GEOLOGIC NOTE

M. King Hubbert and the rise and fall of peak oil theory

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ABSTRACT

In 1956, American geologist M. King Hubbert predicted that United States oil production would follow a bell-shaped curve and peak between 1965 and 1970. When petroleum production peaked in 1970 and subsequently declined for 38 yr, Hubbert's model was corroborated, and he was heralded as a prophet and an oracle. However, Hubbert's peak oil theory was effectively falsified when United States oil production began to increase in 2009 and surpassed the 1970 peak in 2018. A close reading of Hubbert's analysis reveals that the model was flawed from the beginning, because Hubbert had conceded that the life cycle of a resource would not necessarily follow a single curve. Thus, any prediction of a production history made from a single curve had little to no predictive validity. Whereas Hubbert was celebrated for decades, the Cornucopian critics, who were correct in their assessments of resource abundance, were relegated to obscurity. Hubbert was a brilliant scientist who made significant contributions in several areas, but his views on resource exhaustion were influenced by his ideological beliefs. A false belief in the future scarcity of oil driven by peak oil theory resulted in the misallocation of resources. Bad science produces bad public policy.

INTRODUCTION

It was a historic date—April 20, 2020—the day the future contract price of oil became negative. Oil prices dropped more than $50 USD in 1 day, to close approximately $30 USD below zero (Reed and Krauss, 2020). The negative price reflected the reality of a glut of oil on the market so large that it was necessary to pay to find a place to store it. The irrefutable evidence of overwhelming petroleum abundance was a symbolic stake in the heart of M. King

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Hubbert's peak oil theory, a hypothesis that for several decades had been widely accepted as an established fact. Long-standing predictions of petroleum scarcity were blown out of the water.

The price of oil soon rebounded, exceeding $100 USD per barrel by spring 2022. The foray into negative price proved to be a temporary consequence of a decrease in economic activity brought about by the coronavirus disease 2019 pandemic. Nevertheless, the falsification of peak oil theory had already occurred a few years earlier.

Hubbert (1956) estimated the ultimate production of crude oil from the United States to be 150 billion bbl. On this basis, he predicted that peak production would occur in 1965. Allowing for error, Hubbert noted that even if his estimate of cumulative production was low by 50 billion bbl, the peak in United States oil production would only be delayed until 1970. When United States annual crude oil production peaked in 1970 at 3.5 billion bbl, the event was mistakenly interpreted not only as mere corroboration but also as proof of Hubbert's theory. In a posthumous tribute to Hubbert, the US National Academy of Sciences (1990) referred to Hubbert's peak oil theory as a "mathematical proof."

Following the 1970 peak, United States annual oil production declined systematically for 38 yr, in concordance with Hubbert's prediction, reaching a low of 1.8 billion bbl in 2008. After that year, however, the introduction of new technologies resulted in rapid increases. In 2018, the United States produced 4.0 billion bbl of oil, exceeding the 1970 peak. The following year, production peaked at 4.5 billion bbl, more than 13 times what Hubbert (1956) had predicted as most likely, and more than 6 times as large as what Hubbert had considered to be an exaggerated upper bound. As of 2021, cumulative United States oil production was 239 billion bbl, 39 billion bbl larger than the number Hubbert contemplated as an absolute upper limit. Hubbert's predictions were grossly in error.

In retrospect, Hubbert's peak oil theory was flawed from its very inception. Hubbert explicitly conceded that the life cycle of oil production could not necessarily be modeled by a single curve, yet he proceeded to do so. Hubbert never fully grasped the complexity of resource exploitation, and he was biased by his political ideology. Hubbert was a Malthusian, and one of the founders of technocracy, a utopian economic and political system. Tragically, many of the people who correctly predicted resource abundance were discredited and fell into obscurity. It is time to recognize that Hubbert was wrong and his critics correct.

HUBBERT THE TECHNOCRAT

M. King Hubbert's science was influenced by his ideological beliefs. Hubbert was a technocrat. Technocracy was a utopian economic and political system originated by the engineer Howard Scott (1890–1970). Simply put, technocracy advocated replacement of the market system with totalitarian control by a group of technical experts. Technocracy flourished in the United States during the 1930s, when the advent of the Great Depression seemed to confirm the inadequacy of traditional economic and political systems. Technocracy promised "abundance and security, leisure and equality, all achieved through technological progress and control by technicians" (Inman, 2016, p. 44).

