements and new methods in oil production, the rate of oil to be recovered from a certain well changed significantly in the fifty years after World War II. Whereas the recovery factor was only about 10 percent in the earlier years, current estimates range from 35 percent to 60 percent for certain fields.[21] Because of improved recovery rates, the upsizing of existing oil fields that had been assumed to be smaller, and the discovery of new fields, the estimated world oil reserves increased continuously in the second half of the twentieth century. According to calculations based on data from the oil companies, world oil reserves increased from 68.2 billion barrels in 1948 to 1,007.5 billion barrels in 1996.[22]

The continuing success of petroleum geologists and engineers from the 1950s to the 1970s led them to look back at the history of their field with satisfaction and expect a great future for their professions. Apart from the pessimists who had always accompanied the development of the oil industry with the prediction that it would run out of oil, in the 1960s geoscientists, in general, were optimistic that they would increase oil reserves because of new and better techniques for decades to come.[23] In its twenty-fifth anniversary issue, the *Journal of Petroleum Technology*, the official periodical of the AIME, celebrated a quarter century of success in 1973. Reaffirming an old-fashioned faith in technological progress, they reveled in "milestones of . . . reservoir engineering" and improved production techniques through automatization and computerization.[24] Technological improvements were indeed significant. Apart from improved recovery techniques, the increasing capacity of offshore exploration and production was probably most important for the constant growth of reserve estimates in the 1950s and 1960s.[25] While the first oil rig was built in only 20 feet of water in 1947, rigs at depths of 200 feet were possible by 1959, and there were designs for oil rigs in 2000-foot deep water by 1971.[26] Petroleum engineers and geologists exhibited a strong belief in their inventory and exploratory spirit on the basis of these improvements. In general, they believed in progress by means of masculine activity, an attitude which can nicely be captured in the advertisements in the *Journal of Petroleum Technology*.[27] Extending their success story into the future at the beginning of the 1970s, they considered the "world petroleum future" to be one of "large and rising consumption with adequate supply."[28] Since they were the men of "ingenuity, imagination, industry, and perseverance" who had been "so vital and instrumental in making oil and gas available in abundance," they would earn "recognition as the technical and scientific pioneers without whom the world would be almost a century behind in progress, prosperity and freedom from drudgery."[29]

According to their self-perception, petroleum engineers were "resource managers" having the "obligation to analyze all the data available and to interpret it effectively in order to forecast the future performance of the wells and plant."[30] The information provided by engineers and geologists was essential for exploratory efforts, investment strategies, and the financial assessment of various firms.[31] However, while most of them concentrated their forecasts on the performances of specific wells, oil fields, or at best regions, rising energy consumption produced the need for predictions about national and global oil reserves. Yet, forecasts of oil in place and recovery rates, which were already difficult for a specific well or plant, became even more complicated if conducted on a national and international scale. As Gary Bowden has shown, geological estimates of ultimately recoverable crude oil reserves in the United States went up to 220 billion barrels until the second half of the 1950s. Between the late 1950s and 1974, many estimates increased significantly and resulted in a wide range of prognoses of up to 650 billion barrels. However, in the second half of the 1970s, estimates were closer together again and ranged between 150 and 250 billion barrels.[32] Yet, petroleum geologists and engineers disagreed not only over the figures, but also over the methods of estimating future oil reserves.

Each year, the American Petroleum Institute (API) added up the oil companies' numbers of proved reserves in order to estimate the total amount of oil reserves in the United States. Due to the considerable progress in petroleum technology and the fact that estimates of ultimately recoverable reserves always grew over the course of the exploitation of a certain field, geologists and engineers in the 1960s were dissatisfied with the results and questioned the value of the API statistics. In 1965 Wallace F. Lovejoy and Paul T. Homan argued that "proved reserves represent an estimation, under a rather limited and specific definition, of what may be called a 'current inventory' of recoverable oil underlying existing wells within a very restricted geographic and geological circumference . . . they do not reflect the reasonable expectations of the industry concerning the amount of oil that will ultimately be recovered from known fields."[33] Working for the influential think tank Resources for the Future, they demanded "estimates, however rough, of the quantities of reserves that can be expected under different economic and technological conditions."[34] Thus, under the impression of the continuously upgraded petroleum estimates, they suggested a series of steps in order to improve the numbers of the API which, at the end of 1964, estimated 31 billion barrels of U.S. oil reserves. First, they argued that considering the "later proved contents of known fields," one could add "a tentative value of 25 to 35 billion barrels of crude oil" to the original estimate. Moreover, they followed the Interstate Oil Compact Commission (IOCC) in adding another 16 billion barrels "which could be economically recovered by the application of present conventional secondary recovery methods [gas or water injections, RG] to existing reservoirs."[35] In addition, they wanted to project the past improvement of recovery rates into the future in order to account for future technological progress. Taken together, that led to an estimate of between 300 and 400 billion barrels. Finally, there was the "attempted quantification of reserves from oil in fields yet to be discovered." Lovejoy and Homan conceded, however, that "the range of speculation is wide in the face of two unknowns: (1) the quantity of oil in place to be discovered and (2) the percentage rate of discovery."[36] As Hewitt C. Dix had remarked more than ten years earlier, the probabilities of finding and of recovering oil had to be multiplied and would, thus, result in a high degree of uncertainty.[37]

At the beginning of the 1960s, Alfred Zapp had developed another method to reduce uncertainties that produced even higher estimates. While working for the U.S. Geological Survey, Zapp suggested that one would have to drill exploratory wells every two square miles in potentially petroleum-bearing basins in the United States in order to determine the amount of reserves. Extrapolating the average petroleum return from each existing exploratory well, he estimated that there would be 590 billion barrels of crude oil to be found in the United States.[38] Similarly, the Accelerated National Oil and Gas Resource Appraisal (ANOGRE) was designed to produce an estimate of the undiscovered oil and gas resources for the lower forty-eight states of the United States. Subdividing the unproduced reservoirs into measured, inferred (and indicated), and undiscovered recoverable reserves, the idea consisted of the following equation: "The quantity of known recoverable hydrocarbons is to the volume of drilled rocks (both dry and productive) as the quantity of undiscovered recoverable resources is to the volume of undrilled favorable (potential) rocks times a numerical richness factor f."[39] Despite the clear mathematical formula that suggests validity and exactitude, uncertainty would only be reduced on two conditions. The first was if it was possible to determine what "favorable rocks" were, and the second was if we knew how to determine the value of "f." However, even at a conference organized by the American Association of Petroleum Geologists that brought together more that fifty experts at Stanford University in 1974, nobody came up with a convincing strategy to determine f: "A lively discussion ensued regarding the logic of assigning values of 1.0 and 0.5 to the probability factor, f. It was generally thought that f was smaller than 0.5."[40] Hence, ANOGRE veiled rather than decreased the uncertainty in geological estimates of ultimately recoverable reserves.

