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The Status of World Oil Reserves: Conventional and Unconventional Resources in the Future Supply Mix

By

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Introduction

Are We Running Out of Oil?

For decades, experts have been debating the timing of a peak in the discovery and production of conventional oil reserves. In 1998, geologist Colin Campbell predicted that global production of conventional oil would begin to decline within 10 years.[1] His forecast, commonly referred to as "peak oil," was endorsed and elaborated on by many respected geologists and commentators, including Princeton University geologist Kenneth Deffeyes.[2] At the heart of most predictions of peak oil is a prediction made by Marion King Hubbert in 1956. In the mid-1950s, Hubbert used a curve-fitting technique to correctly predict that U.S. oil production would peak by 1970. The so-called Hubbert curve is now widely used in the analysis of peaking production of conventional petroleum. According to the Hubbert curve, the production of a finite resource, when viewed over time, will resemble an inverted U, or a bell curve. This follows from the technical limits of exploitation, where the estimated parameters of the curve determine the rate of ascent and descent before and after the peak. "Peak oil" is the term used to describe the situation where the rate of oil production reaches its absolute maximum and begins to decline.

Hubbert's thesis has been applied to world oil production, and peak oil advocates have in recent years been arguing that the majority of the world's oil production was concentrated in mature, aging fields from which the extraction of additional supplies will be increasingly costly as mechanical or chemical aids are used to induce artificial (as opposed to natural) lift. According to Peak Oil Theory, as each older field peaks, world production will fall and oil prices will rise.

Part and parcel of this depletion-oriented view of world oil resources is the conventional wisdom that as mature fields become rapidly depleted in the Western world, the last remaining barrels will be found in the most prolific oil basins of the Middle East. To meet an ever-increasing demand for oil, so the argument goes, oil prices will have to rise significantly to accommodate the exploitation of more expensive, technically complex unconventional resources, such as oil and natural gas from shale deposits, oil sands, and other difficult geologic formations. This geologically based world oil market structure is thus predicted to bring Middle East producers increasingly higher returns for their remaining scarce supplies in the coming years, as competition from conventional resources in other regions such as North America, Latin America, Africa, and Asia fades with depletion.

This view of the world oil market gained renewed popularity in the 2000s as oil prices were climbing. Rising prices were explained as evidence of increasing depletion across the globe, including the Middle East, and commentators speculated that a looming crisis was on the horizon.[3] However, we will argue that technology has increasingly upended traditional discussions of impending oil scarcity and created a world where the costs of developing unconventional oil, the costs of converting one form of hydrocarbon to another, and the costs of providing alternative automotive engine technologies have rendered almost all energy sources increasingly substitutable for one another. The increasing substitutability of other fuels for oil will temper oil demand and prices.

We suggest further that artificial and geopolitical barriers to resource exploitation in the Middle East, by creating a temporary scarcity premium, have hastened technological innovation in unconventional resources at a time when resource abundance still remains a strong feature of the world energy market. Moreover, the higher oil prices rise and the longer they remain high, the faster the pace of technology development and substitution will be, irrespective of the stage of depletion world oil markets are experiencing.

Thus, rather than reap ever-higher returns for their remaining conventional resources, Middle East producers may find themselves facing increasing competition for market share with unconventional supplies of oil from Canadian oil sands, North American shale oil, shale gas, and liquids converted from natural gas supplied at prices that are driven by technological innovation rather than depletion curves. At the same time, temporary price spikes have encouraged oil-consuming countries to adopt energy efficiency measures that will curb the long-term growth in global oil demand, potentially delaying the timeframe when actual depletion may benefit the Middle East, if it comes at all.

The Current Facts of World Oil Production

Dire predictions that world oil production rates would begin to fall by the 2000s did not, in fact, materialize. Our ability to produce more oil from countries outside of the Organization of Petroleum Exporting Countries (OPEC) has not actually declined in recent years, though the rate of gain has slowed. In 2010, non-OPEC production rose by roughly 850,000 barrels a day (b/d) to 47.771 million b/d, up from 46.913 million b/d in 2009, despite significant declines in the United Kingdom (7.7 percent), and Norway (9.4 percent).[4] U.S. oil production actually gained for the second consecutive year from 7.271 million b/d in 2009 to 7.513 million b/d in 2010, and this trend would have likely gained momentum but for the Macondo accident and related drilling moratorium. Energy Intelligence Group is projecting non-OPEC production to grow by 450,000 b/d or so in 2011 based on gains from South America and the former Soviet Union while the International Energy Agency (IEA) is forecasting a 300,000 b/d increase for 2011. Investment firm Morgan Stanley is more pessimistic, projecting that large gains from the former Soviet Union, South America, and Canada will be offset by sharp declines elsewhere, leaving a net loss in non-OPEC production of 380,000 b/d in 2011.

As oil and natural gas prices were rising sharply in the 2000s, investments aimed at developing unconventional resources similarly skyrocketed, opening up new domains for oil and natural gas production not previously expected in mainstream forecasts for the 2000s and 2010s. Onshore United States is the best case in point where shale oil production is now on the rise, with output from the Bakken play in North Dakota growing from less than 100,000 b/d in 2005 to an estimated 375,000 b/d for 2011.[5] Innovations in the Bakken shale—such as longer lateral lengths and the use of multistage fractures—have allowed production rates to increase dramatically in recent years. In fact, these innovations have led some analysts to predict that despite the projected declines in offshore output due to the extended moratorium, total U.S. oil production will remain relatively flat largely because of oil supply increases from the Bakken shale, which is projected to increase to up to 800,000 b/d by 2013.

The cost of production for Bakken liquids is in line with the costs of conventional U.S. onshore production. Moreover, current high prices are stimulating interest in Wyoming oil shale as well. Based on small-scale field tests, Shell has argued that shale oil "will be competitive at crude oil prices in the mid-$20s per barrel." If true, this would certainly be a game-changer in the oil world, in much the same way recent developments in shale *gas* have been for natural gas markets.

Oil shale resources such as those in the Green River Basin in the Western U.S. are distinct from the *shale oil* deposits of the Bakken play. The distinction is largely related to the differences in geologic and physical properties, which result in the use of different recovery techniques for extraction. On the one hand, *shale oil* is developed by creating porosity in a liquids-rich shale formation. There is no reservoir to be tapped into that allows the flow of hydrocarbons to the wellbore due to pressure differential. Rather, the "reservoir" and resultant flow are created through the act of fracturing the shale formation. *Oil shale*, on the other hand, is a solid so cannot be pumped directly from the ground. Instead, it is developed either through conventional mining techniques and processed to a liquid above ground or through *in-situ* retorting, a process by which the rock is heated and the oil pumped to the surface in liquid form.

The resource assessments for oil shale are far larger than those for shale oil, but recovery is also generally more costly. In a 2005 study, the Rand Corporation[6] wrote:

> The largest known oil shale deposits in the world are in the Green River Formation, which covers portions of Colorado, Utah, and Wyoming. Estimates of the oil resource in place within the Green River Formation range from 1.5 to 1.8 trillion barrels. Not all resources in place are recoverable. For potentially recoverable oil shale resources, we roughly derive an upper bound of 1.1 trillion barrels of oil and a lower bound of about 500 billion barrels. For policy planning purposes, it is enough to know that any amount in this range is very high. For example, the midpoint in our estimate range, 800 billion barrels, is more than triple the proven oil reserves of Saudi Arabia. Present U.S. demand for petroleum products is about 20 million barrels per day. If oil shale could be used to meet a quarter of that demand, 800 billion barrels of recoverable resources would last for more than 400 years.

