Parabolic Projection of World Conventional Oil Production Based on Year 2000 Resource Assessment of the U.S. Geological Survey

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Abstract

The world production of conventional oil was projected parabolically using preliminary data posted on the Web by the U.S. Geological Survey in advance of the formal publication of the Year 2000 Assessment (DDS-60) of undiscovered oil resources. This major study was released at the time of the 16th World Petroleum Congress held in Calgary, Alberta, 11-15 June 2000. This technique was employed to estimate the timing and magnitude of the peak in conventional oil production for the world as a whole. The Mean Value of the assessment was employed in the parabolic calculation to derive two boundary cases due to the uncertainty concerning a large quantity of oil termed 'reserves addition.' Oil in this category was assumed to contribute to output only after the peak has passed at one extreme (Case 1) and to be continuously available throughout the production period at the other (Case 2). The actual production is likely to lie between these limiting cases.

In two sensitivity tests, oil production based on the smaller oil resources at 95% probability was calculated in Case 3 and the larger resources at 5% probability in Case 4 which represent two extremes of the assessment values. In Case 1, world conventional oil production peaked at 29.38 gigabarrels (GB) per year in 2017.1; in Case 2 - 31.1 GB/yr in 2026.9; in Case 3 - 28.53 GB/yr in 2012.1; and in Case 4 - 30.60 GB/yr in 2024.1. Cumulative and per capita data were also calculated from these four projections.

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Introduction

Oil provided 40.0 % of the world's commercial primary energy consumption (excluding the biomass) and 45.8 % of the carbon dioxide emissions from the fossil fuels in 2000.[1] By far the greater proportion was obtained from conventional reservoirs although the production of oil from non-conventional sources (the oil sands and heavy oils) are of growing importance in this country. The parabolic method for projecting oil production was devised to focus on the magnitude and timing of the peak output of conventional oil as there are good reasons to believe that the world energy system will behave differently once this point has passed.[2] Before the peak, there are three main attributes of oil which influence the situation. First, oil and its main refined products are liquids and thus can meet almost all energy needs one way or another. It is much more difficult to cover the full range of demand with the other two fossil fuels - natural gas and coal. Second, oil, as a liquid, is cheap to move long distances on both land and sea on an energy basis. Coal is expensive to move on land but is cheap to move on the sea in bulk carriers. Natural gas is intermediate in cost to move on land but expensive to move in liquefied form in specialized tankers on the sea. Third, oil is supplied to world markets in an inverted cost pattern. Expensive oil sands plants are operating at capacity and being expanded in Canada though large reservoirs, mainly in the Middle East with low technical costs of production, are idling. Oil, the leading item in international trade, may not be unique in this inverse supply pattern in that diamonds may be marketed in the same way but this situation is inherently unstable. This inverse supply pattern could change right-side-up tomorrow but this condition has persisted despite disruptions of one kind or another for decades. This effect is probably responsible for the exceptional stability in world per capita consumption of oil in recent years which has remained a constant at about 4.43 barrels per capita (Standard Deviation of 0.068) since 1983.[3]

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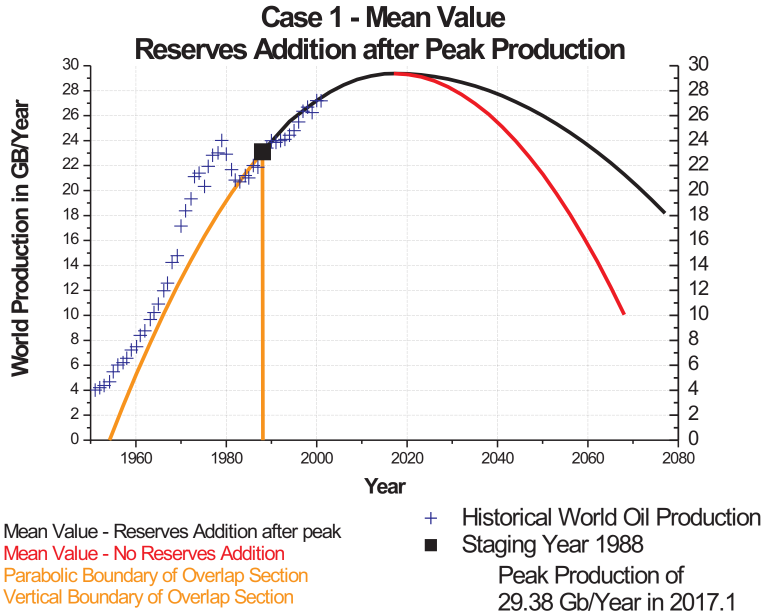