In the second half of the 1950s, Marion King Hubbert developed a fundamentally different approach from his colleagues. Before joining the U.S. Geological Survey, Hubbert taught at Columbia and Stanford universities, worked for several government agencies and as a geologist for Shell Oil and Shell Development Companies.[41] Already a well-known and respected geologist, he published his basic idea commonly known as "Hubbert's peak" in 1956 and reformulated it in 1962. His approach took the finiteness of minerals seriously and tried to correlate the rate of oil discovery and the rate of production statistically. Noting the change of production over time for any finite resource, Hubbert argued that the curve would have the following characteristics: "It must begin with $P = 0$, and, after passing through one or more maxima, it must ultimately decline to zero. This last state would be due either to the exhaustion of the resource or to the abandonment of its production for other reasons."[42] Focusing his analysis on the United States at first, he analyzed two series of statistical data, namely the "quantity of crude oil produced in the United States per year" and the "estimates of proved reserves of crude oil in the United States made annually since 1937 by the Committee on Petroleum Reserves of the American Petroleum Institute."[43] Concerning the rate of proved discoveries Hubbert argued that it would be a bell-shaped curve with its inflection point in 1956. Since one could only produce the oil that had already been discovered, Hubbert argued that the curve of the rate of production had to peak shortly after the rate of proved discoveries. Calculating that the time span between the curves would be ten and a half years, he predicted a production peak in 1967, which he later corrected to 1970. Hubbert predicted that around 170 billion barrels crude oil would be produced ultimately in the United States. After this estimation of U.S. petroleum reserves, Hubbert applied the same method to the world as a whole and concluded that the "culmination of world production should occur about the year 2000 AD."[44] Often using an enormous time scale from 5000 BC to 5000 AD, Hubbert argued that the use of fossil fuels as a whole would only be a very short period in the history of mankind, ending around the turn of the century.[45]

Despite the fact that Hubbert worked as a research physicist for the U.S. Geological Survey from 1963 to 1976, it was not until the early 1970s that his colleagues started to accept his method of estimating oil reserves. As Gary Bowden has argued, this shift may be attributed not only to the fact that U.S. oil production had really peaked around 1970 but also to the changing interest structure within the oil industry.[46] Yet, even after 1973–1974, many petroleum engineers refused to follow Hubbert's conclusions and continued to believe in the application of new concepts and tools to large unexplored (offshore) regions.[47] Hubbert's estimates had been under attack from various sides since their first publication. Geologists criticized Hubbert's method because it was not based upon geological evidence in a strict sense.[48] Rather, Hubbert had extrapolated statistical trends by means of a mathematical formula. But, as M. J. Ryan argued in the *Journal of Petroleum Technology*, "there is no fundamental law of physics insuring that cumulative discoveries or cumulative production will follow a logical pattern in the future."[49] Ryan added that there was no reason to assume that 1956 was the real inflection point of the curve and to deny the possibility of further peaks in discovery that might result from technological improvements or exploratory efforts.

Hubbert's critics were motivated by two vested interests beyond an optimistic belief in their own ingenuity and scientific progress. First, they sought to preserve their own expert knowledge in determining future petroleum reserves against a colleague who deprofessionalized this politically highly valuable task. Discussing the various methods of estimating oil reserves in the *Bulletin of the American Association of Petroleum Geologists*, the Venezuelan geologist Anibal R. Martinez argued that "the only scientific approach to the problem of estimating oil resources is, precisely, the application of geological principles and the understanding of the factors which control petroleum occurrence."[50]

While Martinez acknowledged Hubbert's method to be useful for estimating the duration of the availability of oil reserves, Lewis Weeks argued more rigorously that estimates that were "based on statistics without regard for the controlling fundamentals should not be dignified as estimates of resources."[51] Without mentioning Hubbert in his response to Martinez, he asserted that the "very real factors of geological environment and history that control oil occurrence" had to be taken into consideration in order to achieve correct estimates. Secondly, the oil industry for which many of the geologists worked had an interest in larger estimates since higher expectations of ultimately recoverable petroleum reserves would induce further exploratory investments and therefore result in more oil production. To a certain extent, high expectations could turn into self-fulfilling prophecies in the same way as low estimates would prevent investments and reduce the amount of oil ultimately produced.[52] Until the early 1970s, when the oil industry started to substitute profit maximization by volume with profit maximization by margin—thus increasing prices—there was a strong incentive for high reserve estimates.[53] When oil production peaked in the United States at the beginning of the 1970s, petroleum geologists worried about their job security, the structure of their academic education and saw the need to enhance their general position in society.[54] Many of them simultaneously expressed skepticism concerning overly optimistic petroleum estimates and the concepts employed to produce them. For example Earl Cook, a professor at Texas A&M University, developed the problem of an overly materialistic conception of the "resource base" in the process of assessing ultimately recoverable reserves: "Poorly defined terms and unjustifiable usages of figures representing a wide range of uncertainty are barriers to general understanding of fossil energy futures. Geologic estimates of oil in place tend to project past costs of exploitation and to ignore exponential increases of work cost with depth and with reservoir recalcitrance; they also ignore the probability that 'substitution' technology will outpace petroleum technology, and will transform most 'undiscovered reserves,' if they exist into mere geologic anomalies."[55] Because of these problems, Cook concluded that non-geologic methods of estimating future availability of oil and gas, such as Hubbert's, might be better guides than geologic methods.

Skepticism was even more appropriate as more and more experts claimed that the availability of oil was not only determined by geological, but also to a rising extent by economic and political factors. As M. J. Owings, a representative of Gulf Oil Corporation, declared at the 46th meeting of the Society of Petroleum Engineers in New Orleans in 1971, "the most influential factors governing future supply and demand of hydrocarbons are the sociological and political tendencies, policy decisions, and the possible discovery of large new oil sources."[56] While government officials like President Richard Nixon's energy adviser Charles DiBona still assured the engineers and geologists that their work was needed more than ever because there were too many "simplifiers" and too few "complexifiers," the profession was in turmoil as economists and political scientists increasingly claimed oil expertise for themselves.[57] In 1973, the U.S. Geological Survey published a huge volume on *Mineral Resources in the United States* in order to demonstrate the importance of seventy essential minerals for modern civilization and raise awareness for the work of geologists who were recovering them. In their introduction, Donald A. Probst and Walden P. Pratt recognized a growing interest in natural resources but, distinguishing between reserves and resources, they criticized the fact that most public resource estimates lacked geological expertise:

> The almost universal tendency of such articles is to discuss mineral resources principally from the perspective of economic availability under a given set of circumstances, thereby overlooking the vital fact that reserves are but a part of resources. The results are, we feel, disturbing. Evaluations predicated only on knowledge (or estimates) of current reserves can easily lead to forecasts of the death of the industrial society in a short time. On the other hand, evaluations based on another kind of assumption suggest that a rise in prices will increase the reserves and bring much more material to market economically . . . This reasoning too is fallacious because elements are available in the earth's crust in very finite amounts. But in both instances, the reasoning leads to serious misinterpretations because it does not give adequate consideration to the single factor that ultimately determines all levels and degrees of mineral potential: geologic availability.[58]

As geologic availability was the basis of economic availability, geologists demanded to be ultimately responsible for the conduct of oil and resource policy. Yet, when the president of the American Association of Petroleum Geologists formulated this claim in 1974, economists and political and social scientists had already become highly influential over the course of the so-called first oil crisis.[59]

"It's the Economy, Stupid": Exhaustibility and the Rise of Energy Economics

By the early 1970s, economists and political scientists had already become busy speculating on the future of petroleum reserves. In contrast to geological predictions, however, their estimates were largely disconnected from the material oil reserves. Energy economists designed sophisticated statistical methods in order to predict the future developments of the oil market. In general, political and economic decision makers are not interested in the physical size of the oil reserves, but rather in the price and duration of the availability of oil. Both depend heavily on the growth of energy consumption. Thus, economists and political and social scientists engaged in the business of oil prediction estimated future demand and market behavior. In contrast to petroleum geologists, energy economists concentrate their analyses on the oil market and on the price mechanism in particular. Single papers on energy economics focusing on the specific conditions of economic processes involving, in principle, finite minerals had appeared throughout the twentieth century. However, it was not until the upheavals of the oil market in the 1970s that petroleum turned into an important topic for economists and energy economics became a respected sub-discipline within the field of economics.[60] After a period of intense scholarly debates in economic journals in the 1970s and 1980s, a number of textbooks appeared, introducing students to the now well established field of study.[61]