The Rand report goes on to say that surface mining is "unlikely to be profitable unless real crude oil prices are at least $70 to $95 per barrel (2005 dollars)." The report does not minimize the difficulties of developing the resource. In fact, it concludes, "Under high growth assumptions, an oil shale production level of 1 million barrels per day is probably more than 20 years in the future, and 3 million barrels per day is probably more than 30 years into the future." But Shell's experience, noted above, indicates that costs could come down quickly over time with more investment.

The Example of Unconventional Gas

For U.S. natural gas, a prominent role for production from unconventional resources (coal bed methane and tight gas formations in particular) has been the norm for decades. However, since 2000, as volatile U.S. natural gas prices climbed to record highs, the pace of investment in unconventional gas resources increased significantly in North America. The resulting expanded production of natural gas from shale formations has dramatically altered the global natural gas market landscape. In fact, the emergence of shale gas is perhaps the most intriguing development in global energy markets in the last decade and one that flies in the face of peak resource depletion theorists. Beginning with the Barnett shale in northeast Texas, the application of innovative new techniques involving the use of horizontal drilling with hydraulic fracturing has resulted in the rapid growth in production of natural gas from shale. Knowledge of shale gas resources is not new, as geologists have long known about the existence of shale formations. Accessing those resources was long held in the geology community to be an issue of technology and cost. In the past decade the technology has advanced, bringing about substantial cost reduction.

In 1997, Rogner[7] estimated over 16,000 trillion cubic feet (tcf) of shale gas resource in-place globally with just under 4,000 tcf of that total estimated to be in North America. At that time, only a very small fraction (<10 percent) of this was deemed to be technically recoverable and even less so economically. As indicated above, recent innovations made this resource accessible both by providing the technological capability and by reducing costs, thereby enhancing economic feasibility. The IEA recently estimated about 40 percent of the estimated resource in-place by Rogner (1997) will ultimately be technically recoverable. A more recent assessment by Advanced Resources International (2010) notes an even larger global resource in-place, with most of the addition coming from North America and Europe.

The state of knowledge regarding the portion of shale gas that is economically recoverable has changed rapidly over the last 10 years. In 2003, the National Petroleum Council,[8] using estimates largely derived from U.S. Geological Survey (USGS) data, estimated that about 38 tcf of technically recoverable resources were spread across multiple basins in North America. As recently as 2005, the Energy Information Administration was using an estimate of 140 tcf in its *Annual Energy Outlook* as a mean for North American technically recoverable shale gas resource. In 2008, Navigant Consulting, Inc.[9] estimated a range of between 380 tcf and 900 tcf of technically recoverable resource, putting the mean at about 640 tcf. In 2009, the Potential Gas Committee[10] put its mean estimate at just over 680 tcf, and in 2010 Advanced Resources International reported an estimate of more than 1000 tcf for North America, with over 700 tcf in Lower 48 U.S. gas shales alone.[11] Note that although each assessment is from an independent source, the estimates are increasing over time as more drilling occurs and technological advances are made.

From 2007 to 2009, the average lateral length of horizontal drilling for shale rock resources increased by a factor of five, allowing for a tripling of the initial production rate in some shale formations. This technological advance substantially lowered costs and allowed for greater technical access to the shale gas resource in-place. Currently in North America, break-even prices for some of the more prolific shales are estimated to be as low as $3 per thousand cubic feet (mcf) , with a large majority of the resource accessible at below $6/mcf. Ten years ago, costs were three to four times higher. As firms continue to make cost reducing innovations, it is likely that the recoverable resource base is larger than presently estimated.

As the shale gas experience demonstrates, one outcome of the recent price spikes of the 2000s is that high prices encouraged innovations in the exploitation of hydrocarbon resources that were previously too expensive or considered technologically infeasible. As these techniques are increasingly utilized, experience allows firms to “learn by doing,” and thereby lower the overall development costs of producing unconventional resources, leaving continued development feasible even as prices sink again cyclically.

This pattern should be no surprise since it followed the 1970s oil price shocks as well, opening new domains for oil production such as deepwater and onshore subsalt plays. Global offshore deepwater oil production was virtually nil in the 1980s, but following the price spikes of the late 1970s and early 1980s, climbed to 5 million b/d in 2009. Today, deepwater activity accounts for the majority of new conventional oil production, and the IEA projects that deepwater production will increase to 9 million b/d by 2035, or to almost 50 percent of world offshore oil production, up from about one-third currently.[12]

Substitution Technologies

Beyond the dramatic progress made in lowering costs for the exploitation of unconventional oil resources, other factors that must be considered in analyzing the future structure of the world oil market are the costs and availability of substitutes for oil and the changing costs for conversion and use technologies. Again, oil price shocks tend to encourage investment in substitute fuels and energy efficient technologies, eventually ushering in more broadly competitive markets that again endure beyond the cycle of high prices and, in fact, help bring renewed downward pressure on oil prices in the long run. This trend was apparent as oil prices rose in the 2000s. Beyond the current global economic downturn, future oil demand is likely to see competition from rising renewable energy production and more efficient end-use technologies, particularly in the automotive sector.

Role of Technology and Price in Determining Oil Reserves

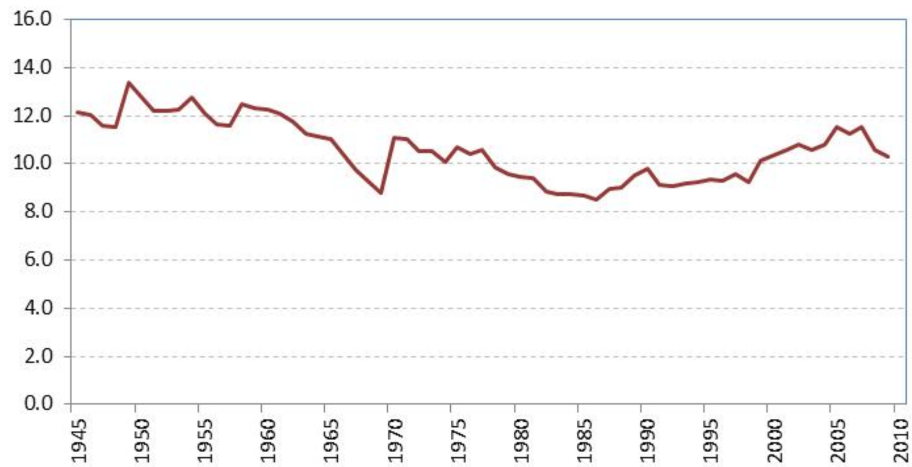
Oil is a finite resource, and therefore it is indisputable that at some point in the future oil production capabilities will be limited. The question of when the world will reach a production “peak” has been the subject of debate since the late 1880s. In 1939, the U.S. Department of the Interior announced that U.S. reserves would run dry in about 13 years. Similar concerns were raised in the 1970s and, again, more recently. In the spring of 1998, Colin J. Campbell wrote the following in an article echoed for more than a decade:

