
**American Petroleum Institute
Policy Analysis And Strategic Planning Department**

Are We Running Out of Oil ?

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Table of Contents

EXECUTIVE SUMMARY	xi
 CHAPTER 1. INTRODUCTION	 1
MOTIVATION	1
ORGANIZATION	4
 CHAPTER 2. THE RECORD OF OIL RESOURCE ASSESSMENT.....	 7
AN OLD QUESTION:HOW MUCH IS LEFT?	7
ESTIMATING PETROLEUM RESOURCES: THE U.S. EXPERIENCE	8
<i>Early Estimates of Remaining U.S. Oil Resources.....</i>	<i>8</i>
<i>Emergence of Formal Reserves Concepts.....</i>	<i>9</i>
<i>Reserves versus Resources: Post-WWII Attempts at a Broader Measure.....</i>	<i>11</i>
<i>The Hubbert Dissent:Heresy or Prophecy?</i>	<i>13</i>
<i>Uncertainty in Recent Estimates</i>	<i>16</i>
ESTIMATING WORLD OIL RESOURCES	17
<i>Proven Reserves: Apparent Increases in Worldwide Resource Abundance.....</i>	<i>20</i>
<i>Are Published Reserve Estimates Reliable Signals of Resource Abundance?.....</i>	<i>20</i>
<i>Broader Measures of World Oil Resources.....</i>	<i>21</i>
<i>The Campbell Dissent: a New Hubbert?.....</i>	<i>22</i>
<i>Increased Recovery Efficiency for Conventional Oil.....</i>	<i>23</i>
<i>Unconventional Sources.....</i>	<i>24</i>
SUMMARY: ESTIMATES OF RESOURCE CONSTRAINTS.....	25
 CHAPTER 3. SUPPLY AS IF ONLY GEOLOGY MATTERED.....	 27
OF COURSE GEOLOGY MATTERS	27
THE 1994 USGS ASSESSMENT	29
UNCERTAINTY IN THE USGS ASSESSMENT.....	30
TWO IMPLICATIONS FOR FUTURE MARKETS	31
<i>Imminence of Declining World Petroleum Supply.....</i>	<i>32</i>
<i>Future Interval of Increasing Supply Concentration by OPEC.....</i>	<i>32</i>
ONE CAUTION: SURPRISES HAVE ALREADY OCCURRED	33
IMPLICATIONS OF GEOLOGICAL CONSTRAINTS FOR SUPPLY	34

CHAPTER 4. OTHER THINGS THAT MATTER:ECONOMICS, TECHNOLOGY, AND POLICY... 35

LIMITED TREATMENT OF UNCERTAINTY IN RECENT WORLD RESOURCE ASSESSMENTS.....	35
SENSITIVITY OF OUTLOOK TO TECHNOLOGY	36
THE DYNAMICS OF RESOURCE ESTIMATES.....	36

CHAPTER 5. IS THERE CAUSE FOR CONCERN?..... 39

CONCERNS REAL AND IMAGINED	39
<i>Resource Exhaustion: An Imagined Concern</i>	39
<i>A Real Problem: Remaining Institutional Barriers</i>	42
THE ROLE OF MARKETS AND GOVERNMENTS.....	43

CHAPTER 6. SUMMARY AND CONCLUSIONS..... 47

THE GOOD NEWS: RESOURCE ABUNDANCE	47
THE BAD NEWS: OPPORTUNITIES MAY BE SQUANDERED.....	47
CONCLUSION: INSTITUTIONS, NOT RESOURCES, ARE MORE LIKELY TO CONSTRAIN SUPPLY.....	48

REFERENCES..... 49

List of Tables

TABLE 1. EARLY ESTIMATES OF U.S. OIL RESOURCES, 1908-21	10
TABLE 2. ESTIMATES OF THE U.S. PETROLEUM RESOURCE BASE, 1946-1962	13
TABLE 3. POST-1974 ESTIMATES OF THE DOMESTIC RESOURCE BASE	16
TABLE 4. ESTIMATES OF THE WORLD OIL RESOURCE BASE, 1920-1994	21
TABLE 5. KNOWN UNCONVENTIONAL CRUDE OIL RESOURCES	25
TABLE 6. USGS ESTIMATE OF WORLD CONVENTIONAL CRUDE OIL RESOURCE VOLUMES, 1/1/93	28
TABLE 7. ESTIMATES OF REMAINING CONVENTIONAL CRUDE OIL RESOURCE VOLUMES, 1/1/93	29
TABLE 8. CHANGES IN USGS ESTIMATED WORLD PETROLEUM RESOURCES, 1982-1994.....	34