One of the seminal works that can exemplify the basic problems of energy economics that puzzled economists was Harold Hotelling's *The Economics of Exhaustible Resources*, published in 1931.[62] Using the example of a single mine owner producing an exhaustible resource that is an "absolutely irreplaceable asset," Hotelling tried to determine the ideal rate of production in order to "make the present value of all his future profits a maximum."[63] The basic economic problem results from the so-called scarcity rent, the assumption that under the conditions of scarcity the value of his non-financial asset will rise in the future. Hotelling states, "If a mine-owner produces too rapidly, he will depress the price, perhaps to zero. If he produces too slowly, his profits, though larger, may be postponed farther into the future than the rate of interest warrants."[64] Thus he has to find a course between these two poles, determining if it is "more profitable to complete the extraction within a finite time, to extend it indefinitely in such a way that the amount remaining in the mine approaches zero as a limit, or to exploit so slowly that mining will not only continue at a diminishing rate forever but leave an amount in the ground which does not approach zero."[65] Against contemporary conservationist ideas that exhaustion could never be too slow for the public good, Hotelling argued that there was an optimal rate of production if the change in the net price over time equaled the changing discount rate. In other words, the oil price must cover not only the marginal costs of producing it but also the present value of marginal profits given up by producing it now instead of later. Thus, "each unit value must increase at a rate linked to the rate of interest which states the return gained by holding the asset instead of selling it."[66]

While studies on energy issues had become more frequent in economic journals in the late 1960s, the early 1970s witnessed an explosion of papers on the economics of energy and oil due to the transformation of the oil market. In 1977, F. M. Peterson and A. C. Fischer reviewed the first wave of literature on the economic problems of exhaustible resources that had been triggered by the energy crisis and the worries about the "limits to growth" propelled by the MIT report to the Club of Rome. From an economic point of view, these broader concerns about scarcity and exhaustion appeared to be unfounded. As Peterson and Fischer concluded "perhaps surprisingly" on the basis of the new economic literature, it turned out that "virtually all of the evidence, drawing on a variety of measures of cost and price, points in the same direction: we have not been running out in an economic sense."[67] From a strictly economic perspective that treated mineral resources as non-financial assets and neglected their material quality, the idea of "exhaustibility" became questionable on principle. To this day, many economists continue to bluntly deny the concept of exhaustible minerals if it is meant to suggest that at a certain point there might be a high demand for a mineral but no supply because its reserves have been used up. Hendrick S. Houthakker, who was a member of Nixon's Task Force on Oil Imports and his Council of Economic Advisors, argues that this idea results from a too materialistic and narrow geological understanding of reserves that neglects the economic price mechanism. Houthakker states, "Disagreement arises when many geologists infer from the finiteness of mineral resources that sooner or later each mineral (assuming it is useful) will be exhausted. I shall argue, on the contrary, that under plausible assumptions no mineral will ever be exhausted. More explicitly, exhaustion cannot occur if market forces are free to operate."[68]

Probably the most fervent supporter of this position was the MIT energy economist Morris Albert Adelman.[69] According to Adelman, "oil and other minerals will never be exhausted. If and when consumers will not pay enough to induce investment in new reserves and capacity, the producing industry will dwindle and disappear."[70] In other words, because of the price mechanism the oil industry will lose its customers before the oil runs out. Adelman started his analyses of the oil market in the late 1960s and soon became highly influential. He denied the idea that anything like a fixed resource stock exists that might be used up through excessive consumption.[71] According to Adelman, the oil in place was found; oil reserves, however, were developed. Thus, he saw the "oil reserve" as a constructed or "inventory" concept signifying an estimated cumulated production over time.[72] From his economic perspective, a proved developed reserve appeared as a real non-financial asset and oil had no intrinsic value apart from the investment to find and produce it. Hence, Adelman argued, under competitive market conditions the oil price should remain close to the marginal costs.[73] Moreover, due to the inventory character of reserves, "proved reserves increased not *despite* interim production, but *because* of it." Successful oil explorations would lead to intensified investments in further exploration and development thereby augmenting the total amount of reserves. As he put it, "since the whole earth is finite, any subset must be finite, but this truism is no measure of the subset. A mineral stock at any moment reflects current knowledge—science and technology—hence current costs. As knowledge and cost change, so must the stock, mostly up sometimes down."[74] Adelman saw no reason to believe that this process should stop at any point. Under free market conditions, there would be a movement from cheaper to more expensive production sites, he argued, and the rising production costs would result in a higher oil price until people were not willing to buy it anymore or a so-called "backstop technology" could set in and substitute the oil.

In the late 1960s and early 1970s, Adelman judged the production costs of petroleum to be very low and oil reserves to be abundant. Therefore, under normal market conditions, price increases could not have occurred and Adelman had to introduce other factors into his theory in order to explain the rising prices. In his opinion, oil has never become scarce, but all oil price hikes since 1970 were due to artificially decreased output or raised prices by the "OPEC cartel" in cooperation with the multinational oil firms.[75] Even though Adelman thought that the reasons for the belief in energy scarcity were "a well kept secret which the economist cannot penetrate," he acknowledged that "belief in this fiction [was] a fact."[76] Propelled by this erroneous assumption and other interests, he argued, the U.S. government had implicitly and explicitly encouraged OPEC to raise the oil-price and the multinational corporations functioned as "OPEC's tax collectors." Adelman saw the State Department, in particular, as politically responsible for this development because "this agency is deplorably poorly informed in mineral resource economics, the oil industry, the history of oil crises and the participation therein of Arabs with whom it is obsessed."[77] Thus, according to Adelman, a false political strategy due to a lack of economic knowledge pursued by the United States had resulted in the rise of OPEC. Therefore, OPEC had acquired power over oil prices, and world oil supply was "threatened by one and only one danger: a concerted shutdown by the OPEC nations."[78] Despite the political origins of the situation in the early 1970s Adelman did not concede the interpretative hegemony to politicians and political scientists. Giving expert testimony in front of the U.S. Senate Committee on Foreign Relations in 1975 concerning the political and financial consequences of the oil price increases, Adelman explained to the senators that only the principles of economics governed the behavior of the oil market. Adelman stated, "High world prices are due neither to scarcity, nor politics, but to the cartel of governments. To explain prices by 'political factors' is superfluous nonsense. When a seller raises prices and increases revenues, he is acting reasonably. Whatever King Faisal really wants, money is the royal road to it, and more money is what he seeks. . . . The cartel governments use the multinational companies to maintain prices, limit production, and divide markets."[79]

While Adelman's position was fueled by the same belief in technology and progress as the perspective of many petroleum engineers; his argument concerning the future availability of oil was strictly economical. It did not refer to the geological realities of the reserves, but only to the forces of the market and theories of investment. Other economists voiced criticisms of Adelman's encouragement of further oil exploration investments and tried to integrate geological knowledge and Hubbert's peak into their theories. Since the second half of the 1970s, Ferdinand E. Banks has criticized Adelman and Hotelling for neglecting the physical realities of oil production because "getting the economics right is not always a prelude to getting the forecast right—especially in the oil market."[80] Following Hubbert's theory, Banks argues that "the peak is explained by economics and not geology,"[81] or at least that the essential element constituting the peak, namely the reserves/production ratio or the so-called "mid-point depletion rule" is "as much an economic as a geological phenomenon."[82] As Banks has laid out in various textbooks on energy economics and, in particular, the economics of petroleum, the performance of a specific oil field depends on the intensity of oil production. "In general, it is uneconomical to produce more than 10 percent of the recoverable oil in a field during a single year, since if this is done, the amount of oil that can eventually be recovered is reduced."[83] Even if the reason for not overproducing the field is economic, i.e., the expectation of smaller revenues in the future leads the owner to cut down production, the constraint to production is physical or rather geological. Hence, it does not matter if one produces at a certain field with an increasing or a constant rate; there will always be a point at which the ideal R/P ratio sets in and determines the production rate. Thus, normally at some point when between 40 and 60 percent of the ultimately recoverable oil in place has been produced, oil production will start to decline. What applies to a single oil field, according to Banks, has to apply to the world as a whole, too: "world oil production is going to peak, and when this happens there is going to be plenty of oil in the ground."[84]