> The world is using up its geological endowment of oil at a prodigious rate, and that rate will increase as newly wealthy countries, particularly in Asia, enter the industrial phase of growth … At the same time, and despite astounding advances in the science of geology and in techniques of finding fossil fuel deposits, discovery rates of new oil reserves are falling sharply. For every four barrels used, only one is found. The lines of discovery, consumption, and extraction are bearing down on one another and will inevitably cross, probably in the year 2003; at that point, the world will pass its peak production of oil, meaning that more than half of the world's finite supply of conventional oil will have been extracted and consumed.
>
> … There are about 995 billion barrels yet to be produced (proven reserves). Of this, about 17 percent is yet-to-find. Annual consumption stands at 24 billion barrels and rising, and contrasts with the current discovery rate of just over 5 billion barrels a year on a falling trend. On this basis, the midpoint of depletion and corresponding production peak will arrive when a further 93 billion barrels have been produced, which will be in less than five years.[13]

Campbell's argument about peak oil hinges on definitional concepts. By dividing a static *conventional* "proven reserve" statistic for oil reserves and consumption without considering the impact of changes in price on technology or commercial accessibility to unconventional oil over time, Campbell overstated the nature of the problem and, like others before him, was unnecessarily alarmist.

Proven reserves are defined by the U.S. Securities and Exchange Commission (SEC) as "the estimated quantities of crude oil, natural gas and natural gas liquids which geological and engineering data demonstrate with reasonable certainty to be recoverable in future years from known reservoirs *under existing economic and operating conditions* (i.e., prices and costs as of the date that the estimate is made)."[14] Proven reserves numbers are often revised, therefore, to take into account new technologies that alter recovery factors, decline rates, and reservoir drive mechanisms. Changes in oil price also play a role in defining the level of proven reserves since under very high prices larger quantities of oil can be produced commercially than in conditions of lower prices, all else equal. Thus, "proven" is not solely a geologic concept but also an accounting and economic one. In fact, reserve data relate to "use, not availability."[15]

Figure 1. U.S. Crude Oil R-P Ratio (1945-2009)



Source: Reserves and production data from the U.S. Energy Information Administration

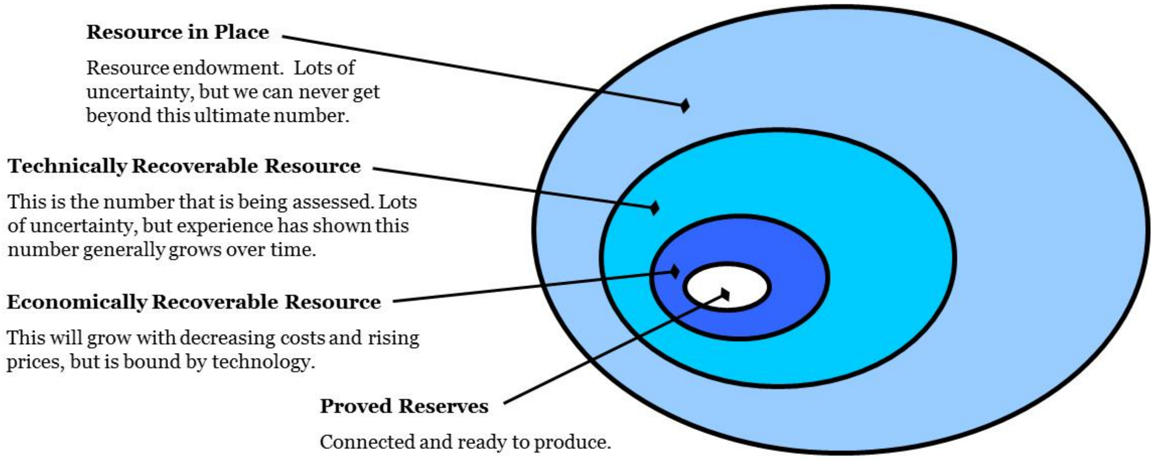
Due to the specific definition of proved reserves used by the SEC, focusing on proved reserves as a measure of potential is misleading. For example, the crude oil reserve-production (R-P) ratio in the United States, depicted in Figure 1, has fluctuated between 13.4 and 8.5, averaging 10.6, over the past 65 years. This would indicate, if proved reserves could not change, that the United States should have ceased producing oil long ago. The fallacy of using the R-P ratio as a legitimate indicator of the production potential in the United States should be self-evident. Thus, it is important to understand more complete estimates of production potential, as defined by assessments of technically and economically recoverable resources. These assessments have been increasing in recent years, largely due to cost-reducing innovations in developing unconventional oil and gas resources.

Defining the Resource

In many ways, the debate surrounding an impending peak in production is centered on understanding the scale of the recoverable resource. Moreover, the scale of the economically recoverable resource is dynamic because it depends on the total resource in-place, existing technologies, field development costs, and price. Figure 2 highlights this point. Proved reserves are a subset of resources defined to be economically recoverable. Beyond this, resources that are economically recoverable are a subset of technically recoverable resources, which are a subset of all resources in-place. Falling costs and/or rising prices will cause the economically recoverable resource to expand, just as innovations will cause the technically recoverable resource base to grow. The innovations witnessed in shale gas, for example, have effectively increased both the technically recoverable and economically recoverable resource.

Often, analysts focus on different measures of reserves, in particular the multi-“P” designation. In addition to proven reserves, measures such as 2-P reserves, 3-P reserves, and so on are used to indicate the likelihood of recovery from a hydrocarbon system. The most oft-cited measure when discussing a region’s potential is 2-P reserves, which are usually defined to be the quantity of oil *likely* to be retrieved from a reservoir (that is, proven and probable reserves). Importantly, estimates of 2-P reserves depend on assessments of the resource in-place and the expected recovery factor, which is determined not only by geology but also by technology and cost. Probable reserves are an estimate of oil not yet identified but existing in an area where other resources have been identified and are producing. These generally are an estimate of the collective set of field extensions and additions over the life a producing formation.

Figure 2. A Simplified Representation of the Resource Envelope



Expanding our scope to include resources hypothesized to exist in formations that have not yet been identified allows us to discuss the concept of technically recoverable resource assessments, or 3-P reserve estimates. The U.S. Geological Survey (USGS) mean assessment of conventional oil resources that have yet to be found in regions with conducive geology stands at approximately 724 billion barrels (bbls). Summing this with proved reserves (1,354 billion bbls) and the USGS assessment for growth in existing formations (1,398 billion bbls) yields a total technically recoverable resource base of conventional oil of 3.4 trillion bbls, which is almost triple the estimate of proved reserves.

While conventional oil resource assessments are substantial, moving forward, reserve accounting must increasingly include measures of unconventional resources. To the extent that unconventional oil becomes a growing part of world oil production, calculations that focus solely on reserve replacement of conventional production may not be as instructive to future world oil supply trends. Today's proven oil reserves, totaling around 1.35 trillion bbls, represent the highest level of proven reserves ever estimated (see Table 1). These proven oil reserve estimates are up by one-third since 2000 and have more than doubled since 1980. Increases in estimates of proved reserves of Canadian oil sands, now estimated at more than 170 billion bbls, constitute a large portion of the recent gains to world totals, but since 1980 the vast majority of increases in proved reserves have been characterized as "conventional" resources.