There are two consequences to these attributes. First, the owners of oil may take whatever share of the energy market they wish at any time and at any place by simply reducing prices. Second, if an attempt is made to introduce a new energy technology of importance in the market place before the peak is reached, all that happens is that the price of oil falls.The situation changes after the peak is passed. There will be little excess productive capacity in the conventional oil supply system outside of the Middle East and the system will loose resilience significantly. Prices will no doubt be higher but perhaps more predictable and less volatile. The situation may well become more rational in the post-peak period. This may be the ultimate paradox in a system becoming increasingly paradoxical as the economy dematerializes.

Because of the importance of the timing of the peak, a parabolic approach was devised to project geological assessments of the world's remaining resources of undiscovered conventional oil.[4] This technique differs in two main ways from such methods devised classically by Hubbard[5] and more recently by Duncan and Youngqvist.[6] First, the future is not determined by the production-time pattern of the past before a certain chosen 'staging' date. This aspect is particularly important in view of the major disruption in oil supply which occurred during the events of the 1970s. The Staged Parabolic Method does depend, however, on the pattern of production after this date. Second, the technique relies upon geological assessments: it does not attempt to estimate oil resources from the historical production-time pattern.

The U.S. Geological Survey has long been a leader in the assessment of undiscovered oil resources. In 1995, it released an authoritative assessment of the United States oil and gas resources[7] (results available on one CD-ROM), and the new assessment of the world as a whole requires a 4 CD-ROM set to hold this extensive study.[8] In March of 2000, an understanding was reached with the International Energy Agency whereby the USGS will be recognized as the main source of information in this field for this multilateral organization.

The preliminary results from the Year 2000 Assessment posted on the Web in advance of publication give the Mean Value for undiscovered conventional oil for the world as a whole as 724.2 gigabarrels (ranging from 394.4 GB at 95% probability and 1,202 GB at 5% probability). The category termed 'Oil reserve growth' was placed at a high 612 GB for regions outside of the U.S. Adding 60 GB to this value for the U.S. itself taken from the 1995 Assessment[7] leads to a world total of 672 GB for oil resources in this category. These values were employed in the calculations that follow.

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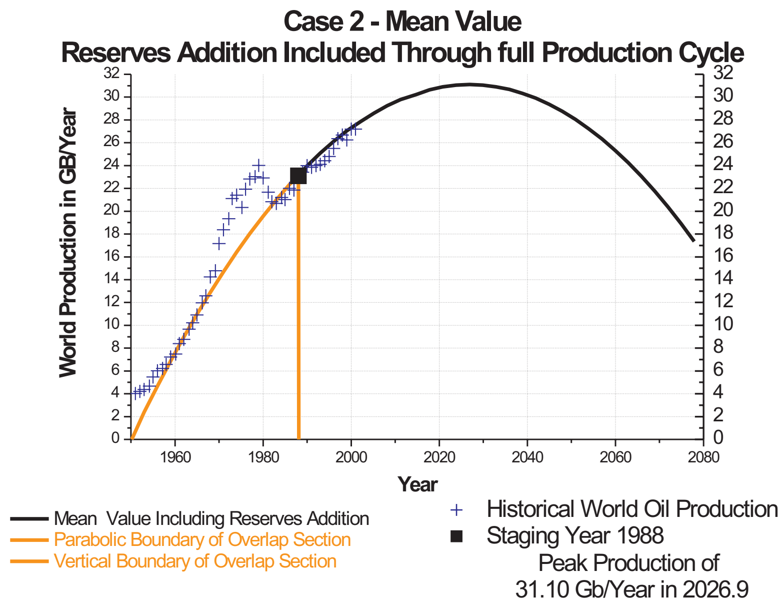