The young Hubbert became an enthusiastic convert to technocracy. Writing to his sister, he confessed, "I am for an overhaul of this country from top to bottom so thorough that the plans of the socialists and communists look cheap by comparison" (Inman, 2016, p. 45). In 1934, Hubbert authored the definitive manual of technocracy, *Technocracy Study Course*. It is an astonishing book. The text begins with a treatment of the most basic topics considered by science: matter, units of measurement, energy, thermodynamics, engines, the human engine, the flow of energy on Earth, dynamic equilibrium among energy-consuming devices, and energy in human history. The discussion then progresses to modern industrial growth, industrial growth curves, and mineral resources.

The bugaboo of the technocrats was the price system, or what is usually called traditional free market economics. Technocrats regarded the price system as a relic of pretechnological human societies. To Hubbert, it was "inconceivable that the institutions and customs which evolved to meet the needs of a society composed of hunters, peasants, sheepherders, warriors, priests, petty merchants, and usurers should be adequate for the needs of a society operating a billion horsepower of prime movers with its consequent array of high-speed transportation,

communication, and productive equipment" (Hubbert, 1934, p. 122). However, the price system allows economies to function by transmitting information, providing incentives for production, and regulating the distribution of income (Friedman and Friedman, 1980).

Technocrats envisaged human societies as machines that had to be highly regulated and controlled to function at any reasonable modicum of efficiency. Private property, a remnant of agricultural societies, constituted a hindrance to central control. In Lesson 22.2 of *Technocracy Study Course*, "The Solution," Hubbert described an organization that would "operate the entire physical equipment of the North American Continent" (Hubbert, 1934, p. 214). People in the group would be chosen entirely on the basis of technical qualifications. By way of analogy, Hubbert offered the telephone company as an "operating example" of a "functional organization" that worked on technocratic principles (Hubbert, 1934, p. 215). This organization would be responsible for both producing and distributing goods and services to every member of the community. Economic production was to be standardized. Houses and automobiles would be limited to a few basic designs and models. Every adult was to be issued an "energy certificate," based on an equitable share of the total value of the economic production of the country.

The society envisaged by the technocrats was perhaps the most totalitarian scheme in human history. Hubbert described it as "a continental system of human conditioning" (Hubbert, 1934, p. 233). He blithely dismissed "all philosophic concepts of human equality, democracy and political economy," because they "have upon examination been found totally lacking" (Hubbert, 1934, p. 223). The technocratic utopia was to function as an absolute dictatorship under the control of one person, "the Continental Director … the chief executive of the entire social mechanism" (Hubbert, 1934, p. 222).

Hubbert's advocacy of technocracy was astonishing in its implicit ignorance of Western economic and political theory. Since Adam Smith (1723–1790) published *An Inquiry into the Nature and Causes of the Wealth of Nations* in 1776, it has been recognized that free markets are the best way to generate economic prosperity. Smith noted that the type of centrally planned and directed economy the technocrats envisioned was a chimera: "No human wisdom or knowledge could ever be sufficient [for] the duty of super-intending the industry of private people, and of directing it towards the employments most suitable to the interest of the society" (Smith, 1778, p. 290).

From the days of the Roman Republic, it has been recognized that the essential problem in government is to limit and balance power. Describing the Roman Republic, Polybius (ca. 200–118 BC) concluded that "it is not possible to invent a more perfect system of government … for when any branch of it, swelling beyond its bounds, becomes ambitious, and aims at unwarrantable power, it is manifest that, no one of them being … absolute, but the designs of each subject to the contradiction and control of the other two, no one can run into any excess of power" (Polybius, 1758, p. 435, 437). Borrowing from Montesquieu, James Madison (1751–1836) explained that "the accumulation of all powers legislative, executive and judiciary in the same hands, whether of one, a few or many, and whether hereditary, self appointed, or elective, may just be pronounced the very definition of tyranny" (Madison, 1788, p. 92–93).

In the fourth century BC, Aristotle (384–322 BC) noted that any political system had to be consistent with human nature: "Political science does not make men, but takes them from nature and uses them" (Aristotle, 1885, p. 18–19). However, Hubbert was blind to the reality of human nature. His authoritarian, technocratic system required perfect people, but thousands of years of recorded history demonstrate that human beings are corruptible and will almost always act in their own self-interest rather than for the common good. Accordingly, any political or economic system that is not designed to limit the centralization of power must fail.