As is so often pointed out in proved reserve analysis, 56 percent of these reserves are located in the Middle East. In addition, an even larger proportion of the assessed technically recoverable conventional oil resource lies in the Middle East. These facts are often used to explain that the world will become increasingly dependent on Middle East oil as other resources become depleted, and the Middle East remains the only region with the ability to continue to produce large amounts of oil.

Table 1. Proved Oil Reserves

Country	Proved Oil Reserves (Total Unconventional and Conventional) Units: billion bbls
Africa	119.1
North America	204.7
South America	124.6
Oceania	3.5
China	20.4
India	5.6
Other Asia	10.6
Europe	13.3
Russia	98.9
Middle East	753.4
World	1354.2

Note: The numbers are rounded.
Source: Energy Information Administration

But, as discussed, this analysis assumes that conventional resources are the exhaustible resource from which global consumption must derive without any accounting for the manner in which unconventional resources may be ultimately booked as reserves in response to innovations and changes in price and/or cost. In addition, the location of unconventional oil resources renders this argument even less valid, especially in light of the fact that most of the world's identified unconventional oil lies in Canada, the United States, and Venezuela (see Table 2). Thus, when thinking about the long-run future of world oil production, one must take into consideration the massive technically recoverable unconventional oil resources.

The assessment for technically recoverable unconventional oil is incredibly large at over 2.1 trillion bbls. Unlike the assessments for conventional oil, the bulk of these unconventional reserves are not "yet to be discovered" but in fact, much is known about their location and scale. As innovations allow recovery factors to increase in oil sands and in extra heavy oil deposits, the extent of this resource base may expand significantly.

Table 2. Unconventional Oil Resources Outside the Middle East

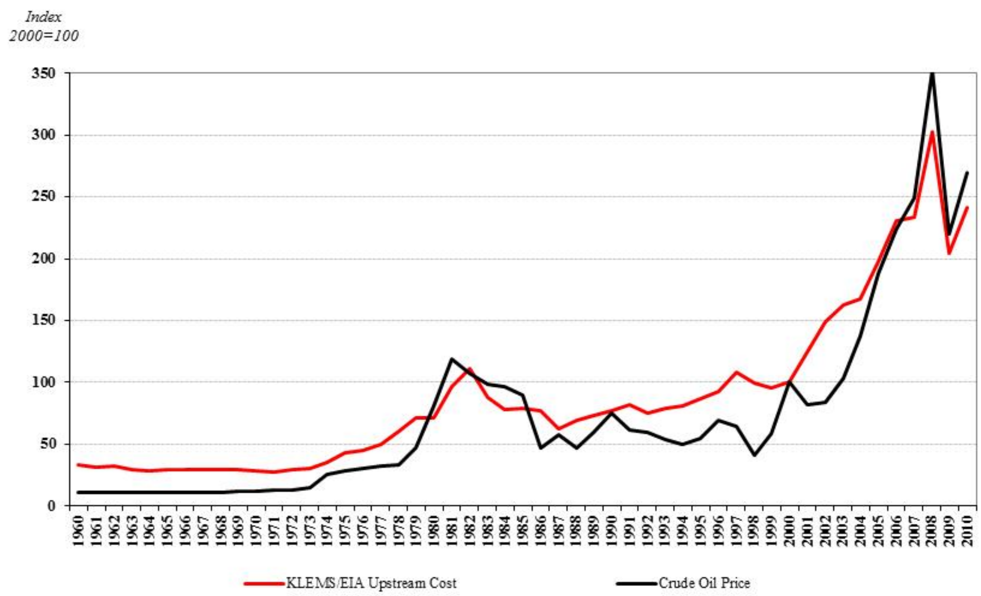
Country	Total Technically Recoverable Unconventional Oil (billion bbl)
United States	801.7
Canada	500.0
Other/South America	543.2
Russia	160.3
Caspian	124.3
World	2129.5

Source: World Energy Council

As noted above, a large proportion of the world's identified unconventional oil lies in the Western hemisphere. Heretofore, it has simply been less costly to develop conventional oil resources. However, *relative* costs for developing unconventional oil have been falling. This raises another important point—namely, that the proper focus is the *relative* cost of resource developments. For example, nominal cost estimates for breakeven in the Athabasca oil sands of Canada have fluctuated significantly since the 1990s, ranging from as low as $15/bbl in the late 1990s to current estimates of around $50/bbl. However, costs have recently been much higher than they will be in the long run since they reflect scarcity of inputs such as skilled labor, rigs, and steel generated by the exceptionally rapid expansion of the industry and the strong demand for commodities in general spurred by high economic growth in Asia. Costs will likely return to a more moderate level once scarcity of the various inputs is alleviated. Moreover, active interest in these unconventional resources has been accelerating, as witnessed by record acreage sales in Alberta in 2010. If oil prices continue to remain above $75/bbl, it is reasonable to expect interest in developing other unconventional oil resources will similarly accelerate, particularly as innovations bring down their relative costs.

Figure 3 is indicative of the long-run relationship between upstream costs and oil prices. As can be seen, upstream costs tend to cycle with the price of oil. Depicted in the figure are two series, each indexed to the year 2000 and expressed in nominal terms.

Figure 3. Upstream Costs and Crude Oil Price (Nominal Index, 2000=100)



Source: U.S. Bureau of Economic Analysis and U.S. Energy Information Administration

The series labeled "KLEMS/EIA Upstream Cost" is a broad index constructed from the Bureau of Economic Analysis and the Energy Information Administration that accounts for all upstream costs in the oil and gas mining industry. Note that the cost data generally moves with the price of crude oil. Moreover, the cost index indicates that on average, projects in the mid-1990s were about one-fourth the cost of projects in 2008. Thus, expectations of a high cost environment should be tempered by the realization that recent history has been a high point in the price-cost cycle.

The Rise of Unconventional Resources

If the world's energy resources were to be developed efficiently in the absence of uncertainty, production would occur first with those resources that can be produced at least cost. Then, as those resources are depleted, production would move to more costly supplies. In a competitive market, this process would occur naturally with prices rising to signal the depletion of lower cost reserves and the profitability of moving to higher cost resources. This trend to ever-increasing prices can be tempered by technological change that lowers exploration and development costs.[16]

However, the global oil industry does not fit this competitive model. A lack of access to lower cost resources (propelled by OPEC's policies and the noncompetitive practices of national oil company [NOC] monopolies) has forced private capital to seek other options, which is why there is already substantial investment in unconventional resources, even as large, untapped low cost conventional reserves remain to be developed. In effect, geopolitical barriers and bureaucratic inefficiencies block the timely investment in some of the most inexpensive onshore and shallow water oil resources.

The IEA projects that over the next 30 years, $5 trillion in new investments will be needed in the global oil sector to meet rising world demand.[17] Despite these tremendous capital requirements, many governments continue to intervene in energy markets in a manner that is slowing or even discouraging this needed investment. The IEA notes in its 2009 *World Energy Outlook* that as a result of the global financial crisis and related credit crunch, NOCs have reduced upstream spending by 7 percent in 2009 compared to 2008, while the largest international oil companies (IOCs) have held spending relatively flat.[18] This trend comes despite historically high oil prices.

