Hubbert's Peak

Deja vu All Over Again

*By John Ryan**

A recent article in a popular periodical predicts that "… somewhere between two and six years from now, worldwide oil production will peak. After that chronic shortages will become a way of life."[1] This article is based on an interview with Kenneth Deffeyes and relies on his work, *Hubbert's Peak.*[2]

Sooner or later Deffeyes' apocalyptic vision must come to pass, but must it come so soon? After all, the savants have been making this dire prediction since the virtual dawn of the industry. For example, around 1910 the U.S. Geological Survey warned that the nation was running out of crude oil and that it should be conserved for its superior uses in illumination and lubrication. About 1920 a learned Michigan State professor argued that the roadside would soon be littered with abandoned automobiles for which their former owners could no longer obtain fuel. And, more recently, a geologist formerly associated with Shell Oil, Dr. M. King Hubbert, wrote in a study for the National Academy of Sciences in 1963, that the lower forty-eight states had passed their period of peak discoveries and that production must inevitably follow this decline in discoveries in about ten years. He further forecast that the maximum cumulative production from these states could not exceed about 170 billion barrels.[3] Now, using the Hubbert methodology, Deffeyes extends this prediction to the entire world to reach his forecast of impending world-wide scarcity.

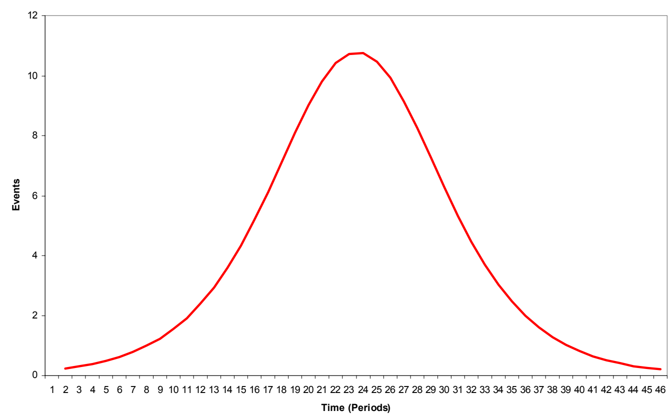
Can the experts have finally gotten it right this time? To answer this question it is helpful to consider the methodology employed, the underlying assumptions of the analysis and, of most importance, how the earlier Hubbert predictions have fared in the almost forty years of history that we now have.

Before discussing methodology, however, a brief digression is in order. Neither Hubbert or Deffeyes allows for the possibility that a rise in the relative price of crude oil could result if the supply should actually become markedly scarcer and that this increase might have a significant impact on the total volume of crude oil that would be ultimately produced. Most economists, I think, would disagree with this implicit assumption. On the other hand, Deffeyes' explicit assumption that nothing much – in the absence of some catastrophic event – can have a significant affect on the supply of crude oil during the next ten years or so would probably meet with general agreement.

The basic methodology employed by both Hubbert and Deffeyes has been around for over 150 years, has been primarily used for characterizing growth patterns and was employed in its early days for describing the life cycle of Drosophila, or fruit fly. Hubbert implicitly analogizes the life cycle of a barrel of oil to that of Drosophila.

In laboratory experiments in the mid-nineteenth century a limited number of fruit flies were introduced into a bottle containing a precise amount of food. Neither the dimensions of the container nor the amount of the food supply was allowed to change during the course of the experiment. Observations were made over various time periods of the composition of the fly population – living or dead – in order to establish some sort of life cycle. The biostatisticians assumed that the initial fruit flies would breed rapidly since there would be no constraints on their growth. But, as the bottle became more crowded and food supply was slowly depleted, the rate of reproduction would taper off. Gradually, the rate at which new fruit flies hatched out would equal the mortality rate of the live flies and the number of living flies would reach a peak. The process at that point would gradually reverse with flies dying off more rapidly than they hatched. This process would accelerate until the last fly died and life would come to a halt in the bottle.

Figure 1
Events per Period



The biostatisticians constructed a simple mathematical relationship which described such a life cycle and observed that it gave a very good description of the course which life actually took in the bottles. The rate at which the flies were hatching out followed a bell shaped curve such as that illustrated in Figure 1. The equation which generated this curve was called the logistic equation (from the French word for domicile – in this case the bottle – and not from the Latin word for logical, as one might have assumed). This curve has the important property that it is perfectly symmetrical about its peak which occurs at the mid-point of the experiment. And, since the area under the curve represents the cumulative number of fruit flies which have hatched, symmetry implies an equal number hatching both before and after the mid-point. This characteristic of the logistic equation was to be of critical importance to the analyses of both Hubbert and Deffeyes.