The United States recovered from the Great Depression of the 1930s to reach new levels of prosperity. The collapse of the Soviet Union and the fall of the Berlin Wall in 1989 established a consensus regarding the superiority of market systems (Ellman, 2007). When M. King Hubbert was most infatuated with technocracy in the early 1930s, the dangers of highly authoritarian governments were perhaps not fully appreciated. The horrors perpetrated by Nazi Germany and Stalinist Russia had not yet occurred. Nevertheless, to have ignored more than 2000 yr of Western political and economic theory and practice was remarkably naïve on Hubbert's part.

HUBBERT'S MODEL

The definitive presentation of Hubbert's peak oil theory was in his 1956 paper "Nuclear Energy and the Fossil Fuels," published in the American Petroleum Institute journal *Drilling and Production Practice*, but the roots of his paper and model had been laid down decades earlier.

The earliest traceable influence on Hubbert's approach to resource depletion appears to have been the work *Cycles in Metal Production* by D. F. Hewett (Hewett, 1929; Clark, 1983; Priest, 2014). Hewett was a pessimist. He concluded that "many of our outstanding districts of a few years ago show signs of exhaustion, and we are sustaining or increasing national totals by turning quickly to new sources of lower grade. If science and technique can keep up the pace, we have no cause for concern. Personally, I doubt that they can much longer" (Hewett, 1929, p. 92).

In his *Technocracy Study Course*, Hubbert drew a bell-shaped curve that he claimed was "characteristic of the exploitation of any non-recurrent material, such as all mineral resources" (Hubbert, 1934, p. 101). This explicitly included oil. In 1941, Hubbert published "Economic Transition and Its Human Consequences" in the journal *Advanced Management*. Therein we find a drawing of a bell-shaped curve that is said to be "descriptive of the rate of production of all non-recurrent mineral resources" (Hubbert, 1941, p. 99). The next sentence is a frank admission that the entire peak oil theory that flourished for several decades was always flawed. Hubbert conceded, "The curve rises to one or more maxima and ultimately declines to zero as the resource is exhausted" (Hubbert, 1941, p. 99). If the curve can have "one or more maxima," then it has no single peak. If the curve has no predetermined or definable shape, then no estimate of resource depletion can be made, because there is no way to know whether a single peak will not be followed by another peak ad infinitum. The whole point of peak oil theory was to model and predict resource exhaustion. For example, on the basis of a single bell-shaped curve, Campbell and Laherrere (1998) predicted that world oil production would peak shortly after 2000 and then begin a systematic and irreversible decline. However, Hubbert conceded from the beginning that no single model could have any predictive validity.

Other critics have also noted that from its very inception the Hubbert model never had any validity for forecasting future oil production and depletion. Lynch (2016, p. 76) concluded "the creator of the Hubbert curve admitted that there was no underlying reason to use a bell curve"; thus, "neither theory nor reality supports the argument." McCabe (1998, p. 2132) argued that a Hubbert-style analysis "does not hold up to scrutiny of its basic assumptions." He documented that "the shape of a production curve is as much controlled by the demand for the energy source as it is by its availability" (McCabe, 1998, p. 2132). The historical production of anthracite coal in Pennsylvania has closely followed a symmetric Hubbert curve, but the resource is not exhausted. Production declined because of a decrease in demand (McCabe, 1998, p. 2125).

In 1949, the United Nations held a conference on the conservation and utilization of resources at which American geologist A. I. Levorsen (1894–1965) delivered a paper titled "Estimates of Undiscovered Petroleum Reserves." Levorsen estimated that the total undiscovered petroleum resources of the world amounted to 1500 billion bbl (Levorsen, 1950, p. 98), but he tempered his estimate by noting that "such estimates merely reflect the state of technical development and geological understanding at the time of the estimate." Levorsen noted that "as ideas have developed, estimates have increased and may be expected to increase in the future" (Levorsen, 1950, p. 94), and concluded that the world contained sufficient petroleum "to meet world demand over the next several hundred years" (Levorsen, 1950, p. 99).