Large undeveloped oil potential exists throughout the Persian Gulf, Latin America, Africa, and Russia, and there remain key areas such as Iraq's western desert that have yet to be explored fully. But private sector firms in the best position to channel the capital required to make major high risk, long-term investments in promising resources have been frequently denied access to many of these promising regions. Some of these regions have national oil companies that could, at least in theory, develop these attractive known reserves. However, generally speaking, in recent years, many governments have been siphoning oil revenue from their NOCs to meet domestic requirements for socioeconomic welfare priorities or to meet budget deficits, leaving NOCs without sufficient capital (and in some cases, know-how) to engage in needed reserve replacement and oil production capacity expansion activities.[19]

The tendency of oil-dependent governments to siphon oil revenues from national oil companies for other national spending priorities hinders the firms from sustaining core operations, a point made clear in Eller, Hartley, and Medlock (2010).[20] The list of NOCs with flat or declining oil production capacity is long and includes major resource holders such as Iran's NIOC, Mexico's PEMEX, and Venezuela's PDVSA.

Many NOCs are not only having trouble retaining the necessary funds to increase their resource base and expand oil and gas production, they are also facing serious production problems as older fields mature and funds are not available either to slow natural declines in output flows by tapping expensive enhanced oil recovery techniques or to drill new prospects to replace falling output at older fields. Lower investments in oil field projects in Venezuela have translated into a significant loss of production capacity from 3.6 million b/d in 1998 to just over 2 million b/d currently. Mexico is another example where lack of funding for new drilling and exploration is beginning to show in a rapid decline, as Mexico's output has fallen from 3.68 million b/d in 2006 to 2.72 million b/d in 2009.

Geopolitical factors also play a role as international sanctions, regional conflict, local unrest, and bureaucratic infighting create barriers to investment and exploration/development activities. In several important resource-rich countries, important violent and nonviolent social movements are raising the costs of investment, disrupting exploration and production, and generally interfering with the flow of primary commodities. This is especially true in Africa where some local communities are resisting oil development on environmental and social justice grounds and where violence by rebel groups has hindered oil development and exports. For example, in 2002, Nigeria set its sights on increasing oil production to 4 million b/d with the help of increases in foreign direct investment. But violence in the Niger Delta region has curbed the country's production rates, with monthly output in 2009 actually falling to a low of 1.51 million b/d in August. About two-thirds of Royal Dutch Shell's production in Nigeria, or about 800,000 b/d, was closed in November 2009.[21] Infrastructure in the region has been heavily damaged by the fighting, and the pace of new investment remains constrained.

In many regions, hyper-mobilized social movements have also created new risks, which have in turn had negative consequences for international capital inflows and have also curtailed energy supplies in the region. For countries like Bolivia, such hyper-mobilization has virtually eliminated foreign direct investment and precipitously slowed development of the country's hydrocarbon resources. In the Middle East, resource nationalist sentiment among populations and rulers alike has blocked or slowed investment in a number of countries including Kuwait, Iraq, and Iran. Turmoil in Libya will undoubtedly slow the country's resource development in 2011 and beyond.

These geopolitical trends in conventional resource development, combined with other factors such as the restrictive oil production policies of OPEC, allowed world oil and natural gas prices to reach levels above historical averages, thus encouraging investment in unconventional resources.

At present, about 6 percent of world oil production comes from deep offshore fields. Canadian oil sands production is averaging 1.2 million b/d and is projected to rise to 2.2 million b/d by 2015 and 4.2 million b/d by 2030, according to the well-regarded Canadian Energy Research Institute (CERI). A recent Baker Institute study[22] forecast that U.S. unconventional oil production will take an increasing share of domestic output by 2040, reaching 1.2 million b/d in 2040 and possibly 7.3 million b/d by 2050 as oil prices move higher over time (see Table 3).

Table 3. Projected U.S. Oil Shale Production

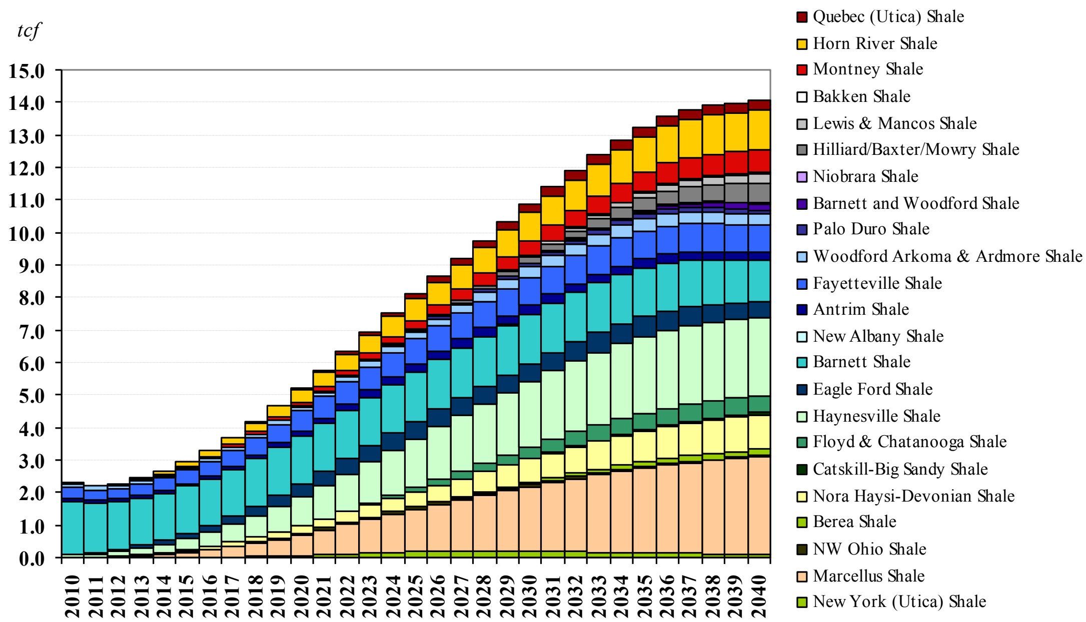
Year	Unconventional Production (million b/d)	Total Production (million b/d)	Percent of Total Production
2035	0.01	3.6	0.2%
2040	1.2	4.6	26.1
2045	3.8	7.3	52.1
2050	7.3	10.9	67.0

Note: Production from oil shale primarily comes online around 2035 (according to the model). The figures in the table do not include shale oil from the Bakken formation, for example, which approach about 900,000 b/d then slowly decline after 2020.

Source: Hartley and Medlock, Rice World Energy Model, 2010

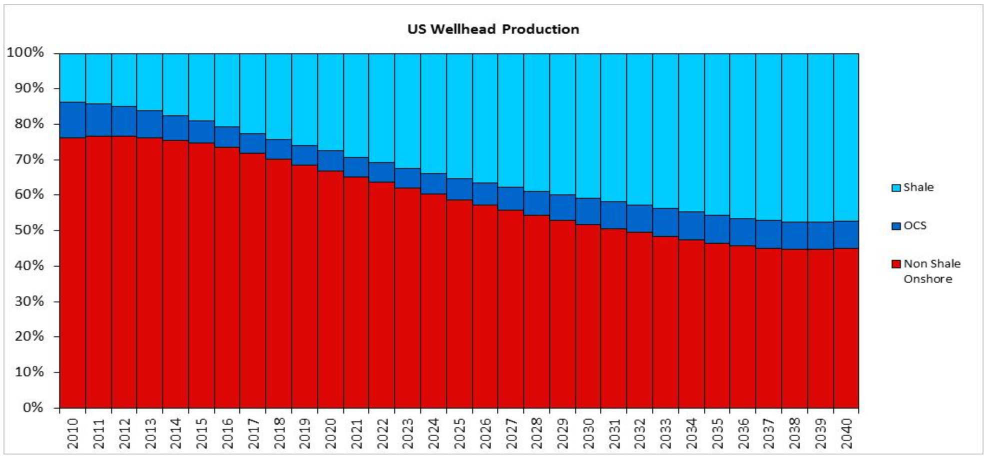
The outlook for natural gas production from shale is even more impressive. U.S. natural gas production from coal bed methane and shale gas formations rose to about 5 tcf in 2009, up from only 1.5 tcf in 1998. Of that, more than half in 2009 derives from shale gas, which is up from virtually nothing in 1998. Shale gas output in particular is expected to grow in the coming years to over 14 tcf in the United States and Canada alone (see Figure 4), eventually reaching more than 50 percent of total U.S. natural gas production (see Figure 5).