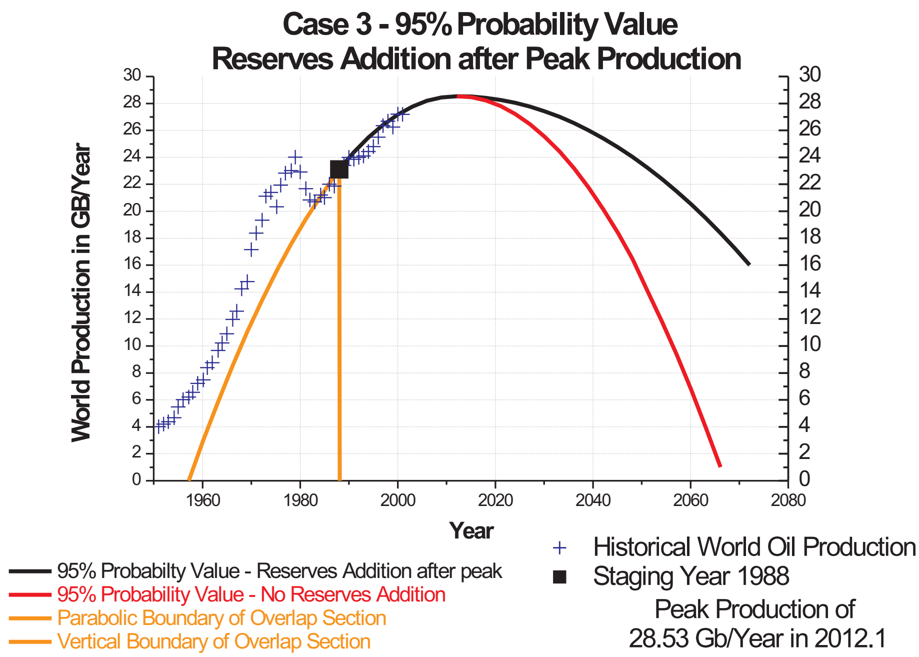
Methodology

The first step was to estimate the Ultimate Recoverable Resources termed here Qu. The world cumulative oil production to the end of 1998 was calculated by adding the production in each of the years from 1988 to 1998 derived from the *BP Review of World Energy* to the cumulative total of 610.1 GB estimated to the end of 1988 by Masters et al.[9] which resulted in a total of 857.2 GB. The world reserves to the end of 1988 (also published in the *Review*) were accepted at their face value of 1052.9 GB despite the views of some experts that this number may be overstated for a variety of political and commercial reasons especially in the Middle East. For the Mean Case, Qu was taken as the sum of the cumulative production to the end of 1998, the published reserves at the end of 1998, and the USGS assessment of undiscovered resources which total 857.2 + 1052.9 + 724.2 = 2634.3 GB. Similar calculations were made for the boundary 95% and 5% probability cases with Qu taken as 2304.5 and 3112.3 GB respectively.

The staging year was chosen as 1988 because of the reliable estimate of the world cumulative production to that date and because a full ten-year period of stable and growing world oil production occurred during the period to to 1998 and beyond. The details of the calculation employed in the forward-looking Staged Parabola method are given in the earlier paper[4] and will only be summarized here.

In essence, a parabola is selected to represent the future track of oil production on the grounds that a large number of reservoirs summed together will show a tendency to increase to a peak and then decline. The economic justification for this choice is that by reason of the attributes of oil noted previously, oil will tend to displace the other fossil fuels should demand decline because of its low technical cost of production and distribution, and its wide range of application in the energy system. Consequently, the production of conventional oil is taken as determined more by the magnitude of the resource discovered at a given time than any other factor.