List of Figures

FIGURE 1. WORLD CRUDE OIL PRODUCTION	1
FIGURE 2. WORLD CRUDE OIL RESERVES	2
FIGURE 3. CRUDE OIL PRICES.....	3
FIGURE 4. U.S. CUMULATIVE OIL PRODUCTION AND PROVEN RESERVE ADDITIONS	11
FIGURE 5. MODIFIED MCKELVEY BOX	12
FIGURE 6. THE HUBBERT CURVE.....	14
FIGURE 7. CUMULATIVE U.S. OIL PRODUCTION AND ESTIMATED TOTAL OIL RESOURCES	17
FIGURE 8. PRODUCTION BY REGION, 1948-1993.....	17
FIGURE 9. WORLDWIDE CUMULATIVE PRODUCTION AND PROVEN RESERVES	20
FIGURE 10. WORLD PROVEN RESERVES OF CRUDE OIL.....	20
FIGURE 11. ESTIMATES OF WORLD CRUDE OIL RESOURCES.....	22
FIGURE 12. USGS 1994 WORLD RESOURCE ASSESSMENT BY RESOURCE CATEGORY	30
FIGURE 13. UNCERTAINTY IN USGS ESTIMATE OF REMAINING WORLD OIL RESOURCES	31
FIGURE 14. WORLD PETROLEUM SUPPLY, THREE RESOURCE LEVELS.....	32
FIGURE 15. OPEC SHARE OF WORLD PETROLEUM SUPPLY, THREE SCENARIOS	33
FIGURE 16. COMPARISON OF USGS ASSESSMENTS,.....	33
FIGURE 17. EFFECT OF GROWING RECOVERY EFFICIENCY ON REMAINING RESOURCE VOLUMES.....	36
FIGURE 18. EFFECT OF IMPROVED RECOVERY ON WORLD OIL SUPPLY PROFILE.....	36
FIGURE 19. BREAKDOWN OF LOWER 48 RESERVE GROWTH AT FIELDS DISCOVERED BY 1966	37
FIGURE 20. AVERAGE RECOVERY EFFICIENCY BY YEAR OF ESTIMATE, LOWER 48 FIELDS DISCOVERED BY 1966 .	37

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Executive Summary

Since the dawn of the petroleum industry in the mid 19th century, there have been recurrent waves of concern that the exhaustion of the world's petroleum base was imminent. As early as 1874, the chief geologist for the State of Pennsylvania predicted that kerosene used for lighting would exhaust U.S. petroleum resources by 1878. But nature has consistently been far more generous than anticipated. By 1993, the U.S. had produced over 164 billion barrels of crude oil, and another 80 to 100 billion barrels are now estimated to be eventually recovered from the domestic resource base. Worldwide evidence of growing abundance is even more striking. By 1950, the world was producing 10 million barrels of crude oil a day, and proven reserves were 90 billion barrels, sufficient to satisfy then current rates of consumption for another 24 years. But in the next 43 years, 650 billion barrels were produced, as world production expanded sixfold. But still, exploration, development, learning and technology were adding reserves far faster than growing production was depleting them. Between 1950 and 1993, world reserves expanded more than tenfold to about a trillion barrels, enough to sustain 1993 production for another 45 years. Obviously, like Samuel Clemens' observation that "reports of my death have been highly exaggerated," the persistent concerns of petroleum resource exhaustion have (so far) been premature.

Virtually all empirical indicators continue to signal a growing world abundance of crude oil. Proven oil reserves worldwide are at an all-time high, and real crude oil prices are approaching record lows. Nonetheless, most recent long term oil market forecasts expect an increase in real crude oil prices over the next two decades, attributable to an expectation of increased resource scarcity. It is this stark contrast between the historical record of growing resource abundance and these renewed assertions of impending resource scarcity that motivates this study. The objective is to examine carefully both the historical record and the most prominent recent geological assessments to answer or at least address

several unresolved issues. Is the long predicted "wolf" of oil scarcity finally at the door, or at least headed unambiguously toward the house? Or, on the other hand, are current perceptions of impending scarcity as myopic as in the past? Do we have sufficient information to distinguish meaningfully between the two possibilities? Does it even matter to any broader assessment of the long run sustainability of U.S. or worldwide economic growth? And finally, do either the resource prospects themselves or their implications for future supply patterns raise concerns that might call for government policy actions?

One possible explanation of the gap between experience and expectation could be faulty empirical data. An overview of the historical record of resource assessment, both in the U.S. and abroad, reveals little basis for confidence in the precision of such estimates. Not only have such estimates in the past been poor predictors of either supply or the ultimately recoverable resource base, even the most narrow and well defined of the measures (that of proven reserves) has been plagued by gross and persistent misunderstanding that has more often misguided energy policy than enlightened it. From the mid-20's to the present day, proven reserve estimates have consistently been widely interpreted as the stock of remaining resources, rather than the working inventory of the industry that it actually represents. Moreover, standards for such measurement vary widely across countries, making cross country comparisons often meaningless or highly misleading.

But the conceptual problems associated with proved reserves are generally amplified by moving to a more comprehensive measure of remaining resources, inclusive of those volumes in the earth's crust which have not yet been identified with sufficient certainty to be considered "proved." These resources consist of conventional oil yet to be discovered, further additions to reserves yet to be developed at known locations, and future increases in recovery from known sources attributable to

improved economics, learning, or technical change. Almost all of these categories are unobservable, and obviously highly speculative.

Nonetheless, particularly since World War II, this information was regarded as essential. In both world wars, it was recognized that oil had become a key strategic commodity, and that most of that commodity had been supplied by domestic U.S. resources. Moreover, especially after World War II, it was becoming increasingly clear that massive low cost reserves in the Middle East would eventually draw the world into a dependence that would raise concerns about security of supply.

A large number of resource estimates, both for the U.S. and the world, began to appear after World War II. Initially, estimates for the U.S. seemed to suggest that the domestic resource base could grow almost indefinitely, as production surged to satisfy rapid growth in demand in the postwar years. By the mid 60's, estimates of the amount of oil that would be ultimately recoverable in the U.S. were approaching 600 billion barrels. But this unbridled optimism was disturbed in the mid 50's by the dissident voice of a respected geologist, M. King Hubbert, who insisted that such estimates were not only grossly overstated, but that in fact a peak in domestic supply in only a few years was imminent. This heresy initially brought Hubbert widespread professional ridicule, at least until the early 70's, when declining domestic production revealed that a peak had been crossed, timed almost precisely as Hubbert had predicted.