It also proved useful to determine the cumulative number of fruit flies – living or dead – that had ever lived in the bottle at each period in time, i.e., the area under the bell curve at each point in time. This curve is an elongated S-shaped curve. (See Figure 2 for an example of such a curve.) It, like the bell curve, starts out increasing rapidly as it moves to the right. At the precise time that the bell curve begins to decline, the *growth rate* of the S-curve begins to taper off and the curve gradually flattens out until it reaches its ultimate limit; at that point life has ceased to exist in the jar. There is now a reverse sort of symmetry in that the right hand half of the curve is a reverse mirror image of the left. The number of flies which had hatched up to this halfway point was equal to the number which were to hatch out afterwards.

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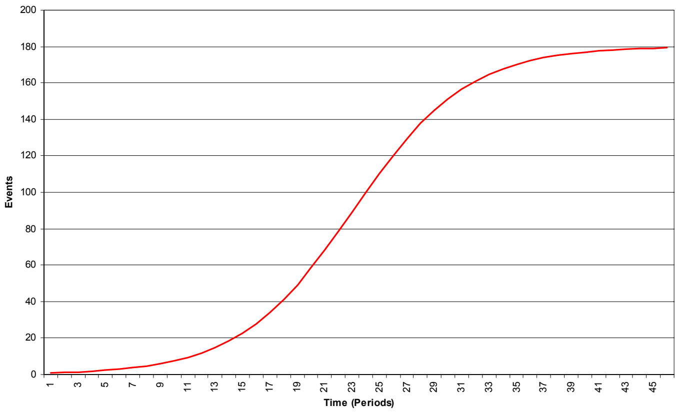
[1] See footnotes at end of text.

Figure 2
Cumulative Events



Demographers became enamored of this particular equation and soon attempted to apply it to human populations, but with less than indifferent results.[4] For a given geographical area, they would fit a logistic equation to that area's birth data. Then they projected mortality with an identical logistic curve displaced into the future by the average life expectancy. The difference between these two curves was an estimate of the living population of that area at that time.

In 1910, this logistic method projected a U.S. population of about 180 million in 2000 and an absolute maximum of 200 million. But, the actual population came in at over 280 million in the year 2000, more than fifty percent higher than the logistic had predicted and well over the absolute maximum. It is still growing.

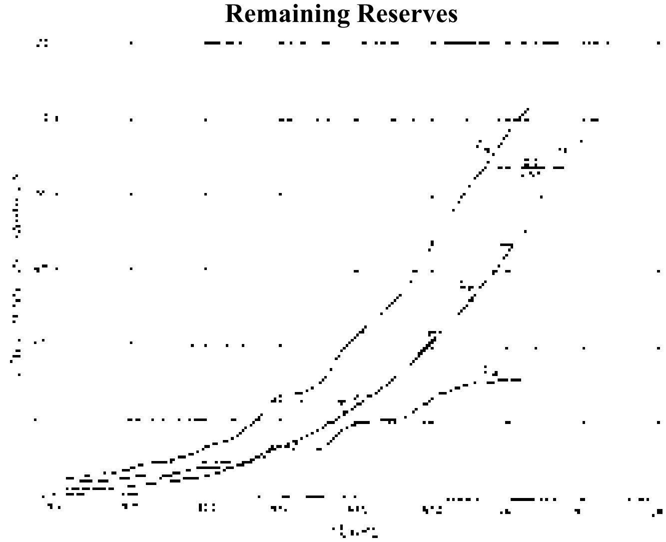
The flies behaved almost exactly as expected, so what went wrong with the human "experiments"? The simple answer is that the flies were living and dying under strictly controlled laboratory conditions and the humans were not. The human populations were not confined in a bottle, but were free to move in and out of their "domicile" in response to changing conditions. Furthermore, humans did what humans do: they imported food when it ran short (if they could), they applied more fertilizers to their crops, they invented vaccines to cure heinous diseases and, in short, they did everything in their power to improve and to lengthen life. Birth rates increased, mortality rates declined and people lived longer, on average, and some people migrated in or out.

The result was to destroy the symmetry of the growth pattern. As people lived longer, and the area experienced net in-migration, the right hand portion of the bell curve rose, the population grew at an even faster rate and earlier forecasts were increasingly short of the mark. In other words, the population became "skewed to the right" (a statistician would say that the mean exceeded the mode). The converse would also be true, of course. The skewed curves were no longer symmetrical and it is was no longer true that there was an equal number of events on both sides of the peak. And the elongated S-curve of the actual events grew ever greater than had been predicted by the logistic model.