Figure 4. North American Shale Gas Production through 2040



Source: Hartley and Medlock, Rice World Gas Trade Model, 2010

Figure 5. Composition of U.S. Wellhead Natural Gas Production



Source: Hartley and Medlock, Rice World Gas Trade Model, 2010

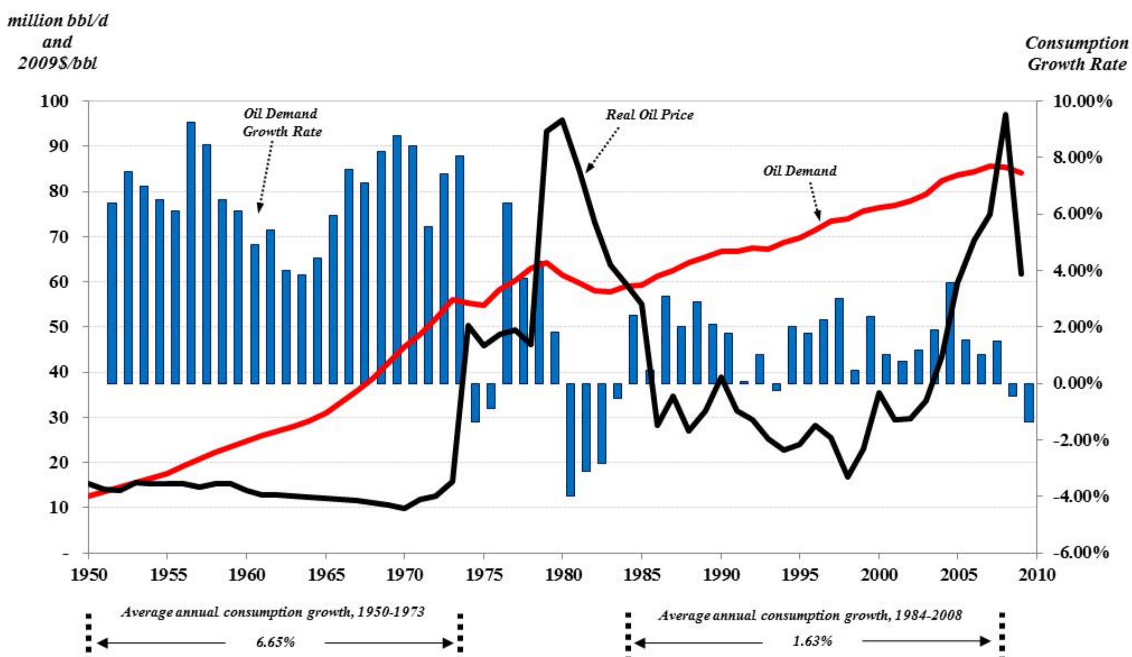
The recent successes of shale gas producers in North America have triggered global interest in finding and developing similar resource plays around the globe. To the extent success is reached in Europe and Asia, unconventional gas will become an ever-increasing part of the global energy mix. As gas abundance relative to oil, reflected in the relative price of the two fuels, becomes increasingly the norm, natural gas is likely to compete into traditional oil end-uses. This substitution will effectively mean unconventional natural gas is replacing crude oil. The rising competition for global energy market share from shale gas will be a truly game-changing event in light of the fact that nobody was expecting shale gas to become such an important part of the energy mix as recently as 10 years ago.

Efficiency Gains and Increasing Substitutability among Energy Resources

Global oil demand growth has varied substantially over the last 60 years, with much of the variation directly attributable to response to movements in price. In fact, the average annual growth rate of oil demand from 1950 to 1973 was about 6.7 percent, but after the oil price shocks of the 1970s and early 1980s, demand growth slipped to only 1.6 percent from 1984 to 2008 (see Figure 5). The lessons of the past should not be dismissed when considering future demand. The price shocks of the 1970s and early 1980s ushered in greater levels of efficiency and conservation at all levels of consumption. This materialized through investments in capital that forever altered the energy required per unit of useful output. Once efficiency improvements are adopted in the wake of high prices, they are not undone even should price decline. Thus, the future growth rate of demand will be altered by the types of efficiency improvements and other technical or structural changes that are adopted in response to high prices.

Heretofore, the transportation sector has relied almost exclusively on oil, but competition among a variety of fuels—including oil, coal, and natural gas—has characterized the industrial, residential, commercial, and power generation sectors. In the power generation sector, renewables and nuclear also compete for load share, making it relatively insensitive to shocks that affect the price of only one fuel. This stands in stark contrast to the transportation sector's lack of fuel substitution capability, which is hinged largely on the dominance of oil-using capital in that sector.

Figure 6. Long-Run Effects of Short-Term Oil Price Increases



Source: UN Energy Statistics, BP Statistical Review, author's calculations

Little is expected to dramatically change on this point, with most forecasts predicting that growth in transport demand will be the main driver of future oil demand. The IEA states it well, saying, "In the New Policies Scenario, transport accounts for almost all of the increase in oil demand between 2009 and 2035."[23] The lack of fuel choice in transportation has given oil producers market power not available to other resource suppliers. However, this influence will likely dissipate over time, particularly as technological breakthroughs lower the costs at which other fuels can be substituted directly or indirectly for oil in the transportation sector.

Over time, continued advances in technology will erase this protected enclave for the oil industry, driven potentially by a widening differential between oil prices and the prices for natural gas and coal. Historically, the ratio between oil price benchmark West Texas Intermediate crude oil and Henry Hub natural gas prices fluctuated in the range of 8-to-1 and 12-to-1, meaning that an oil price of $100/bbl would coincide with a natural gas price between $12.50/mcf and $8.30/mcf.[24] However, as ample shale gas resources have come to market, the ratio between oil and gas prices widened to over 20-to-1 in 2010, which is promoting consideration of alternatives to crude oil as the primary fuel in transportation. Depending on price differentials between natural gas, oil, and coal, as well as innovations in conversion technologies, gas-to-liquids and/or coal-to-liquids technologies will provide increasing competition of fuels in the transportation sector.

The IEA's "Blue EV Success" scenario allows electric vehicles to reach a 90 percent light-duty market share worldwide in 2050, achieving "a two-thirds reduction in petroleum fuel use in 2050 compared to the baseline in that year."[25] By the same token, a greater number of coal-to-liquids and gas-to-liquids conversion projects are being undertaken globally now than in the past. The IEA forecasts that total output could exceed one million b/d by 2035,[26] with gas-to-liquids output forecast to grow to 750,000 b/d.[27] Of course, the extent to which these forecasts come to pass will depend on the *relative* price of oil, but the salient point is that there will likely be increasing competition with petroleum in the transportation sector.