While the value of Hubbert's prediction continues to generate controversy, after 1970 most U.S. estimates were revised sharply downward toward levels similar to those estimated by Hubbert. However, particularly since the late 70's, official estimates have increasingly been presented as a range rather than point estimates, in an attempt to explicitly incorporate uncertainty into those estimates. As domestic production stabilized in the first half of the 80's, then resumed its fall thereafter, it has become increasingly clear that the supply potential of the domestic resource base is much more complex than the Hubbert approach would suggest. More recent resource estimates

have attempted to measure the sensitivity of such estimates to factors such as technology, policy, and economics. By the 90's, estimates of the domestic resource base were again creeping upward into the 300-plus billion barrel range, nearly double the Hubbert estimates, but only about half the most optimistic estimates of the mid 60's.

World oil resource estimates have also been prepared frequently since World War II. Proven reserve estimates have been published annually for decades in several trade journals, based principally on official reserve estimates made by the major producing countries. Such estimates are even more problematic than those for the U.S., insofar as the definitions of even narrow concepts such as proven reserves differ greatly across countries. Moreover, when broader measures of resources are required (inclusive of undiscovered resources and future reserve additions at known fields), the problem of cross-country comparison is further amplified. Also, the coverage of the estimates (whether offshore resources are covered, for instance, and to what water depth) have varied over time and across estimators. Nonetheless, since the mid 60's, estimates of the world's ultimately recoverable conventional oil resources have varied over a wide range between 1.5 and 2.5 trillion barrels, but with no clear trend either up or down.

While the various assessments have their individual strengths and weaknesses, four of them are of particular interest, namely the last four assessments of conventional crude oil prepared for the World Petroleum Congress by the U.S. Geological Survey. These assessments, performed at four year intervals covering a 12 year period, use standardized resource concepts across countries, use consistent methodology over time, and explicitly quantify the uncertainty associated with their estimates. Such assessments at least address the major problems of cross-country and intertemporal comparisons which plague most of the other available world oil resource assessments, and do so over a substantial period covering the very recent past. Consequently, those four assessments provide a valuable window on geological thinking from which to examine trends with clear implications for future supply.

More importantly, perhaps, the explicit representation of uncertainty in these assessments also conveys a sense of the confidence that the assessors themselves acknowledge to be contained in their own estimates.

Several key observations arise from an examination of these assessments.

First, the most recent USGS resource assessment estimates that the total worldwide recoverable resource base of conventional oil amounts to 2.4 trillion barrels. Of that, about 700 billion has already been produced, 1.1 trillion are already identified (though mostly not yet proven, in the U.S. sense of the term), and nearly 600 billion remain to be discovered. While the “identified” category differs markedly from the proven reserves reported in the trade press for many countries, those differences are largely offsetting, so that the aggregate world total is only about 10% above the trade press estimate of proven reserves. As a consequence, the USGS 1994 assessment estimates that identified world conventional oil resources would sustain recent production rates for about 50 years, and that new discoveries would be expected to extend that horizon by an additional 25 years. Consequently, the message of resource abundance conveyed by the trade press numbers is generally upheld, and to some extent enhanced, by the 1994 assessment.

Second, there is an enormous amount of uncertainty in these numbers that is explicitly acknowledged by the USGS. In particular, it estimated that undiscovered resources could be as low as 292 billion barrels or as high as a trillion barrels, implying that the remaining world resources (sum of identified and undiscovered resources) ranges from as low as 1.4 trillion barrels (62 years) to as high as 2.1 trillion barrels (94 years) at recent production rates. As a point of reference, it is worth noting that this 700 billion barrel range between the lowest and highest of these cases is about equal to the total cumulative world oil production from 1859 until 1993.

Third, despite this wide range of uncertainty, translation of these resource estimates into plausible forecasts of world supply yield two

characteristic market features that appear generally robust to variations in remaining resource volumes over this wide range. The first such characteristic is the imminence of world production decline well within the first half of the next century, for even modest levels of sustained demand growth between 1% and 2% per year. The second feature is a sharp rise of OPEC’s market share, possibly to record levels, during that period of growth. These are precisely the features of the future market captured by most major forecasts. The USGS assessments appear to be broadly consistent with, if not explicitly or implicitly at the root of, such market forecasts.

Fourth, despite the wide range of the band of uncertainty considered by USGS in its 1994 assessment, there is no claim that such a range captures all of the uncertainties relevant to such future resource volumes, or even the most significant ones. In fact, USGS explicitly acknowledges that its resource estimates are static in the sense of assuming a fixed technology and current economics. Over a short time, such an assumption is of little consequence, but over a span of decades there is evidence, principally from historical U.S. data, that such changes are of major consequence, particularly as the resource base matures. Even within the span of the four resource assessments completed by USGS, covering only a dozen years, there is strong evidence that a major source of reserve additions has been missed. This evidence appears in the form of estimates plagued by a persistent propensity for being surprised. In the 1994 USGS assessment, for instance, the mean estimate of ultimate recovery was 2.4 billion barrels. A mere dozen years earlier, despite far more favorable economics expected at that time, USGS had attached less than a 10% probability to the possibility that ultimate recovery could reach such a level.