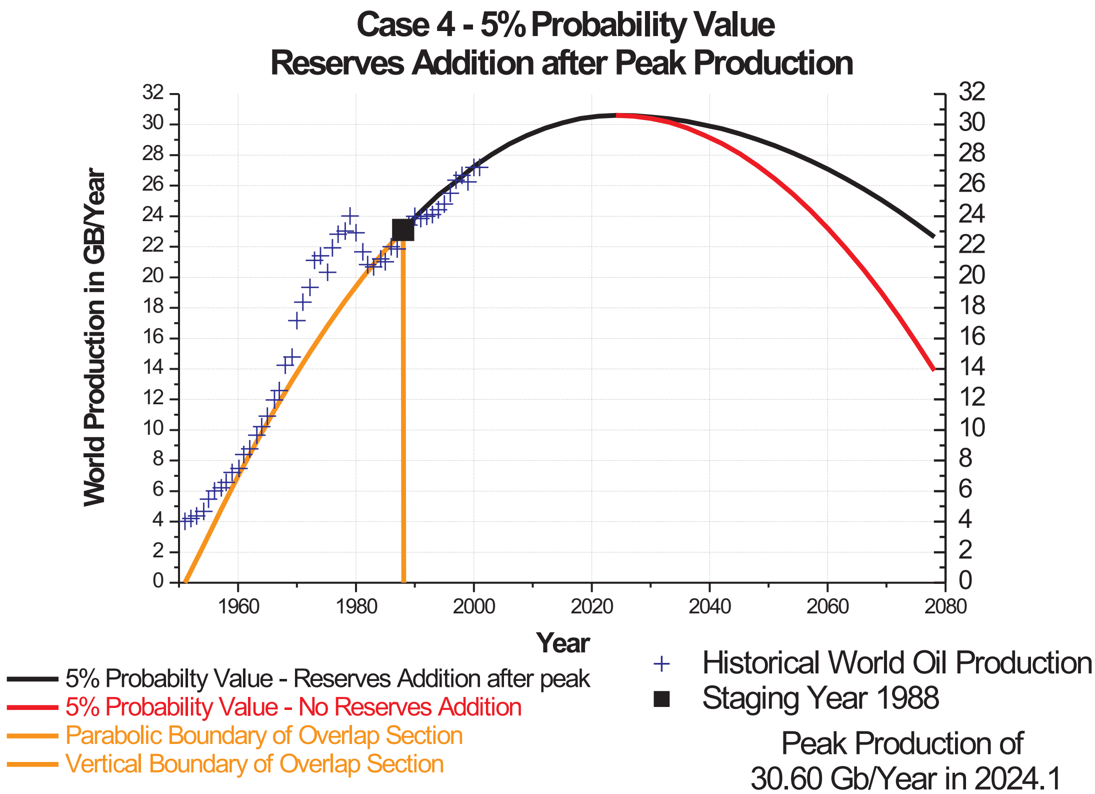
Since the focus is on the peak production period in this paper, no attempt is made to model the 'tails' at the start and finish of the oil era to avoid constraining the shape of the curve by inflection points on either side of the peak. As the parabolic production curve starts at the staging point, there is no concern about the output prediction in the early years: it is only when production falls to low values in the late years of the new century that major deviations from the parabolic relationship are to be expected. Hence the two intersections of the staged parabola with the base line at zero production have only useful mathematical significance in this method.



A parabola is drawn through the staging year defined such that its area (designated Qs) plus the cumulative production to the end of the staging year less the oil contained in the overlapping section (which covers the area of the Staged Parabola before the chosen staging year) totals the ultimate recoverable resource Qu. The method of solution is an iterative one in which an estimate is made of the ratio of the oil in the overlap section to the area of Qs - a value of (q1988/Qs) that must lie between zero and one. Since many parabolas could be drawn that meet the requirement of passing though the staging year and still encompass the specified quantity of oil, another piece of information is required. It is convenient to choose the most recent year for which world production data is available, in this case 1998. Iterations continue of the ratio of q1988/Qs until the curve of the parabola passes through this point. The final parabola will pass through the staging year (here 1988), the most recent year (1998), and meet the requirement to encompass the needed quantity of oil, Qu in total.

One precaution is needed. Since the production of oil in any one year is more variable than the cumulative production to that year, a consistency check is required. The cumulative production between the staging year and the final year is measured approximately by summing the area of a rectangle and a right-angled triangle in the space between the two years and this result is compared with the known value. This check of the area differed by 0.72% here which is judged sufficiently accurate in view of other uncertainties. If this discrepancy were greater as it may be in the corresponding natural gas case, the iteration is based upon setting this area between the two years the same as the known value. This disadvantage of this latter procedure (though more accurate) is that the parabolic line would not necessarily pass exactly through the second (1998) point.

