Risky Diet 2005

Global Energy Resource Adequacy

Center for Energy Efficiency
and
Renewable Technologies

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Executive Summary

Oil prices make headlines

Oil prices caught the world's attention in 2004 with the benchmark U.S. crude oil price climbing 70% by mid-October to reach a record high in nominal dollars. Prices fell back somewhat by year end but rebounded this spring to set new records. U.S. natural gas prices have kept pace with oil. Wall Street is worried, fearing that the additional cost of energy will drag down the global economy. The reasons behind the leap in oil prices are being hotly debated.

Earlier editions of CEERT's *Risky Diet* series have focused on the North American natural gas situation. This year we are compelled by the recent events in oil markets to expand our outlook to include global oil, gas and coal resources, and to consider the impacts of these fuels on global warming. The outlook is not a pleasant one.

Official government agencies assure us that oil will remain plentiful and prices will return to earlier low levels. Their business-as-usual scenarios project that oil consumption will increase nearly 50% in two decades and prices will fall. They count on Russia and Saudi Arabia to rapidly expand production to satisfy global demand as projected.

However, conventional oil resources are finite and are being rapidly depleted. Saudi Arabia's giant oil fields have been producing for many decades and are experiencing problems. Spare capacity is now gone, and some experts doubt the Saudi's can maintain current production levels, much less satisfy the growing global appetite for oil.

Approximately one-half of the world's original endowment of conventional resources, as estimated by the U.S. Geological Survey, will have been extracted and burned a decade or so from now. The increasing rates of consumption forecast by the U.S. Energy Information Administration in its business-as-usual scenario would accelerate this depletion. To satisfy the USEIA projections, the rate at which remaining conventional oil resources are exploited would nearly double.

The media is fond of pointing out that today's oil prices are not record highs when the effects of inflation are included. However, during the earlier "oil crisis" in 1980, when prices reached $80 per barrel in today's dollars, oil supplies were limited by *political* constraints.

The media has failed to point out that today's elevated oil prices are driven by *resource* constraints. OPEC admitted this spring that it has little spare capacity remaining. New production projects are underway, but they will be hard pressed simply to make up for declining production from existing fields.

Moreover, some experts believe that global oil production will peak and begin to decline in a few years. Using an analytical technique first used by geologist M. King Hubbert to correctly forecast the peak and decline in U.S. oil production, these analysts predict the peak in worldwide production to occur some time in the next decade or two.

If oil production begins to decline, consumption must decline as well, of course. Competition for limited supplies of oil will drive up prices, and more people simply will not be able to afford to buy as much oil as they would like. The impact on the global economy and on people's everyday lives will be enormous.

Risky Diet 2005 looks at the official optimistic projections in light of resource constraints and concludes that the business-as-usual scenario of continued plentiful and inexpensive oil is highly improbable. This report finds that oil prices are likely to continue to rise as resource depletion restricts production and consumers compete for limited supplies. Higher prices will effectively ration oil to the decreasing few still able to afford it. The age of plentiful and inexpensive oil is drawing to a close.

There is now talk of producing synthetic crude oil from bitumen in Canada, shale in Wyoming, and other low grade potential sources of petroleum. Currently, only about 1% of the world's oil comes from these sources. Enormous amounts of capital are required to produce syncrude from these unconventional resources. Many billions of dollars would be required merely to double syncrude production and supply 2% of today's demand. Whether syncrude investments sufficient to offset depletion of conventional resources will appear quickly enough appears doubtful.

Risky Diet 2005 concludes that the days of plentiful and cheap oil are rapidly coming to an end and that a plan to deal with the transition to reduced supplies of oil and vastly higher prices is urgently needed. The efficiency with which oil and other forms of energy are used must increase rapidly, and other sustainable energy resources must be deployed as quickly as possible.

Global trade in natural gas expands

As chronicled in earlier editions of *Risky Diet*, the U.S. has become dependent on imports of natural gas from other continents in the form of liquefied natural gas (LNG). *Risky Diet 2005* notes that this dependence increased further in 2004 as LNG imports grew 50%. Although LNG continues to supply only a small fraction of U.S. gas, today's high gas prices would be much higher without the imports.

The U.S. is not alone, of course. The booming economies of India and China need large amounts of energy and are rapidly expanding their imports of gas through pipelines and as LNG. Australia, Russia, Qatar, Nigeria and other countries with large gas resources are expanding production to meet the growing demand. Natural gas is increasingly a global commodity.

Currently there are some 40 proposals for LNG import terminals active in the U.S., including 4 in California. U.S. gas prices are well above the cost of importing LNG making importation appear lucrative. Only a fraction of the proposed terminals are expected to be built, however. Whether these will supply enough gas to drive down U.S. prices in the future remains to be seen. Despite increasing imports of LNG into the U.S. in 2004 and marginally lower consumption, the market absorbed the additional gas with no decrease in U.S. prices.

In response to current prices, drilling activity for gas in the U.S. and Canada is at record levels. Nevertheless, production is marginally lower. It appears that U.S. gas prices cannot fall significantly without lowering domestic production, thereby creating the need for even more LNG.

It appears impossible for the U.S. to avoid increasing its reliance on LNG somewhat in the near term, but every effort must be made to ensure that the U.S. does not become permanently dependent on imported gas as it has on imported oil.

Global natural gas resources also are being depleted. The expected rapid increase in world gas consumption will increase the rate of depletion. If natural gas is used to augment dwindling oil supplies, depletion will accelerate even faster. Even at currently projected rates of consumption, approximately one-half of the world's original endowment of gas will have been burned three or four decades hence.

Risky Diet 2005 concludes that there is cause for concern over global gas supplies in the not very distant future. Depletion of global gas resources could be felt in world markets within two decades, even though production is expected to continue to expand. The current official enthusiasm for imported LNG should be reconsidered and a sustainable energy policy developed. Again, the solution is to become more efficient consumers and to rely instead on alternative energy resources.

The role of coal

In response to limited supplies of natural gas and associated higher gas prices, there are now over 100 new coal-fired power plants proposed to be built in the U.S. Most of these plants would use old-fashioned combustion technology and would release vast quantities of pollution into the atmosphere.

90% of all coal burned in the U.S. is used to generate electricity. The U.S. is already dependent on coal for half its electric generation, and the use of coal has been increasing steadily. The addition of dozens of additional coal burning power plants would accelerate this trend with tragic consequences.

The primary concern is not the adequacy of the resource, as with oil and gas, since coal is plentiful in the U.S. The problem is that conventional coal combustion technologies add billions of tons of carbon dioxide to the atmosphere every year, the greenhouse gas primarily responsible for global warming. Earth can ill afford the additional warming that 100 new coal-burning power plants would create.

Fortunately, a new coal-based electric generation technology has been developed that not only burns coal more efficiently but may have the potential to avoid adding to the global warming problem. This technology is known as integrated gasification combined cycle generation (IGCC). In an IGCC plant, solid coal is converted into a gas, from which impurities can be removed to reduce pollution. In this process, the carbon in the coal is converted into carbon dioxide which can also be removed before the gas is burned to generate electricity.

If the carbon dioxide is able to be "sequestered" and kept out of the atmosphere, an IGCC power plant would contribute little or nothing to the global warming problem. A handful of the 100+ proposed coal burning power plants would use the IGCC technology. Unfortunately, none of the proposed IGCC plants is believed to include carbon dioxide sequestration. The IGCC technology is more expensive than old-fashioned coal combustion, and sequestering the carbon dioxide, if this is indeed feasible, would add additional cost. Nevertheless, the total cost of electricity from an IGCC plant is estimated to be comparable to electricity from modern gas-fired plants at today's gas prices.

The U.S. has not yet agreed to limit global warming, as have other major developed countries, but eventual agreement appears inevitable. *Risky Diet 2005* concludes that new coal-fired power plants should be restricted to those using the IGCC technology.

Global Warming

Since the last edition of *Risky Diet*, the Kyoto Protocol has gone into effect. Signatories to the Protocol, which include all the major developed countries except the U.S. and Australia, pledge to reduce emissions of "greenhouse" gases that are responsible for global warming, primarily carbon dioxide.

Scientific understanding of the causes and consequences of global warming has increased tremendously in the last year. The official scientific bodies of every major country, including the highly regarded U.S. National Academy of Sciences, recently published a joint document confirming that 1) global warming is a real, measurable, and dangerous phenomenon and 2) that it is caused by human activity, primarily by the burning of fossil fuels.

Further studies are urgently needed to understand the details of how rapidly the Earth will warm and what the consequences of global warming will be. However, there now is no serious *scientific* disagreement over the fact that dangerous warming is occurring and that we humans are responsible. There is, of course, *political* disagreement over what, if anything, should be done about it.

Risky Diet 2005, briefly summarizes the ongoing effort to better understand how our planet is responding to the warming, projections for the future, and the role that energy consumption plays. The surface of Earth has already warmed more than one degree Fahrenheit (between 0.6° and 0.7°C) in the last century. Sea levels have risen over an inch in the last decade. Moreover, Earth's temperature responds slowly and will continue to increase another degree *even if no additional greenhouse gases were to be emitted*. Unfortunately, emissions of carbon dioxide are projected to increase 50% in the next 20 years.

Conclusion

This report concludes by pointing out that the most effective responses to both the colossal looming problems of fossil energy resource depletion and global warming are one and the same –

the rate at which fossil fuels are consumed must be reduced by improving efficiency and deploying alternative energy resources.

It is impossible to overstate the urgent need for significant reductions in our reliance on fossil fuels. We are now burning billions of tons of fuel annually, and this rate simply cannot be sustained much longer. Conventional fossil energy resources, especially the oil on which our transportation system depends, are rapidly being depleted. Meanwhile, the carbon dioxide being released by burning all the fossil carbon is literally changing the face of the earth.

Energy technologies exist today to begin to cope with these problems – we need not wait for some future miracle source of energy to be developed. We have the technology to become more efficient. We have the technologies to replace fossil fuels. The Center for Energy Efficiency and Renewable Technologies has patiently labored to promote these technologies for 15 years. But time is running out – immediate action is now required.

As this report points out, the solutions will not be inexpensive. Enormous amounts of capital must be deployed in new ways. Solutions will not be immediate. It will take many years to make the required major changes. But we must begin.

The *Risky Diet* series has had an excellent analytical record understanding the North American natural gas situation. Readers are encouraged to review previous editions and judge for themselves. But the related twin problems of global resource adequacy and global warming have become so urgent that we can no longer limit our consideration to one small piece of the global energy picture.

Risky Diet 2005 is our attempt to examine the global energy scene with the series' usual high standards of scholarship. The data on which we have relied have been documented and come primarily from official government sources. Readers are encouraged to critique our analysis.

We have, however, reached conclusions quite different from those proffered by the U.S. government. We believe the sanguine business-as-usual response is a recipe for imminent disaster. The energy-related problems facing mankind require immediate attention.

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June, 2005.

Chapter 1 Our Energy Future – Risky Diet 2005

Introduction

Every year since 1981, more crude oil has been extracted and burned worldwide than was discovered.[1] For the last two decades known deposits of petroleum have been increasingly depleted every year. Global natural gas resources are less constrained but also are being consumed at an increasingly rapid pace. Consumption of fossil fuels cannot be sustained for long at current rates.

The need to conserve energy resources has been given additional urgency by the recognition of potentially disastrous global warming. Scientists are virtually unanimous that global warming is caused primarily by the combustion of fossil fuels. To reduce the rate of climate change and to slow depletion of the energy resources it is essential to reduce the rate at which fossil fuels are consumed.

Global dependence on fossil fuels is enormous, and the difficulty of reducing this dependence must not be underestimated. Fortunately, technologies exist today which can significantly reduce the need for fossil fuels. In order to do so, however, large amounts of capital must be shifted in new directions. Trillions of dollars will be required worldwide to improve the efficiency with which energy is used and to deploy non-fossil technologies sufficient to significantly reduce the need for fossil fuels.

It is extremely difficult to change the direction in which massive amounts of capital flow. Sectors of the economy that currently have access to capital will resist attempts to direct it elsewhere, and these sectors have enormous political power. Nevertheless, it is important to understand that reducing dependence on fossil fuels is a political problem, not a technical one.

This edition of *Risky Diet* examines the global outlook for all three major fossil fuels – oil, natural gas and coal. Official government projections assume that these fuels will remain abundant and inexpensive. However, based on the most reliable data available, this report finds that depletion of the world's conventional energy resources is already affecting global supplies. The evidence assembled in this report leads to the conclusion that:

> Competition for limited resources has already raised the price of fuel, and this trend is likely to continue.
>
> The optimistic projections of abundant fuel, low prices and increasing consumption appear highly unlikely unrealistic.

Immediate action is required to deal with the impending energy crunch and with rapidly warming global temperatures. It is hoped that the evidence assembled in this report will help provide the impetus needed to begin the monumental task of altering the ways in which the world obtains and uses energy.

Addressing energy resource depletion

Some people believe that resources will continue to grow more or less indefinitely as technology improves and/or more money is invested. Estimates of remaining energy resources are based on currently available technologies, and these estimates are indeed likely to grow over time. In addition, low grade fossil resources now considered uneconomic will be exploited as conventional resources are further depleted and prices rise. However, there is no doubt that the inexpensive conventional energy resources on which the world has come to depend are being consumed faster than they are being discovered. The question is – what will replace them and at what cost?

It is impossible to know what energy resources will be available many years in the future. 50-year projections based on current resource estimates are acknowledged to be much more uncertain than projections for the next few decades. Nevertheless, long range projections based on currently available resources are useful – they tell us what we can expect to happen *unless* energy technology and/or economics change dramatically. The degree to which one expects these projections to change with time depends on the assumptions one wants to make.

This edition of *Risky Diet* makes the assumption that energy resources available for exploitation will increase primarily because prices will increase. Technology will improve, but it will also become more expensive. Accessing oil and gas from fields deep beneath the ocean has become technically feasible, for example, but is substantially more expensive than production from shallow wells. Projections based on current resource estimates therefore tell us what we can expect to happen if prices were to remain more or less as they are today.

This report does not attempt to estimate how high prices will go as resources are depleted. Higher prices tend to increase resource availability, but also tend to depress consumption. The task of estimating the price at which supply and demand will balance in the future is exceedingly imprecise and such estimates are always questionable. Currently the global price of oil is well above the cost of obtaining additional oil supplies, but no one knows where prices will go next. Prices could come down if sufficient capital is invested, but prices could go higher if capital is not invested quickly enough.

The salient feature of our energy system is that enormous amounts of capital are required to expand resources significantly. Even maintaining oil production at current levels would require investments of trillions of dollars over the next two decades.[2] Capital markets require assurance of adequate returns on these investments which in turn require sustained attractive prices.

Projections of resource depletion in this report are made with an important caveat – they represent only the conventional resources on which we currently rely. When these conventional resources are insufficient to meet demand, it is expected that supplies will expand somewhat in response to increasing prices. However, experience indicates that these price increases will be substantial, perhaps high enough to disrupt the global economic system. Those who would dismiss the effects of energy resource depletion do so at considerable risk.

The global energy picture

Resource depletion is the underlying cause of the record high oil prices in recent months. Nevertheless, government agencies forecast that consumption of crude oil will accelerate in the next two decades, markedly increasing the rate of depletion. Further depletion of global crude oil resources inevitably will be reflected in rising oil prices. Official government reports continue to forecast plentiful supplies of oil and low prices for at least two decades, however.[3] *Risky Diet 2005* includes a look at the global oil situation and finds that optimistic official forecasts based on business-as-usual scenarios are highly improbable.

World energy markets received a shock last year as the U.S. price of crude oil spiked to a record of $55 per barrel in late October before falling back into the mid-$40 range by year end. A new record high was reached in the spring of 2005. As the media is fond of pointing out, the high prices were records only when inflation is neglected; the price of oil in constant dollars has been much higher in the past. Nevertheless, as the media *failed* to point out, the recent run-up in oil prices marks an historic turning point in the history of global oil.

High oil prices in the 1970s were due to *political* constraints on oil supplies. Current high prices are due to *resource* constraints. For the first time since its formation in 1960, the Organization of Petroleum Exporting Countries (OPEC) attempted to moderate global oil prices by increasing production but could not do so. OPEC officials now admit that their system of production quotas is irrelevant – there is virtually no spare production capacity left.[4] The era of plentiful and inexpensive oil is over.

Previous editions of CEERT's *Risky Diet* series focused on North American natural gas markets and chronicled the peak and subsequent decline in regional natural gas production. As reported last year, the U.S. is becoming increasingly dependent on gas imported from other continents in the form of liquefied natural gas (LNG), much as it has been dependent on imported oil for over 30 years. With the U.S. competing in global gas and oil markets, a more comprehensive treatment of global energy issues is now required to understand the dynamics that will determine energy prices in the years ahead.

This edition of *Risky Diet* provides an overview of recent trends in the global use of oil, gas, and coal. There is reason to believe that global petroleum supplies will be inadequate to provide the energy that government forecasts would require even with the incentives provided by current prices. Energy prices can be expected to continue to rise in the future, perhaps dramatically. Furthermore, there is absolutely no possibility that the U.S. will become energy self-sufficient in the foreseeable future, despite foolish political promises to the contrary.

Chapter 1 examines the implications of oil consumption at the increasing rates assumed in business-as-usual scenarios for global petroleum resources. There are those who believe oil supplies will increase sufficient to satisfy the business-as-usual scenario with little or no increase in prices. This appears unlikely. Higher prices will be needed to spur investment in exploration and production of conventional resources. Investment in unconventional energy resources such as the Athabasca oil sands or Wyoming oil shale also depends on sustained higher prices. Increasingly rapid depletion of conventional petroleum resources will make it impossible to meet projected consumption without significantly higher prices and massive investment in unconventional resources.