A missing source of reserve additions not captured in the USGS estimates is the revisions which occur over time as a result of slow but sustained increases in the average recovery efficiency -- the share of the original oil in place that actually is recovered before the property is abandoned. This increase results from the learning which occurs with experience in

developing the known resources, and with technical change which permits more thorough resource recovery, and in some cases is due to improved economics. As a petroleum producing area matures, such improvements become an increasingly significant part of total reserve additions. In the U.S. in 1966, about 29.5% of the original oil in place discovered up to that time was thought to be recoverable. By 1979, the average recovery efficiency at that same set of fields (those discovered before 1966) had risen to 32.1%, an increase of about 0.2% per year. These small changes accounted for over 56% of the Lower 48 reserve additions during that period, exceeding the reserve additions attributable to discoveries in subsequent years.

Unfortunately, the data required to monitor these increases is no longer available for the U.S. since 1979, and has generally never been available for the world. Nonetheless, assigning plausible parameters to the world resource base suggests that such improvements could be extremely significant over a long period, with each 1% increase in worldwide recovery efficiency adding 60 to 80 billion barrels to recoverable world oil resources. Sustained increases such as those experienced in the U.S., of about 0.2% annually, would raise recovery efficiency from its current level of about 34% to as much as 54% a century hence, adding 1.2 trillion to 1.6 trillion barrels to the recoverable resource base, potentially doubling the current mean estimates of remaining conventional resources. While highly speculative, such changes can hardly be dismissed as fanciful, insofar as technologies currently available often offer recovery efficiencies well in excess of 54% in areas of limited applicability.

What then are the lessons derived from this exercise? There are two concerns that the analysis addresses, one obvious, the other more subtle.

The obvious concern, that of the imminent exhaustion of world oil, is actually the most easily dismissed. Nature continues to be quite generous in the resources available for future oil development. Identified resources alone could sustain recent production rates for about half a century, and new discoveries could easily

extend this by another two decades or more. Moreover, plausible improvements in technology or simply the diffusion of existing technology could extend this outlook to a century or more. Modest growth in world demand, at 1% to 2% annual rates, could advance these peaks to the first half of the 21st century, but only the combination of an unprecedented halt in technological improvement and extremely disappointing volumes of new discoveries could lead to a resource constrained peak in world production as early as two decades hence. Even if world supplies peak within the first half of the next century, the subsequent decline is likely to be extremely slow, insuring that conventional oil could remain a major source of world energy supply well into the latter half of the 21st century. Moreover, even if the most pessimistic of the conventional oil resource scenarios should materialize, normal market processes would trigger higher prices to improve recovery efficiencies from conventional sources and potentially bring into production unconventional oil resources known to exist in extremely large magnitudes in the Western Hemisphere.

However, there is a second concern that cannot be so easily dismissed. The optimism expressed above pertains strictly to the *potential* supply made available by nature. But the resource opportunity afforded by nature is a *necessary* condition for future supply growth, not a *sufficient* one. Even identified conventional oil resources require a substantial development effort to translate such resources into actual supply. Even a modest 1% to 2% annual growth will require between 7 and 15 million barrels of new supply within a decade.

While development of incremental supply capacity at such a rate is by no means unprecedented, this development continues to occur against a backdrop of highly politicized institutional constraints in most of the major oil producing areas. While the failure of socialism worldwide has revived a commitment to markets and privatization of the oil industry in a large and growing number of countries, major institutional barriers to new supply remain in virtually all of the major producing areas. In the United States, regulatory constraints

seriously restrict access to the most promising domestic petroleum prospects. In the Former Soviet Union, major issues of taxation, property rights, revenue sharing, and contract enforcement need to be settled in Russia, and several of the bordering states face serious political obstacles to the establishment of transportation links over hostile or politically risky routes. In Mexico, the liberalization and privatization in many sectors of the economy has to date not been extended to most portions of the petroleum sector. In the Middle East, there has been only very limited attempts to privatize the petroleum sectors or open access to foreign capital, and in some of the recent attempts to do so, sanctions by the U.S. have attempted to deliberately thwart the effort. Most of the countries of the Gulf continue to flirt with potential future supply restrictions via OPEC to address short term fiscal difficulties, as if past attempts to do so had not discredited such efforts, and seemingly oblivious to the potential damage that such flirtations have in compromising the perceived reliability of oil as an energy source. At the same time, terrorism, weapons proliferation, and internal and external disputes among the Gulf states offer the constant threat of future supply disruptions in a key producing region. Thus, there are an array of institutional hazards to the supply growth that will be required to satisfy growing world demand.

Finally, we come to the question of why these resource assessment exercises are even necessary. Generally, such efforts have been motivated by government concern that markets were incapable of preventing exhaustion of finite resources, or even signaling its imminence, and that government action was required to facilitate the transition to alternate fuels. Such assessments, in principle, were designed to signal the imminence of such exhaustion. In fact, while there is historical experience with fuel transitions, the historical record provides no illustrations of government ability to effectively aid in such transitions. In fact, that record is rife with examples of repeated attempts by government to allocate energy resources in response to real or perceived crises, usually in ways that aggravated the perceived problem by defeating the price signals via which energy markets

themselves can be expected to generate and utilize the information required to reasonably guide such transitions.

Whether necessary or not, there are both promising and troubling features of future world oil markets that these assessments point out. Most obviously, they point to the continued abundance of energy resources that nature continues to provide. More importantly, they point out the need for major new world supply additions to sustain even modest rates of growth in world demand. Whether or not the opportunities afforded by nature are in fact realized will hinge more on success in overcoming an array of institutional barriers than it does on resource constraints.