Not only Ferdinand Banks's reflections had been propelled by the transformations of the oil market in the early 1970s and the simultaneously increasing worries about the environment and the possible *Limits to Growth*. As mentioned above, many economists moved into the new field and discussed how fast a resource should be depleted and if market forces alone could produce acceptable depletion rates.[85] For example Partha Dasgupta and Geoffrey Heal attempted to steer a course between apocalyptic fears of resource exhaustion and the opposite faith that exhaustion could never occur because of the price mechanism.[86] According to them, a resource is "exhaustible if it is possible to find a pattern of use which makes its supply dwindle to zero."[87] Then, they suggested a couple of techniques reducing uncertainty and stabilizing markets in order to create the most equal and constant social value of the resource over time.[88] In his Richard T. Ely lecture in front of the 86th meeting of the American Economic Association in 1974, Richard Solow argued in a similar way. Because the market tended to consume exhaustible resources too fast, he introduced the concept of "intergenerational equity," demanding that "consumption per head be constant through time."[89] At the end of his elaborate considerations concerning the possibility of integrating intergenerational equity into the process of production and consumption, however, Solow had to admit that "nothing I have been able to say takes account of the international oil cartel, the political and economic ambitions of Middle Eastern potentates, the speeds of adjustment to surprises in the supply of oil, or the doings of our friendly local oligopolists."[90] Thus, he acknowledged that purely economic considerations of oil reserves and their future use could not account for geological and political factors, just as geological estimates had neglected politics and economics.

Supply, Demand, and the Future Availability of Oil as Political Problems

For two reasons, oil reserves do not depend only on geology and economics. First, political decisions influence the consumption of different sources of energy in significant ways and thereby affect the future availability of oil. Second, large parts of the known global oil reserves are located in the Middle East, a region that has been politically unstable since World War II. In the second half of the twentieth century, the importance of political factors for predictions of the oil market increased. Political scientists, as well as specialists for the oil-producing regions, became more vocal in assessing the developments of demand and the possibilities of politically motivated interruptions of supply. The foundations of the rising significance of politics were laid in the postwar economic boom in Western industrialized countries which was fueled by the abundance of cheap energy, above all oil.[91] Between 1950 and 1970, the energy market underwent significant changes in all OECD countries and oil replaced coal as the primary source of energy. In France in 1960, for example, two-thirds of the primary energy had been supplied by coal and only one-third by oil. By 1970 these numbers had reversed.[92] The substitution of coal by oil was not only due to the latter's apparent advantages of higher energy efficiency, cleanness, and fluidity, but also to the intensive lobbying of the oil companies. Yet, despite the fact that the rising demand for oil was partly an intentional process fostered by the multinational oil companies, the dynamic increase in consumption was not anticipated. As Joel Darmstadter and Hans Landsberg argue, "none of the three principal lines of development . . . —the rapid growth of world energy consumption as a whole, the continued shift toward oil everywhere and the rapidly rising volume of American oil imports—was adequately anticipated in the succession of energy projections that have appeared since around 1960."[93] Not surprisingly, most of the long-range forecasts which became common in the 1960s and even more frequent in the 1970s failed.[94] However even short- and mid-term anticipations of consumption were surprisingly inaccurate. In 1970, President Nixon's Task Force on Oil Imports had projected a demand of 18.5 million barrels per day for the United States in 1980 and estimated that 5 million barrels per day would have to be imported by then. Yet, U.S. oil imports had already surpassed 6 million barrels per day by 1973.[95] Not only the oil-import-dependency of European countries and Japan had increased over the course of the 1950s and 1960s; the United States had become dependent on foreign oil as well.

Accordingly, oil and energy started to play a bigger role in political science and international relations studies. Already in 1963 the RAND Corporation had produced a study for the U.S. Air Force concerning the potential effects of crises in the Middle East for the energy supply of Europe. The author rejected emphatically the "illusion that oil no longer constitutes a serious problem for Western energy security."[96] According to the study, the illusion resulted from the erroneous assumption that the states in the Middle East would not act collectively and would not risk financial losses in order to achieve political goals. Generally speaking, the dependency of Europe and increasingly the United States on Middle Eastern oil did not necessarily imply "vulnerability, which describes the expected damage from interrupted supply."[97] Until the Six Day War in 1967, U.S. oil production possessed enough surplus capacity to counter embargo threats by increasing its own quotas. Yet, in 1970 U.S. delegates to the OECD Oil Policy Committee warned their colleagues that the United States had no spare capacity left to support Europe in supply crises.[98] In 1971, many voices, including the National Petroleum Council, an industry advisory board to the Secretary of the Interior, warned that the "continuation of present government policies and economic conditions would lead to significantly increased U.S. dependence on foreign energy resources, mostly in the form of oil from Eastern Hemisphere countries."[99]

While Western industrialized countries became more and more dependent on oil from the Middle East, the importance of the Organization of Petroleum Exporting Countries (OPEC) grew. Moreover, the creation of the Organization of Arab Petroleum Exporting Countries (OAPEC) in 1968 increased the number of political players involved in the oil game and amplified the necessity to acquire knowledge about the Middle East. Several journals observed the political and economic developments of the region in order to make the future development of the oil market predictable. From 1956 on, the *Middle East Economic Survey*, published by Middle East Research and Publishing Center in Beirut, provided executives in the oil industry, government officials, and oil experts with weekly information concerning petroleum-related events in the region. In 1961, Wanda Jablonski's *Petroleum Intelligence Weekly* started to observe and summarize oil-related news from all over the world with a particular focus on the Middle East, and Jean-Jacques Berreby founded *Orient-Pétrole* in 1969, reporting every second week mainly on the actions and plans of OPEC and OAPEC. In the early 1970s, political assessments of the conditions in the Arab oil-producing states in particular gained in importance because of the rising nationalism in the Arab world.[100] Simultaneously, papers on oil, energy, and the Middle East became more frequent in political science journals like *Foreign Affairs*, *Foreign Policy*, *International Affairs*, or *International Organization*, and political scientists intensified their studies of the political economy of oil in general and the Arab world in particular. Their attempts to predict the future availability of oil relied not on geological but rather on economic and especially political evidence.

One of the best examples of the political perspective on oil reserves are the writings of James Akins who worked as an energy expert for the State Department before briefly joining the White House and being appointed ambassador to Saudi Arabia. Addressing the 43rd Annual California Regional Fall Meeting of the Society of Petroleum Engineers in 1972, Akins "captured the attention and respect" of the audience by explaining that the current energy crisis had to be understood as the "end of the brief era of available low priced energy derived from hydrocarbons."[101] According to Akins, the crisis was due to the exhaustibility of mineral resources, the unexpectedly rapidly growing demand in the industrialized countries, the resulting dependence of the United States on oil from the Eastern hemisphere, and coherence of OPEC which was overlooked by "academics" and "politicians" showing an "impressive ignorance of contemporary politics and even a lack of knowledge of current events."[102] Alluding to Adelman, Akins declared in front of the Institute of Gas Technology at the same time that "only a few disgruntled and by now largely discredited academics still maintain that supplies of hydrocarbons are nearly infinite; that competition will bring down prices world wide and that there can never be a danger of restriction in supplies for economic or political reasons."[103] When questioned about Adelman's view in front of the Senate Committee on Foreign Relations, Akins became more explicit, explaining that "Professor Adelman does not have a terribly good record of predictions on international or even domestic oil matters" and continuing that Adelman's theory "totally ignores the geographic distribution of the oil; it totally ignores the political aspirations of the oil producers; it totally ignores any desires to save oil for future use."[104] Akins, however, thought that OPEC wanted to limit its production in order to postpone the exhaustion of its reserves and that the United States would have to act accordingly. His internal memorandum may not have received the amount of attention he had wished, but it still greatly intensified the debates on the restructuring of U.S. energy policies in 1973.[105]