Increased investment will continue to expand supplies for several years, but then depletion of conventional oil resources will limit expansion and supplies will begin decrease. Conventional oil production has not yet reached its peak yet but is likely to do so within a 10-20 year time frame. Consumption must therefore also peak and decline as competition for limited supplies drives up prices.

When the peak in conventional oil consumption will occur depends on the size of remaining resources. There is considerable controversy among experts over how much oil remains available globally to be exploited. Official estimates by the U.S. Geological Survey have been severely criticized and appear to be overly optimistic. But even if the USGS estimates are accurate, the fraction of remaining known oil resources consumed annually in the business-as-usual scenario would increase from its current value of about 2% to 4% by 2025.[5] Extracting enough oil to allow consumption to increase as projected would require the industry to *double* the rate at which known resources are being depleted. Further increasing the rate of depletion would raise the price of petroleum products which would also reduce consumption below projected values. The inherent limitations of petroleum resources will almost certainly become increasingly apparent to global markets and governments within the next two decades. The business-as-usual scenario therefore appears unlikely.

There are three potential options for increasing crude oil production:

1. Extraction from existing oil and gas fields can be increased through higher levels of investment and better technology;
2. New oil and gas fields can be discovered and exploited; and
3. Unconventional sources of oil and gas can be developed.

All three strategies already are being pursued at present, but increases in oil production sufficient to satisfy the business-as-usual projections would require substantial additional amounts of capital investment which will occur only if prices increase markedly.

The International Energy Agency estimates that global investment of about $200 billion per year is needed to increase production sufficiently. Whether this investment will be forthcoming, and whether it will be adequate to satisfy the projected consumption, remains to be seen.

The global price of oil is already higher than the cost of production, indicating that consumers are paying “scarcity rents”. The rapidly expanding economies of India and China now also compete for their share of world supplies and help to drive up prices. Competition for depleting supplies is certain to increase in the coming years as economies and populations expand, further raising prices.

Chapter 2 describes a “bottom-up” analysis of petroleum supplies based on the way production from oil fields changes over time. Production begins slowly when the first wells are drilled, rises quickly, reaches a peak when about half of the ultimate production has occurred, and then begins to decline until the field is abandoned as uneconomic. Oil from any group of oil fields behaves similarly, as does all oil everywhere. Analysis based on oil field production histories was first used by geologist M. King Hubbert to correctly predict the peak in U.S. oil production around 1970 and is widely used to forecast future global oil production.

Using the best estimates of remaining oil resources, the bottom-up analysis yields results similar to those from the top-down approach of Chapter 1. Agreement of the two different analyses provides addition credibility to the conclusion that depletion of conventional oil resources is expected to limit production and consumption within the next two decades or so.

The source of major disagreement between the official optimistic scenario and those who believe oil production and consumption will soon decline is the amount of oil that Saudi Arabia will produce in coming years. It is agreed that Saudi oil production, already the world's largest, must increase dramatically if global consumption is to continue to grow. It is impossible to know with certainty how much oil remains under Arabian sands since reported oil reserves are notoriously unreliable. To satisfy its consumption projections, US Energy Information Administration assumes that Saudi Arabian production will more than double in the next two decades. Other experts scoff at this assumption, believing that Saudi Arabian production is nearing its peak.

Much of the current debate is over the timing of the coming peak and future decline in oil *production*, but consumers should note that there will be a simultaneous decline in oil *consumption. As e*conomists are fond of pointing out, petroleum supplies will *always* equal demand, despite resource depletion. If production decreases, higher prices will decrease consumption by exactly the same amount. As supplies become increasingly limited and prices rise, economics will force consumers to buy less oil.

Even today, oil is effectively rationed by price. Wealthier consumers can afford to buy more oil than poorer consumers. As the price of oil increases, more consumers can be expected to fall into the poor category. Consumers know next to nothing about energy – what they care about is the price and whether they can afford to buy gasoline or to pay the electric and gas bills.

Recent estimates of prices sufficient to reduce demand are very high, more than double current prices.[6] Unless consumption of petroleum is carefully managed by enlightened governmental policies, the result could be runaway prices, market failures, and the potential for armed conflict over remaining supplies. The current war in Iraq may be a dreadful harbinger of things to come.

As documented in earlier editions of the *Risky Diet* report, North American gas production has apparently reached its peak and is beginning to decline, much as North American oil production peaked around 1970. As a result, U.S. consumption is increasingly dependent on imports of LNG which increased 50% in 2004. Chapter 3 of *Risky Diet 2005* continues to document this trend and also provides a look at global natural gas resources. World supplies of natural gas likely are adequate to meet projected consumption for the next two decades. Not long afterward, however, global supplies of natural gas also will encounter depletion problems similar to those facing global oil today.

Coal is the other major source of energy today, supplying about as much energy worldwide as natural gas. The coal industry is fond of pointing out that U.S. coal reserves could sustain 200 years of U.S. consumption at current rates, conveniently ignoring the fact that the rate of consumption is steadily growing. Moreover, U.S. coal reserves are among the largest in the world – *global* reserves can provide much less than 200 years of projected *global* demand. Chapter 4 includes an analysis similar to that used for oil and gas which indicates that global consumption of coal is likely begin to decline around the middle of this century. Moreover, energy provided by all three conventional fuels together – oil, gas and coal – is expected begin to decline within about three decades.

No treatment of global energy consumption would be complete without consideration of its impact on Earth's climate which is discussed in Chapter 5. The major component of all three fossil fuels is carbon which combines with oxygen from the air during combustion. The energy released when carbon combines with oxygen to form carbon dioxide is the energy used to operate vehicles, generate electricity, heat our houses, and so on. Carbon dioxide generated during the combustion process is routinely emitted into the atmosphere. Since the beginning of the industrial revolution, the amount of carbon dioxide in the air has increased about 45%, reaching a level higher than at any time in the last 400,000 years.

Unfortunately, heat that would otherwise escape into space is trapped by increasing carbon dioxide in the atmosphere, thereby warming the Earth's surface – the "greenhouse effect". The burning of fossil fuels is the single largest contributor to the well-documented global warming which is projected by scientists to have major consequences for human society by the end of this century.

The Kyoto Protocol agreement between most developed countries (with the glaring exception of the U.S.) recently went into effect, promising to significantly reduce emissions of carbon dioxide and other greenhouse gases. The task is daunting. As noted earlier, global economies will have difficulty adjusting to the limits on fossil fuel consumption imposed by resource depletion. Attempts to further limit fossil fuel consumption, such as those promised by the Kyoto Protocol, will add to the difficulty. Despite growing understanding of the threat posed by global warming and vows to respond, virtually all the remaining conventional fossil energy resources likely will be burned in this century.

One strategy to limit global warming from fossil fuel consumption is to capture the carbon dioxide generated and "sequester" it permanently so that it never enters the atmosphere. Suggestions have been made to pump carbon dioxide into abandoned coal mines and oil or gas fields. Other schemes involve combining carbon dioxide chemically with other substances to form inert minerals. Simply growing trees and other plants which turn carbon dioxide into vegetative matter like wood might be an effective sequestration strategy. All of these approaches are as yet unproven at the scales required.

Sequestering carbon dioxide underground or as a mineral is technically feasible, although the costs are uncertain. Moreover, capturing carbon dioxide is only practical for large stationary sources like power plants, many of which burn coal. It would be impossible for mobile sources like automobiles and airplanes and infeasible for small sources like houses. The benefits of growing trees to cleanse the air of excess carbon dioxide are disputed, since forests are subject to fires which would re-release the carbon dioxide back into the atmosphere. Even if protected from fire and human destruction, trees eventually die and decay. The benefits of growing trees or other plants are difficult to quantify, but likely will be part of any multi-faceted global warming strategy. The extent to which sequestration can ameliorate global warming is not known.

Any energy strategy sustainable in the long term must necessarily rely on sources other than fossil fuels. Nuclear power plants emit no carbon dioxide during their operation but nuclear waste is highly toxic and storage is problematic. Sustainable energy sources rely on energy from the sun or earth – solar, wind, and geothermal energy. Biomass from plants grown sustainably is renewable and can be burned as fuel with no net increase in atmospheric carbon dioxide.

All these non-fossil energy sources are likely to play a role in the global transition away from fossil fuels. Among the existing energy technologies, however, only solar and wind resources appear to be sufficient to provide the amount of energy to which the world has become accustomed. In the future, new technologies to provide primary sources of energy may become available, such as nuclear fusion. It would be foolish, however, to postpone action until new technology is developed.

It would be prudent for public policy-makers to prepare for decreasing availability of fossil fuels and global warming by increasing reliance on existing non-fossil technologies. U.S. energy policies, such as they are, assume that additional subsidies and relaxation of environmental regulations for U.S. oil, gas and coal producers will provide adequate supplies and allow consumption to continue increasing unabated. Rather than focus almost exclusively on supply-side investments in fossil fuels to increase production, prudent energy policies require substantial investments that reduce demand for energy and replace energy from fossil resources with energy from sustainable, inexhaustible solar, wind and geothermal resources.

A strategy to reduce oil and gas demand is urgently needed as insurance against the very real possibility of global economic catastrophe in which greater numbers of people will be impoverished. Failure to reduce future oil and gas consumption voluntarily incurs a significant risk that price rationing will reduce global demand involuntarily. Currently, a large fraction of the world's population has access to adequate supplies of energy at prices they can afford. As prices rise, fewer people will be able to afford energy sufficient to fulfill basic needs.

As if the threat of expensive energy were not serious enough, global warming makes husbanding our fossil energy resources imperative. Excessive use of fossil energy by previous generations may be excused by a lack of understanding of resource limitations and climate change. We have no such excuses today.

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[1] Williams, "Debate over peak-oil issue boiling over, with major implications for industry, society", *Oil & Gas Journal*, July 14, 2003. Data updated through 2004.
[2] "IEA concerned about capital", Oil & Gas Journal, May 16, 2005. IEA estimates that $16 trillion will be needed for the energy sector by 2030, including investments in electricity infrastructure.
[3] See, for example, World Economic Outlook, International Monetary Fund Report, April 2005, Chapter 4.
[4] "As Oil Demand Surges, Saudis Offer to Boost Output", *Wall Street Journal*, April 7, 2005.

[5] The term “resources” includes both known “reserves” and oil yet to be discovered. Estimates of annual depletion rates depend on the estimate of remaining resources.
[6] “Goldman Sachs: Oil Could Spike to $105”, Reuters, 3/31/05.

Chapter 2 Oil Business as Usual?

Introduction

Official government agencies are remarkably sanguine about future supplies of oil, the lifeblood of modern economies. The US Energy Information Administration (USEIA) forecasts that oil will remain plentiful and inexpensive through 2025. The International Energy Agency (IEA) makes similar projections. The purpose of this chapter is to examine the basis for these outlooks. We conclude that the official projections are unreasonably optimistic, and that resource constraints are likely to raise prices significantly over the next two decades. Oil production, and hence also consumption, are likely to be substantially less than projected.

The business-as-usual scenario

In business-as-usual (BAU) scenarios, the future looks pretty much like the past with no unpleasant surprises. The global economy continues to grow at more or less the same pace as in recent years, and energy requirements also continue to grow. Resources remain plentiful and prices increase slowly if at all. The world today faces a crucial question – "how long will the oil business continue as usual"? Petroleum resources on which the global economy depends are shrinking. As a consequence, prices are volatile and rising. Will oil be plentiful in the future as BAU scenarios assume, or will competition for limited supplies raise prices sharply?

The BAU scenario projection for future global oil production produced by the USEIA computer model is shown in Figure 2-1[1]

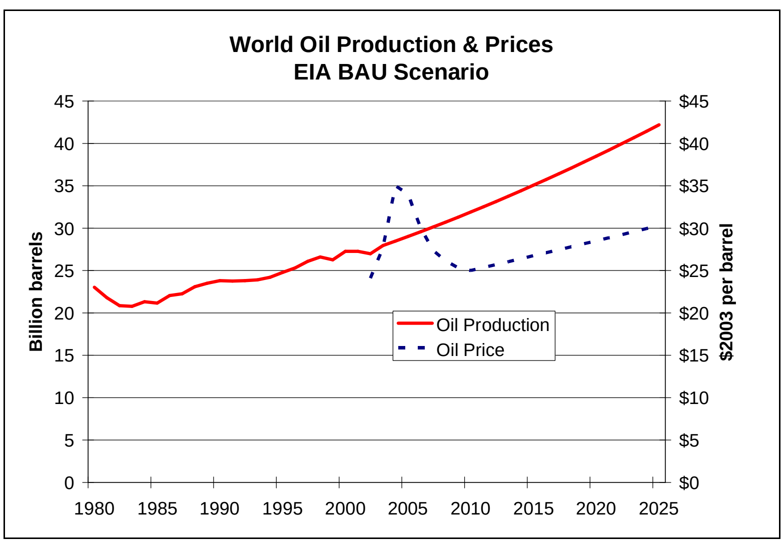

Figure 2-1 World oil production and prices

In the USEIA projection, world crude oil consumption in 2025 is projected to increase by 50% over 2004 levels. During the 22 year period, 769 billion *more* barrels of oil will be burned, nearly as much as all the oil consumed since the discovery of oil in the 1800s. Despite this large increase in consumption, USEIA projects that currently higher oil prices are temporary and will return to earlier low values.

Where will the 769 billion barrels of oil projected by USEIA to be burned between 2004 and 2025 come from?

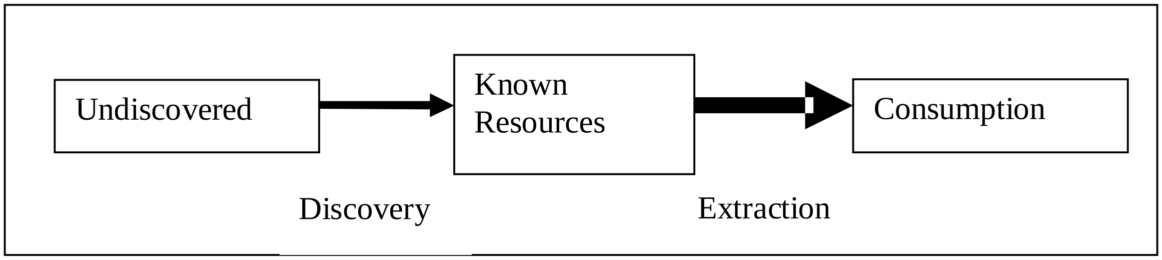

Figure 2-2 Schematic diagram of oil development

Oil is extracted from fields that have been discovered and explored. The amount of known resources increases when new fields are discovered and decreases as oil is extracted, as the diagram above indicates. Limited discoveries of conventional oil will made in the next two decades, and some of this oil will enter the supply chain. But virtually all of the oil required by the business-as-usual scenario will come from existing known resources.

Resources also can increase over time through “reserve growth” as improving extraction technologies allow for higher percentages of oil to be extracted before fields are abandoned. In addition, sources of unconventional oil will be developed, although amounts are expected to be relatively small in the near term.

Known petroleum resources

The U.S. Geological Survey published a study in 2000 estimating the world’s conventional petroleum resources remaining in 1996.[2] Conventional oil was divided into three groups: existing reserves, reserve growth, and oil yet to be discovered. USGS also provided estimates of the uncertainty in their values. They estimated greater than a 95% probability that the actual values are larger than their low estimates and less than a 5% probability that the actual values are larger than their high estimates.

The USGS estimates, as updated through 2003,[3] are shown in Table 2-1.

USGS Assessment 2000 (updated to 1/1/04) Crude Oil, including Natural Gas Liquids – Billion Barrels			
Probability	>95%	Mean	<5%
Undiscovered conventional	364	808	1458
Reserve growth (conventional)	198	647	1095
Remaining Reserves	959	959	959
Cumulative production	931	931	931
Total	**2452**	**3345**	**4443**

Table 2-1 USGS petroleum resource estimates

Unfortunately, there is no international consensus on what oil should be counted as "reserves" as opposed to oil in known fields that should be counted as available for future "reserve growth". Data from many major producing countries for these individual categories is unreliable; even supposedly standardized reporting is controversial as Shell Oil Company shareholders learned last year.[4] Because the boundary between these categories is murky, the two will be lumped together for the purposes of this report and referred to as "known resources".

Furthermore, the USGS estimates are hotly contested by independent experts.[5] They argue convincingly that even the mean estimate is too high, based on their own studies which produced estimates similar to the USGS low values. The arguments will not be repeated here; for the purposes of this report, the "actual" value for conventional oil resources is assumed to lie somewhere between the USGS low value and a higher value equal to the USGS mean value, as shown in Table 2-2.[6]

Conventional Crude Oil Resources Remaining as of 1/1/04 (Billion barrels)		
Category	Low estimate	High estimate
Undiscovered	364	808
Known resources (reserves + reserve growth)	1157	1606
Total yet to be produced (summation)	**1521**	**2416**

Table 2-2 Remaining conventional crude oil resources

Future oil discoveries

An assessment of the BAU scenario requires an estimate of how quickly the remaining undiscovered oil will be located and added to known resources. The International Energy Agency has published a chart of historical oil discoveries in its World Energy Outlook 2004 shown here as Figure 2-3:

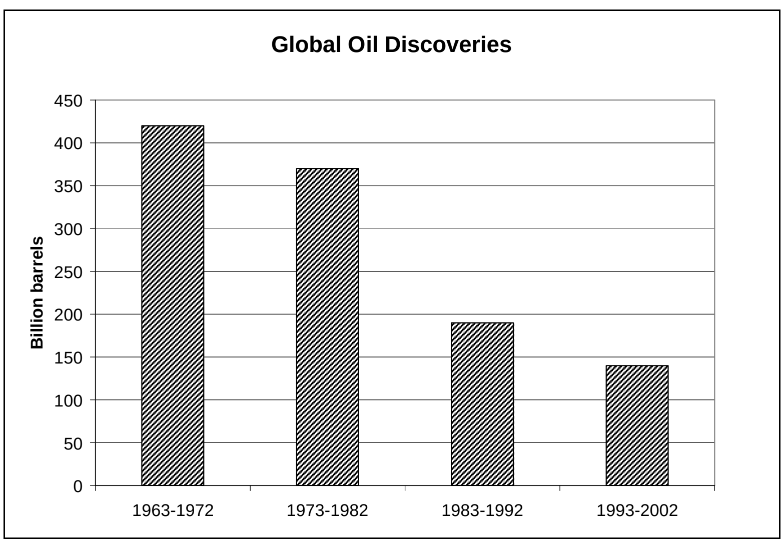

Figure 2-3 Global oil discoveries

Discoveries have been decreasing rapidly over the last 40 years as new prospects become scarcer. If discoveries continue to decrease, about 130 Bbbl of new oil would be discovered by 2025.[7]

The average rate of new discoveries in the decade 1993-2002 was about 14 Bbbl annually. One might optimistically assume that the dramatic decline illustrated in Figure 2-3 will cease, and discoveries will continue at the 1993-2002 rate of 14 Bbbl/yr. Under this assumption, about 320 Bbbl would be found by 2025.