Turning from fruit flies and people to barrels, Hubbert substitutes a barrel of new crude oil discoveries for the birth of a human or the hatching of a fly. He substitutes the production of a barrel of crude oil for the death of a fly or human. After that switch, the analysis is the same. Hubbert assumes that the curve of annual new crude oil discoveries rises to a peak (as, indeed, it must at least once) and then declines to zero. He observes further that the curve of annual crude oil production has a similar shape and that historically it lags discoveries by about 10.5 years.[5] These assumptions are entirely consistent with the available data and the fact that the oil obviously must be found before it can be produced. Then, in order to make his forecast of future discoveries and production in the U.S. lower forty-eight states, he fits the logistic equation to the historical discovery and production data (as the biostatisticians and demographers had done with birth and death data in earlier years) and projects these two curves into the future.

In Figure 3, Hubbert subtracts actual cumulative production (Q_P) from actual cumulative discoveries (Q_D) to obtain the reserves remaining to be produced (Q_R) in the same way that the demographers predicted the living population earlier by subtracting cumulative deaths from cumulative births.[6] He notes that this measure – remaining proved reserves — has a slight "dip" about 1960 and that it "clearly" reached its peak about the end of that year. (Similar conclusions from Figure 3 could have been reached from the "dips' in 1958 and 1932 and, perhaps, from the "semi-dips" occurring in 1922 and 1941. With the passage of time, it has become obvious, however, that these "dips" and "semi-dips" were mere perturbations, what the information theorists refer to as "noise" rather than "signal." It would have been amusing – though not particularly instructive – to have projected ultimate recoveries in 1932 using the logistic method and the data that were then available.)

Figure 3
Cumulative Production and Discoveries
Remaining Reserves



If the peak in remaining reserves occurred about 1960, and if the curves were symmetrical and if the cumulative production curve lagged the cumulative discovery curve by 10.5 years, then the peak of discoveries occurred around 1955 with the peak of production 10.5 years later. For technical reasons, that had little to do with his logistic equation, Hubbert chose 1957 as the peak year for U.S. discoveries (ex Alaska) and, therefore, has production peaking out some time in the late1960s. This forecast of the peak year of production in the lower 48 states was really quite good as the actual peak occurred in 1970. At the time of this presumed peak in the annual discovery rate (1957), about 82-85 billion barrels of crude oil had been discovered in total. "*By assuming that this is near the half way point,* ultimate discoveries … would be about 164-170 billion barrels [emphasis supplied]." [7]This was Hubbert's estimate of the maximum volume of crude oil that could be recovered from the lower forty-eight states. It was this critical assumption — that the lower forty-eight had produced half of its ultimate potential when annual discoveries reached their peak — that led Dr. Hubbert astray.

There were two important factors working against Hubbert's assumption of symmetry in the producing curve. The first is that those responsible for estimating new reserves are inclined to be highly conservative in their initial estimates. They base their estimates on then current knowledge of geology and the existing technology, not some extrapolations into the unknown future or guesses of what reserves lie in as yet unexplored sediments. One reason for this is that such estimates are used in planning investments in development and related downstream facilities. A deliberate decision to be conservative can generally be rectified at some relatively modest cost, if subsequent events warrant, but excessive investments would have to be largely written off. This fact tends to impart a conservative bias to early reserve estimates. Then, as subsequent producing history confirms deposits greater than initially supposed, these early estimates are revised upwards. (Downward revisions are made as well, but the preponderance is upward.) Subsequent production levels are, therefore, greater than could have been expected from the initial reserve estimates. The result is equivalent to an increase in the life expectancy on a population forecast. It is impossible to quantify this inherent bias toward early underestimation, but the effects in the case of the petroleum industry can be observed.

Of more importance, perhaps, is the fact that there have been dramatic improvements in oil recovery techniques and in our ability to extract the oil from the porous rocks in which it is trapped. The "rocking horse head" pumps which dot the landscape in the U.S. Southwest, California, Southern Illinois and elsewhere are a tribute to man's effort to pump more oil out of the ground and into the right-hand tails of the bell curves and to postpone indefinitely the time at which the tails actually fall to zero.

The effects of these "stripper wells" is insignificant, however, compared to the results of more recent enhanced oil recovery developments. Principles of chemistry and physics and improved understanding of geology and oil reservoir mechanics have been used to improve recovery rates from older reservoirs, both here and abroad, and hence to increase substantially ultimate recoveries. Today, the so-called giant fields, from which much of our production comes, seem to be like old soldiers; they never die, they only fade away. The Bradford field in Pennsylvania, for example, one of our domestic giants, was discovered in 1871 and is still producing.