Publishing his analysis in *Foreign Affairs* in April 1973, Akins declared that energy prognoses solely relying on geological and economic knowledge failed to capture the essential factors currently influencing global energy flows: "To look simply at the world's oil reserves and conclude that they are sufficient to meet the world's needs no longer can be acceptable."[106] According to Akins, such a perspective presupposed that world oil was geographically distributed in such a way that adequate amounts were always "available to all users, in all circumstances and at reasonable prices." But this assumption was not well founded because "at least 300 billion of these proven 500 billion barrels are in the Arab countries of the Middle East and North Africa."[107] The geographical distribution of world oil demand and supply turned the question of the availability of oil into a political issue. Threats to cut off supplies became not only more frequent, but also more realistic.[108] OPEC's new power had become apparent in the Tehran and Tripoli agreements in 1971, in the course of which the producing countries managed to enlarge their government shares and increase the posted price for oil.[109] In the end, one might say that the success of the oil companies in raising demand for oil in the Western world had led to increasing demands by producing countries to participate in oil revenues and, thereby, to a greater importance of political factors for the availability of oil.[110]

The developments in Libya, in particular, were a case in point and were studied as such in the Western world.[111] After the discovery of large oil fields, the experts had first expected Libya to be a convenient and secure source of Western European oil supply. Yet, after Gaddafi's acquisition of power it turned into a pioneer of the nationalization of oil companies and an advocate of the usage of oil for political purposes. The events in Libya significantly transformed "the political landscape of the international oil industry."[112] While some experts as well as the public media and many officials in the U.S. administration continued to explain OPEC and OAPEC actions by orientalist stereotypes,[113] others referred to the "lingering heritage of emotional resentments against former colonial administrations and concessionary circumstances."[114] In contrast to those views that clearly distinguished the Arabs from Westerners, a third position discerned a general economic and political logic that was also used by the Arab oil-producing countries. Again it was Akins who reminded his colleagues that most of the OPEC economists had attended excellent Western universities and were "fully as capable of making supply-demand calculations as [were] Western economists. And they reach the same conclusions."[115] But, unlike Adelman, Akins saw the governments of the oil-producing countries not only as economic, but also as political actors. For him the question as to whether Saudi Arabia or any other OPEC country with large oil reserves would intentionally disrupt supply was "a question of the behavior of men in control of national governments, affected by political factors as much as by theoretical economics."[116]

The oil embargo and the deliberate reduction of production quotas in the wake of the Yom Kippur War in October 1973 seemed to prove the preponderance of political over geological and economic factors affecting the oil supply.[117] The general insecurity about the supply and especially the price of oil increased immediately and the world energy outlooks changed significantly.[118] Most OECD countries had already started to develop new energy programs trying to diversify their energy sources, but the oil crisis turned energy security into a top priority. Lacking necessary data, consulting mechanisms and crisis reaction strategies, they formed a new international institution, the International Energy Agency, together, in order to cope with future supply disruptions. The new realm of governmental activity intensified a wave of scholarly writing on securing energy supplies by means of international politics.[119] In 1972, for example, the editors of *Foreign Policy* acknowledged that oil had "already become an important foreign policy issue" and published more articles on the topic throughout the following years.[120] On a domestic level, political and social scientists emphasized the importance of their expertise for the security of the future availability of oil. Since demand was essential for the duration of oil supplies, they wanted to quantify and predict people's behavior as well as their reactions to certain measures in the field of energy policy. As Marvin J. Cetron and Vary T. Coates put it in an issue of the *Proceedings of the Academy of Political Science* devoted to energy in 1973, "any way that the problem of energy is approached, from diplomatic-military contingency plans to solar-energy systems, it has an undeniable relationship with the social environment."[121] During and after the "oil crisis," political and social scientists met at innumerable conferences all around the world trying to explain past events in the oil market and develop new government strategies. Turning the first "oil crisis" into a paradigm case which had to be studied in order to assess and manage the future availability of oil, they tried to acquire the discursive hegemony over the assessment of oil reserves.[122] By 1975, oil reserves appeared to be as much an economic, political, and social issue as a question of geology.

Conclusion: Petroknowledge and the Irony of Success

This chapter has ideal-typically distinguished between three different groups of experts who developed heterogeneous estimates of "oil reserves," i.e., the future availability of oil, from the 1950s to the 1970s. Depending on their scientific backgrounds, petroleum geologists and engineers, energy economists, and political scientists approached the issue from different angles, claiming to predict the unknown and to make it manageable for political actors. Because of this common theme, their knowledge claims intersected and they fought over intellectual hegemony in the field of oil reserve estimates and their political application. Thus, contributing their expertise, geologists, economists, and political scientists did not only reduce specific uncertainties surrounding the oil reserves, but their contradictory knowledge claims also increased a general sense of uncertainty concerning the future availability of oil.

Because these various forms of petroknowledge were involved in the prediction of the unknown and its management, the future availability of oil cannot be treated as a single "unknown" that had to be managed. The concept of the "reserve" itself already depended on the scientific and practical context within which it was defined. Being negotiated in different disciplines, oil reserves are surrounded by a complex structure of heterogeneous unknowns that interact in various and often unforeseeable ways. Not only the actual physical size of worldwide oil reserves as estimated by petroleum geologists is essential for answering the question of how much oil will be available to whom in the future. Moreover, economic factors influence the demand of oil and its availability. In addition, political factors such as the strategies and actions of the governments of the oil states and industrialized nations affect the oil supply. The sheer complexity of the global oil economy and the various disciplines dealing with it constrain the possibility of singling out certain factors that will determine its future development.

As I have tried to show, even in a single discipline, be it petroleum geology/engineering, economics, or political science, the task of predicting oil reserves is highly complicated and not easy to achieve. Yet, in addition, there is an even more severe problem resulting from the heterogeneous systems of knowledge that are essential for an appreciation of reserves. Even if a single discipline manages to eliminate the unknown that stands in the focus of its research interest, it still has blind spots that result in the neglecting of important factors that might influence the oil reserves. Hence, none of the disciplines alone succeeded in predicting the future availability of oil, i.e., in managing the unknown. Until the 1960s, petroleum engineers and geologists were the dominant managers of the oil reserves. In the postwar era, they were highly successful in improving the methods of estimating the sizes of oil reserves and increasing production. Thus, in the years of the economic boom, they could satisfy the rising demand for oil which was in turn further fueled by their own estimates of continuously growing oil supplies. Optimistic predictions of a hydrocarbon future or an "oil-dorado" were intensely propagated by the oil industry.[123] The unexpectedly rapid rise in demand, however, led to a situation in which petroleum geology was no longer capable of managing the unknown with its own methods. From the 1960s onward, and to an even larger extent since the first oil crisis in 1973–1974, economists and political scientists have assumed the task of predicting the unknown and managing the oil supply. One might be tempted to describe this process as the self-marginalization of an expert culture because of its own success. Even though petroleum engineers and geologists remained highly important for resource estimates throughout the 1970s and up to the present, their capacities to manage the unknown are circumscribed by economists and political scientists.