Among Levorsen's remarks was one that especially irritated Hubbert. Levorsen claimed that "any undiscovered oil or gas pool at best exists only as an idea in the mind of the geologist" (Levorsen, 1950, p. 94). Hubbert was unable to fathom this sort of reasoning. He apparently did not appreciate that science, as a process conducted by human beings, must take human psychology into account. Hubbert criticized Levorsen's reasoning as "essentially metaphysical in nature" (Levorsen, 1950, p. 103). Although Hubbert explicitly acknowledged "that in the past the estimates of the ultimate reserves of petroleum have usually been wrong on the low side—and often grossly so" (Levorsen, 1950, p. 104), he underestimated the difficulty of the process, claiming that past "estimates … were not comprehensively made

by means of a detailed inventory of the sedimentary rocks of the whole world, and are, therefore, not comparable in validity to those which have been so made in the light of recent data" (Levorsen, 1950, p. 104). Hubbert argued that the size of the ultimate petroleum resource "is in no manner influenced by our thoughts or opinions concerning it" (Levorsen, 1950, p. 104), but he missed the point that the size of the ultimate petroleum resource could never be known, only "thoughts or opinions concerning it."

The same year as the United Nations conference, Hubbert published an article in the journal *Science* titled "Energy from Fossil Fuels" (Hubbert, 1949) Again, Hubbert explicitly conceded that there was no single production curve for a resource: "We may announce with certainty that the production curve of any given species of fossil fuel will rise, pass through one or several maxima, and then decline asymptotically to zero … there is an infinity of different shapes" (Hubbert, 1949, p. 105).

The article in *Science* also revealed Hubbert the technocrat, the biocentrist, and the Malthusian. Hubbert referred to the Industrial Revolution, a turning point in human welfare, as a series of "major social and economic disturbances" (Hubbert, 1949, p. 103). Human societies are thermodynamic systems that are entirely dependent on the flow of energy through them: "As the environment improves in subsistence potential, the culture advances in complexity" (Meggers, 1955, p. 120). Energy use in human civilizations correlates with life expectancy, literacy, education, and prosperity (Epstein, 2022), but Hubbert decried "the human species' proclivity for the capture of energy" as "one of the most disturbing ecological influences of recent millennia" (Hubbert, 1949, p. 104). He criticized contemporary human society for being stuck in "the sacred-cow behavior patterns of our agrarian and prescientific past" (Hubbert, 1949, p. 109). Hubbert characterized this as a "cultural lag" and predicted "a succession of crises," including "overpopulation, exhaustion of resources and eventual decline" (Hubbert, 1949, p. 109). The apparent remedy was to transition to a utopian "high-energy industrial civilization" that would use "low-grade concentrations of materials" and subsist "by means of the energy from sunshine alone" (Hubbert, 1949, p. 109).

In the 1956 presentation of his model, Hubbert preceded his theoretical prediction of peak oil production in the United States with a discussion and plotting of some select cases of the history of mineral production. These cases included the world production of coal and crude oil (Hubbert, 1956, p. 9), United States production of coal and crude oil (Hubbert, 1956, p. 10), and Texas production of crude oil and natural gas (Hubbert, 1956, p. 10). All of these curves showed exponential growth without decline. To extrapolate the curves, Hubbert invoked two axioms. First, production must begin and end at zero. Second, the total area under the production curve had to equal the size of the ultimate resource, a static number in Hubbert's mind. Because Hubbert was well aware that theoretical models needed empirical corroboration, he invoked the case history of petroleum production in the state of Ohio. Hubbert noted that production began a "sharp rise in 1884, passed through three maxima between 1890 and 1900 with the peak about 1896, and since then has undergone a slow, steady decline" (Hubbert, 1956, p. 12).

A second case considered by Hubbert was oil production in the state of Illinois. The production curve for Illinois did not resemble the curve for Ohio. In the case of Illinois, there were two separate peaks, with the second peak being approximately four times higher than the first peak. Any prediction of resource exhaustion inferred from the first part of the curve would have been grossly in error. Hubbert noted that the existence of the two peaks was due to the introduction of new technology: "A new cycle of exploration using the seismograph was initiated in 1937" (Hubbert, 1956, p. 12).

Apparently dismissing or ignoring the implications of the case of Illinois for making valid predictions of future production, Hubbert proceeded to make predictions for peak oil production for both the United States and the world from a single bell-shaped curve. A common misconception is that Hubbert's curves were Gaussian. This is not correct. The curves in the 1956 predictions were drawn by hand. Later, Hubbert (1982) formally based production curves on the logistic equation originally derived by the Belgian demographer Pierre François Verhulst (Deming, 2001).