There is a role for government here, but it is not one of micromanaging a transition to alternate fuels in time to avoid an imminent shock of global resource exhaustion. Rather, the appropriate role is a very traditional one. Internationally, it involves pursuing traditional diplomatic and military means to protect growing world trade, in energy as in other goods, and to encourage the free flow of capital to enhance prospects for world supply growth and diversification. Domestically, government has responsibilities to provide a reasonable regulatory framework for continued domestic supply development in a manner consistent with environmental protection. In the case of domestic resources on public lands, government has stewardship responsibilities to protect those lands from environmental degradation, without compromising its fiscal responsibilities to this and future generations of protecting the economic values associated with the mineral wealth of those properties.

There is a very real danger that attempts by government to address the non-problem of resource exhaustion will distract from or even aggravate the real challenge of removing remaining institutional barriers to supply growth.

Chapter 1.

Introduction

“...Hurry, before this wonderful product is depleted from Nature’s laboratory!”
-- advertisement for “Kier’s Rock Oil”, 1855
(four years *before* the first U.S. oil well was drilled)

“...the peak of [U.S.] production will soon be passed -- possibly within three years.
-- David White, Chief Geologist, USGS, 1919

“...it is unsafe to rest in the assurance that plenty of petroleum will be found in the future merely because it has been in the past.”
-- L. Snider and B. Brooks, *AAPG Bulletin*, 1936

“Past...prophecies of “reserves running out” have been notoriously erroneous, but finite resources have by definition a finite existence. Perceptions of impending shortfall will cast a shadow forward, well into the period between now and 2020.”
--World Energy Council, *Energy for Tomorrow's World*, 1993

Motivation

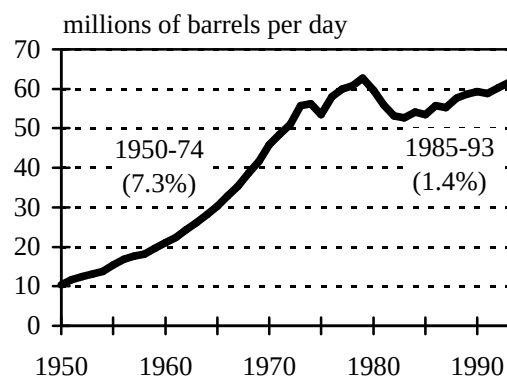
Since the dawn¹ of the petroleum industry in the mid 19th century, there have been recurrent waves of concern that exhaustion of the world’s petroleum resource base was imminent. In the light of historical hindsight, such concerns of exhaustion have been obviously premature. Despite the inevitability of an eventual peak and decline in world oil production at some future date, there is little empirical evidence to

suggest that such a date will be any time soon, or that it will result from global resource exhaustion.

In fact, the available empirical evidence suggests just the opposite -- by most measures, world oil resources are more abundant today than ever before. World production in recent years has resumed the growth that was briefly interrupted in the 70’s and early 80’s (though at a lower rate), as seen in Figure 1.

¹ While the “dawn” of the petroleum industry in the U.S. is usually considered the drilling of Drake’s well in Titusville, Pennsylvania in 1859, actually petroleum is one of the oldest substances used by mankind. Greek legends indicate an understanding of the properties of “burning water,” used as a weapon in sea battles. Noah is said to have caulked his ark with pitch gathered from the shores of the Dead Sea. Nehemiah used “napthar” for altar fires. Ancient Syrians mixed petroleum with ashes for use as fuel. Zoroastrians worshipped in the glow of burning gas at Baku on the Caspian Sea. Native Americans, and later European settlers in the area of New York, Pennsylvania, and Ohio, used crude oil for medicinal purposes. George Washington acquired a parcel of land in western Pennsylvania known to contain a natural seep which he called a “burning spring.” All these early uses were supplied principally by naturally occurring seeps. Later, in the 19th century, oil was occasionally found by accident in drilling shallow brine wells in search of salt, and such oil was principally used for lighting. The technology of drilling such shallow brine wells inspired Drake to drill his first oil well.

Figure 1. World Crude Oil Production²

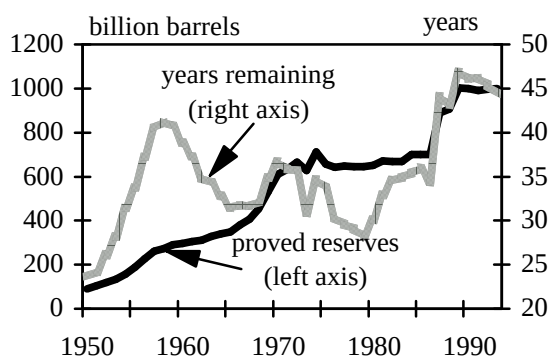


² Unless otherwise stated, supply for this study is taken to mean crude oil only.

World production rose more than sixfold between 1950 and its peak in 1979 (at nearly 63 million barrels a day). After a sharp decline in the first half of the 80's attributable to the Iran/Iraq war and an ultimately futile attempt by OPEC to defend an unrealistic price, supply began growing again after 1985, averaging about 1.4% per year since that time, and is expected to soon surpass the previous peak.

Despite this massive expansion of supply, there is little evidence of the effects of depletion available in the historical record. As seen in Figure 2, in 1950 proven reserves were 90 billion barrels, sufficient to sustain production at the 1950 rate for about 24 years. By 1993, reserves had expanded to nearly a trillion barrels, sufficient to support 1993 levels of production for another 45 years. Moreover, this more than tenfold expansion of proven reserves occurred despite the fact that 650 billion barrels had been consumed in the interim.