The finding rate of 14 Bbbl per year in the last decade represents about 1 – 2% of the undiscovered oil estimated by USGS in 1996. For the purposes of assessing the BAU, we assume that 2% of remaining undiscovered oil will be found every year. Using the estimates of currently undiscovered resources from Table 2-2 above, a 2% finding rate would result in 130 to 290 Bbbl *discovered* and added to known resources by 2025. However, not all this oil will be *produced* during the forecast period.

Implications of USEIA scenario

The 769 Bbbl that USEIA projects that will be burned between 2004 and 2025 must come from resources known in 2004 plus those to be taken from the "undiscovered" and added to the "known" category by discoveries during the period. Resources that can be exploited during the period are therefore estimated as between about 1290 and 1900 Bbbl as shown in Table 2-3:

Conventional Oil Resources Available 2004-2025 (Bbbl)		
Category	Low estimate	High estimate
Discovered 2004-2025	130	290
Known 1/1/04	1157	1606
Total (summation)	**1287**	**1896**

Table 2-3 Conventional Oil Resources 2004-2025

Note that these estimates include *all* global conventional oil resources expected to accessible by 2025, including new discoveries made during that time and *all* of the potential reserve growth estimated by USGS. The 769 Bbbl projected to be consumed in the BAU scenario is 60% of the lower value and 41% of the higher value. In other words, the BAU scenario assumes that approximately one-half of all remaining accessible conventional oil resources will be burned in the next 22 years. Figure 2-4 illustrates the decrease in oil resources over time as projected in the BAU.[8]

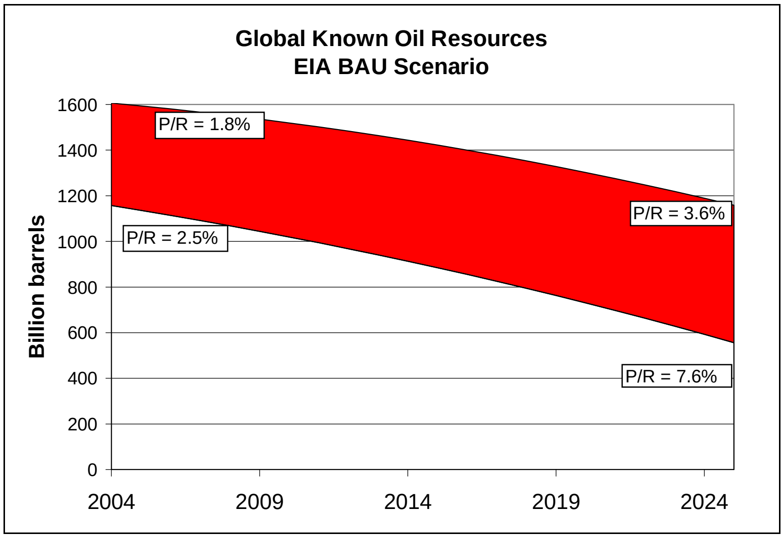

Figure 2-4 Impact of USEIA BAU scenario on world oil resources

In Figure 2-4, known resources begin at the values given in Table 2-3 and then decline as more oil is extracted, despite being augmented by new discoveries. Known resources continue to decline because the rate of discovery is less than the projected rate of extraction. The width of the band represents the uncertainty between the low and high resource estimates shown in Table 2-3 as projected into the future by the BAU scenario.

Also shown in Figure 2-4 are the ratios of production to remaining known resources for both estimates at the beginning and end of the period.[9] Since the BAU scenario assumes extraction will increase while resources are declining, the oil industry must extract an *increasing* fraction of the remaining resources each year. In the lower resource case, a whopping 7.6% of the remaining resources must be extracted annually by 2025 according to the BAU scenario. Even in the higher resource case, 3.6% must be extracted annually by 2025, double the current rate. While not physically impossible, it is highly implausible that rapidly increasing fractions of remaining resources can be extracted each year without equally rapidly increasing prices.

Even if extraction were to follow the BAU scenario through 2025, it cannot be sustained indefinitely, as we see by extrapolating Figure 2-4 out in time.

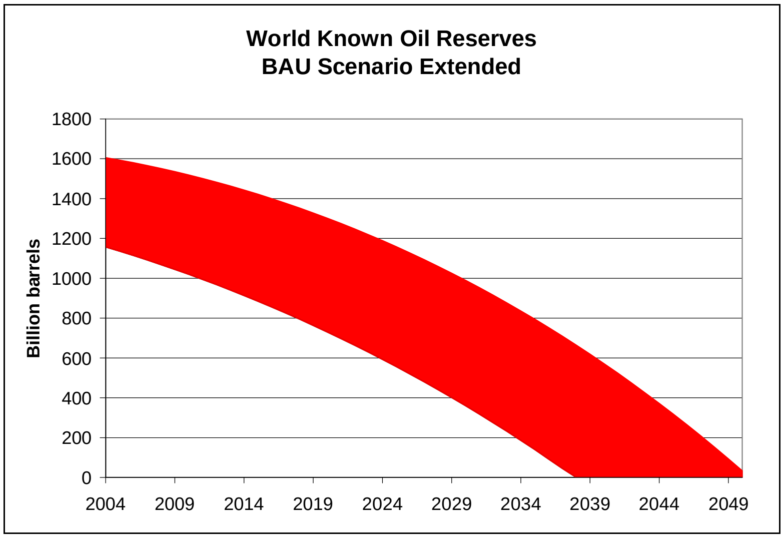

Figure 2-5 Resource exhaustion in hypothetical continuation of BAU

Ever increasing fractions of remaining resources would be required to sustain increasing consumption until sometime between 2038 and 2050 all the conventional resources would be gone. This result is impossible in the real world. We conclude that while the fraction of resources that are extracted may increase in some years and in some countries, as in Saudi Arabia in 2004, the accelerating depletion of oil resources projected by the BAU cannot be sustained for long.

Alternative scenarios

Scenarios in which the rate of oil extraction is a *constant* fraction of the remaining resources could be sustained indefinitely. Current extraction rates are between 1.8% and 2.5% of known resources, depending on which resource estimate is used. Holding these rates constant produces the two scenarios shown in Figure 2-6, again assuming that undiscovered oil is found at a rate of 2% per year.

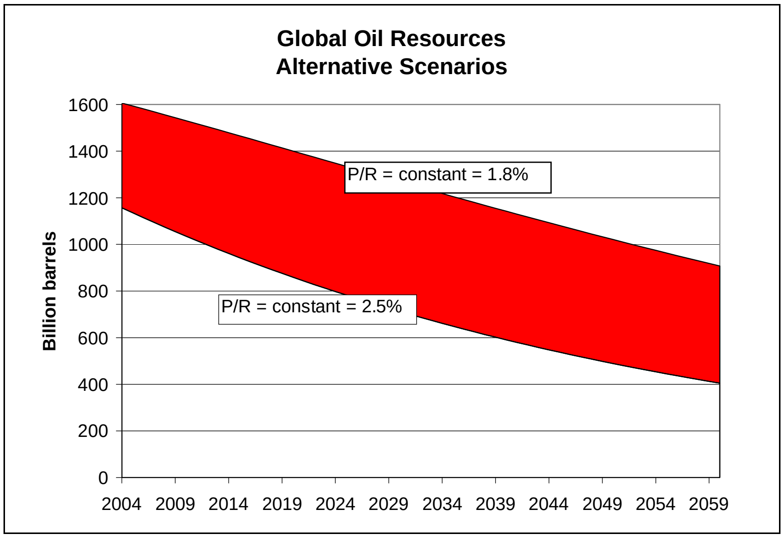

Figure 2-6 Sustainable scenarios in which known resources are depleted at constant rates

In these sustainable depletion scenarios, consumption beings to decrease immediately and continues to decrease as resources are depleted. In any year, production is a fixed percentage of known resources augmented by discoveries. Production in the gradual depletion scenarios is significantly less than in the BAU scenario as shown below in Figure 2-7:

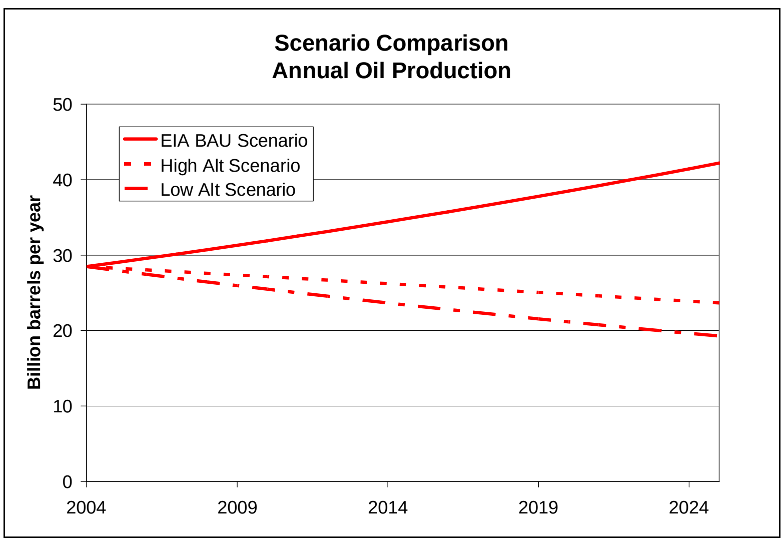

Figure 2-7 Comparison of BAU and sustainable scenarios

Finding "new"oil

Cumulative production in the sustainable scenarios is less than projected in the BAU scenario by 195 to 250 Bbbl. In other words, if production is to follow the BAU projection without leading to disastrous results, approximately 225 Bbbl of "new" oil must be obtained by 2025. There are three options for obtaining new oil:

1. Known resources may be increased if reserve growth is more than assumed by USGS due to better technology and higher levels of investment[10];

2. More undiscovered oil may exist and/or undiscovered oil may be found more quickly than assumed in the scenarios discussed above; and

3. Unconventional sources of oil may be developed.

Option #1 – Increased recovery from existing fields

The first option for obtaining additional oil that is often cited in support of the BAU scenario is that improving technology will significantly improve oil recovery from existing fields beyond the "reserve growth" assumed by USGS and thereby increase known resources.[11]

When a new oil field goes into production, drillers target the more accessible oil first. As the field matures, more sophisticated drilling techniques are required to access smaller, more difficult targets.[12] Pressurizing the field with water, natural gas or carbon dioxide may improve flows. Toward the end of a field's useful life, production is sometimes enhanced by injecting steam or solvents into the field to assist the remaining oil flowing into the well.

But sooner or later, the time, energy and money required to remove additional oil becomes more than the oil is worth and production is halted. At this point, there is still a substantial amount of oil left in the field; it is simply uneconomical to try and remove the remainder. Estimates of reserve growth would increase if less oil were left behind when a field is abandoned, and new technology may make this possible. Higher oil prices would make it economically feasible to maintain production longer, thereby also increasing the amount recoverable.

Option #2 – Discovery and exploitation of new fields

Oil exploration activities, especially in arctic regions, will undoubtedly discover new oil fields, and increased investment in exploration will find them more quickly. New resources in the Caspian Sea region are expected to be found as production there increases. Oil exploration may begin in the controversial Arctic National Wildlife Refuge in northern Alaska, although the results are uncertain. Siberia is said to be underexplored. How much accessible global oil remains to be discovered is a topic of extensive debate among professional geologists. This report agrees with other analysts that the high USGS value is unrealistically high, and the USGS low and mean values have been used here as plausible estimates. Much higher prices would allow more thorough exploration of new and difficult territories and may increase the value toward the USGS high estimate.

An increase in the rate at which "undiscovered" oil becomes "known resources", perhaps through better technology and/or higher prices, would increase the amount in the latter category. However, this strategy does not increase the *total* amount of oil; it merely allows the total resource to be depleted more quickly. The amount discovered reduces the amount of undiscovered oil that remains available to be found later by the same amount.

Option #3 – Unconventional oil resources

As discussed above, increasing production from existing fields and discovering more new oil will make additional supplies of conventional oil available. The third option is to expand the use of unconventional oil resources such as oil sands and oil shales.[13] The amount of technically recoverable oil from these resources has been estimated to be in excess of 1,000 Bbbl,[14] so that development of only a fraction in the next two decades would be sufficient to satisfy the BAU scenario without straining reserves of conventional oil. Less than 1 Bbbl were produced in 2004 from unconventional resources, however.[15]

The largest unconventional resources now in production are the Athabasca "tar sands" in Alberta, Canada. The resource consists of shallow deposits of "bitumen" or thick "tar" mixed with sand which can be mined with shovels and trucks. The material extracted requires substantial treatment to produce synthetic crude from which petroleum products such as gasoline and diesel can be made. "Syncrude" production at Athabasca is now about one million barrels per day (0.37 Bbbl per year) and is expected to double (to 0.73 Bbbl/yr) by 2010. According to Athabasca oil sands developers, production capacity could be increased fivefold (to 1.83 Bbbl/yr) in 10 years. Total recoverable oil from the Athabasca sands, the largest such deposit in Canada, is estimated at 177 Bbbl using current technology.[16]

Prospects for sufficient "new" oil

By combining sufficient activity in the three options for obtaining new oil supplies discussed above, it is at least theoretically possible that consumption projected in the USEIA BAU scenario could be met. However, it would be dangerous simply to assume that this will be the case, since economic chaos could result if the new oil does not materialize. Each option requires more careful examination.

Option #1 considerations – expanding known resources

The USGS estimates of potential reserve growth shown in Table 2-1 have been severely criticized by other experts.[17] They argue that historical reserve growth from onshore development in the US on which USGS based its global estimates is not relevant to offshore and international fields. In the large fields discovered decades ago, such as Prudhoe Bay in Alaska, resources were initially underestimated and appeared to grow as better information became available. Today, however, seismic exploratory technology is highly developed and new fields are much smaller, so that less underestimation is expected. This report agrees with the USGS critics to the extent that the high USGS estimate will be ignored as too unlikely - our analysis uses only the USGS low and mean estimates as the basis for likely scenarios.

Nevertheless, higher prices will enable more oil to be extracted from known resources than can be obtained through techniques employed by the industry today. Increased capital investment will be required to develop and deploy new technology that could extract a higher percentage of oil. This requires higher prices to provide an acceptable return on capital, compensate for risks involved, and justify increasing production budgets.

Technology developed in recent years now makes it possible to access offshore oil fields in water more than a mile deep, but costs are much higher than for production in shallow water or on land. Moreover, access to new fields made possible by expensive new technology does not necessarily translate into higher recovery rates, since maintaining expensive equipment in place longer operating increases costs. Rather than squeezing a few more barrels of oil from a nearly exhausted field by keeping expensive equipment in place longer, there is economic pressure to move on unless the value of oil has increased.

Successful development of new technology and the investment of additional billions of dollars required to deploy it will occur gradually over a period of many years. Even if such investment is forthcoming and more oil can be extracted from existing fields, it would not increase oil supplies immediately.[18]

There is insufficient data from which a quantitative relationship between higher prices, increased capital requirements and expansion of recoverable resources can be derived, but the qualitative relationship is clear. We conclude that further increases in oil prices will be required if known resources are to increase significantly. Moreover, unless prices increase substantially in the next few years, little additional oil will be available from enhanced recovery technology before 2025.

Option #2 considerations – undiscovered oil

There is not an unlimited amount of oil underground waiting to be exploited. The USGS estimates of undiscovered oil may be incorrect, but the value, whatever it is, is finite. The world has been quite thoroughly studied by petroleum geologists using sophisticated seismic imaging techniques. Despite these efforts, no new "elephant" oil fields have been discovered in recent decades, as Figure 2-3 indicates.

Unexplored potential oil producing areas remain unexplored for good reason. Exploration efforts have avoided these regions because they are mostly remote, difficult, expensive, and thought to contain relatively small amounts of oil. Technical studies of oil field size distributions provide a sound basis to expect that the average size of newly discovered oil fields will continue to decrease over time.[19] Nevertheless, increasing exploration budgets would increase the rate at which new oil resources are discovered and developed would increase reserves in the near term.

It must be remembered, however, that merely decreasing the amount of oil left to be discovered does not *create* any more oil. If increased exploration activities succeed in finding more oil than expected in the next two decades, that much less oil remains to be found in later years.

There also are limits to how quickly discoveries can occur. The Arctic National Wildlife Refuge (ANWR) is an example. USGS now estimates that 10.4 Bbbl eventually may be recovered from the ANWR area if Congress allows exploration and development to proceed.[20] However, little of this amount is expected to be available in the next two decades, even if industry is given the green light to proceed tomorrow. Seismic studies in this challenging environment would be required, potential targets identified, investment decisions made, and roads, pipelines and equipment installed before drilling could even begin. The challenges of finding and producing oil from Earth's last undiscovered fields ensure that it will take many years to bring this oil to market.