Hubbert (1956) estimated that the size of the ultimate recoverable resource in the United States was 150 billion bbl. Being fully aware that past estimates had been too low, sometimes grossly so, Hubbert also calculated a curve for the higher number of 200 billion bbl. He characterized the extra

50 billion bbl as "an amount equal to 8 East Texas oil fields," the implication being that he considered this to be an absolute, if not exaggerated, outer limit of what was possible (Hubbert, 1956, p. 18). The two curves yielded peaks in the years 1965 and 1970, respectively. Hubbert conceded that secondary recovery techniques could increase his estimates of the resource size, but he only anticipated that the "effect of improved recovery will be to reduce the rate of decline after the culmination" (Hubbert, 1956, p. 18). The timing of peak production would remain unchanged. Hubbert pressed ahead with this analysis even though the admission of its very unsoundness was explicit. He assumed, without justification, that oil production in the United States would mimic the case history of Ohio, not that of Illinois. Ironically, the production curve for crude oil in Ohio, which appeared to follow Hubbert's peak oil model for several decades, later diverged and exhibited multiple peaks. In 2019, the oil production of Ohio exceeded 27 million bbl, surpassing peak production in the 1890s (US Energy Information Administration, 2023).

Hubbert continued to revisit the peak oil hypothesis for the rest of his career. In 1967, he noted that there had been a "succession of recent assurances that the oil present in the United States may be as much as 3-5 times that discovered already" (Hubbert, 1967, p. 2208), but stuck with his earlier appraisal that the size of the ultimate recoverable petroleum resource in the United States would not exceed 200 billion bbl. Hubbert again explicitly conceded that "the curve reaches one or more maxima" (Hubbert, 1967, p. 2209), but then stuck with his original 1956 prediction of peak oil production between 1965 and 1970, based upon a single symmetric curve.

MALTHUSIANS AND CORNUCOPIANS

The debate between Hubbert and his critics can be viewed in an ideological context as an example of the long-running debate between Malthusians and Cornucopians. In 1798, Thomas Malthus (1766–1834) published *An Essay on the Principle of Population*. Malthus argued against the "perfectibility of man and of society" (Malthus, 1798, p. 7) because exponential growth in population must always outstrip linear growth in the food supply. In Malthus's words, "The power of population is indefinitely greater than the power in the earth to produce subsistence for man" (Malthus, 1798, p. 13). "This law," Malthus concluded, "pervades all animated nature … and it appears, therefore, to be decisive against the possible existence of a society, all the members of which, should live in ease, happiness, and comparative leisure" (Malthus, 1798, p. 16–17).

Malthus and resource depletion are irrevocably linked because population growth drives demand and the utilization and exhaustion of resources. This is true even for nonhuman species. In 1944, a herd of 29 reindeer was introduced onto St. Matthew Island in the Bering Sea. The deer population subsequently followed a classic case of exponential growth followed by catastrophic collapse. By the summer of 1963, the size of the herd had increased to 6000 animals. The reindeer exhausted the food supply, and during the following winter, all but 42 animals starved to death. All of the surviving reindeer were females; thus, the population was doomed to extinction (Klein, 1968).

Almost immediately, Malthus's proposition was rebutted by critics who would ultimately be called Cornucopians. In 1820, William Godwin (1756–1836) argued that "the progressive power of increase in the numbers of mankind, will never outrun the progressive power of improvement which human intellect is enabled to develop in the means of subsistence" (Godwin, 1820, p. 626). In the late decades of the twentieth century, the best known of the Cornucopians was economist Julian Simon (1932–1998). Simon argued that "raw materials and energy are getting less scarce. The world's food supply is improving. Pollution in the United States has been decreasing. Population growth has long-term benefits, though added people are a burden in the short run" (Simon, 1990, p. 1).

The rate of human population growth peaked near 2.2% in 1962, and neo-Malthusian thought flourished during the mid- to late 1960s (Lam, 2011, p. 1233). In the 1968 book *The Population Bomb*, Paul Ehrlich infamously (and falsely) predicted "the battle to feed all of humanity is over. In the 1970s, the world will undergo famines—hundreds of millions of people are going to starve to death" (Ehrlich, 1968, p. xi). Concern over unchecked population growth and resource depletion peaked in the early 1970s with the publication of *The Limits to Growth* by an organization known as The Club of Rome. The Club of Rome predicted the world would undergo a classic Malthusian collapse early in the twenty-first

century as exponential population growth consumed a finite supply of nonrenewable resources (Meadows et al., 1974, p. 124).