Figure 2. World Crude Oil Reserves



However, there may be less here than meets the eye.

“Proven reserves” do not, have not, and were never intended to provide a measure of remaining resources, or even an approximation to such a measure. Rather, they are and always have been defined to represent a working inventory, continually replaced by new exploration and development. Current reserve estimates no more represent the remaining supply of oil resources than current inventories of groceries on the shelf are a measure of future

food supplies³. Nonetheless, the level of proven reserves at any point does say *something* about future supply potential. Namely, it generally provides a *lower* bound on remaining resource potential⁴, rather than the *upper* bound it is often misinterpreted to represent.

That upper bound, the amount of oil remaining in the earth, is clearly finite and, unlike proven reserves, clearly declines with cumulative production. However, its magnitude is unobservable, and more importantly, it is not clearly even relevant to the imminence of exhaustion. That is, oilfields are typically abandoned far before the oil in place is completely removed. On average, only about a third of the oil is recovered at the point where it typically becomes technically or economically impractical to continue production.

Consequently, the “remaining resources” of oil to be developed in the future lies somewhere between the level of proven reserves and that of remaining oil in place, with the actual level determined as much by technology and economics as geology.

Assessing the future path of such constraints is highly speculative, but one signal of increasing resource scarcity would be that of sustained long run increases in the price of oil. *Ceteris paribus*, as resource development proceeds to progressively lower quality deposits, depletion will raise replacement cost. But in practice, *ceteris paribus* often doesn't hold long enough to be of much consequence. That is, as depletion drives costs up, experience and technological change drive it down. At some point, depletion

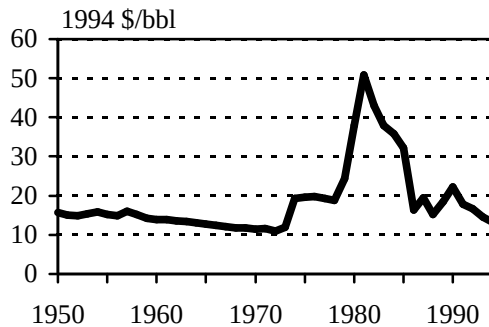
³ Proven reserves here are taken from *Oil and Gas Journal*, “Worldwide Issue,” various years. While these are the most widely cited reserve estimates, they are generally close or equal to the official estimates for each country. As discussed later, this is a potential problem, since there is a very wide assortment of definitions and motives for such official estimates across countries. In particular, standardized financial reporting requirements give rise to United States reserve estimates far more narrow than those of most other countries.

⁴ While definitions vary, the quantities represented by proven reserves are producible with existing technology and economics. While there is still some nonzero probability that such volumes could be overstated, the proven reserve classification is intended to indicate an extremely high probability of that future production. will be both technically and economically feasible.

may get the upper hand, signaled by a sustained increase in market price.

However, an examination of world oil prices provides no evidence that the market is signaling such an alarm. As seen in Figure 3, the sharp increase in prices in the 70's was not such an alarm. By now, those increases have already been largely reversed. In real terms, recent prices of crude oil are similar to those of 40 years earlier, despite the fact that the world consumed over 650 billion barrels of oil during that period.

Figure 3. Crude Oil Prices⁵



Nonetheless, despite growing world production of crude oil, proven world reserves at an all time high, and crude prices (in real terms) at levels no higher than in the fifties, most recent long run forecasts of world oil market trends estimate that real oil prices will rise over the next decade⁶, owing largely to expected declines in world oil supplies by early in the next century.

These current “warnings” claim to be more credible than those of the past (although not surprisingly, past assessments claimed greater credibility than their own predecessors⁷). Such improvement is claimed on the basis of superior technology and/or the accumulation of knowledge from progressively more extensive exploration and development efforts. And of

course, accumulated knowledge should improve the accuracy of any set of estimates over time.

Beyond this, the credibility of recent worldwide resource assessments has been bolstered by three facts.

First, the world has already experienced serious oil supply scarcity, in adapting to the supply restraints imposed by OPEC from 1973 to 1985. While hindsight makes it clear that this was a scarcity contrived by the OPEC cartel, rather than the result of a resource constraint, the distinction often is not made⁸.

Second, in two of the largest three oil producing areas, the United States and the Former Soviet Union, production has peaked and is declining. While in both areas there are clearly factors other than resource constraints at work⁹, the relative importance of such entangled factors is often hard to identify¹⁰.

Finally, and perhaps most importantly, past concerns of imminent exhaustion were usually quickly discredited by the discovery of major new supply sources which supported continued supply growth, or the imminent development

⁸ At least the long run effects were contrived. That is, the 1973 supply interruption was associated with the use of oil as an “economic weapon” in an Arab embargo against the U.S. and the Netherlands in response to their support of Israel in the 1973 Arab-Israeli War. Similarly, the 1979-80 disruption was associated with the revolution in Iran and subsequently the outbreak of war between Iran and Iraq. Neither disruption could be characterized entirely as contrived. Nonetheless, the supply behavior in response to those disruptions was clearly contrived, as potentially offsetting unused capacity in the other OPEC countries, particularly those in the Gulf, were deliberately left idle in a lengthy attempt to artificially maintain oil prices.

⁹ That is, political and institutional barriers to upstream investment in the FSU, and constraints on land access in the United States, have played extremely significant roles in supply limitations in each area.