Notes

1. *Energiekrise—Europa im Belagerungszustand? Politische Konsequenzen aus einer eskalierenden Entwicklung,* Bergedorfer Gesprächskreis zu Fragen der freien industriellen Gesellschaft 58 (Hamburg-Bergedorf, 1977), 14.
2. Ibid., 19
3. Leonardo Maugeri, *The Mythology, History and Future of the World's Most Controversial Resource* (Westport, CT, 2006), xi; Joel Darmstadter and Hans Landsberg, "The Economic Background," in *The Oil Crisis*, ed. Raymond Vernon (New York, 1976), 15–38, 22; Vaclav Smil, *Energy at the Crossroads: Global Perspectives and Uncertainties* (Cambridge, MA, 2003), 121, 149–161.
4. To give an example of the differences among informed resource estimates: In March 1974 the U.S. Geological Survey estimated that there would still be between 200 and 400 billion barrels of oil in the United States while Mobil Oil's most optimistic appraisal was 88 billion barrels. John D. Haun, "Methods of Estimating the Volume of Undiscovered Oil and Gas Resources: AAPG Research Conference," in *Methods of Estimating the Volume of Undiscovered Oil and Gas Resources*, ed. John D. Haun, (Tulsa, OK, 1975), 1–7, 1. See also Earl Cook, "Undiscovered or Undeveloped Crude Oil 'Resources' and National Energy Strategies," in ibid., 97–106 ("Estimates of ultimately recoverable crude oil in the United States published within the past 10 years range rather widely. The highest estimate of recoverable oil remaining to be discovered is 15 times the lowest estimate" (97)).
5. Kenneth S. Deffeyes, *Hubbert's Peak: The Impending World Oil Shortage*, (Princeton, NJ, 2003); for a popular version see the award-winning documentary "The Oil Crash" (2007) by Basil Gelpke and Ray McCormack. Prominent opponents include Morris A. Adelman, *The Genie out of the Bottle: World Oil since 1970* (Cambridge, MA, 1995); Maugeri, *The Mythology*, xv.; Robin M. Mills, *The Myth of the Oil Crisis: Overcoming the Challenges of Depletion, Geopolitics, and Global Warming* (Westport, CT, 2008).
6. Christoph Engel, Jost Halfmann, and Martin Schulte, eds., *Wissen—Nichtwissen—unsicheres Wissen* (Baden-Baden, 2002); Peter Wehling, "Ungeahnte Risiken. Das Nichtwissen des Staates—am Beispiel der Umweltpolitik," in *Das Wissen des Staates: Geschichte, Theorie und Praxis*, ed. Peter Collin and Thomas Horstmann (Baden-Baden, 2004), 309–337; Jakob Vogel, "Von der Wissenschafts- zur Wissensgeschichte: Für eine Historisierung der 'Wissensgesellschaft,'" *Geschichte und Gesellschaft* 30, no. 4 (2004).
7. Timothy Mitchell, "Carbon Democracy," *Economy and Society* 38, no. 3 (2007): 417; Timothy Mitchell, "The Resources of Economics: Making the 1973 Oil Crisis," *Journal*

of Cultural Economy 3, no. 2 (2010); Timothy Mitchell, "Hydrocarbon Utopia," in *Utopia/Dystopia: Conditions of Historical Possibility*, ed. Michael D. Gordin, Gyan Pakrash, and Helen Tilley (Princeton, NJ, 2010), 117–147.

8. Because of their distinct professional identities it may seem like an oversimplification to group engineers and geologists together. Yet with respect to the future availability of oil, their knowledge claims exhibited very similar characteristics.
9. Edward Constant, "Science in Society: Petroleum Engineers and the Oil Fraternity in Texas 1925–65," *Social Studies of Science* 19 (1989): 450; Earl Kipp, "The Evolution of Petroleum Engineering as Applied to Oilfield Operations," *Journal of Petroleum Technology* 23, January (1971): 107; for an extended definition of petroleum engineering see Benjamin C. Craft and Murray F. Hawkins, *Applied Petroleum Reservoir Engineering* (Englewood Cliffs, NJ, 1959), 3–4.
10. For exact periodization, see Constant, "Science in Society," 444; Carl E. Reistle, "Reservoir Engineering," in *The History of Petroleum Engineering*, ed. D. V. Carter (Dallas, 1961), 811–846.
11. Kipp, "The Evolution of Petroleum Engineering," 111; Constant, "Science in Society," 454; see also Henry J. Ramey, "Reservor Enginering in the 70s and 80s," *Journal of Petroleum Technology* 23 (1971): 34.
12. Kipp, "The Evolution of Petroleum Engineering," 113; numbers for different years in Constant, "Science in Society," 451.
13. Norman C. Smith, "AAPG Is a Long Time and a Lot of People," *Bulletin of the American Association of Petroleum Geologists* 56 (1972): 680.
14. Lester C. Uren, *Petroleum Production Engineering: Oil Field Exploitation*, 3d ed. (New York, 1953), 1.
15. Earl Cook, "Undiscovered or Undeveloped Crude Oil 'Resources,'" 99.
16. Donald A. Brobst and Walden P. Pratt, "Introduction," in *United States Mineral Resources*, ed. Donald A. Brobst and Walden P. Pratt (Washington DC, 1973), 1–8; Vincent E. McKelvey, "Concepts of Reserves and Resources," in *Methods of Estimating the Volume of Undiscovered Oil and Gas Resources*, ed. John D. Haun (Tulsa, OK, 1975), 11–14; Mary C. Rabbitt, *The United States Geological Survey 1879–1989*, U.S. Geological Survey Circular 1050 (Washington DC, 1989), 42–52.
17. C. H. Dix, *Seismic Prospecting for Oil* (New York, 1952), 6–16.
18. Carl Gatlin, *Petroleum Engineering: Drilling and Well Completions* (Englewood Cliffs NJ, 1960), 37.
19. Ibid., 34.
20. Deffeyes, *Hubbert's Peak*, 7f.; John E. Brantly, *History of Oil Well Drilling* (Houston, 1971), 1488.
21. Gilbert Jenkins, "World Oil Reserves Reporting 1948-1996: Political, Economic, and Subjective Influences," *OPEC Review* 21 (1997): 95; Ferdinand E. Banks, *The Political Economy of World Energy: An Introductory Textbook* (London, 2007), 15.
22. Jenkins, "World Oil Reserves Reporting 1948–1996," 94. For professional reasons engineers and geologists tend to underestimate the size of the oil fields they examine; see Deffeyes, *Hubbert's Peak*, 6.
23. "Reserves—Tomorrow's Storehouse," in *Petroleum Panorama: Commemorating 100 years of Petroleum Progress* [The Oil and Gas Journal 57, no. 5 (1959)], B-30–32, B-31.

24. W. C. Skinner, "A Quarter Century of Production Practices," *Journal of Petroleum Technology* 25 (1973): 1425.
25. See the most accessible account in Deffeyes, *Hubbert's Peak*, 70–112, older histories are D. V. Carter, ed., *The History of Petroleum Engineering* (Dallas, 1961); Brantly, *History of Oil Well Drilling.*
26. M. S. Kraemer, "Producing Operations of the Future," *Journal of Petroleum Technology* 23 (1971): 28.
27. See also "It Takes Men to Drill Wells," in *Petroleum Panorama,* C-10–11.
28. H. A. Nedom, "Planning the Energy Years," *Journal of Petroleum Technology* 23, January (1971): 13; L. B. Curtis, "The First Ten of the Next Hundred Years," *Journal of Petroleum Technology* 23 (January 1971).
29. James A. Clark, "The Energy Revolution," in Carter, *The History of Petroleum Engineering*, 14; for the self-perception of petroleum geologists, see John D. Haun, "The President's Page. Why Teach Petroelum Geology?," *Bulletin of the American Association of Petroleum Geologists* 53 (1969); Merrill W. Haas, "The President's Page," *Bulletin of the American Association of Petroleum Geologists* 50 (1966): 1: "When you project the image of the petroleum geologist, please keep in mind the fact that you are a breed of scientists in an industry where, to paraphrase a great Englishman, never have so many owed so much to so few."
30. J. S. Archer and C. G. Wall, *Petroleum Engineering: Principles and Practice* (London, 1986), x.
31. Craft and Hawkins, *Applied Petroleum Reservoir Engineering*, 105.
32. Gary Bowden, "The Social Construction of Validity in Estimates of US Crude Oil Reserves," *Social Studies of Science* 15 (1985): 211.
33. Wallace F. Lovejoy and Paul T. Homan, *Methods of Estimating Reserves of Crude Oil, Natural Gas, and Natural Gas Liquids* (Baltimore, 1965), 2–3.
34. Ibid., 4.
35. Ibid., 148.
36. Ibid., 150.
37. Dix, *Seismic Prospecting for Oil*, 51.
38. A[lfred] Zapp, *Future Petroleum Producing Capacity of the United States: Contributions to Economic Geology* (Washington, DC, 1962); Bowden, "The Social Construction of Validity," 216f.
39. William W. Mallory, "Accelerated National Oil and Gas Resource Appraisal (ANOGRE)," in Haub, *Methods of Estimating*, 23–30.
40. Haun, "Methods of Estimating," 3.
41. Bowden, "The Social Construction of Validity," 234.
42. Marion K. Hubbert, *Energy Resources: A Report to the Committee on Natural Resources of the National Academy of Sciences—National Research Council* (Washington, DC, 1962), 34.
43. Ibid., 50.
44. Ibid., 75.
45. Ibid., 91.
46. Bowden, "The Social Construction of Validity," 223–226.
47. Michel T. Halbouty, "Methods of Estimating the Volume of Undiscovered Oil and Gas Resources: Introductory Remarks," in Haun, *Methods of Estimating*, 8–10.