The mass famines predicted by Ehrlich and others never occurred. Over the next several decades, food per capita for the world increased in a near monotonic fashion (Lam, 2011, p. 1238). It continues to increase. Innovative technologies dramatically increased crop yields, exactly as William Godwin had predicted in 1820. In the United States, corn yields per acre from 1866 through the mid-1930s averaged approximately 25 bushels, with only small variations from year to year. In 1940, yields began to systematically increase, reaching a peak of 177 bushels per acre in 2021. The higher corn yields can be attributed to the development of hybrid seed varieties, as well as "nitrogen fertilizer, chemical pesticides, agricultural mechanization, and overall improved soil and crop management practices" (Nielsen, 2022). Ironically, by the end of the twentieth century, it had become apparent that the problem was too much food. The world now suffers from an obesity epidemic (Abelson and Kennedy, 2004), a startling contrast to lurid Malthusian predictions of mass famine.

Malthusians failed to anticipate and understand the emergence of the demographic transition, the decline in birth rates that occurs when a society makes the transition from a rural, agricultural society to an urban, industrialized, and technological civilization. The concept of the demographic transition was first proposed in 1929 by Warren Thompson. Thompson noted that Europe "is very rapidly approaching the stage of no [population] increase and that this will soon be followed by its actual decline in numbers" (Thompson, 1929, p. 974). However, the reality of the demographic transition was not widely recognized and accepted for many subsequent decades. By 2009, the demographic transition had "become one of the most solidly established and generally accepted empirical regularities in the social sciences" (Myrskylä et al., 2009, p. 741). A recent projection estimated that the world population will not continue to grow without restraint, but peak in the year 2064 at 9.73 billion and then begin to slowly decline (Vollset et al., 2020, p. 1285). Projections by the United Nations also anticipate that the world population will peak and begin to decline by the end of the present century (United Nations, 2022).

Inherent in Hubbert's model is the concept that the amount of petroleum in the earth's crust is a static number. Setting aside the possibility of abiogenic recharge from the mantle (Gold, 1999), the fixed nature of the natural endowment is indisputable. However, Hubbert never fully appreciated the dynamic nature of human technology in exploiting natural resources such as petroleum. As long ago as 1933, economist Erich Zimmermann (1888–1961) noted that "the word resource is an expression of appraisal and, hence, a purely subjective concept" (Zimmermann, 1933, p. 3). In Zimmermann's view "the resource concept is relative … not only according to human wants, but also according to the abilities of man to make use of his environment and to shape it to fit his designs" (Zimmermann, 1933, p. 3).

In 1957, in an apparent rebuttal to Hubbert's prediction of an imminent decline in United States oil production, Richard J. Gonzalez noted that "recent estimates that the United States will only produce 150 to 200 billion bbl of oil will prove conservative because of improved producing techniques and additional discoveries in old and new provinces" (Gonzalez, 1957, p. 14). Referencing a 1956 report by the US Department of the Interior (US Department of the Interior, 1956, p. 82), Gonzalez noted that "the Department of the Interior considers 300 billion bbl as the ultimate reserves of the United States to be a reasonable figure, and even that may seem conservative in another 20 years" (Gonzalez, 1957, p. 14). Hubbert disparaged Gonzalez as "about the worst offender in the oil industry in propagandizing the public with overestimates" (Inman, 2016, p. 188). By the end of 2021, cumulative production of crude oil in the United States had reached 239 billion bbl, well in excess of the largest amount Hubbert thought possible. Gonzalez's prediction proved more accurate than Hubbert's, yet Gonzalez was relegated to the dustbin of history, whereas Hubbert was honored.

Hubbert's leading adversary was the geologist Vincent McKelvey (1916–1987). As early as 1959, McKelvey professed a Cornucopian view of energy resources. Writing in the journal *Science*, McKelvey concluded that Malthus "vastly oversimplified the relation man bears to his environment and underestimated man's ingenuity in developing and utilizing its resources" (McKelvey, 1959, p. 876). He argued that "resources of usable raw materials and energy may be increased to an unpredictable extent by the development and application of ingenuity" (McKelvey, 1959, p. 880). McKelvey was right. In the second

decade of the twenty-first century, new petroleum technologies enabled the 38-yr-long decline in United States oil production to reverse, reaching a new production peak of 4.0 billion bbl in 2018. Hydraulic fracturing and horizontal drilling enabled production from low-permeability strata such as shales (Maugeri, 2013). In Hubbert's lifetime, the wholesale production of petroleum directly from shale was inconceivable.