¹⁰ The role of resource constraints and government policy are often difficult to disentangle, because misguided policy may generate self-fulfilling expectations. For example, domestic price controls and allocation schemes in the U.S. in the 70's gave rise to real shortages by crippling ordinary market responses which would have restrained demand and encouraged domestic production. In so doing, it aggravated the international problem (i.e., it artificially stimulated U.S. import demand, both by encouraging consumption and discouraging domestic supply), and reinforced public perceptions of shortages.

⁵ Measured as average U.S. wellhead value, expressed in 1994 dollars computed using the U.S. GDP deflator.

⁶ See, for example, International Energy Agency [1994], U.S. Department of Energy [1995], World Energy Council [1993], Energy Modeling Forum [1992].

⁷ For example, the 1922 USGS/AAPG study claimed that “Fortunately estimates of our oil reserves can be made with far greater completeness and accuracy than ever before.”

of discoveries already made. Now, however, there have been no new discoveries in the past several decades of sufficient magnitude to substantially alter periodic geological assessments of world crude oil resource potential.

It is the stark contrast between this recent historical record of growing resource abundance and a renewed consensus of impending resource scarcity that motivates this study. The objective is to examine carefully both the historical record and the most prominent recent geological assessments to answer or at least address several unresolved issues. Is the long predicted “wolf” of oil scarcity¹¹ finally at the door? Or, are current perceptions as myopic as in the past? Do we have sufficient information to distinguish meaningfully between the two possibilities? And finally, how important is it that we do? In particular, is there a case for broader government intervention in petroleum markets to correct for a failure by markets to signal impending resource scarcity?

Organization

The first task, addressed in the next chapter, is to review the long history of geological estimates of remaining resource potential, both in the U.S. and, more recently, the rest of the world.

There was a steady increase in the assessed volumes remaining to be produced by the domestic industry from the turn of the century until the early 60’s, suggesting a strongly conservative bias to those estimates¹². Experts were repeatedly subjected to large surprises in supply potential year after year. By the 60’s, a strong debate developed in the geological community over the sustainability of growth in domestic supply. The range of estimates of the total volumes which would ultimately be produced in the U.S. expanded greatly, with the high estimates (nearly 600 billion barrels) triple

or even quadruple the volumes of the low (150 to 200 billion barrels).

After U.S. production peaked in 1970, fulfilling the predictions of the pessimists in this running debate, most estimates of remaining potential fell sharply. More recently, those estimates of U.S. potential have begun to rise again, though such estimates are increasingly qualified to recognize their very strong sensitivity to economics and technology. Ironically, the recognition of such increased domestic resource potential has coincided with one of the sharpest declines in domestic upstream activity in history, not the result of a resource constraint, but rather to the availability of more competitive, lower cost resources abroad, combined with progressively more severe policy restraints on access to the most promising remaining domestic resources.

Next, the chapter turns to estimates of worldwide supply potential. While several official estimates of this potential were made well before the 1920’s, the frequency and significance of the estimates increased rapidly after World War I, which had demonstrated that oil was a key strategic commodity in modern mechanized warfare. World War II reinforced this strategic importance. By that time it was clear that the world’s largest and least costly oil resources were not in North America but in the Middle East. It became apparent that imports of petroleum would play a significant role in U.S. oil supply (not to mention a far more significant role in the postwar economies of Europe and Asia).

Again, there was frequent concern that worldwide resources were in danger of exhaustion. Geological estimates of remaining worldwide potential began to appear on a regular basis. Early estimates grew steadily, as they had in the United States, and were usually rather quickly overtaken by actual production. More recent estimates, while fluctuating by large amounts, have not exhibited any clear trend since the mid 70’s, despite the rapid pace of worldwide industry growth and geographical dispersion in the postwar period.

What emerges from Chapter 2 is a somewhat chaotic history of geologists’ attempts to

¹¹ Metaphor used by Akins [1973].

¹² That is, estimates of remaining potential were usually exceeded by actual production within a short period following the estimate.

estimate the world resource base during this period, and the implications of these resource limits for future supply. While it is clear that many past estimates of the U.S. resource base have been overly conservative, not all have been so. In fact, in light of the decline experienced in U.S. production since 1970, estimates of domestic resource potential were revised sharply downward. Similarly, estimates of worldwide resource potential, made principally since World War II, ended their upward trend in the mid-60's. Generally such estimates have been interpreted as implying that sustained modest growth in world oil supply may not be feasible beyond the first half or even quarter of the next century.

Chapter 3 examines this proposition, taking the most recent worldwide resource assessment prepared by the U.S. Geological Survey as given, and examines its likely implications for future world petroleum supply. What emerges from this analysis are two characteristic features of the current conventional wisdom, both of which follow directly from geologic constraints contained in the USGS assessment. First, it appears that, under plausible assumptions, world petroleum supply will peak early in the next century. Second, it appears that, because of the heavy concentration of remaining conventional petroleum resources in the Middle East¹³, world supplies will eventually become increasingly concentrated in that region. Nonetheless, the assessment also admits to a sizable band of uncertainty that must reasonably accompany any estimate of future supply potential. Even when only that portion of the uncertainty associated with the level of future discoveries is considered, the difference between the high and low estimates of future discoveries amounts to nearly 700 billion barrels, roughly equivalent to cumulative world consumption from 1859 to the present.