Figures 1 and 2 illustrate hypothetical annual and cumulative production curves as Hubbert (and Deffeyes) assumed them to be. In theory, as our knowledge of the volume of oil originally in place increases and our technology for extracting it improves, the production curves should become skewed to the right as we are able to extract more oil than we first thought possible. The upper limit in Fig. 2 simply ceases to exist and the production curve moves ever higher. The grand cosmological constant which Hubbert sought – the ultimate amount of crude oil to be produced – becomes a moving target depending on the technology that is available at the time of the estimate. But, Hubbert simply assumed the problem of improving technology away.

On the other hand, Deffeyes recognizes part of the problem with improving technology and attempts to address it. He assumes that the explorationists first picked off the easier to find fields nearer the surface. Then, gradually improving exploration technology led to substantially larger discoveries during the fifties and sixties when the geologists found many of the larger, deeper reserves such as the North Sea, the Bass Strait and Saudi Arabia. As the century draws to a close, he argues, the pace of discovery accelerates, but the finds are smaller and the curve begins to flatten out.[8]

This observation is not entirely consistent with the history of the discovery of large crude oil fields. For example, the largest field in the lower forty-eight, the East Texas field, was discovered in 1930; the largest field in North America, Prudhoe Bay, was found in 1967. The largest known oil field in the world (up to now) is Ghawar in Saudi Arabia. Its discovery well was completed in 1938, but its official discovery date is ten years later in 1948. Burgan was found in Kuwait in 1938, Ebano-Panuco in Mexico 1901, Bibi Eybat in Russia in 1850, Coalinga in California in 1887 and Carito in Venezuela in 1917. This handful of examples doesn't prove anything, but it does suggest that Deffeyes' generalization may, perhaps, be overly broad.

What is more important, however, is that Deffeyes does not allow for the fact that improvements in recovery factors simply means that more oil than was originally anticipated will be found and that it will be produced in later rather the than earlier years in the life of a given field. Furthermore, improvements in recovery factors in existing fields cannot be introduced on a massive scale overnight; the lag between the discovery of a new technology and its application can be a matter of years. Thus, even if no more improvements in extraction technology were to take place, we would still expect there to be higher production in some older fields than we predict today and that the estimates of reserves in those fields would be revised upwards in the future.

In sum, we should expect that the more recent discoveries would appear to be getting smaller and should not be unduly alarmed. If history is a reliable guide, the shortages looming around the corner will probably be displaced until some time in the more distant future. And we should also recognize that the producing patterns of individual fields — and, hence, of the universe of all fields — will also probably tend to be skewed to the right and asymmetrical.

Despite misgivings about the underpinnings of the Hubbert and Deffeyes approach, it may still yield acceptable results. Accordingly, Hubbert's 1965 projections have been tested against the actual historical data. The available discovery rate figures are wildly erratic, but Hubbert's logistic equation for discoveries seems to be fairly representative of the history at the time of his forecast.[9] The production rate data are more well-behaved and seem to follow the logistic rather well except for the 1920s. Hubbert does not show his estimates of future (post-1965) discoveries and production, but merely states that the cumulative discovery curve will eventually level out at about 170 billion barrels.

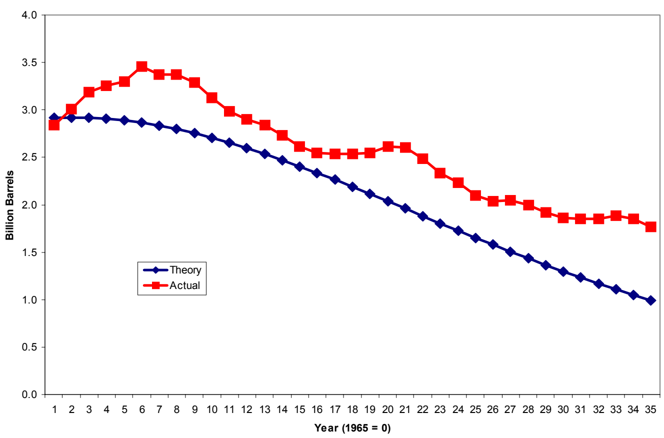
I have calculated the projected values of the logistics curve after 1965 using the parameters of Hubbert's 1965 equation. The numbers do indeed rise slowly and approach

Hubbert's upper limit of 170 billion as expected. However, these forecast data fall considerably short of reality according to the Department of Energy figures.