In 1970, the United States oil production peaked and began to gradually decline, but the consumption of oil worldwide continued to increase. By 1973, the price of oil had doubled, and United States imports had increased from 3.2 to 6.2 million bbl/day (Yergin, 1991). On October 6, 1973, the Middle East erupted in war as Israel was invaded simultaneously by Egypt and Syria. In retaliation for the United States support for Israel, on October 20, Saudi Arabia and other Arab countries imposed a total ban on exports of oil to the United States (Yergin, 1991). The oil embargo was accompanied by a significant reduction in overall production, driving up prices and making it more difficult to replace the embargoed oil by purchases on the world market. Oil prices quadrupled (Yergin, 1991). Americans, who had become used to decades of cheap, abundant gasoline now found themselves waiting in long lines at gas stations: "The age of shortage was at hand … the shortfall struck deep at fundamental beliefs in the endless abundance of resources" (Yergin, 1991, p. 616). The corroboration of Hubbert's predicted peak was mistaken for confirmation, and proof of the peak oil model, rather than a short-term trend.

On January 20, 1977, United States President Jimmy Carter was inaugurated. An immediate priority for his administration was a new energy policy. The policy was foreshadowed in *The New York Times* on April 4, 1977, by columnist Anthony Lewis. Lewis described the "central operative premise" of Carter's policy as the conviction that "the world's supply of oil is finite, it is running out, and no easy substitute is in sight" (Lewis, 1977, p. 29). Hubbert's influence was waxing. Lewis noted that "it is very new for the United States Government to accept Hubbert's thesis as the premise of its policy" (Lewis, 1977, p. 29).

On April 18, 1977, President Carter addressed the nation. The tone of the speech was pessimistic and the rhetoric Malthusian. Carter began with a warning, "The energy crisis has not yet overwhelmed us, but it will do so if we do not act quickly." "Resources," Carter claimed, are "rapidly shrinking … the oil and natural gas that we rely upon for 75 percent of our energy are simply running out" (Carter, 1977). The solution he proposed was not to increase supply, but to make "profound changes … to lower oil consumption." Carter predicted that "world oil production can probably keep going up for another 6 or 8 years" (Carter, 1977). President Carter was wrong. World oil production did not peak in the mid-1980s as he predicted. In 1977, total world crude oil production was 21.7 billion bbl. By 2018, world oil production had reached 34 billion bbl. The size of the ultimate resource is now thought to be in the neighborhood of 10 trillion bbl (Lynch, 2009).

When the Carter administration began in January 1977, Vincent McKelvey was director of the US Geological Survey (USGS). When energy became political, so did geology. With Malthus and Hubbert in favor, McKelvey, the Cornucopian, became disfavored. McKelvey was pressured into resigning as director, effective January 1, 1978. An article in the journal *Science* described McKelvey's forced resignation as "tantamount to a firing," and expressed the concern that "it is a first step towards politicizing [the] USGS, whose excellent scientific reputation has been based partly on its independent character" (Shapley, 1977, p. 1264).

Hubbert was elated by McKelvey's dismissal. He wrote to Harlen Bretz that McKelvey "got caught in the misinformation he had been feeding the government since 1961 about the supplies of oil and gas in the United States … his present attempt to give it a political flavor is simply a continuation of the deceptions he has been engaged in for the last 16 years" (Inman, 2016, p. 280). With the president of the United States publicly proclaiming an energy crisis and imminent exhaustion of the world's petroleum resources, Hubbert was publicly celebrated as a "prophet" and an "oracle" (Inman, 2016, p. 283).

CONCLUSION

It is undeniable that Hubbert was a genuinely great scientist and brilliant man. Setting peak oil theory aside, he made other contributions of lasting scientific significance. These include his work on scale models (Hubbert, 1937) and a classic paper on the theory of groundwater motion (Hubbert, 1940). In 1953,

Hubbert showed that hydrodynamic conditions alone could lead to the entrapment of petroleum (Hubbert, 1953). Perhaps his most important and enduring contribution was the demonstration that the state of stress in the earth depends on pore-fluid pressure (Hubbert and Rubey, 1959). Collaborating with William Walden Rubey (1898–1974), Hubbert showed how fluid pressure affected the state of stress within the earth and could provide an explanation for the long-standing problem of the apparent mechanical impossibility of large overthrust faults. Subsequent experiments by John Bredehoeft and his colleagues at the USGS corroborated the Hubbert-Rubey hypothesis by showing convincingly that movement on faults depended on the ambient fluid pressure (Raleigh et al., 1976).