48. Bowden, "The Social Construction of Validity," 221; Lewis G. Weeks, "Estimation of Petroleum Resources: Commentary," *Bulletin of the American Association of Petroleum Geologists* 50 (1966).
49. J. M. Ryan, "Limitations of Statistical Methods for Predicting Petroleum and Natural Gas Availability," *Journal of Petroleum Technology* 18, (March 1966): 282.
50. Anibal R. Martinez, "Estimation of Petroleum Resources," *Bulletin of the American Association of Petroleum Geologists* 50 (1966), 2005.
51. Weeks, "Estimation of Petroleum Resources," 2009.
52. Deffeyes, *Hubbert's Peak*, 70. Concerning self-fulfilling prophecies, see Robert K. Merton, "Die Eigendynamik gesellschaftlicher Voraussagen," in *Logik der Sozialwissenschaften*, ed. Ernst Topitsch (Königstein/Ts.1980), 144–161.
53. Paul H. Frankel, "The Oil Industry and Professor Adelman: A Personal View," *Petroleum Review* 27 (September 1973): 348; see also Bowden, "The Social Construction of Validity." However, it is unclear if the new strategy of profit maximization induced different reserve estimates or if it was the other way round.
54. Haun, "The President's Page. Why Teach Petroelum Geology?"; Bernold M. Hanson, "The President's Page. Are We Doing Our Part?," *Bulletin of the American Association of Petroleum Geologists* 58 (1974); Edd R. Turner, "The President's Page: Needed—Active Geologists," *Bulletin of the American Association of Petroleum Geologists* 58 (January 1974); James E. Wilson, "The President's Page. Nonprofit, Okay—Deficit, No," *Bulletin of the American Association of Petroleum Geologists* 56 (1972).
55. Cook, "Undiscovered or Undeveloped Crude Oil 'Resources,'" 97.
56. "Technology—A Look at Petroleum's Future," *Journal of Petroleum Technology* 23 (November 1971): 1337.
57. Charles DiBona to the American Association of Petroleum Engineers, Anaheim, CA, May 14, 1973, 3, 14, National Archives and Records Administration, Nixon Library, WHCF, SMOF, EPO, Box 31.
58. Brobst and Pratt, "Introduction," 5.
59. Merrill W. Haas, "The President's Page: Elements of National Energy Policy," *Bulletin of the American Association of Petroleum Geologists* 58 (1974).
60. James L. Smith, "Oil and the economy: Introduction," *The Quarterly Review of Economics and Finance* 42 (2002): 164; P[artha] Dasgupta and G[eoffrey] M. Heal, *Economic Theory and Exhaustible Resources* (Cambridge, 1979), 1: "One could read the whole of the very extensive literature of the 1950s and 1960s on economic growth in the long run without ever realizing that the availability of natural resources (other than labour) might be a determinant of growth potential."
61. Allen V. Kneese and James L. Sweeney, eds., *Handbook of Natural Resource and Energy Economics* (Amsterdam, 1993), vol. 3; Jeroen C. J. M. van den Bergh, ed., *Handbook of Environmental and Resource Economics* (Cheltenham, 1999); Ferdinand E. Banks, *Energy Economics: A Modern Introduction* (Boston, 2000).
62. Harold Hotelling, "The Economics of Exhaustible Resources," *Journal of Political Economy* 39 (1931); Hotelling took up considerations that had already been put forward by Lewis C. Gray, "Rent Under the Assumption of Exhaustibility," *The Quarterly Journal of Economics* 28 (1914).
63. Hotelling, "The Economics of Exhaustible Resources," 140.
64. Ibid., 139.

65. Ibid.; Ferdinand E. Banks, *The Political Economy of Oil* (Lexington, MA, 1980), 54.
66. Morris A. Adelman, "World Oil Production & Prices 1947–2000," *The Quarterly Review of Economics and Finance* 42 (2002): 181.
67. F. M. Peterson and A. C. Fisher, "The Optimal Exploitation of Extractive Resources: A Survey," *The Economic Journal* 87 (1977): 705.
68. Hendrik S. Houthakker, "Are Minerals Exhaustible?," *The Quarterly Review of Economics and Finance* 42 (2002): 418.
69. Morris A. Adelman, ed., *The Economics of Petroleum Supply: Papers by M.A. Adelman, 1962–1993* (Cambridge, MA, 1993).
70. Adelman, *The Genie out of the Bottle*, 1; see also Adelman, "World Oil Production & Prices," 172.
71. Morris A. Adelman, *The World Petroleum Market* (Baltimore, 1972), 25–28; Adelman, "World Oil Production & Prices," 181.
72. Adelman, *The World Petroleum Market*, 25f.; Adelman, *The Genie out of the Bottle*, 1, 328.
73. Adelman, "World Oil Production & Prices," 180.
74. Ibid., 180f.; Adelman, *The World Petroleum Market*, 28.
75. Adelman, "World Oil Production & Prices," 175.
76. Morris A. Adelman, "Is the Oil Shortage Real? Oil Companies as OPEC Tax Collectors," *Foreign Policy* (1972–1973): 73, 91.
77. Ibid., 71.
78. Ibid., 101.
79. U.S. Congress. Senate. Committee on Foreign Relations, *Political and Financial Consequences of the OPEC Price Increases: Hearing Before the Subcommittee on Multinational Corporations* (Washington, DC, 1975), 3; see also Morris A. Adelman, "Politics, Economics, and World Oil," *The American Economic Review* 64, No. 2 Papers and Proceedings (1974).
80. Ferdinand E. Banks, "Beautiful and Not So Beautiful Minds: An Introductory Essay on Economic Theory and the Supply of Oil," *OPEC Review* (March 2004): 32.
81. Banks, *The Political Economy of World Energy*, 101.
82. Ibid., 38.
83. Banks, *The Political Economy of Oil*, 46.
84. Ibid., 48.
85. See, for example, Geoffrey M. Heal, "Symposium on the Economics of Exhaustible Resources: Introduction," *Review of Economic Studies* 41 (1974).
86. Dasgupta and Heal, *Economic Theory and Exhaustible Resources*, 3; Partha Dasgupta and Geoffrey M. Heal, "The Optimal Depletion of Exhaustible Resources," *Review of Economic Studies* 41 (1974).
87. Dasgupta and Heal, *Economic Theory and Exhaustible Resources*, 3; similarly James L. Sweeney, "Economic Theory of Depletable Resources: An Introduction," in *Handbook of Natural Resource and Energy Economics*, 761: "A resource is depletable if (1) its stock decreases over time whenever the resource is being used, (2) the stock never increases over time, (3) the rate of stock decrease is a monotonically increasing function of the later resource use, and (4) no use is possible without a positive stock."
88. Dasgupta and Heal, *Economic Theory and Exhaustible Resources*, 471–473.