Based on declining historical discovery rates shown in Figure 2-3 and the relative paucity of remaining exploration targets, it appears highly unlikely that discovery rates will increase sufficiently to provide the additional oil required in the BAU scenario, even if the price of oil increases substantially. Moreover, policies serving only to hasten the finding of as yet undiscovered oil increase supplies only marginally in the near term and decrease oil available for the future.

Option #3 considerations – unconventional oil resources

Substantial amounts of capital are required to expand production from unconventional resources like oil sands and shales. Energy and operating costs are also high. Over $20 billion dollars ($US) of investment was required to reach existing levels of syncrude production from the Athabasca oil sands, currently about 1 million barrels per day. Projects costing another $26 billion are forecast to be completed by 2013 which will double production.[21]

Nevertheless, interest in unconventional oil resources is growing as the realities of the global oil future are becoming better understood. For example, Chinese oil companies have recently expressed an interest in Athabasca oil sands projects and a pipeline from Alberta to British Columbia in order to export syncrude.[22]

Based on available data and using the Athabasca tar sands as a proxy for unconventional oil resources, we estimate conservatively that the capital investment required to develop unconventional oil projects with initial production of 1 billion barrels of syncrude per year is in the neighborhood of $US50 billion. Assuming the same depletion rate as for conventional resources and ignoring the time required to bring a project on line, such investment would yield about 200 Bbbl of new oil between 2003 and 2025. In actual practice, there often is a delay of up to 8 years before projects can begin production, which would decrease the potential amount available in the near term.

In addition to large capital requirements, a potentially more serious problem is that oil production from unconventional resources requires substantial inputs of energy. The *net* amount of energy recovered from unconventional petroleum resources is less than from conventional.

As with the other options, we conclude that higher prices will be required before significant investment in unconventional oil resources occurs and production becomes a major part of the world’s oil supplies.

Outlook for “new” oil by 2025

Option #1 – reserve growth. Reserve growth greater than estimated by USGS is unlikely to occur before 2025 in the.

Option #2 – rapid discovery. Remaining oil yet to be discovered is not sufficient to provide significant additional supplies, even if higher prices provide incentives to increase discovery rates markedly.

Option #3 – unconventional oil. Unconventional oil is unlikely to contribute more than marginally to supplies in the absence of sustained higher prices sufficient to significantly increase investment.

Conclusion of oil business as usual

Unless new sources of oil are obtained, oil production as envisioned in the USEIA BAU scenario will require doubling the rate at which oil is withdrawn from known resources.

Increasing the rate of withdrawal of known resources can put additional supplies in the market for a few years, as it did in 2004, but cannot be sustained. We conclude that sources of new oil will be required.

However, new oil obtained merely by accelerating discovery of as yet undiscovered resources adds little to supplies and is not a viable long term strategy since it merely robs future generations to fuel the present. Meaningful amounts of new oil can only be obtained by decreasing the amount left underground when oil fields are abandoned and by building the infrastructure required to develop unconventional resources. Both of these strategies will require significantly higher prices in order to attract the necessary capital.

We conclude that production will be less than projected by USEIA and that competition for limited supplies will raise prices substantially in the next two decades.[23] The era of plentiful and inexpensive oil appears to be coming to an end.

Oil business as unusual

The computer model used by USEIA to develop the BAU scenario does not consider resource limitations. It assumes that supplies are always plentiful, that sellers compete for customers in the marketplace, and that oil prices are determined by the cost of producing marginal supplies.

The price of oil from Athabasca oil sands is currently the most expensive now in production, estimated to be about $30 per barrel. Yet the mere fear of shortages in the U.S. drove prices to $55/bbl in October, 2004, and prices remain above $40/bbl today. The price of natural gas in the U.S. is perhaps twice the marginal cost of production. Electricity prices soared to 10 times the cost of production in the infamous California electricity market fiasco. The fundamental USEIA assumption, that market prices are determined by the marginal cost of supply, clearly is not always valid.

Yet as Figure 2-1illustrates, EIA continues to believe that current higher oil prices are temporary and prices will soon drop back down. There is no evidence to support the USEIA low price projection. Such a “buyers’ market” is unlikely to exist during the next two decades. A “sellers’ market” has developed, as current prices indicate. We find it likely that this sellers’ market will persist and force prices considerably higher.

When oil supplies are limited, as our analysis indicates they will be over the next two decades, competition for these limited supplies can drive the market price of oil to extreme values above the cost of production. If market forces are allowed to work, higher prices will reduce consumption below the USEIA projection and increase production somewhat. It is impossible to predict the future price at which limited consumption will equal limited production,[24] but this price is certainly much higher than prices today.

The projected shortfall in oil production could result in prices double today’s prices or higher,[25] and standard computer models are useless in such extreme situations. Energy consumption is perceived as a “necessity” and responds very slowly to prices. Prices high enough to decrease consumption to match declining production will be extremely high indeed. We should expect that oil will effectively rationed be by price in order for supply and demand to balance. The number of people unable to afford adequate supplies of energy will grow.

It is distinctly possible that the economic impact of likely high oil prices will cause global economic recession. All of the recessions experienced in the last three decades have been preceded by higher oil prices. Yet even recession and higher prices may not decrease demand for petroleum products much. During the previous major oil crisis in the early 1980s, prices reached $80/bbl in today's dollars but global oil consumption fell only from 63 million barrels per day in 1979 to 53 mmb/d in 1983, a drop of only 16%. During that crisis, supplies were limited by political forces in the Middle East which were eventually resolved. The coming crisis will be caused by physical limitations of global oil resources, a much more difficult problem to address.

Oil markets could fail

The U.S., European countries and Japan rely on global oil markets to allocate oil to consumers on the basis of price. If global oil production should go into a period of decline and prices rise dramatically, these markets could become dysfunctional. When producers can *increase* revenue by selling *less* oil and letting the price rise, it is in their economic interest to do so, and they can be expected to do so. Markets fail in such situations.

Some countries appear to be anticipating this eventuality. The highly publicized takeover of Yukos, a private oil company, by the Russian government is clearly a political move to maintain government control over Russian oil. Oil resources in all of the OPEC countries are under government control. Control of oil in China, which recently surpassed Japan as the world's second largest oil consuming country, remains under the control of the government. Rather than rely exclusively on oil markets, the Chinese are signing long term contracts with producing countries and taking ownership or partnership positions in projects around the world. If oil markets collapse, the Chinese may be in a better position than the U.S..

In the worst case scenario, supply limitations would cause oil prices to skyrocket, markets and economies to collapse, and consuming countries to resort to military force in attempts to acquire oil. The military occupation of Iraq by the U.S. may be a precursor of future widespread conflict over oil resources.

We conclude that the rosy USEIA BAU scenario is improbable and that even the worse case scenario is possible. Efforts to meaningfully increase supplies by better utilizing both conventional and unconventional resources may increase production somewhat and delay global crises by a few years, but significantly higher oil prices appear inevitable within the next decade or so.

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[1] Data used in this report are from the U.S. Energy Information Administration unless otherwise noted. Annual BAU projected consumption figures are interpolated from five year projections in USEIA's International Energy Outlook 2004, tables A4 and A5.
[2] U.S. Geological Survey World Petroleum Assessment 2000- Description and Results.
[3] USGS Assessment 2000 estimates as of 1/1/96 have been updated to account for production through 1/1/03. Updating is difficult due to different reporting methodologies by various international organizations. The estimates used here are believed to be sufficiently accurate for purposes of this discussion.
[4] Shell reduced its estimated reserves sharply downward in 2004.
[5] See, for example, Kjell Aleklett, "IEA accepts Peak Oil – An analysis of Chapter 3 of the World Energy Outlook 2004", Association for the Study of Peak Oil&Gas. Available at www.peakoil.net.

[6] An even higher value would be obtained by using the USGS 5% estimate. This value would increase the estimated time at which oil production peaks by several years but does not change the qualitative conclusions.
[7] Aleklett.
[8] Resource depletion projections in this report are made with the caveat discussed in Chapter 1. They represent conventional resources expected to be available at approximately current prices. This report does not attempt to estimate how prices will behave in the future and how resources may expand as a result of higher prices.
[9] Note that R refers here to total known resources, including oil to be discovered and additions to reserves. P/R ratios cited in the literature customarily refer production divided only by "proved reserves".
[10] Note, however, that known resources includes *all* the potential reserve growth estimated by USGS, even though some of this growth is expected to occur after 2025.
[11] Oil reservoirs are not completely exhausted even when production efforts are abandoned as uneconomical due to depletion. Typically, only about 50% of the original oil is recovered. Higher levels of investment may increase this fraction, thereby increasing "reserve growth" beyond USGS estimates.
[12] See, for example, "Petroleum", Encyclopedia Britannica.
[13] See, for example, USGS, "Heavy Oil and Natural Bitumen – Strategic Petroleum Resources", Fact Sheet 70-03, August 2003.
[14] Ibid.
[15] Most production from unconventional oil comes from Canadian oil sands with a lesser amount from Venezuela. See Athabasca Regional Issues Working Group Fact Sheet, "Canada's Oil Sands", June 2004. Available at www.oilsands.cc.
[16] Ibid.
[17] See, for example, Jean Laherrere, "Forecast of oil and gas supply to 2050", Proceedings of Petrotech 2003, Hydrocarbons Resources. Available at www.hubbertpeak.com/laherrere/Petrotech090103.pdf.
[18] It should be noted that even the current high oil prices have not significantly increased corporate budgets for exploration and technical development.
See, for example, Marilyn Radler, "Industry spending to rise but at lower rate in 2005", Oil&Gas Journal Online, April 4, 2005.
[19] Laherrere.
[20] USGS, "Oil & Gas Assessment of Central North Slope, Alaska", May 11, 2005.
[21] Athabasca Regional Issues Working Group Fact Sheet, "Canada's Oil Sands", June 2004. The $25 billion figure may be underestimated. The Northern Lights oilsands project is expected to cost $4.5 billion and produce 100,000 bbl of syncrude per day.
[22] Editors, "Enbridge, PetroChina to cooperate on oil line," Oil&Gas Journal, April 18, 2005.
[23]The increase in prices will attract additional capital and reduce demand. These "feedback" mechanisms will decrease the shortfall. The price of oil is a determined by a complex relationship of supply and demand factors as well as market dynamics and cannot be accurately predicted. Historical relationships are unlikely to be reliable guides for the future.
[24] Oil production and consumption are always very nearly equal since little oil is stored after being extracted.
[25] A widely reported analysis by the Goldman Sachs Group released 3/30/05 indicates that oil prices above $100/bbl are possible in the near future.

Chapter 3 Resource depletion and implications for oil supplies

Introduction

In Chapter 2, we examined three strategies for increasing oil supplies to see if any reasonable combination of these strategies could result in supplies adequate to meet the BAU projections made by USEIA. We concluded that the BAU expectations for global oil production were unlikely to be met and that dramatic increases in oil prices are likely within the next two decades. In this chapter we use a different approach to examine the issue and arrive at the same conclusion.

Oil production profiles

A rule of thumb used by petroleum geologists is that when cumulative production from an oil field reaches approximately one-half of its ultimate total, the rate of production begins to decline. For example, if an oil field will produce a total of 2 Bbbl over its productive life, the rate of production is expected to begin to decline when about 1 Bbbl has been produced. The same rule of thumb can be used for any collection of oil fields, include all those in the United States and all those in the world.

In 1956, a petroleum geologist working for Shell Oil Co. named F. King Hubbert risked ridicule by relying on this rule of thumb and his estimates of ultimate U.S. oil production to predict that U.S. production would begin to decline in the early 1970s.[1] He and his theory were vindicated when U.S. oil production did in fact begin to decline as forecast.

Hubbert also predicted that global conventional oil production would begin to decline around the turn of the century. This has not yet occurred, but many observers believe that the underlying theory is correct and that by using more recent resource data the inevitable peak in oil production can be correctly estimated. There has been a considerable amount of theoretical work done by geologists since Hubbert that provide a sound basis for such projections, and sophisticated analyses of oil and gas resource depletion based on his work appear in the mainstream industry trade press.[2] The theory is not without its detractors, however.

Hubbert's analysis requires an estimate of how much oil will ultimately be produced. The study cited in Chapter 2 performed by USGS and published in World Petroleum Assessment 2000 was undertaken explicitly to provide these estimates. USGS reported an average estimate of "ultimate oil" that was about 50% higher than that used by Hubbert, an estimate that has been challenged.[3] The inherent difficulty of knowing how much oil will be produced in the future is indeed a problem for the theory.

In addition to an estimate for ultimate production, Hubbert's theory requires an assumption that production will follow a predictable pattern over time, a generalized graph of which is shown in Figure 3-1.

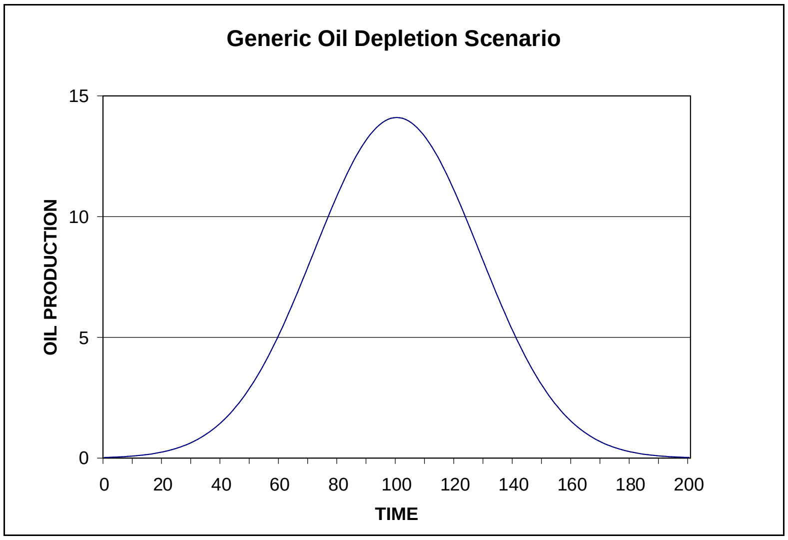

Figure 3-1 Generic symmetric depletion scenario

This curve illustrates qualitatively the expected production over the life of an oil field. Production begins slowly with the first tentative wells then increases as the field is subsequently explored and more wells are drilled. In this particular scenario, production reaches its peak when half of the oil that will eventually be produced has been extracted. Production then declines as oil becomes more difficult to find and extract, falling gradually until production is so small that the field is abandoned.

The depletion curve used by Hubbert has a particular mathematical shape known as a "Gaussian" curve. There are other symmetrical curves that could be used, however. Furthermore, there is no *a priori* reason to believe that the peak will occur exactly in the middle; the curve could be skewed one way or the other. Reliance on symmetric depletion shapes is another weakness of the theory.

Nevertheless, the qualitative features of any depletion scenario must be similar – a gradual increase reaching a peak and then a gradual decline. Simple spreadsheets allow one to test other curves to see which best fits the available data and to test various assumptions about when the peak occurs, how rapid the decline may be, total oil that will be produced, and so forth. As we shall see, the major features are relatively insensitive to the shape of the depletion curve, which is why Hubbert's theory works as well as it does.

Simple Hubbert-style analysis

As discussed in Chapter 2, the resource estimate used by the Hubbert school is approximately the same as the low USGS estimate. They argue that the USGS mean estimate is overly inflated and that the high estimate is altogether unreasonable. This report assumes that the likely "real" value lies somewhere between the USGS low and mean estimates. As in Chapter 2, we will refer to the USGS mean estimate as the "high" estimate. We have also combined the categories of "reserve growth" and "remaining reserves" into "known resources". Table 3-1 provides the same estimates as in Chapter 2, with production through 2003 and total ultimate resources added.[4]

Crude Oil Remaining as of 1/1/04 (Billion barrels)		
	Low estimate	High estimate
A. Undiscovered, conventional	364	808
B. Known resources, conventional	1157	1606
C. Production through 1/1/04	931	931
D. Ultimate oil resources (A+B+C)	2452	3345
E. Oil yet to be produced (A+B)=(D-C)	1521	2416

Table 3-1 Crude oil resources remaining 1/1/04

Using the USGS estimates and beginning where the historical record ends, we can draw two Gaussian curves which match recent production history reasonably well and project 1521 and 2416 Bbbl of oil produced in the future, as shown in Figure 3-2:

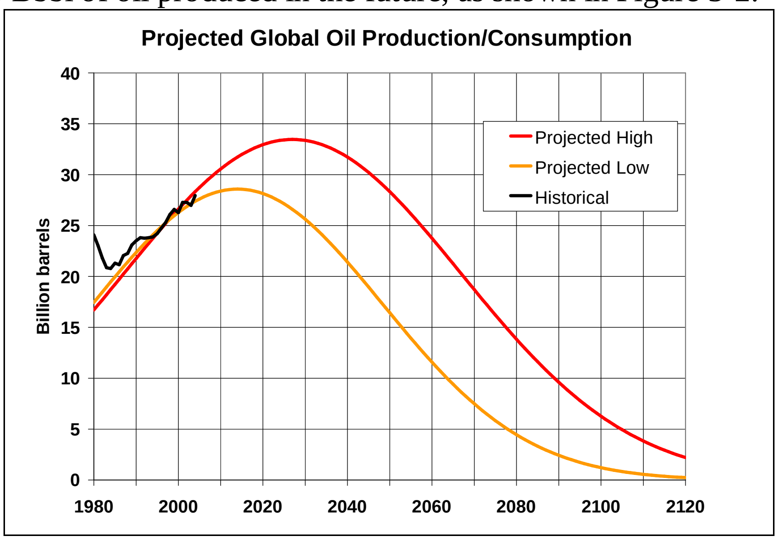

Figure 3-2 Alternative production scenarios

According to these projections, the peak in conventional oil production would occur in 2014 or 2027, depending on the resource estimate, and decline thereafter. Of immediate interest is what happens in the next two decades. Figure 3-3 shows the same chart through 2025, with the EIA BAU projection added.