Moreover, as more hybrid electric and fully electric vehicles come into circulation, electricity—generated by wind and nuclear power, for example—will begin to compete in the transportation sector. An important driver of this substitution is that much of the electricity generating capacity is idle during the night when electric cars could be recharged at low marginal cost. In the case of wind-generated electricity, it is well documented that winds are stronger in the evenings and at night when demand for electricity is lowest.[28] Even nuclear power, a baseload fuel, could gain from higher electricity demand derived from recharging vehicles at night.

Global growth in transport demand will be driven largely by increasing demands in emerging countries such as China and India, but the oil exporting countries of the Middle East are also poised to experience rapid growth in transport demand fueled by a growing per capita income and highly subsidized gasoline prices.[29] It is unclear whether oil exporters will continue to subsidize local fuel consumption. As recent turmoil demonstrates, there will be a strong need to extend public services and employment-generating investments to a rapidly growing population in many of these countries. In the face of a growing population, gasoline subsidies will be difficult to maintain as the total cost to the government will increase. It seems likely, therefore, that at some point these oil-exporting countries—at least those with large populations—will move to at least moderate the subsidies and, hence, local demand growth.

China has been a focus of energy markets for much of the past decade. Rapid growth in per capita GDP has allowed an increasing number of families to reach income levels where owning a car is affordable. But forecasting future vehicle stocks is fraught with uncertainty. Argonne National Laboratory has published one of the more recent forecasts of vehicle ownership in China.[30] In an attempt to capture some region-specific effects they classify countries into three "pattern" groups: the European pattern, the Asian pattern, and a "low growth" pattern. The peak level of per capita vehicle ownership is different in each group, so depending on what pattern China follows, it is possible to generate different forecasts for vehicle stocks. Depending on scenarios for future per capita income and population growth rates, the paper forecasts somewhere between 247 and 287 million highway vehicles—that is, cars, trucks, mini-buses, and buses—and roughly 186-217 million cars by 2030. This compares with current U.S. fleet of roughly 260 million vehicles.

Motor fuel demand depends on the extent to which the vehicle is driven (measured by miles driven) as well as vehicle stocks, so future vehicle ownership is but one determinant of future fuel use. Here, too, researchers have found that while miles driven increase with per capita income, miles driven also tend to level off, reaching a peak in per capita terms. That peak is strongly influenced by urban density and the availability of public transport alternatives. So the development of an alternative transportation option, such as the proposed nationwide network of high-speed rail in China, will reduce the intensity of use of automobiles relative to what would be absent a rail network.

Mileage standards and motor fuel price and tax policies also affect miles driven. It has been shown that an increase in efficiency without an increase in the price of fuel will result in a lower cost per mile, thus encouraging consumers to increase miles driven, resulting in a partially offsetting effect. So the effectiveness of government regulated efficiency standards is not a foregone conclusion, particularly if the so-called "rebound effect" is large. Fortunately, literature indicates that the effect is only partially offsetting and tends to decline with wealth.[31]

Oil-importing countries such as China have already begun to focus seriously on boosting the energy efficiency of its growing automobile stock. Unlike the United States, where fuel efficiency standards are set for the whole corporate fleet, China has set standards for each type of vehicle. The Chinese have also indicated that they will actively promote electric vehicles. *The China Energy Weekly* reported:[32]

> According to a document released by the Ministry of Finance, the policy stipulates that private purchasers of electric cars are eligible to receive government subsidies ranging from RMB 3,000 ($439.24) to RMB 60,000 ($8,784.77), depending on the car model. Under the pilot program, Shanghai, Changchun, Shenzhen, Hangzhou and Hefei will be the first cities to institute the subsidy program.
>
> … The new subsidies are aimed at both promoting the sales of eco-friendly electric cars and encouraging the production and R&D activities of electric car makers in the country.

The potential for efficiency improvements to act as a virtual source of supply, thereby reducing oil demand, is apparent from the U.S. experience. The United States saw considerable improvement in on-road vehicle fuel efficiency between the late 1970s and the early 1990s. This was primarily the result of increased federal fleet efficiency standards and consumer response to high prices. The average fuel efficiency of motor vehicles in the United States was 12.4 mpg in 1978, but increased to 22.1 mpg by 1991. This increase in efficiency coincided with rising vehicle stocks and increased vehicle utilization. So there were more vehicles on the road and people were driving them more, but increased fuel efficiency served as a virtual source of supply, keeping motor fuel use from rising very much. In fact, motor fuel use increased, on average, by only 0.1 percent per year over this time period.

Thus, it is reasonable to wonder if future demand trends will change dramatically on the heels of the most recent spike in prices. Policy measures have already been instituted in an attempt to encourage higher fuel efficiency. The Energy Independence and Security Act of 2007, passed on December 18, 2007, and signed by President George W. Bush, raises automobile fuel efficiency standards (CAFE) to 35 miles per gallon (mpg) by 2020, with the first improvements required in passenger fleets by 2011. Then, in one of its first actions after President Barack Obama assumed office, the Environmental Protection Agency (EPA) granted the state of California a waiver to regulate greenhouse gas (GHG) emissions from passenger vehicles. California in turn agreed to set its standards at the level mandated by the EPA and the National Highway Traffic Safety Administration, which is now requiring that light-duty vehicles reduce their GHG emissions to the equivalent of a fuel economy standard of 35.5 miles per gallon by 2016.[33] Baker Institute analysis shows that a policy that promotes the widespread adoption of electric vehicles that reaches 30 percent of the vehicle fleet by 2050, in addition to existing corporate average vehicle efficiency standards, would make a substantial dent in U.S. oil use. Electric cars could reduce oil use by an additional 2.5 million b/d by 2050 on top of the savings of around 3 million b/d already expected from the implementation of new CAFE standards imposed by the U.S. Congress in 2007 and fortified by the Obama administration's approval of stricter standards.

Recent high energy prices, along with increasing concern about greenhouse gas (GHG) emissions, will spur innovation and investment in energy efficiency and alternative technologies to promote flexibility in fuel choice. The National Academy of Sciences, the National Academy of Engineers, and the National Research Council produced a report, "America's Energy Future: Technology and Transformation," (AEF Report) in 2010.[34] The report argues that technology already exists, or is expected to be developed by 2030, that will reduce total energy use in the United States by 30 percent.

In the transportation sector—which is of primary interest in terms of determining the future demand for oil—the AEF Report points out that some relatively easy modifications such as improving transmission efficiency, using turbochargers, and using more lightweight materials could "reduce new-vehicle fuel consumption by 10-15 per cent by 2020 and a further 15-20 per cent by 2030...For transportation, new power systems and improvements in the efficiency of vehicles could save 1 million barrels per day of petroleum equivalent by 2020 and 4.1 million barrels per day by 2030." An ExxonMobil study finds that simple improvements to the conventional gasoline engine such as turbocharging, cylinder deactivation, and camless valves can increase efficiency by roughly 15 percent.[35]

The AEF study focuses on the United States, but its findings are also relevant for other countries, especially the more advanced industrialized countries. As the study notes:

> The deployment of existing energy efficiency technologies is the nearest-term and lowest-cost option for moderating the U.S. consumption of energy, especially over the next decade. In fact, the full deployment of cost-effective energy efficiency technologies in buildings alone could eliminate the need to construct any new electricity-generating plants in the United States except to address regional supply imbalances, replace obsolete power generation assets, or substitute more environmentally benign sources of electricity.