After the Staged Parabola is determined, it is possible to plot families of post-peak parabolic curves to take into account estimates of oil from enhanced recovery and other more expensive procedures for different estimates of the increase in the effective resource base as explained in detail in the previous paper.[4]

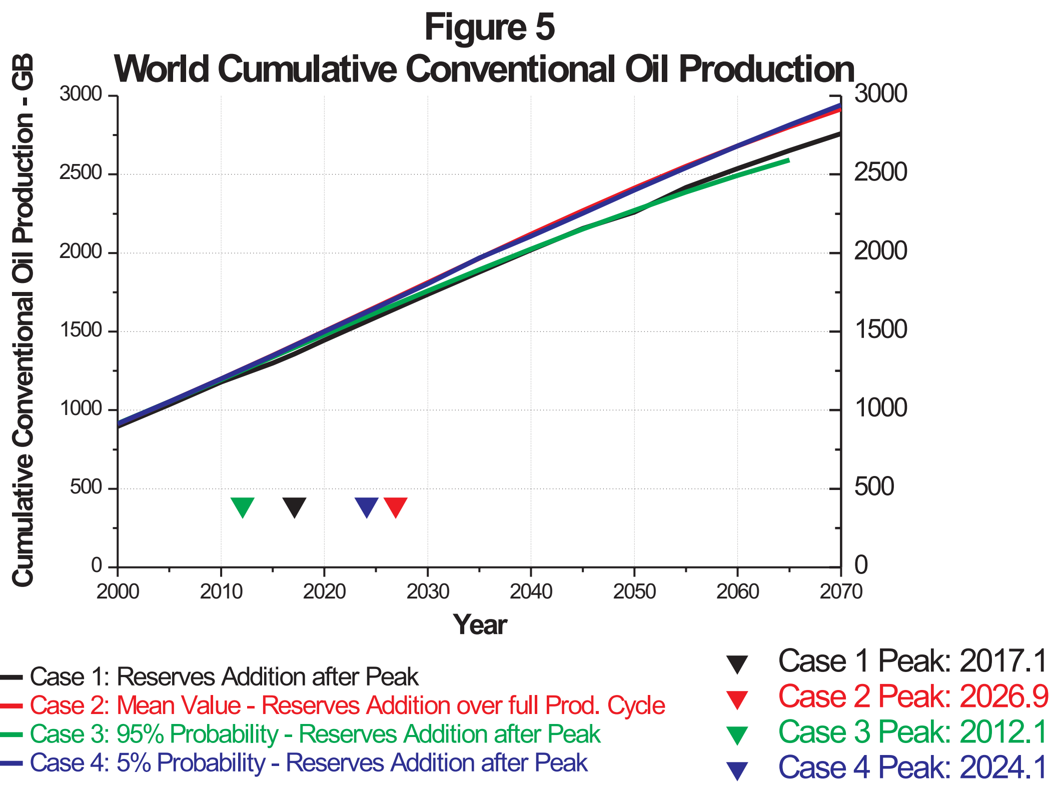


Case 1: Mean Value with Reserves Addition after Peak Production

In Case 1, the Staged Parabola for the Mean Case is calculated based upon a Qu of 2634.4 GB. The reserves addition of 672 GB is added to the resource base after the peak of 29.38 GB/yr (80.49 million barrels/day) occurs in 2017.1. The calculation is conducted in such a way that were the production path to follow the track in the Case 1 Figure, the oil encompassed would include the extra 672 GB from 2017.1 on.

The rationale for this assumption in dealing with the reserves addition in this case is two-fold. First, the peak is not that far off in time and second, only the higher (and more consistent) prices expected after the peak is past would justify the greater cost of the advanced exploration and production techniques needed to recover this much oil. This represents an extreme case with its assumption of no participation of the reserves addition in production before 2017.1.

Two curves appear in the Case 1 Figure for the post-peak period. The upper curve represents the effect of the reserves addition and the lower curve the expected track of production if there were no such addition. It is thus possible to estimate the effect of more modest reserve additions by interpolation post-peak. The historical oil production data included is taken from the *BP Review of World Energy*[1] after 1970 and from Yergin[10] for the earlier years. There is no reason for the historical points plotted on the figure to lie on the parabola before the staging date of 1988. Only after that time is the parabola expected to track the actual output. The severe disruption during the 1970s period is clearly evident.