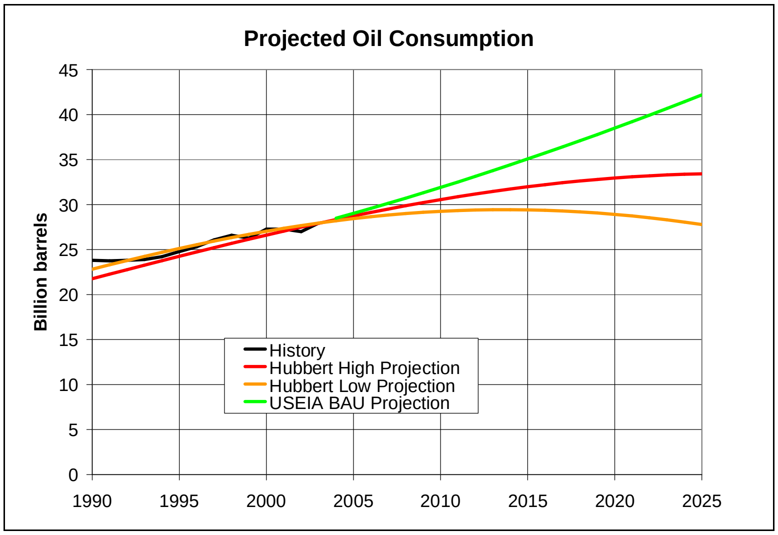

Figure 3-3 Production scenarios through 2025 including the BAU scenario

As Figure 3-3 illustrates, Hubbert-style projections based on the USGS estimates of remaining conventional oil resources indicates in both cases that projected production would be inadequate to meet the demands of the USEIA BAU projection. In these scenarios, the deficits that would have to be made up by "new" oil resources are 76 and 133 Bbbl respectively.

In the two alternative sustainable depletion scenarios considered in Chapter 2, production began to decline immediately. In the Hubbert scenarios shown above, production continues to increase somewhat for a few years before beginning to decline. The implications of both sets of scenarios are strikingly similar, however – oil production is insufficient to meet the USEIA BAU scenario as physical limitations in conventional oil resources limit production within the next two decades.

Addressing shortcomings in Hubbert-style analyses

The symmetrical production curves used above may not accurately reflect how production actually will behave. Higher prices may cause production to increase in the *near term*, as they did in 2004. However, unless *ultimate* production increases, a temporary increase in the near future will result in a more rapid decrease later, as shown in Figure 3-4.

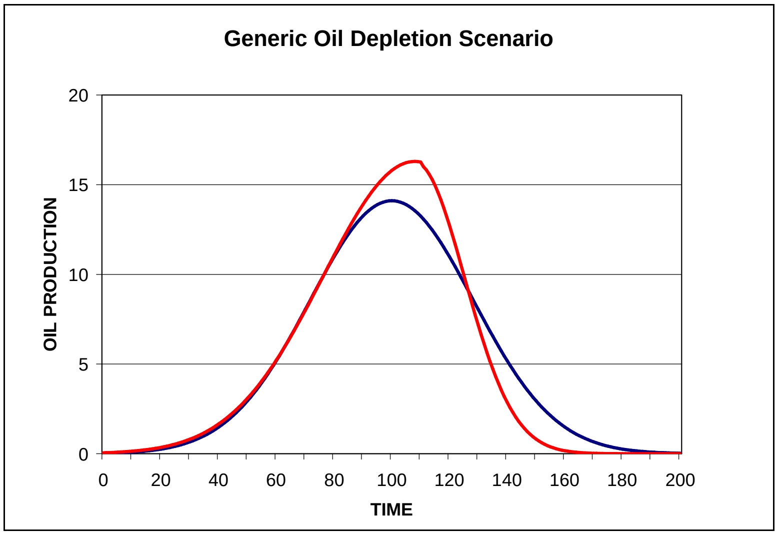

Figure 3-4 Generic depletion scenarios with the same ultimate production

The asymmetric, skewed scenario has the same ultimate production as the symmetric Gaussian scenario but postpones the peak in production a few years. However, the additional oil produced in the vicinity of the peak (represented by the area between the two curves near the peaks) comes at the expense of production in later years (represented by the area between the curves toward the future tails). An appropriate name for this scenario might be the "*après moi le déluge*" scenario – we burn through more oil in the near future and worry about it later.

Using reasonable asymmetric curves in Hubbert-style analyses gives results that are similar to those obtained using symmetric curves. The peak may be delayed somewhat at the cost of a more rapid decline thereafter.

A second problem is that we do not know exactly what resources will be available. This uncertainty is addressed by considering several scenarios representing different resource estimates as we have above. Neither of the two most likely USGS estimates (or any value in between, of course) projects production adequate to satisfy the USEIA BAU scenario through 2025. Resource estimates high enough to satisfy the BAU scenario could be made, but they require unrealistic estimates of "new" oil.

As discussed in Chapter 2, new technology and higher prices may enable the industry to extract a larger fraction of oil from reservoirs, thereby increasing total "ultimate" oil resources (Option #1.) Accessing unconventional resources would also increase ultimate oil (Option #3.) However, merely increasing the rate at which the remaining undiscovered deposits are found and developed (Option #2) produces a curve like Figure 3-4 which raises production in the short term at the expense of future production (the *après moi le déluge* scenario.) Unfortunately, current U.S. policy appears to be pursuing this strategy.

Complex Hubbert-style analysis

More sophisticated analyses can be made. For example, a separate analysis can be made for each type of resource and the results added together. Categories may change over time. For example, when Hubbert made his original estimates, oil production from deep water (>500 meters) was considered "unconventional" and from ultra-deep water (>1500 meters) was considered infeasible. Today, production is occurring in both these regimes and is included in the estimates above.

C. J. Campbell, one of the leading advocates of this approach, has separated crude oil into a variety of resources and estimated future production from each.[5] His categories are conventional oil, bitumen and heavy oil, deepwater oil, polar oil from new arctic regions, and natural gas liquids (NGLs) shown in Figure 3-5.

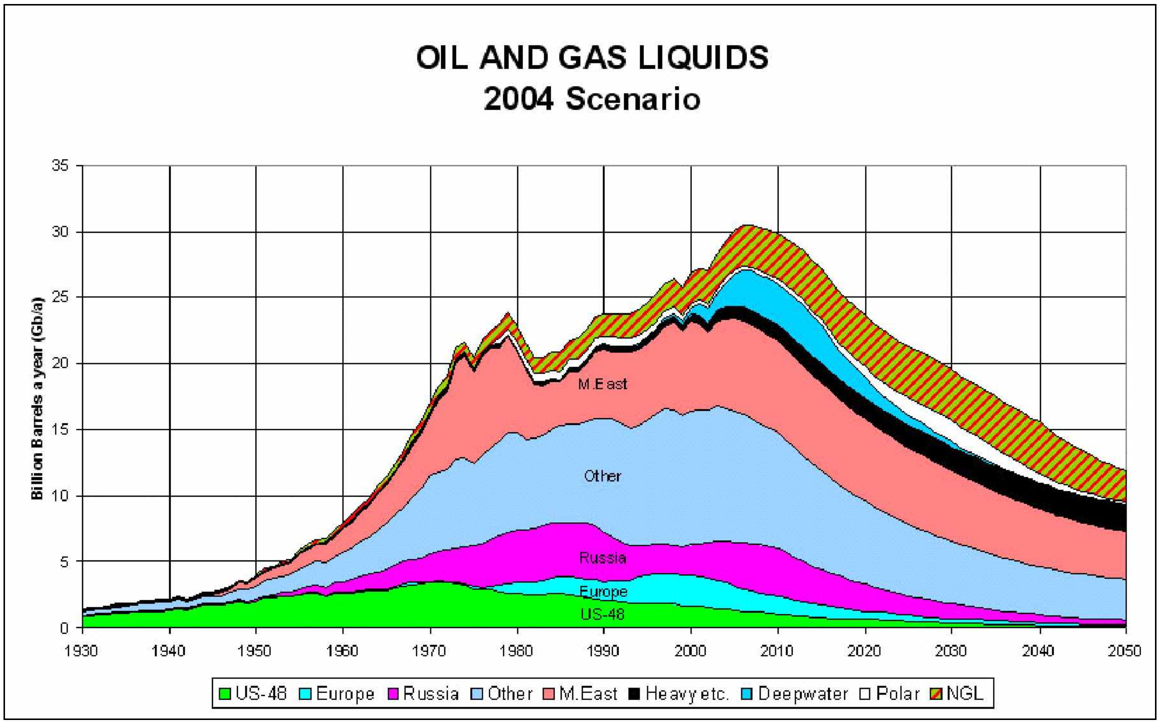

Figure 3-5 World production of oil and gas liquids

Campbell projects a peak in annual total oil production, including NGLs and unconventional heavy oil, of about 31 billion barrels around 2008. The simple low resource scenario above gave similar results.

The unevenness in Figure 3-5 is due largely to changes in Middle Eastern production, especially in the early 1980s. The production decline in Russian oil at the end of the Soviet Union in the early 1990s is also apparent. Political upheavals can reduce production and raise prices, thereby increasing efficiency and postponing consumption until later years. Now that the peak is approaching, any interruptions caused by potential political turmoil will come on top of declines due to depletion.

The International Energy Agency (IEA) has also published a business-as-usual scenario similar to EIA's. In addition, IEA identified the regions from which the projected oil production would come as shown in Figure 3-6.[6]

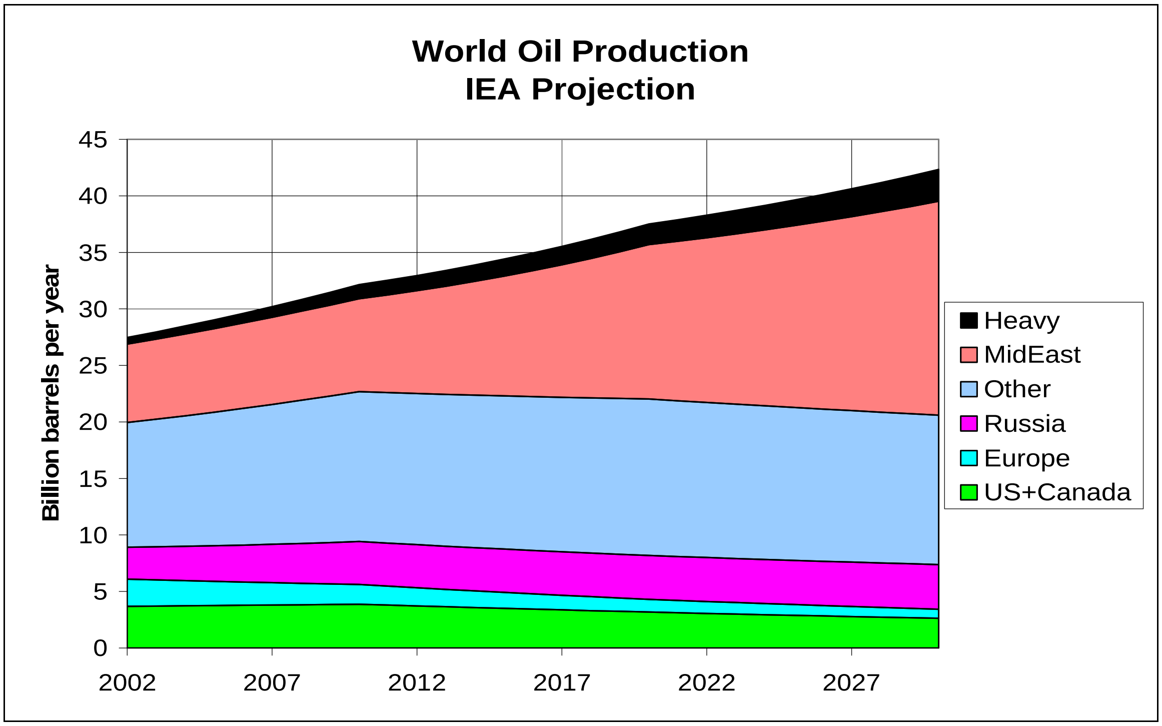

Figure 3-6 IEA oil production projections

The differences between IEA's projections[7] (Figure 3-6) and Campbell's (Figure 3-5) for the same time period are striking. IEA projects "Other" and Russian production to remain constant after 2010 while Campbell projects dramatic declines. The projection for Russia has been called "unjustifiably optimistic" by some analysts.[8] But the most remarkable difference between the two is in Middle Eastern production. Campbell expects a slight decline in Middle Eastern production after 2010, while IEA projects a huge increase from 8.2 Bbbl in 2010 to 18.9 Bbbl in 2030 (an increase of 130%).

Saudi Arabian question mark

The IEA projections *do* agree with other analysts (and with this report) in that oil production in all regions outside the Middle East is expected soon to begin the inevitable decline. The fundamental assumption made by the BAU projection is that production from the Middle East will not only make up for declines elsewhere but will supply all the additional oil needed to satisfy BAU expectations.

Saudi Arabian oil is included in the USGS estimates used above, so the assumption that Saudi production can postpone the peak in global production is not consistent with the symmetrical Hubbert-style analysis. The BAU scenario therefore appears to assume that The Saudi's will be willing and able to continue to increase production beyond the 50% mark.

Saudi Arabia is by far the largest Middle Eastern oil producer, producing nearly as much as all the other countries in the region together. Iran was the second largest in 2002 with output 40% that of Saudi Arabia. Saudi Arabia added 650,000 barrels per day of new capacity last year and is slated to add another 300,000 b/d this year. However, this will not offset the declines in existing fields which are estimated at 600,000 – 800,000 b/d each year.[9] Doubling production in the next two decades while mature fields are further depleted, as the BAU scenarios require, will be a daunting task. Moreover, much of Saudi Arabia's remaining resource is heavier and contains more sulfur making it lower in value than "light sweet" crude.

Conclusion

The bottom-up Hubbert-style analysis in this chapter produces results similar to the economic analysis in Chapter 2. Both agree that the BAU scenario is unlikely to be realized unless global oil resources can be significantly expanded. Such expansion can come through new discoveries, improved extraction technology or development of unconventional resources. Sufficient expansion appears unlikely to occur by 2025.

How much production can be expanded in the longer term, how much capital investment will be required, and how high prices will go are unanswered questions. World leaders should be prepared for unpleasant answers. This report finds that production is likely exceed the pessimistic Campbell projections but nevertheless fail to satisfy the BAU scenario and that prices will rise significantly as a result.

What lies ahead? As time goes by, the key indication of future direction will be Middle Eastern oil production, especially production in Saudi Arabia. Both EIA and IEA maintain excellent publicly-accessible databases of production by OPEC countries that provide excellent ringside seats from which to watch the world's oil future unfold.

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[1] Kenneth S. Deffeyes, Hubbert's Peak – The impending World Oil Shortage, Princeton University Press, 2001.

[2] The Oil & Gas Journal published a remarkable series of articles on the debate surrounding Hubbert's peak. The first was by Rafael Sandrea, "Hubbert Revisited -1, Imbalances among oil demand, reserves, alternatives define energy dilemma today", Oil & Gas Journal, July 12, 2004.

[3] At least part of the difference between Hubbert's estimate of ultimate conventional oil resources and the USGS estimate lies in different definitions of "conventional". For example, oil lying deep under the ocean was not well explored and little exploited in Hubbert's day and was considered "unconventional". Technology and information have improved, and oil in deep water now is considered conventional by USGS. As discussed in Chapter 2, there are other petroleum resources currently considered unconventional which will contribute to supplies in the future. The speed at which these resources are developed is uncertain, making the time at which the peak in oil production also uncertain. However, currently unconventional oil resources contribute only about 1% of total supplies. Although this fraction will increase, it cannot increase as fast as conventional resources are being depleted.

[4] The values for crude oil used in this table include estimates for liquids such as propane and butane. USGS numbers have been adjusted for consumption through 2003.

[5] Dr. Colin J Campbell, Available at http://www.peakoil.net/uhdsg/Default.htm.

[6] Kjell Aleklett, "IEA accepts Peak Oil – An analysis of Chapter 3 of the World Energy Outlook 2004", Association for the Study of Peak Oil&Gas. Available at www.peakoil.net.

[7] IEA World Energy Outlook 2004, Table 3.5. IEA resource regions do not correspond exactly to Campbell's shown in Figure 2.5, but the differences are relatively minor. Natural gas liquids (NGL) are given a separate category by Campbell but not by EIA.

[8] OGJ Newsletter, "IEA's Russian oil production forecast 'optimistic'", Oil & Gas Journal, January 3, 2005.

[9] Williams, "Record supply belies tight oil market", Oil & Gas Journal, August 23, 2004.

Chapter 4 Natural Gas Outlook

Global Natural Gas Picture

Consumption of natural gas world-wide has been increasing rapidly – nearly as much energy is now obtained from gas as from coal (see Figure 5.1). Because gas is less polluting than coal and less expensive than oil, many countries are expanding the use of gas as fuel, especially for electricity production. USEIA projects that global consumption of natural gas will expand at an annual rate of 2.2% through the year 2025, increasing 71% over 2000 levels.[1]

Pipelines are being constructed under the Mediterranean to transport gas from North Africa to Europe. Additional pipelines are underway to feed Russian gas into European, Chinese and Japanese markets. Gas will flow from Myanmar through Bangladesh to India in a new pipeline. More lines will connect Pakistan and India to gas fields in Iran, Turkmenistan and other countries in the former Soviet Union.[2]

Natural gas is easily transported through pipelines over land, so intra-continental movement of gas is inexpensive. It is difficult to move significant amounts of energy in gaseous form between areas separated by oceans. Natural gas can be economically transported by ship only after cooling the gas to low “cryogenic” temperatures below -260 °F at which point it condenses into a liquid. This “liquefied natural gas” or LNG can be carried long distances in specially designed ships, and “regasified” by heating at the receiving destination.