The conclusions of this study are supported by independent work done at ExxonMobil, which concludes that "energy saved through efficiency gains will reach about 300 quadrillion BTUs per year by 2030, which is about twice the growth in global energy demand through 2030."[36]

For residential and commercial buildings, which account for roughly 73 percent of electricity used, the AEF Report argues that "energy savings of 25-30 percent, relative to the IEA reference case, could be achieved over the next 25-30 years." Simply replacing existing lighting with fluorescent lights and light-emitting diodes (LED) could reduce the amount of electricity used for lighting by 35 percent by 2030. While LEDs and small fluorescents are still relatively expensive, the process of shifting away from standard incandescent lighting is already under way. The standard incandescent light bulb may not even be available by the end of the next decade.

The report goes on to say the following:

> Technologies under development promise even greater gains. In lighting and windows, these technologies include 'superwindows' that hold in heat extremely well and dynamic windows that adjust cooling and electric lighting when daylight is available. For cooling, the industry is developing advanced systems that reduce the need for cooling and use low-energy technologies, such as evaporative cooling, solar-thermal cooling, and heat-sensitive dehumidifiers. Other technologies include electronic systems that provide more control over the energy used in homes and very-low-energy-use buildings that combine holistic designs with on-site generation of renewable energy.

An energy-efficient heating-cooling technology that already exits is the use of the ground as a heat sink in the summer and a heat source in the winter. These systems require a higher upfront cost than conventional systems and, hence, are not usually adopted by consumers who focus on the initial outlay of a system and who may not live in the same home long enough to capture the cost savings in energy use. The resale value of homes does not always reflect the energy-saving features of the home in part because of consumer ignorance, but also because buyers are concerned with the level of monthly mortgage payments and do not typically remain in a house for more than a few years.

Importantly, efficiency gains in sectors other than transport will serve to lower the price of fuels used in those sectors and make them more attractive substitutes for oil in the transport sector.

Implications for the Global Market

As we have discussed in this paper, the traditional view of depletion of conventional resources outside the Middle East, however compelling, does not give the whole story about how the structure of the oil market is evolving. Reserves of unconventional oil and natural gas outside the Middle East are not only large, but through new knowledge and experience, have been expanding in the 2000s. Lack of investment in the low cost conventional resources in Middle Eastern countries has not actually ensured the depletion of oil and gas resources in other parts of the world. Instead, it has hastened the development of new technologies to exploit previously expensive unconventional resources at costs that are falling significantly.

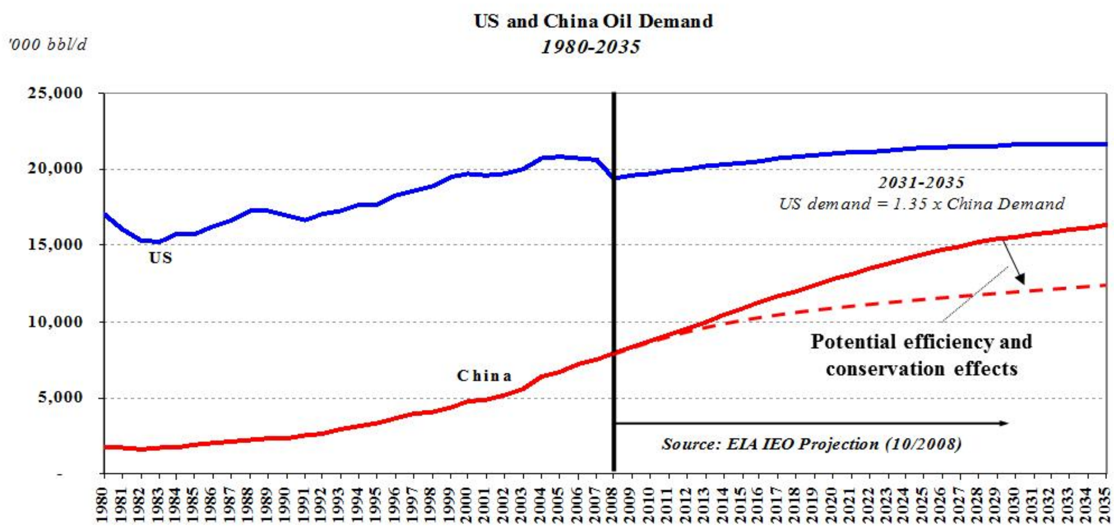
By the same token, new technologies and policies in major oil consuming countries are poised to slow the growth in demand for oil. Taken together, these two major trends are likely to delay the time frame when overall resource depletion may benefit conventional oil producers in the former Soviet Union and the Middle East, if it comes at all.

Significantly, as discussed in this paper, energy resources that are priced too far above their energy content relative to other energy resources will induce innovation and investment that will quicken the process of making other fuels or technologies substitutable for that resource. Thus, the market in 2030 or 2040, rather than centering around a peak in conventional oil, might look exactly as it does today: A managed output of a combination of OPEC resources and a growing proportion of production from unconventional plays such as shale gas, oil shale, ultra deepwater, and oil sands. In this scenario, supply from the Americas may play an increasingly important role.

The recent pace of change in the global natural gas market is instructive of what might be in store for both oil and natural gas over the coming decades. Slowly since the late 1990s, onshore drilling in the United States has produced something no one expected: a giant surplus of natural gas.

Dynamic elements might also combine to sharply alter the picture for oil in the coming decades. For example, under circumstances where China adds efficient equipment in the industrial and other sectors (similar to investments made in the United States in the 1980s), *and* ample availability of domestic unconventional gas in China, together with relatively inexpensive LNG, makes natural gas a competitive alternative to oil in the industrial, residential, and commercial sectors in China, it might be reasonable to measure the oil demand loss experienced in the 1980s in the United States and apply that same rate of change to China. This exercise would be revealing. The United States saw flattening industrial demand for oil and reduced demand in all other sectors except for transportation over the course of the 1980s and into the 1990s. Oil was virtually eliminated as a fuel in the U.S. power generation sector. Could the same thing take place in China? If so, it could shave about 4.5 million b/d of growth off China's demand for oil by 2035, more than half of the current expectation for expanded oil use (see Figure 6).

Figure 7. Past and Projected Oil Demand in the U.S. and China



Source: EIA International Energy Outlook (2008), author's own calculations

The experience of sharply rising natural gas prices in the United States in the 2000s, combined with supply insecurity in Europe, altered the expected future for the global natural gas market, perhaps for the next decade or longer. It remains to be seen whether this same trend could be mirrored in the oil market. Price will be a major variable in the outcome. As oil prices increase, fuel substitution will accelerate, investments in unconventional oil reserves will become more attractive, and energy efficiency will become a higher priority. All of these trend lines seem to be in play at current oil prices.

We suggest that a better approach to consider the future of world oil supply is not to study the depletion of traditional reserves, but to consider both the relative price of oil based on its energy content relative to competing energy resources, and how differing oil prices will or won't induce further innovation and investment that will quicken the process of making other fuels or technologies substitutable for oil.

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