Case 2: Mean Value with Reserves Addition Throughout the Production Period

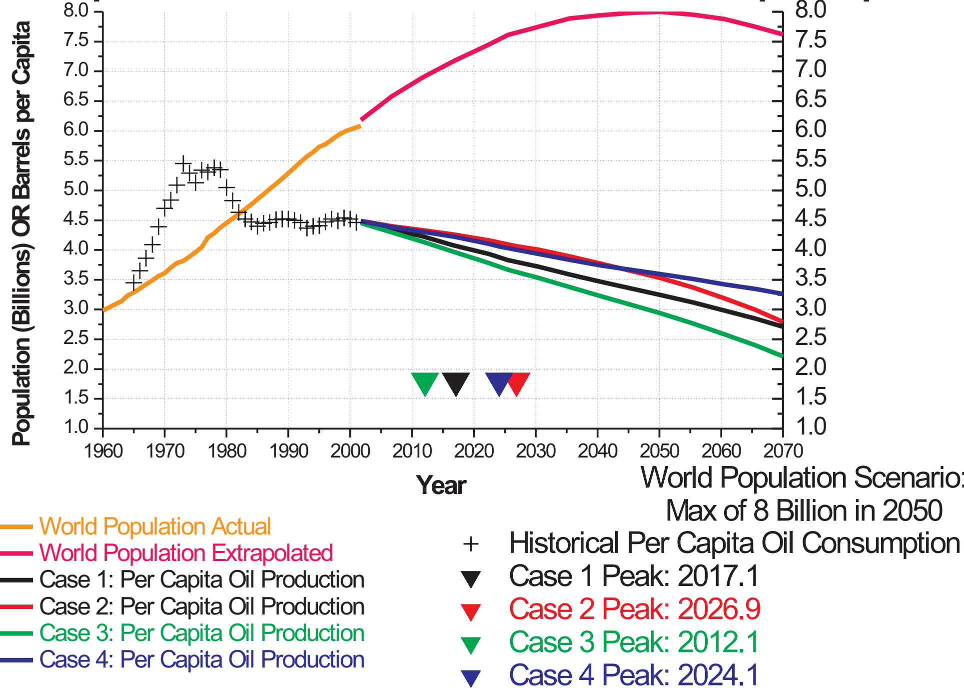
In Case 2, the reserves addition is assumed continuously available throughout the production period. The value of Qu is therefore increased by 672 GB and the Staged Parabola is drawn as before. The peak in production increases to 31.10 GB/yr (85.21 million barrels per day) in 2026.9. Only one parabola appears in the Case 2 Figure since all in-fill drilling and enhanced oil recovery activity is subsumed in the basic underlying production parabola. The peak in production is delayed 9.8 years as compared to Case 1. Historical oil production appears as before.

This case should be considered the opposite extreme as compared to Case 1 when the reserves addition was only operative once the peak has passed. The actual case is expected to lie between these two limits but nearer Case 1.

Case 3: Resources at 95% Probability with the Reserves Addition after Peak Production

The Case 3 Figure illustrates a repeat of the situation in Case 1 where the reserves addition is again only assumed relevant in the post-peak period but with the undiscovered resources at 95% probability assessed at 394.4 GB. The same value of the reserves addition of 672 GB was used as in Case 1 due to lack of information but this value would be expected to be lower for a more certain, constrained assessment typical of 95% probability. Production peaks at 28.53 GB/yr (78.16 million barrels per day) as soon as 2012.1.

Figure 6
World Population and Conventional Oil Production per Capita



Case 4: Resources at 5% Probability with the Reserves Addition after Peak Production

The Case 4 Figure illustrates the case with the undiscovered resources at 5% probability of 1202.2 GB. The reserves addition is again 672 GB. Production peaks at 30.60 GB/yr (83.84 million barrels per day) in 2024.1 Thus the time between peaks in the Case 3 lower 95% probability bound and Case 4 higher 5% probability bound is 12 years - a short period for such a large quantity of oil. The peak in the Case 4 5% probability case occurs 2.8 years earlier than the peak in the Case 2 Mean Value case when the reserves addition was effective throughout the entire production cycle.