U.S. has also become dependent on imported LNG as North American gas resources have been depleted.[3] Japan has been dependent on LNG for many years, International trade in LNG is growing very quickly as China, India, and other countries are expanding their use of gas.[4] The natural gas market is rapidly becoming global in scope, and countries are drawing on suppliers increasingly distant.

The International Energy Agency projects that capacity to liquefy gas for export will increase 600% by 2030 from 2001 levels.[5] LNG imports provided about 6% of the world’s gas consumption in 2001. By 2025 LNG is expected to provide some 19% of the world’s gas, despite a large increase in total consumption.[6]

LNG shipping capacity will also increase dramatically. LNG ships are specially designed to carry the super-cold liquid in insulated tanks that minimize vaporization of the cargo. Vessels capable of carrying 5 million cubic feet of liquid are now commonplace, providing 2.9 billion cubic feet of gas with each trip. Even larger LNG ships capable of holding nearly 9 million cubic feet of LNG (5.3 bcf of gas) are under construction.[7] About 150 LNG ships are now plying the oceans, and the fleet is expected to expand 6-fold as the international trade expands in the next few decades.

Needless to say, the capital required to build all the liquefaction plants, ships and gasification terminals adequate to expand LNG trade by a factor of 6 is substantial. Costs have decreased significantly in recent years and are expected to decline further. Despite the lower costs, IEA estimates that $13 billion will be invested in LNG infrastructure annually during this decade.[8]

The high cost of LNG facilities is offset by the low cost of the gas itself from large fields in the exporting regions. When export via pipelines is impractical, from regions such as Australia, the gas is said to be "stranded" and available at very low cost. Such inexpensive supplies of gas allow LNG to be delivered at a price estimated to be $4-$5 per million Btu, less than the current market price in the U.S. (see Figure 3.5).

Global Natural Gas Resources and Depletion

The booming global natural gas business raises questions of how much gas there is and how long it will last. Global gas resources have been less well studied than oil resources. But as with oil, conventional gas resources are finite and are being depleted by extraction.[9] It is therefore reasonable to ask how fast these resources are being used up.

The USGS assessment of global petroleum resources referred to in earlier chapters included the agency's estimates of natural gas resources, as shown in Table 4-1.

USGS Conventional Natural Gas 'Ultimate' Resources			
	95%	Mean	5%
Trillion cubic feet	10,641	15,401	21,315

Table 4-1 USGS gas resource estimates

According to USGS, the best estimate of Earth's original endowment of recoverable conventional natural gas is 15,401 trillion cubic feet, including 4,669 Tcf of gas yet to be discovered. An estimated 2,420 tcf (16%) have been burned as of 2003,[10] with current consumption running about 93 Tcf per year. A simple-minded calculation would indicate that supplies are adequate for 15,401/93 = 166 years but that would be misleading. Consumption is growing now and will decline as resources are depleted.

The "Hubbert" analysis technique used for oil in Chapter 3 can also be used for gas. As before, it is assumed that global production of natural gas will reach a peak and begin to decline when approximately one-half of the ultimate production has been extracted. Gas consumption must peak and decline virtually simultaneously, of course.[11] Historical gas production data can be fitted to the characteristic shape of the Hubbert curve, using a bell-shaped curve that gives total production for all years equal to the ultimate value provided by USGS.[12]

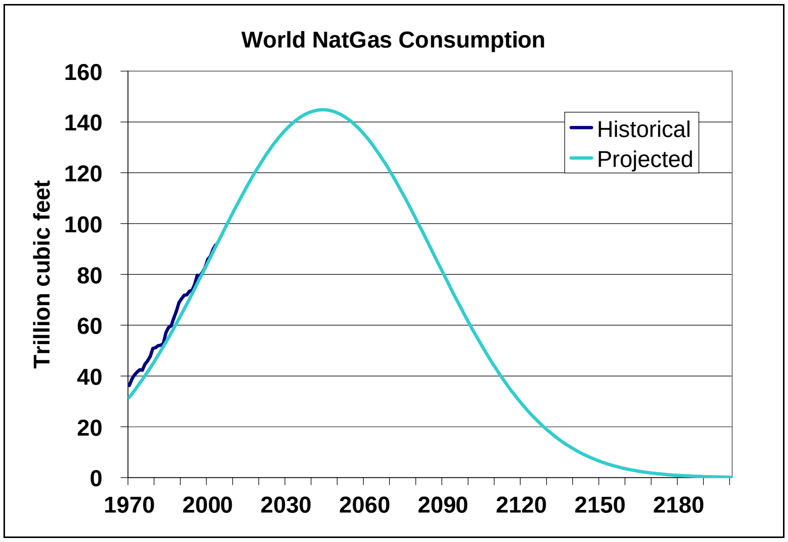

Figure 4-1 Historical natural gas production/consumption and projections based on the USGS mean ultimate resource estimate

According to this analysis, production and consumption of natural gas would peak around the year 2044, approximately two decades after the projected peak in oil production. Other analysts have arrived at an even earlier date.[13] The three USGS estimates of ultimate gas resources can be used to choose three Hubbert curves with peak times of 2028, 2044, and 2058, respectively, as shown in Figure 4-2.

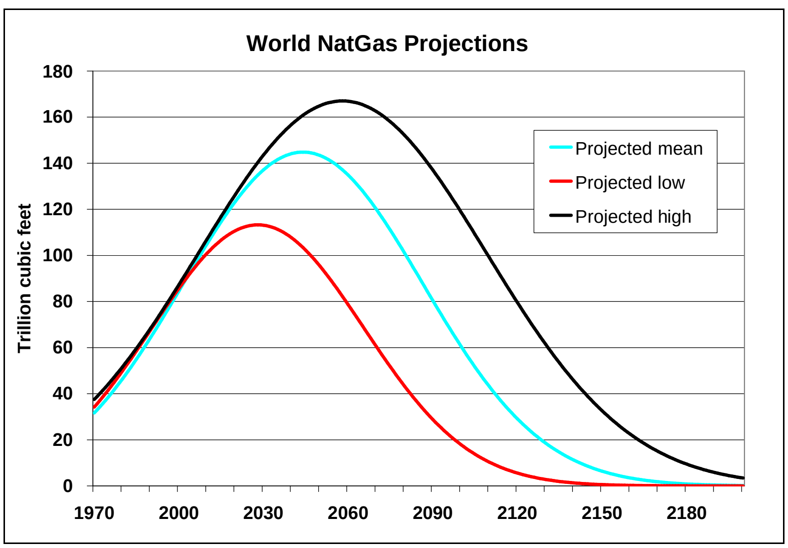

Figure 4-2 Projected natural gas production and consumption for the three USGS estimates of ultimate conventional gas resources.

The above analysis raises serious doubts about the rapid increases in global gas consumption projected by EIA and IEA. Figure 3.3 compares the EIA projections through 2025 with those in Figure 4-3 for the same years.

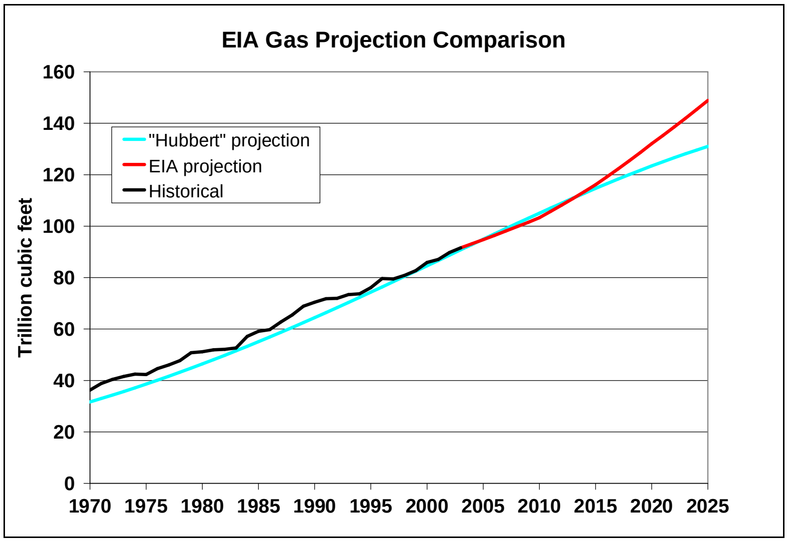

Figure 4-3 Comparing EIA projections to the Hubbert curve

The EIA and Hubbert projections are virtually identical until about 2015 at which time they diverge. After 2015 EIA projects gas consumption continuing to rise sharply, while the Hubbert curve is beginning to flatten as resources are increasingly depleted. Uncertainty about the extent of global natural gas resources makes it difficult to draw firm conclusions from the Hubbert-style analysis. As Figure 4-3 makes clear, however, the EIA projection ignores the potential impact of gas resource depletion.

The U.S. and other countries eager to become dependent on LNG would do well to consider that LNG may not be inexpensive for long. The effects of resource depletion will be felt in the marketplace many years before production is expected to peak and begin to decline, as Figure 4-3 shows. When global gas supplies begin to be limited by depletion, competition will drive up prices to levels above the cost of production, as oil prices are today.

There are many uncertainties which make the timing of the projected peak in gas production and consumption less certain than for the well-studied case of oil. Gas resources are less well explored than oil. Demand for gas may increase to replace more expensive oil, increasing the rate of consumption. International efforts to reduce global warming make gas preferable to coal, perhaps further adding to gas consumption. Development of unconventional gas resources, not included in the USGS estimates, may play a significant role as they do in North America today.

Based on the above analysis, it appears likely that the effects of resource depletion will be felt within a few years, and consumption of natural gas will be forced by into decline perhaps 20 years after the peak in oil consumption. Regardless of the exact time at which consumption of oil and gas begins to decline, virtually Earth's entire original endowment of *both* oil and gas will have been consumed by the end of this century.

The U.S. Situation – Annual Overview

The major trends in the North American natural gas situation that have been documented in earlier editions of the *Risky Diet* report continued through 2004. U.S. gas production continued to struggle and decreased from 2003 levels despite the drilling of more wells.

More gas was imported from Canada to meet demand, as Canadian production increased slightly. An increasing fraction of U.S. consumption was provided by imports of additional liquefied natural gas (LNG). Prices continued to climb. In response to higher prices and mild weather, consumption declined slightly in 2004.

The reality of North American gas resource depletion is now widely acknowledged by the industry as production continues to struggle despite attractive prices and record exploration activity. Even with considerable production from unconventional sources of gas in recent years, it appears that North American gas production has passed its peak and is in decline, perhaps permanently, as shown in Figure 4-4.[14]

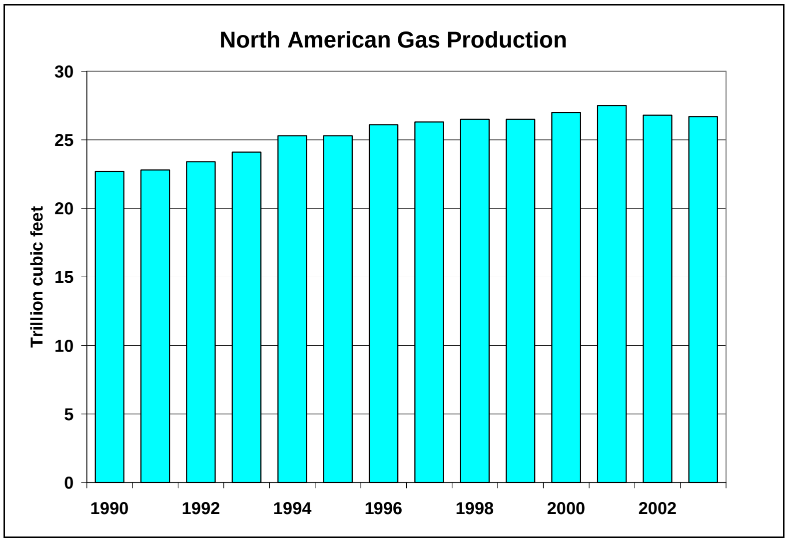

Figure 4-4 North American natural gas production 1990 – 2003

USEIA predicts U.S. prices to remain at current high levels through 2006[15] but nevertheless persists in projecting dramatically lower prices and higher consumption for the years ahead. Despite the lower price projections and recent history, EIA believes that U.S. gas production will *increase* 19% by 2010 over 2004 levels.[16] Such a scenario appears highly unlikely given the results of recent years. Additional facilities to import LNG are scheduled to come on line in 2005, and EIA projects imports to increase 5-fold by 2010,[17] but major gas price reductions are not expected. Prices cannot fall significantly without further limiting domestic exploration and production pushing prices back up.

Prices are expected to remain in the current range through 2010 as LNG imports offset declines in North American production with little, if any, increase in consumption. Quantities of imported LNG sufficient to lower prices are not expected in this time frame. Proposed pipelines from arctic producing regions in Alaska and the Mackenzie River Delta are not expected to come on line in this decade.

Since supplies are expected to be insufficient to accommodate additional consumption, prices will remain high enough to limit increases in consumption for the remainder of the decade. Efforts to reduce consumption by improving efficiency and accelerating the use of renewable energy resources remain the most promising strategies to avoid even higher prices.

Supply

U.S. gas production declined 2.2% (-404 bcf) in 2004 despite a 10% increase in average wellhead prices which spurred an 15% increase in gas wells completed.[18] (See Figure 3.4.) Canadian production increased only marginally by 1.1% (+62 bcf) despite a 15% increase in gas wells completed.[19] U.S. imports from Canada increased 22% (+713 bcf). Meanwhile, exports to Mexico increased 17% (+57 bcf), although their impact on U.S. supplies remains relatively small. Imports of LNG continued to increase, rising 29% (+145 bcf).

The inability of U.S. production to respond to higher prices is clearly shown in Figure 4-5:

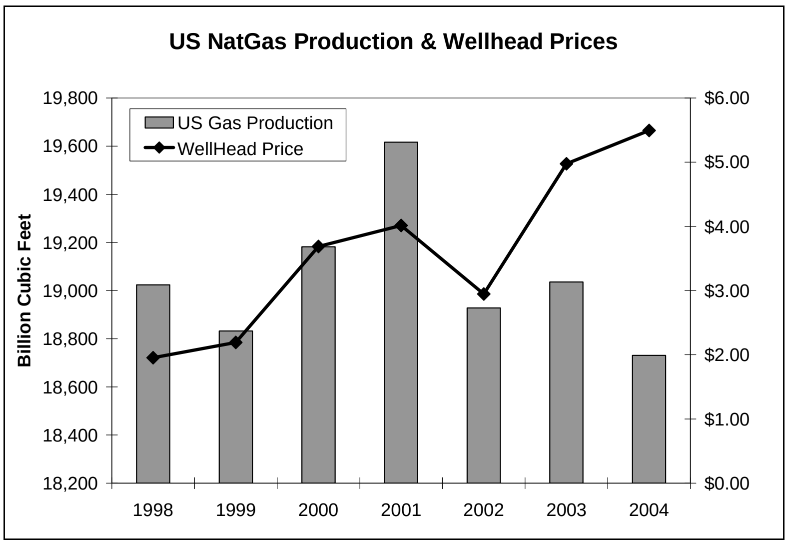

Figure 4-5 U.S. dry natural gas production and average wellhead prices

The inability of U.S. production to increase was not due to lack of exploration. In response to attractive prices, the number of gas wells drilled in the U.S. reached its highest level in recent years, as shown in Figure 4-6:

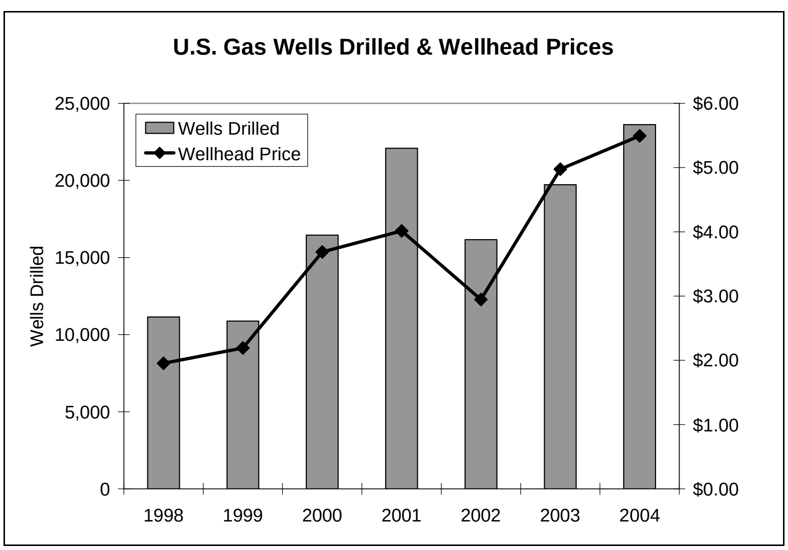

Figure 4-6 Natural gas wells drilled in the U.S. and wellhead prices

Risky Diet 2004 highlighted the growing importance of LNG imports to satisfy U.S. demand. LNG imports rose again in 2004, approaching the maximum capacity of the four LNG receiving terminals in operation. Additional import capacity has come on line in 2005, and the U.S. is expected to become increasingly dependent on LNG in the future. The percentage of U.S. consumption filled by LNG in recent years is shown in Figure 4-7:

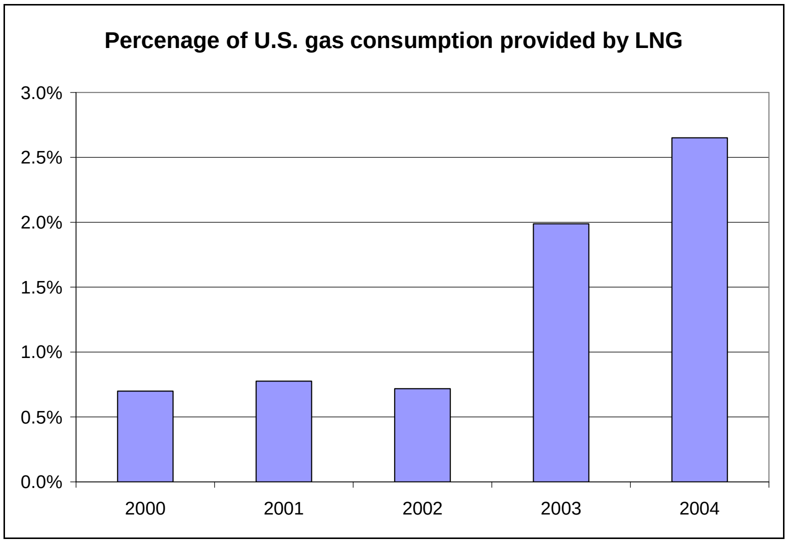

Figure 4-7 U.S. imports of LNG as a percentage of national gas consumption

Consumption

The popular press frequently reports that U.S. consumption of natural gas is growing or even "burgeoning". The large number of gas-fired power plants constructed in recent years is often identified as the cause of the purported increase. However, USEIA data shows that total U.S. consumption has been remarkably flat in recent years and actually declined in 2004 by 0.2% (-51 bcf) (See Figure 4-8). Nevertheless, USEIA persists in projecting that U.S. demand growth will average 1.5% per year between 2003 and 2025.[20]

CEERT's natural gas model separates USEIA consumption data[21] into three sectors –gas used to provide electricity for air conditioning, gas used for heating, and temperature-independent consumption (TIC). TIC includes gas used for industrial and commercial purposes, electricity other than to supply power for heating and air conditioning, and other uses that do not depend on temperature. Figure 4-8 shows that a small increase in TIC was more than offset by reduced heating consumption due to milder weather in 2004. Gas consumption for needed for cooling was virtually unchanged.