Starting in 1968, three years after Hubbert made his forecast, a gap between Hubbert's estimated production levels and actual production began to emerge. By 2000, the total number of barrels of crude oil that had been extracted in the lower forty-eight states exceeded the maximum possible level of 170 billion barrels which Hubbert had predicted. According to his forecast, given actual rates of crude oil production since 1965, the last producing oil well in the lower forty-eight states should literally have run dry some time during the year 2000. Yet the producing industry was still healthy at that time; production in the lower forty-eight states was about five million barrels a day and over seventeen billion barrels of proved reserves remained to be extracted at year's end. Much of the nation's sediments were still unexplored, including some of the nation's most prospective remaining geological provinces which had been declared "off limits" for environmental considerations. They remain largely unexplored today.

Figure 4
U.S. Annual Crude Oil Production

(Actually, if the nation's reservoirs had been approaching a state of exhaustion, it would have been virtually impossible to have achieved the rates of production that were observed. This is just another way of saying that Hubbert's theory is inconsistent with reality.)



In Figure 4 it becomes clear why the Hubbert estimate fell so far short of the mark: the actual curve of production was strongly skewed. Production in the U.S. lower forty-eight states did not decline in the perfectly symmetrical pattern that Hubbert had predicted, i.e. the curve marked "Theory" in Figure 4. Instead, the production profile peaked somewhat later than had been predicted and was skewed markedly to the right. In every year but one after 1965, actual production exceeded the logistic forecast and by far more than insignificant volumes. Furthermore, the excess of actual over forecast was growing modestly over time. By 2000, the excess of actual over forecast amounted to sixteen billion barrels or more than eight years of production at the then current rate.

The Guterl article states, "Nowhere is it written that the oil supply must adhere to a [symmetrical] bell curve. The problem is that Deffeyes sees no reason that it won't."[10] But, if the fact that the curve has not followed such a pattern over the past forty years is not a sufficient reason to think that it may not in the future, one would be hard pressed to find a reason that is sufficient.

Another major problem with Hubbert's analysis is that it excluded Alaska. It is understandable why Hubbert omitted Alaska in his calculations; production had only recently begun, it amounted to only 30,000 barrels a day in 1965 and the potential was a huge question mark. It makes a least as much sense, however, to extend

Hubbert's analysis to the entire continental United States as it does to extend it to the entire world as Deffeyes does. But including Alaska in the analysis further undermines any support for the assumption that the peak of production occurs at the halfway point in the producing life of an area. Since 1965, production in Alaska has added over fourteen billion barrels to the cumulative total, there are now almost five billion more barrels remaining in the ground in Alaska in the form of proved reserves and there is a large volume of highly prospective, but unexplored, sediments. As a result, the skewness of the total U.S. producing curve is greater than that of the lower forty-eight states and will probably grow more so over time. Furthermore, the curve now sports two virtually identical peaks, one in 1970 and the other in 1985. No vestige of symmetry remains.

Clearly the assumptions of symmetry and halfway points led to substantial error, but these problems were only symptomatic of the fundamental flaw in the analysis: the failure to take into account the inherent bias in early reserve estimates and the effects on such estimates of technological progress. Once laboratory conditions ceased to exist, there was no reason for assuming that the growth process of a controlled environment (which is the basis of the logistic equation) would obtain and that a logistic curve (or any other particular curve, for that matter) would give a reasonable projection of future growth.

The Hubbert/Ryan discussion about domestic crude oil availability in 1965 did not take place in a vacuum. It was part of a national debate on whether or not to impose end-use controls on the consumption of oil and natural gas because of a perception of growing scarcity. Specifically, the primary proposals would have prohibited the use of oil and natural gas for boiler fuel in order to conserve them for their "superior uses."[11] The Hubbert analysis was a major weapon in the arsenal of those supporting such restrictions. But even when the Hubbert analysis was first offered, there were strong reasons for rejecting its conclusions as a basis for policy decisions. With hindsight, we know that the nation was well advised to have done so.

Today Deffeyes is reviving this same argument, on a grander scale, to justify his call for a program of Manhattan Project sized proportions — or even larger — to develop alternative sources of energy to avert the looming energy shortage that he foresees. But the reasons for rejecting his recommendations as a basis for national energy policy today are at least as sound as those for having rejected the Hubbert analysis in the 1960s. Particularly in view of the fact that the world-wide discovery and reserve data, which are the basis for Deffeyes' conclusions, are surrounded by an aura of uncertainty probably of order of magnitude greater than that of comparable measures in the United States.

There may be valid reasons for mounting a crash program to develop alternative energy sources in the United States today. A looming energy shortage is certainly not one of them.

(See footnotes on page 26)