World Cumulative Conventional Oil Production

The cumulative oil production for the four cases appears in Figure 5. This figure is included because, unlike other parabolic methods, cumulative production cannot be calculated by simple integration of the parabola. In the Staged Parabolic method it is necessary to know some details of each individual calculation because of the correction necessary for the overlap section. It may be seen that Cases 2 and 4, and Cases 1 and 3 essentially coincide.

From the point of view of estimating carbon dioxide emissions from projections of conventional oil production, there is little difference among the cases until after 2030.

World Population and Per Capita Conventional Oil Production

Figure 6 includes a curve of actual world population and a projection through much of the new century. The projection chosen is one gaining credence in which world population peaks at eight billion in 2050. This projection is at the lower end of most estimates but if world population turns out to be higher than the values used here, the effect on per capita oil production will be even greater than illustrated in Figure 6.

Historical values for oil consumption per capita are also included in Figure 6. Though expressed in consumption terms, these figures are very close to production per capita data since both are calculated over a full year which tends to even out changes in inventories. The remarkable constancy of the world oil consumption per capita in recent years at 4.47 barrels per capita for the nineteen year period inclusive from 1983-2001 is apparent. World oil consumption percapita peaked at 5.45 barrels as early as 1973. Cases 1- 4 of this paper are plotted in Figure 6 on a per capita basis. For a wide range of the resource endowment, the quantity of conventional oil per capita available to the world as a whole declines throughout the century for this population scenario which may well prove somewhat low. The full implications of this effect are not as yet clear, but the period of effective constancy of world per capita oil consumption may be coming to an end in the near future.

Discussion of Limitations to Results

The Staged Parabolic projection method shares with other such techniques a problem with interpreting the present idle capacity in the world production system. Much of this non-operating capacity is in the Middle East and may total on average about five million barrels per day over time. Except in this prolific oil production region, the idle capacity would be expected to be in full operation by the time the world peak in production is reached. For this reason, the Staged Parabolic technique probably understates the magnitude of the peak somewhat as this spare capacity comes into service. The timing of the peak, however, is only shifted by a matter of months by this effect. This problem will be addressed in subsequent papers. [Note added in August 2001: see J.H. Walsh, *Parabolic Adjustment for Idle Capacity in the World Conventional Production System*[11], September 2000].The question of the large category termed the 'reserves addition' appearing in the U.S. Geological Survey Year 2000 Assessment also requires further consideration. In this paper only one value was available for all the cases studied: the reserves addition in actuality would be expected to vary in some way with the size of the resource endowment. At a more general level, the whole question of world reserves requires more attention as it is probably true that these are overstated in terms of a strictly defined definition of this category. [Note added in August 2001: see J.H. Walsh, *The Decline in World Oil Reserves Predicted by the Parabolic Projection of Future Production and Discoveries,* July 2001[12]]

Conclusion

Preliminary results from the Year 2000 World Assessment of Undiscovered Resources were mounted on the Web by the U.S. Geological Survey in advance of the formal publication of this extensive study at the time of the World Petroleum Congress held in Calgary, Alberta, 11-15 June 2000. This data was applied to the Staged Parabolic technique to prepare projections of world oil production. The greatest uncertainty is in the category defined as 'reserves addition' which was explored in two boundary cases in the paper.

Two cases were chosen for the Mean Value of the endowment. In Case 1, with the reserves addition only operative after the crest in world production of conventional oil has passed, the peak was found to be 29.38 GB/yr (80.49 million barrels per day) in 2017.1. In Case 2, with the reserves addition available through the entire production cycle, the peak was 31.10 GB/yr (85.21 million barrels per day) in 2026.9. In the two sensitivity trials, in Case 3 at 95% probability, the peak was 28.53 GB/yr (78.16 million barrels per day) in 2012.1. In Case 4, at 5%

probability, the peak was 30.60 GB/yr (83.84 million barrels per day) in 2024.1.

Cumulative and per capita production were also calculated for all cases. Over a wide range of assumptions, the cumulative production of conventional oil does not differ much among the cases before 2030 which facilitates the estimation of carbon dioxide emissions from this important fossil fuelat least in the medium term. Per capita availability of conventional oil per capita falls continuously from 2000 on for all cases for a likely but conservative world population scenario.

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