Peak oil theory is an attempt to overly simplify a complex subject that depends not just on geology but also human nature, history, and technology. Hubbert may have been seduced by his view that science is a process of simplification. In his 1963 paper *Are We Retrogressing in Science?*, Hubbert described "the evolution of science" as "a progression from the complex to the simple" (Hubbert, 1963, p. 888). "Since it is impossible," Hubbert explained, "for human beings to understand chaotic phenomena, it is necessary that these be reduced to a state of simplicity if they are ever to be understood" (Hubbert, 1963, p. 889). Thus, the lure may have been irresistible. By reducing the problem of resource exhaustion to a single bell-shaped curve—a law, as it were—Hubbert was simply following in the tradition of Isaac Newton, who simplified the complex problem of planetary motion into one equation of universal gravitation, or Johannes Kepler, who inductively derived three laws of planetary motion from an inchoate mass of observational data.

It is not necessary to categorize Hubbert or any human being as all good or all bad. No incongruity exists between possessing a brilliant intellect and making a serious mistake. Galileo Galilei falsely attributed the existence of sea tides to inertial mechanisms rather than the gravitational attraction of the sun and the moon (Deming, 2012). Newton made mistakes. He claimed that if a falling body with an initial velocity parallel to the surface of the earth were allowed to continue its descent to the center of the earth, its path would be a spiral. Newton had to admit his error when Robert Hooke pointed out that the object in fact would assume an elliptical orbit. Hooke was no match for Newton in mathematical physics, but he knew the answer because he had conducted experiments by rolling balls inside various surfaces of revolution (Deming, 2012). Newton also wrote a universal history containing serious errors of thousands of years (Deming, 2012), yet Newton is remembered today for his remarkable contributions, not his mistakes.

Perhaps the most important factor influencing Hubbert was the taint of ideology. The human mind is not objective. As long ago as the early seventeenth century, Francis Bacon had warned "the mind of man is far from the nature of a clear and equal glass, wherein the beams of things should reflect according to their true incidence; nay, it is rather like an enchanted glass, full of superstition and imposture" (Bacon, 1864, p. 276). Bacon called the biases that originate in dogmatic philosophies "idols of the theater" (Bacon, 1858, p. 55). Among the most striking examples in scientific history are the decades near the beginning of the nineteenth century, when the students of Abraham Werner tortured geologic data into conformity with the Neptunist theory of their charismatic teacher (Hallam, 1989).

To the end, Hubbert was an unapologetic Malthusian and technocrat. In a 1983 interview, 6 years before his death, Hubbert pessimistically claimed "we are in a crisis in the evolution of human society. It's unique to both human and geologic history. It has never happened before and it can't possibly happen again. You can only use oil once. You can only use metals once. Soon all the oil is going to be burned and all the metals mined and scattered" (Clark, 1983, p. 22). Hubbert's statement was absurd, even when he made it. Metals can be used more than once. At least 60 different metals are currently recycled (Graedel et al., 2011). Aluminum has been recycled since the beginning of the twentieth century, and gold has been heavily recycled for thousands of years.

What difference does it make? The false belief that oil supplies were dwindling resulted in a misallocation of resources. Energy policy in part is based on projections of the future price of oil, which in turn is determined by scarcity. "Policy-by-oil-price-assumption has resulted in some spectacularly bad decisions" (Helm, 2011, p. 69). Instead of encouraging the development of abundant and proven petroleum resources, governments and individuals wasted much time, money, and effort on fruitless alternatives: "The

false threat of disappearing oil led the government to throw money away on harebrained renewable energy schemes or impose unnecessary and expensive conservation measures on a public already struggling through tough economic times" (Lynch, 2009). It is difficult to quantify the cost of prophetic doom mongering. American oilman Michel Halbouty (1909–2004) was succinct in his criticism: "That man [Hubbert] did more damage to the thinking of Congress and this country than any one man I know" (Inman, 2016, p. 294).

It may be premature to conclude that peak oil theory is completely dead. The entire history of the petroleum industry is one of bust and boom cycles. When there is a glut of oil on the market, exploration and drilling wind down. The excess is then inevitably followed by a deficit and increasing prices. It seems likely that history will repeat itself. Despite decades of false predictions, during some future bottleneck in oil supply, peak oil theory will be trotted out of the graveyard and temporarily revived. Indeed, Malthusian theorists are alive and well, even though we have now lived through more than 200 years of increasing resource abundance. On the day that the world does reach an ultimate peak in oil production, it likely will not be caused by an inherent scarcity, but by a gradual phasing in of nuclear energy.

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