89. Robert M. Solow, "The Economics of Resources or the Resources of Economics," *The American Economic Review* 64, No. 2 Papers and Proceedings (1974), 13, 10; Robert M. Solow, "Intergenerational Equity and Exhaustible Resources," *Review of Economic Studies* 41, Symposium (1974).
90. Solow, "The Economics of Resources or the Resources of Economics," 13.
91. John G. Clark, *The Political Economy of World Energy: A Twentieth-Century Perspective* (New York, 1990); David Edwin Nye, *Consuming Power: A Social History of American Energies* (Cambridge, MA, 1998).
92. Robert J. Lieber, *The Oil Decade* (New York, 1983), 79.
93. Joel Darmstadter and Hans Landsberg, "The Economic Background," in *The Oil Crisis*, ed. Raymond Vernon, (New York, 1976), 15–38.
94. Smil, *Energy at the Crossroads*, 123. British experts consistently underestimated the rise in oil demand. Lord Rothschild to R. T. Armstrong: Report on Energy Policy Reviews, April 28, 1971, National Archives of the United Kingdom, PREM 15/1144.
95. James Akins, "The Oil Crisis: This Time the Wolf Is Here," *Foreign Affairs* 51 (1973): 462; U.S. Cabinet Task Force on Oil Import Control, *The Oil Import Question: A Report on the Relationship of Oil Imports to the National Security* (Washington, DC, 1970).
96. Harold Lubell, *Middle East Oil Crises and Western Europe's Energy Supplies* (Baltimore, 1963), xviii.
97. Lieber, *The Oil Decade*, 3.
98. OECD. Remarks by Dr. Wilson M. Laird. Director, Office of Oil and Gas, U.S. Dept. of the Interior, September 8, 1970, National Archives of the United Kingdom, POWE 63/642.
99. National Petroleum Council, *U.S. Energy Outlook: An Initial Appraisal 1971–1985* (Washington, DC, 1971), 1.
100. Arnold Hottinger, "The Depth of Arab Radicalism," *Foreign Affairs* 51 (1973).
101. James E. Akins, "The Nature of the Crisis in Energy," *Journal of Petroleum Technology* 24 (1972): 1479.
102. Ibid., 1480.
103. James E. Akins: New Myths and Old Prejudices, Institute of Gas Technology, November 16, 1972, National Archives and Records Administration, Nixon Library, WHCF, SMOF, EPO, Box 31.
104. U.S. Congress, Senate Committee on Foreign Relations, *Energy and Foreign Policy: The Implications of the Current Energy Problem for United States Foreign Policy*, May 30–31, 1973 (Washington, DC, 1973), 80.
105. Daniel Yergin, *The Prize: The Epic Quest for Oil, Money, and Power* (New York, 1991), 572f; William P. Rogers: Memo to the President: Petroleum Developments and the Impending Energy Crisis, March 10, 1972, National Archives and Records Administration, Nixon Library, NSC Institutional Files ("H-Files"), Box H-197. Other documents in the box show how Akins's Memorandum led to the production of the National Security Study Memorandum 174 on "National Security and U.S. Energy Policy."
106. Akins, "The Oil Crisis," 490.
107. Ibid., 465.
108. Ibid., 469: "OPEC was not a joke, however."

109. Jack E. Hartsborn, "Erdöl als Faktor wirtschaftlicher und politischer Macht: Die Verhandlungen von Tripolis und Teheran zwischen den OPEC-Staaten und den internationalen Ölgesellschaften," *Europa-Archiv* 26 (1971); Jens Hohensee, *Der erste Ölpreisschock 1973/74: Die politischen und gesellschaftlichen Auswirkungen der arabischen Erdölpolitik auf die Bundesrepublik Deutschland und Westeuropa* (Stuttgart, 1996), 27–43.
110. Walter J. Levy, "Oil Power," *Foreign Affairs* 49 (1971): 668.
111. Ibid.; U.S. Congress. Senate. Committee on Foreign Relations. Subcommittee on Multinational Corporations, *Chronology of the Libyan Oil Negotiations, 1970–1971* (Washington DC, 1974).
112. James Bamberg, *The History of the British Petroleum Company*, vol. 3: *British Petroleum and Global Oil 1950–1975: The Challenge of Nationalism* (Cambridge, 2000), 450; Yergin, *The Prize*, 577–580; concerning nationalizations in general, see Stephen J. Kobrin, "The Nationalisation of Oil Production, 1918–80," in *Risk and the Political Economy of Resource Development*, ed. David W. Pearce, Horst Siebert, and Ingo Walter, (London, 1984), 137–164.
113. Douglas J. Little, *American Orientalism: The United States and the Middle East since 1945* (Chapel Hill, 2002), 27, 35. Reporting on the critical Libyan position during the embargo, Günter Franz Werner, the German ambassador to Libya, explained Ghaddafi's behavior by reference to the "old bazar-custom, trying to bind the partner in order to prevent him from switching to the competitor's camp, while at the same time threatening him with breaking off the lucrative business-relations." Günter F. Werner, Fernschreiben zu Libyens Haltung nach der OPEC-Konferenz vom 17.10. in Kuwait, October 20, 1973, 104991, Politisches Archiv des Auswärtigen Amts, Bestand 36 (Referat 310), 2.
114. Levy, "Oil power," 656–657.
115. Akins, "The Oil Crisis," 483.
116. Ibid., 484.
117. Peter R. Odell, *Oil and World Power*, 6th ed. (Harmondsworth, 1981); Hohensee, *Der erste Ölpreisschock 1973/74.*
118. *World energy outlook: A Reassessment of Long Term Energy Developments and Related Policies* (Paris, 1977), 23.
119. Michael A. Toman, "The Economics of Energy Security: Theory, Evidence, Policy," in *Handbook of Natural Resource and Energy Economics*, 1167–1218; Robert O. Keohane, "The International Energy Agency: State Influence and Transgovernmental Politics," *International Organization* 32, no. 4 (1978).
120. Adelman, "Is the Oil Shortage Real?," 70.
121. Marvin J. Cetron and Vary T. Coates, "Energy and Society," *Proceedings of the Academy of Political Science* 31, no. 2 (1973): 40.
122. See for example Cyrus Bina, *The Economics of the Oil Crisis: Theories of Oil Crisis, Oil Rent, and Internationalization of Capital in the Oil Industry* (London, 1985); Edward N. Krapels, *Oil Crisis Management* (Baltimore, 1980); S. Manoharan, *The Oil Crisis: End of an Era* (New Delhi, 1974); Horst Mendershausen, *Coping with the Oil Crisis: French and German Experiences* (Baltimore and London, 1976); Alan T. Peacock, *The Oil Crisis and the Professional Economist* (York, 1975); T. M. Rybczynski, ed., *The*

Economics of the Oil Crisis (New York, 1976); Vernon, *Oil Crisis*; Allen L. Hammond, William D. Metz, and Thomas H. Maugh, *Energie für die Zukunft: Wege aus dem Engpaß* (Frankfurt a. M., 1974).

123. See for example *Petroleum Panorama*; ESSO's journal *Pétrole progrès*; Ferdinand Mayer, *Erdoel-Weltatlas* (Hamburg-Braunschweig, 1966); Mineralölwirtschaftsverband, *Öl in der Welt von morgen* (Hamburg, [1971]); Esso AG, *Öldorado 1972* (1973).