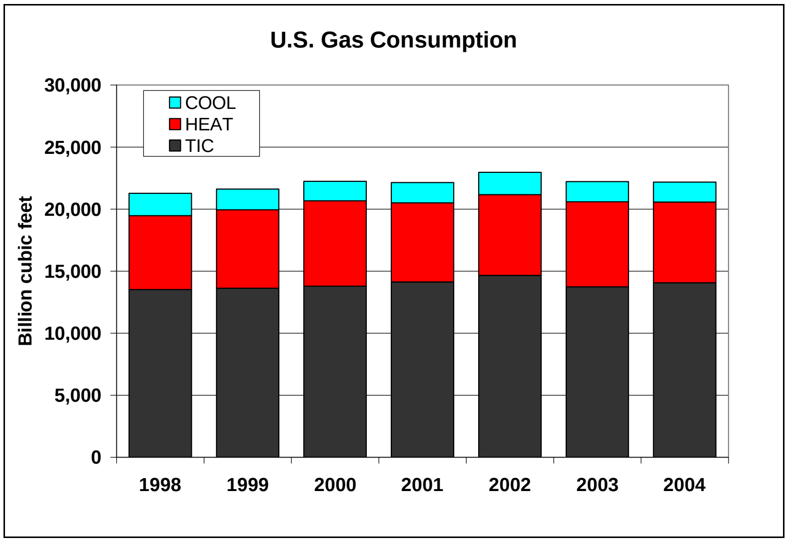

Figure 4-8 Natural gas consumption by component

Gas-fired Electricity Generation[22]

Since 1999, the amount of new electric generating capacity using natural gas as fuel has tripled. The media and even some analysts have therefore assumed that gas burned to generate electricity must also be increasing rapidly. This is not true. Gas burned to generate electricity has remained rather constant in the last six years, increasing somewhat from 1999-2002, but declining in 2003-2004.[23] (See Figure 4-9**)**

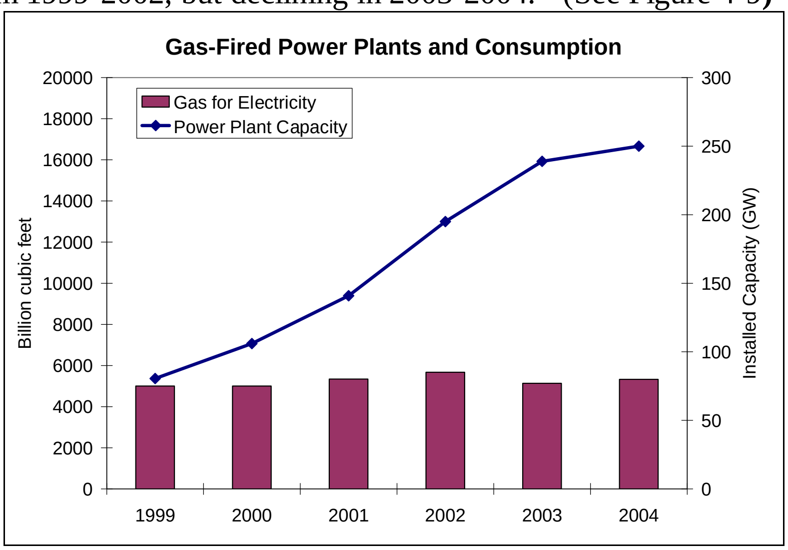

Figure 4-9 Gas-fired electric generating capacity and gas consumed by these power plants.

Although gas used to generate electricity has not changed substantially, the amount of electricity produced by gas-fired generators *has* increased, indicating that the efficiency with which gas is used to generate electricity has improved markedly. A measure of power plant efficiency is the "heat rate", the amount of energy required to generate one kilowatt-hour of electricity. Gas-fired generating heat rates have decreased markedly, indicating improving efficiency, as shown in Figure 4-10.

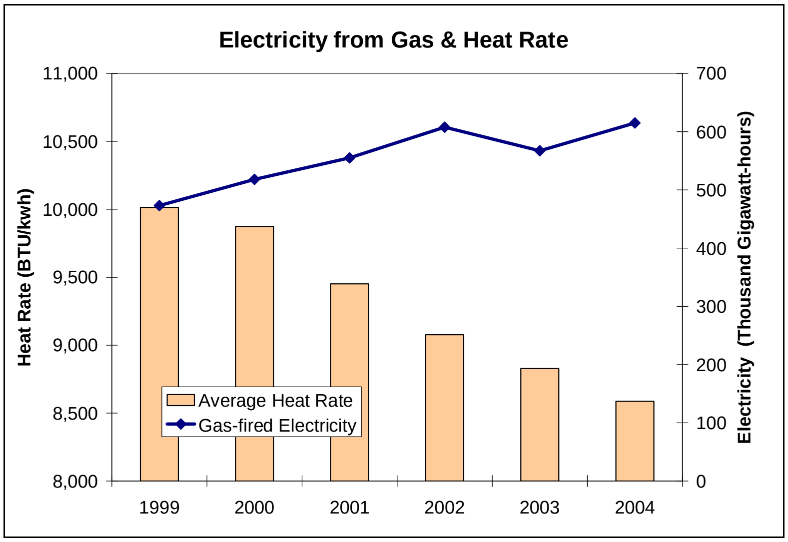

Figure 4-10 Gas required to generate one kilowatt-hour of electricity ("heat rate") and electricity generated by gas-fired power plants

The new power plants being constructed are considerably more efficient than older plants; operations at some older inefficient plants are being curtailed with replacement power generated at newer plants, saving some gas in the process. However, since the installed gas-fired generating capacity has risen much faster than the electricity produced (as shown in Figure 4-9 and Figure 4-10 above), one is forced to conclude that much of the new gas-fired generating capacity is being used infrequently.

How much gas will be consumed to generate electricity in the future is uncertain. USEIA projects this use will increase 3% annually, a major factor driving their projection of a 1.5% annual increase in total consumption. However, these projections are based on an assumption that gas prices will decline significantly, which appears unlikely. If gas prices remain around current levels, the use of coal as a fuel to generate electricity is likely to increase, offsetting the need for additional gas.

Prices and Storage

The gas prices shown in Figure 4-6 are average prices paid to producers "at the wellhead" as computed by USEIA. However, the benchmark wholesale price is established by trades of gas futures contracts on the New York Mercantile Exchange (NYMEX). The "near month" contract is for gas to be delivered to the buyer in the next month; contracts for delivery up to 72 months in the future are traded. Prices for the next several months change daily and are widely reported in the financial pages of newspapers like the *Wall Street Journal*. The daily prices of the near month contract for most of 2004 are shown in Figure 4-11.

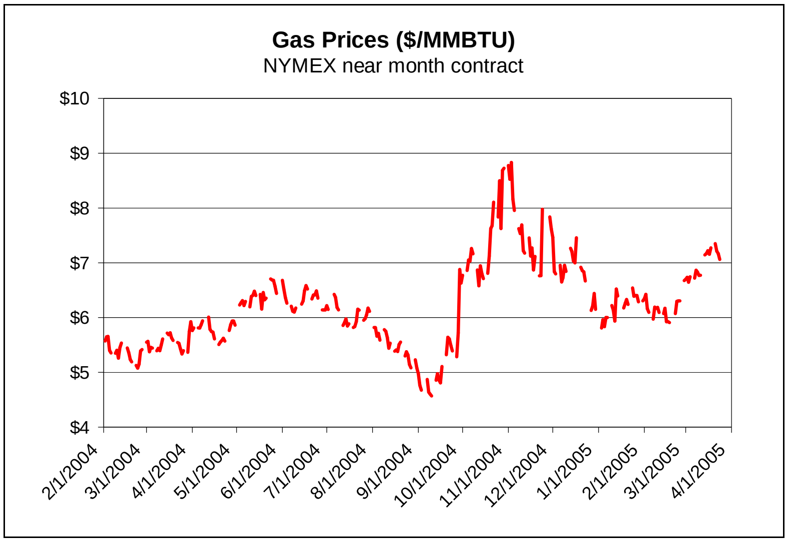

Figure 4-11 NYMEX near month gas prices

After spending most of the year in the $5-$6 range, gas prices leaped higher at the end of September partly due to the effects of Hurricane Ivan on gas supplies. Oil prices were also climbing toward historic levels at this time.[24] However, the fundamental cause of the persistently higher prices is a subject of debate.

The gas market is sensitive to changes in the amount of gas stored for future use, a number reported by USEIA weekly. For example, if more gas is taken out of storage than traders expect, prices generally increase, and *vice verse*. However, by September, 2004, the amount of gas in storage was rising considerably above the 5-year average (see Figure 4-12), which some analysts believe should have depressed prices. Contrarily, NYMEX prices remained strong, reaching nearly $9/MMBtu in November.

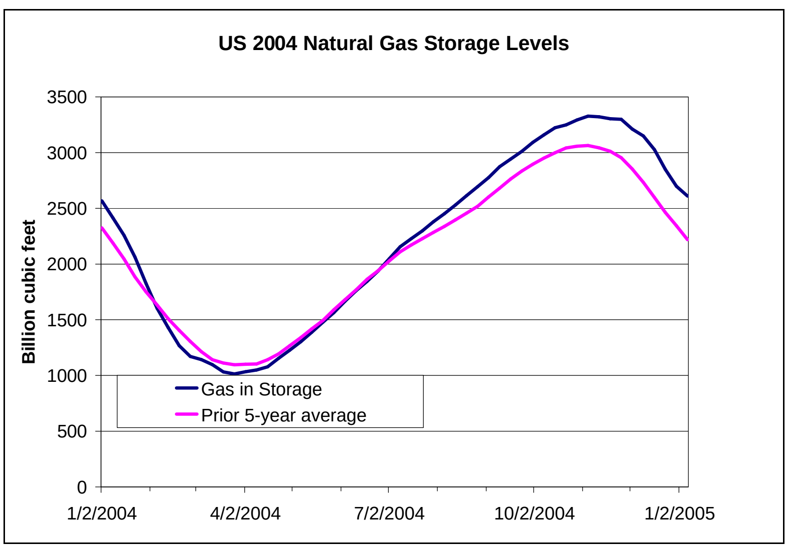

Figure 4-12 Gas storage levels and 5-year average

It appears likely that gas prices are responding to the general weakness in North American production, perhaps coupled with an expectation that consumption may grow as the U.S. economy recovers. Despite additional supplies in 2004 of 713 bcf from Canada and 145 bcf from LNG and a decline of 51 bcf in consumption, gas in storage managed to increase only 116 bcf on the year. This increase was due to reduced heating demand, rather than improving supplies. Should Canadian production follow the U.S. into decline and/or consumption increase due to economic growth or severe weather, a large draw on storage would occur and create the potential for actual shortages next winter. These factors, together with record high oil prices (in nominal dollars) appear to justify current price levels. It is difficult to see how gas prices can drop substantially, even though gas storage levels are above average for the time being.

Outlook for the future

This year's outlook for the U.S. remains much the same as last. Projected growth in the economy will tend to increase natural gas consumption, but additional supplies to meet this growth will be difficult to obtain. North American production is expected to decrease somewhat, despite continued high prices. LNG imports will increase, but they may merely keep total supplies from shrinking.

It appears inevitable that the U.S. will become increasingly dependent on imported LNG. Increasing imports appears to be the only way to maintain U.S. consumption levels, much less to satisfy the USEIA projections of increasing consumption. In response to high prices, efficiency improvements and the movement of gas-intensive industries overseas will serve to reduce growth in consumption. Future gas consumption in the electric generating sector is uncertain, since electricity from wind power and new coal-fired plants is competitive with gas-fired power at today's prices.

The rapid increase in international gas trade will increase the rate of depletion of global gas resources. As shown in Figure 4-3, in a decade or so the effect of depletion will begin to limit currently projected increases in gas consumption. When this occurs, global gas prices can be expected to rise as nations compete for limited supplies, much as oil prices are rising today. It will be several decades before gas production and consumption will decline. A decade or two before that occurs, however, depletion of finite global natural gas resources will begin to limit production, global prices will rise, and consumption will fail to meet the optimistic forecasts now being made.

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[1] USEIA, International Energy Outlook 2004, Table A.2. The 2.2% average annual growth rate cited in IEO 2004 was a significant downward revision from the previous rate of 2.8% forecast in IEO 2003.

[2] New gas pipelines are regular features of articles in the Oil & Gas Journal.

[3] *Risky Diet 2004.*

[4] A good summary of the LNG trade is available from USEIA, "The Global Liquefied Natural Gas Market: Status & Outlook", 2003, DOE/EIA-0637.

[5] Claude Mandil, Executive Director, International Energy Agency, "The Global Outlook for LNG", 14th International Conference and Exhibition on Liquefied Natural Gas, Doha Qatar, 21-24 March, 2004. Available at www.iea.org/textbase/speech/2004/mandil/lng.pdf.

[6] Percentages are based on IEA forecasts of liquefaction capacity and EIA forecasts of gas consumption.

[7] USEIA, "The Global Liquefied Natural Gas Market: Status & Outlook", 2003, DOE/EIA-0637.

[8] Mandil.

[9] The U.S. has begun to access "unconventional" sources of gas, such as gas trapped in coal deposits and rocks with little porosity. There is also a large amount of gas embedded in crystals

of ice known as “clathrates”. This discussion does not refer to such unconventional sources of gas.

[10] USGS World Petroleum Assessment 2000. Consumption data updated through 2003.

[11] Little gas is stored from one year to the next.

[12] Historical data used here are from BP, Statistical Review of World Energy 2004.

[13] Imam, Startzman and Barrufet, “ Multicyclic Hubbert model shows global conventional gas output peaking in 2019’, *Oil & Gas Journal*, August 16, 2004. This model also estimates the ultimate resources to be much less than the USGS mean value.

[14] Figure 9a, *North American Natural Gas Vision*, North American energy Working Group, page 47.

[15] USEIA, Short-Term Energy Outlook, May, 2005.

[16] USEIA, Annual Energy Outlook 2004.

[17] USEIA, Annual Energy Outlook 2005, Figure 85.

[18] Data is from USEIA unless otherwise noted. Most EIA gas data can be easily accessed through their “Natural Gas Navigator” available at http://www.eia.doe.gov/oil_gas/natural_gas/info_glance/natural_gas.html.

[19] Canadian gas data is published monthly in the Natural Gas Market Update from Natural Resources Canada and available at http://www2.nrcan.gc.ca/es/erb/erb/english/View.asp?x=449.

[20] USEIA, Annual Energy Outlook 2005, Table A.2.

[21] The as consumption data cited here and used in the CEERT model are not exactly equal to consumption data published by USEIA. In its monthly reports on the disposition of gas in the U.S., EIA includes a small correction factor called the “balancing item” that is added to total supplies so that they equal total consumption. However, using EIA consumption data in the CEERT model produces peculiar anomalies in heating demand for some months that are believed to be artifacts of the balancing item. Subtracting the balancing item from EIA consumption data removes the anomalies and the corrected consumption data is believed to be a more accurate estimate of total U.S. consumption.

[22] Gas-fired electricity appears in all three of the consumption components discussed above – cooling, heating and temperature-independent consumption (TIC).

[23] USEIA, Monthly Energy Review, Table 7.2b, “Consumption of Combustible Fuels for Electricity Generation: Electric Power Sector.

[24] Why gas prices should rise “in sympathy” to oil prices at these is unknown. On an energy basis, oil has recently been more expensive than gas, so there should be little competition between these fuels.