But even this broad band only partially captures the uncertainty surrounding future supply

potential. That is, the level of future discoveries is not the only source of uncertainty affecting future oil supply. It may not even be the most important one. Economics and technology are explicitly assumed to be static in the USGS assessments. This is a useful convention to follow, insofar as it provides a standardized "format" to facilitate comparisons among expert geologists, thereby providing a basis for aggregating their results to worldwide totals. However, it has drawbacks, as well. Most importantly, it fails to capture effects that, while difficult to predict or even quantify, are clearly neither static nor inconsequential. On the contrary, technology and economics are widely recognized to have major implications for future supply potential, as they have in the past.

Chapter 4 develops this treatment of uncertainty further, with an examination of the sensitivity of the geologic assessments to plausible variations in economics and technology. It indicates that, while a peak in world oil supply *might* well be reached in the first half of the next century, it is certainly not necessary. Other plausible scenarios, such as low growth in world demand coupled with modest but sustained technological improvements which increase average recovery rates, could postpone the peak of world production until well after 2050. Even in these cases, however, not much more than half of the conventional oil in place is actually recovered, nor are the enormous known volumes of unconventional oil resources, primarily in the Western Hemisphere, significantly touched.

With this assessment as background, Chapter 5 addresses what is perhaps the most important question posed by these data, which is -- "so what?" That is, are there features of this outlook that are cause for concern, and if so, can those concerns be remedied by government action? Specifically, there are two concerns to be addressed -- one imaginary, the other very real. More importantly, there is a role for governments here, but a danger that misguided actions aimed at the imaginary concern may neglect, distract from, or even aggravate the real one.

Chapter 6 summarizes the study and its principal conclusions, which are threefold.

¹³ See Energy Modeling Forum [1992] for a comparative review of forecasts from a set of the most commonly used world oil market models. These two characteristics -- growing resource scarcity and growing supply concentration in the Middle East, are common to virtually all of the forecasts prepared by the modelers. This is perhaps the most enduring characteristic of most forecasts since the mid 70's (see Lynch [1992]).

First, resource availability is not likely to be a binding constraint on supply growth for at least several decades, quite possibly far longer. Second, however, expansion of such supply at even modest growth rates will require substantial new investments in capacity over the next decade, of a magnitude that will be formidable under even the most optimistic of world investment climates. Finally, however, realizing such potential gains may be seriously threatened by institutional barriers in all of the largest current producing countries (the U.S., the FSU, Mexico, Venezuela, and the Persian Gulf), despite the fact that such barriers have been declining in many other areas since the collapse of socialism. It is these institutional barriers that are likely to be more serious impediments to future worldwide oil supply growth than any scarcity imposed by nature.

Chapter 2.

The Record of Oil Resource Assessment

“Essential materials in our civilization are wood, water, coal, iron, and agricultural products. ... We have timber for less than 30 years. ... We have anthracite coal for but 50 years, and bituminous coal for less than 200. Our supplies of iron ore, mineral oil, and natural gas are being rapidly depleted, and many of the great fields are already exhausted.

-- Pinchot, G., *The Fight for Conservation*, 1906

An Old Question: How Much is Left?

Petroleum is an exhaustible resource. Like coal and natural gas, it was originally generated by infinitesimally slow geologic processes occurring over a span of millions of years, in which fluids and gases from organic matter were trapped in the pore space of sedimentary rock formations. At such a pace, the amount of natural replacement occurring over the span of even a few hundred years would be trivial, so for all practical purposes the volume of original oil-in-place in the earth's crust at the birth of the petroleum industry in the mid-19th century imposes an upper bound on what can ultimately be produced over the industry's entire lifetime.

Consequently, in a (trivial) sense, we are always “running out” of oil in the sense that each barrel consumed brings us precisely one barrel closer to that upper bound. That is, at any moment, the amount of resource remaining is simply this upper bound less the cumulative production up to that point. If this upper bound were known with certainty, and consumption was expected to grow indefinitely, the imminence of exhaustion would require a simple calculation comparing expected rates of consumption to this stock of remaining resource.

But of course, this is a very big *if*. While production volumes are measured with relative precision, the remaining resource volume is completely unobservable and consequently

highly speculative¹⁴. Moreover, there are prices in the range of historical experience at which world consumption has stopped growing, or even declined, as was seen in Figure 1.

At some point, of course, oil use *will* be displaced by some other fuel, just as U.S. coal consumption in some uses was replaced by oil in the early part of this century, or wood was replaced by coal in England at the onset of the industrial revolution. Seldom if ever has such a transition been due to exhaustion of the resource or even to increases in resource cost. Rather, it often simply represents the emergence of a new use in which an alternative fuel has one or more characteristics superior to its predecessor¹⁵. As a consequence, both the amount of oil originally in the ground at the industry's birth and the amount remaining after the industry's demise are both unknown numbers, not necessarily of significant empirical importance. Nonetheless, those numbers have always been of interest, both to the industry

¹⁴ There are a number of reasons why oil and gas deposits pose uncertainties quite different from other mineral resources. First, there are currently no known technologies for establishing the existence of such resources short of drilling the prospect. Other minerals are often identified by outcroppings or by exploratory techniques less expensive than oil drilling. Second, even if a well confirms the existence and areal extent of an oil or gas resource, the amount recoverable depends on the mobility of the resource within the formation and the technology and production methods used.

¹⁵ The initial use of oil was for lighting, not transportation. Some of the early warnings of exhaustion were expressed as fears that the “lights will go out.” Many of these concerns were expressed well before the scope of oil's principal use -- as a transport fuel, was even appreciated.