Chapter 5 The Role of Coal

Introduction

Coal has provided energy for modern society since the beginning of the industrial revolution and currently supplies approximately one-quarter of the world's primary energy, about as much as natural gas.[1] (See Figure 5-1)

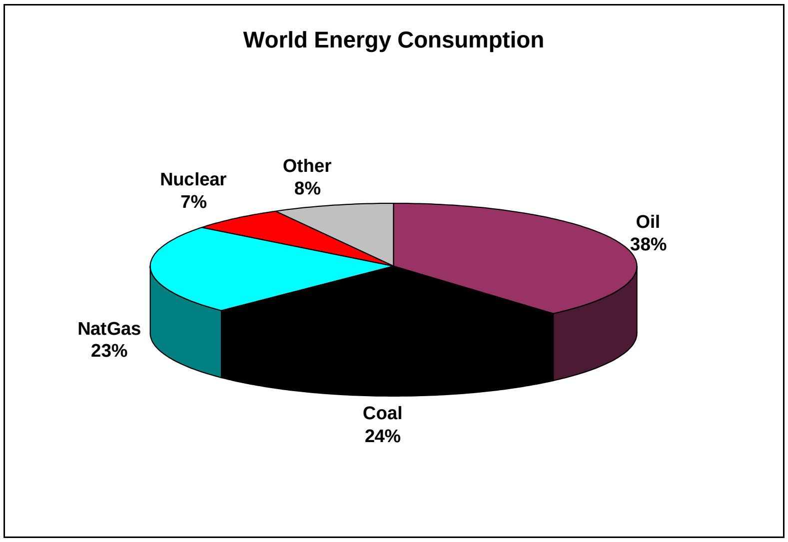


Figure 5-1 World energy by fuel type

The use of coal has increased inexorably, although less rapidly that oil and gas, and is projected to continue to climbing as shown in Figure 5-2.[2]

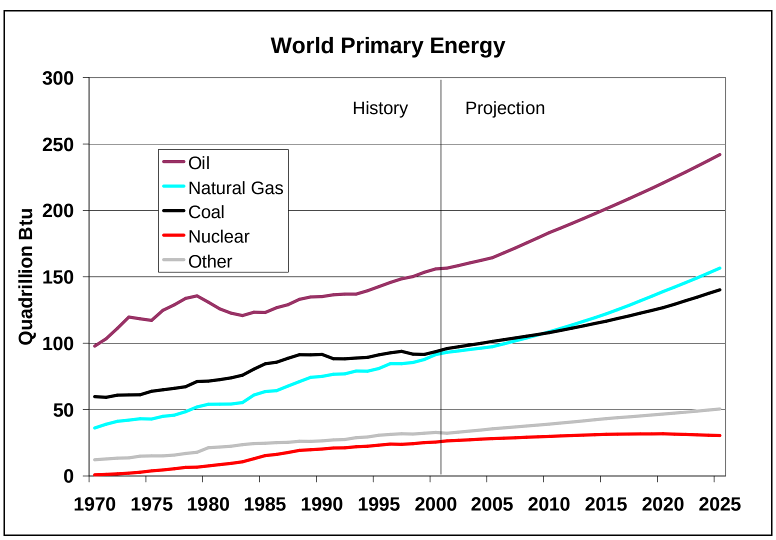


Figure 5-2 Global consumption of coal and other primary energy sources

Because coal is a solid substance, it cannot easily be pumped through pipelines and is usually moved by rail or by ship or else burned near the mine.[3] Once the primary fuel for railroads and shipping, coal is now burned almost exclusively in stationary industrial facilities such as steel mills and power plants.

The primary component of coal is carbon, but other substances are present as well, notably sulfur. When coal is burned, these substances form undesirable compounds which create pollution if not controlled. In addition, particles of ash and soot can be released that seriously degrade air quality. The original "smog" was found in London, a mixture of smoke from coal and fog, and was hazardous to health. Developing countries such as China that use large amounts of coal have serious air quality problems as a result. Modern pollution control equipment can reduce undesirable emissions from coal burning substantially, but coal remains the dirtiest of the fossil fuels.

Moreover, coal burning produces more carbon dioxide than oil or gas to generate the same amount of energy and is the largest single contributor to global warming, as discussed below. Because the primary uses of coal are in large stationary equipment, coal is also the easiest fuel to replace with other forms of energy. As we have seen in earlier chapters, the world's oil and gas resources are being rapidly consumed. Concerted efforts to reduce the use of oil and gas can extend the life of these resources, but despite the best intentions it is nearly certain that the most of the world's remaining oil and gas will be consumed in this century. To meaningfully reduce global warming it is imperative that the burning of coal be reduced or technologies developed which prevent the carbon dioxide generated from entering the atmosphere.

Global Coal Resources

There are varying grades of coal, ranging from anthracite with the highest carbon content and the fewest impurities, down through bituminous, lignite and subbituminous. USEIA reports global reserves by country in two categories, anthracite and bituminous, and lignite and subbituminous. World total recoverable reserves for both categories together are about 981 billion metric tonnes[4] and are distributed regionally as shown in Figure 5-3[5]:

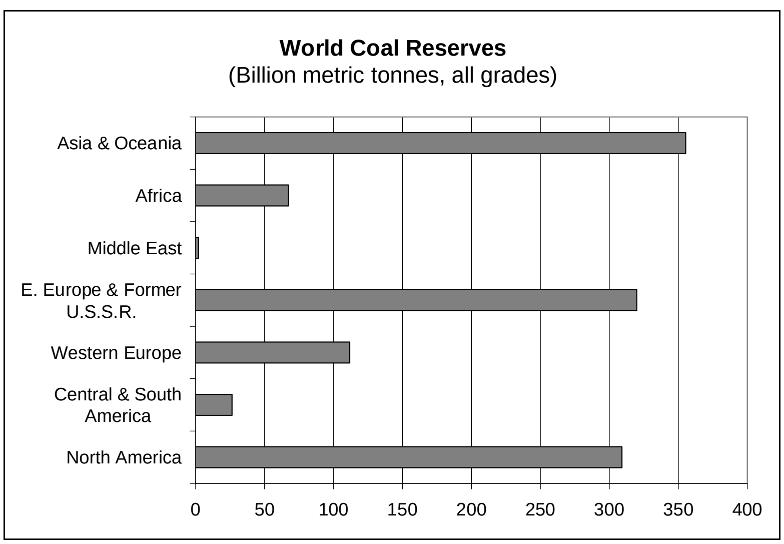


Figure 5-3 World coal reserves by region

Depletion of coal resources

Annual world coal consumption is currently about 5 billion metric tonnes and is projected to grow at 1.6% per year.[6] Global reserves are adequate for about 200 years at *current* rates of consumption, as the industry is fond of pointing out. However, as with oil and gas, coal reserves are being depleted and consumption must inevitably begin to decline at some point. A simple Hubbert analysis, similar to that used earlier for oil and gas, can be used to estimate when the peak in coal production and consumption will occur. In addition to known coal reserves identified in Figure 5-3, perhaps 260 billion metric tonnes have been burned to date. If ultimate recoverable coal resources are taken to be 1245 billion metric tonnes, consumption would begin to decline around 2060, as shown in Figure 5-4:

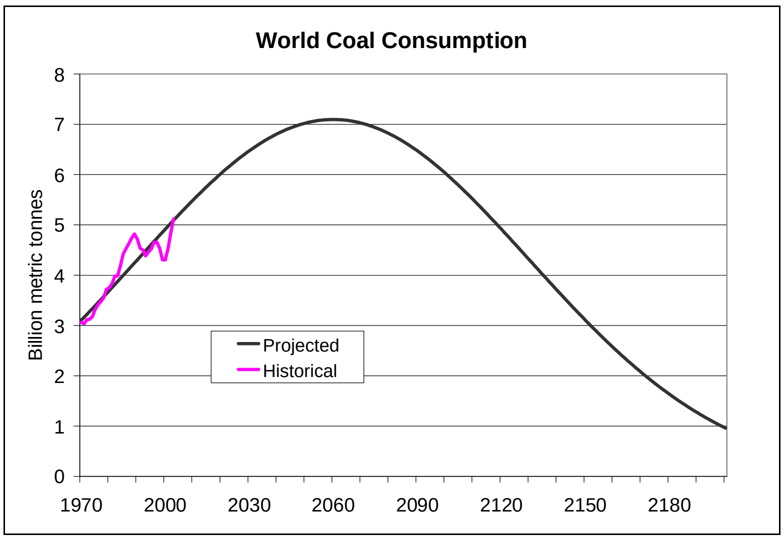


Figure 5-4 Projected coal production/consumption

As with other fuels, assuming that coal consumption is going to remain constant and then suddenly cease is grossly misleading. Consumption, and hence depletion, of coal resources, has been increasing for many years and can be expected to continue to do so for some years to come. Since these increases cannot continue forever, at some point consumption must begin to decline. Although the above projection is unlikely to be a precise description of the future, indications are that within 5 or 6 decades, the world economy must prepare for decreasing amounts of energy from the burning of coal. Attempts to replace petroleum-based fuels with fuels made from coal, as discussed below, would accelerate depletion and hasten the time at which coal supplies begin to decline.

U.S. coal

Natural gas has captured most of the electricity headlines in recent years, but 50% of all electric energy in the U.S. is generated by power plants burning coal. The overwhelming use of coal, about 90%, is for electricity generation, and the use of coal as a power plant fuel has continued to climb inexorably as shown in Figure 5-5.

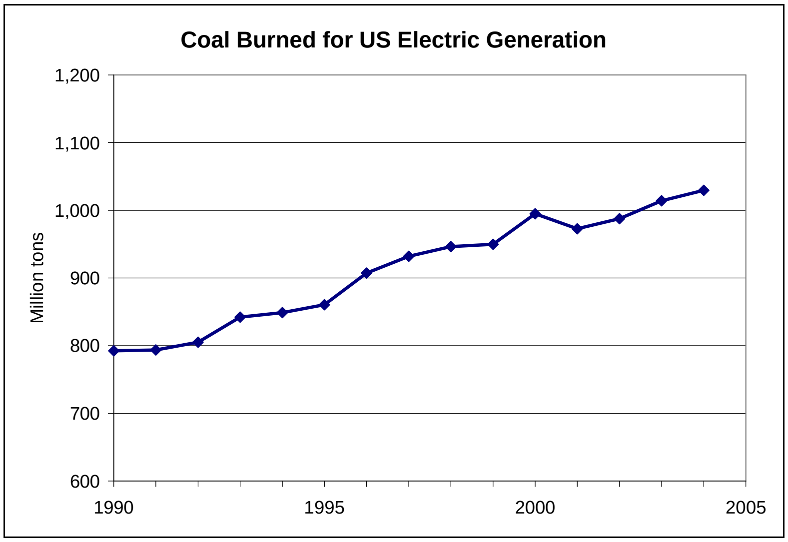


Figure 5-5 U.S. coal consumption for electric generation.[7]

Since 1990, the use of coal has increased of 2% per year on average. If this trend were to continue, approximately 300 million more tons of coal would be burned annually to generate electricity ten years hence, as shown in Figure 5-6.[8]

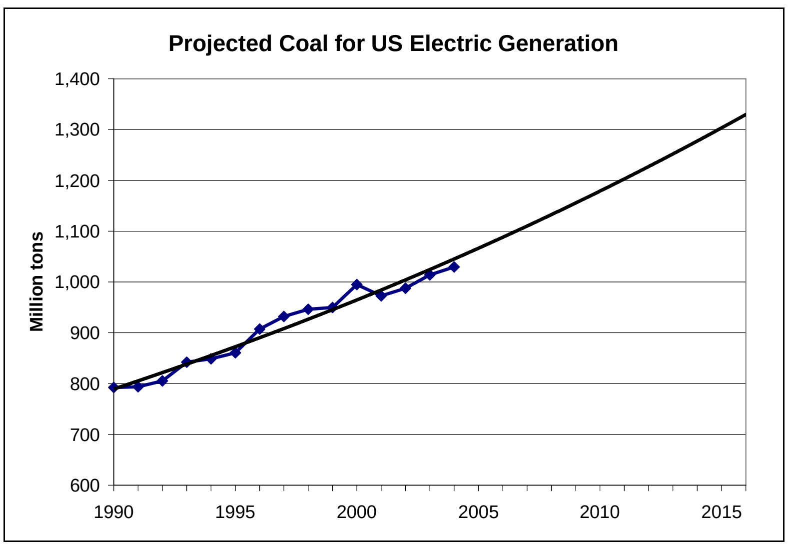
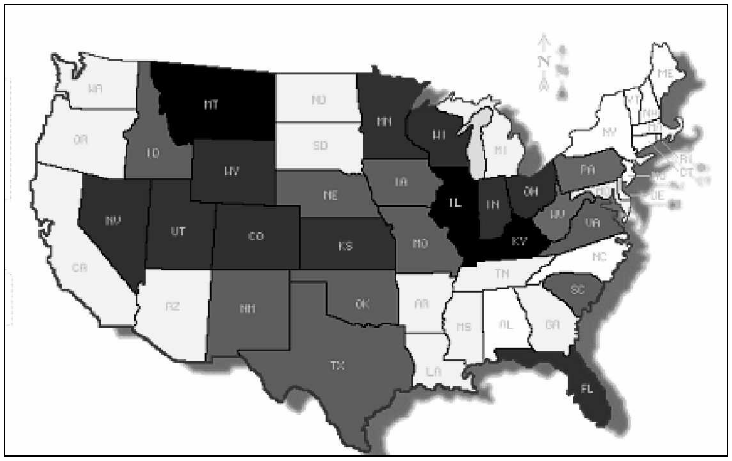


Figure 5-6 Coal consumption for electric generation projected to 2015.

Many U.S. coal plants were built decades ago and make inefficient use of the energy provided by the fuel. The average U.S. coal plant in 2004 required 10,584 Btu of energy to generate one kilowatt-hour of electricity (i.e. they had an average heat rate[9] of 10,584 Btu/kwh[10]) compared to only 8,587 Btu/kwh[11] for gas-fired plants. New coal-fired power plant technology also is expected to achieve heat rates around 8,500 Btu/kwh (see discussion of IGCC below). Consumption of coal could be reduced considerably by retirement of existing coal-fired power plants and replacement with the new coal burning technology.

Building a new, modern coal-fired power plant is capital intensive compared to gas-fired plants. However, coal is a much less expensive fuel than gas. In 2004, coal delivered to U.S. power plants cost $1.35 per million Btu (MMBtu) while natural gas cost $5.88/MMBtu.[12] In anticipation of continued high natural gas prices, 114 new coal-fired plants are now on the drawing boards. States with proposed coal-fired plants are shown in the map in Figure 5-7.[13] How many of these will be built remains to be seen.



Proposed Power Plants by State
6 or more – IL, KY, MT
5 – CO, FL, OH, NV, WI, WY
4 – PA, WV
3 - IN, KS, MN, UT
2 – AK, IA, ID, MO, NE. NM, OK, SC, TX, VA
1 – AR, AZ, CA, GA, LA, MD, MI, MS, ND, OR, SD, TN, WA

TOTAL = 114 as of 3/30/05

Figure 5-7 Location of proposed new coal-fired power plants with shading indicating number of plants

The U.S. has a generous endowment of coal resources estimated at 250 billion tons[14]; unlike oil and gas, U.S. coal production could continue to increase for many years. However, burning coal generates much more pollution, emitting acid rain-causing sulfur dioxide, smog-causing nitrogen oxides, and mercury, a neurotoxin. The environmental impacts of continuing increases in coal consumption will be significant unless stringent pollution controls are employed.

Coal is also more carbon intensive than oil or gas. On the basis of energy released when burned, it produces the most carbon dioxide, the primary “greenhouse” gas responsible for global warming. In 2003, coal provided 23% of the primary energy used in the U.S. but was responsible for 36% of carbon dioxide emitted by the energy sector.[15] Although the Kyoto Protocol to limit greenhouse gas emissions went into effect among signatory nations in early 2005, the U.S. has not yet agreed to participate and no U.S. regulations limit emissions of carbon dioxide.

However, scientists are virtually unanimous in the belief that steps must be taken to reduce the extent of global warming, and it is only a matter of time before the U.S. joins the world community to limit carbon dioxide emissions. As we saw in earlier chapters, global oil consumption is expected to begin declining in a few years as resources are exhausted. Natural gas emits few pollutants and less carbon dioxide, but resource depletion is expected to limit gas consumption a few decades after oil peaks. Depletion of oil and gas will create pressure to burn even more coal, and world coal resources are large. If global warming is to be controlled, emissions of carbon dioxide from the burning of coal must be limited.

The best way to do so is to leave the coal in the ground – once it is mined, it is burned. The major use of coal is to generate electricity, much of which is wasted by inefficient buildings, lights and electric equipment. Major investment in modern facilities and equipment would reduce the need for coal significantly. Moreover, renewable energy resources like wind provide electricity with virtually no pollution or carbon dioxide emissions at roughly the same cost as coal-fired power. The burning of coal could be substantially reduced by an aggressive program to expand the use of renewable resources.

The third option for reducing greenhouse gas emissions from coal burning is to capture the carbon dioxide and permanently "sequester" it so that it never enters the atmosphere. It is theoretically possible to do this with conventional coal-fired power plants, but expensive. A new technology is being explored which not only would burn coal more efficiently, but would make carbon dioxide capture less expensive.

IGCC – Integrated gasification combined cycle

The new coal combustion technology currently being touted as the solution to the coal problem is known as "integrated gasification combined cycle" technology, or simply IGCC. Combined cycle power plants burn gaseous fuel to generate power in two steps. The fuel is burned in a turbine much like a modern airplane engine and the turbine spins a generator. Hot exhaust from the turbine is then used to create steam in order to drive a secondary turbine and make additional electricity. Combustion takes place at high temperatures which makes the combined cycle process quite efficient. Large gas-fired power plants now routinely use combined cycle technology and can attain efficiencies of 50% or more.

What is new and challenging about IGCC coal technology are initial steps that convert solid coal into gaseous fuel, primarily hydrogen, which feeds the turbine. In addition, copious amounts of carbon dioxide are generated – one molecule of CO_2 for each atom of carbon in the coal. The CO_2 can be separated from the hydrogen, diverted from the system, and made available for potential sequestration. After gasification, sulfur and other pollutants from the coal also can be removed from the "syngas" so that the combustion process emits fewer polluting materials into the air. Hence the oxymoronic name "clean coal".

A schematic diagram of the IGCC process is shown in Figure 5-8.

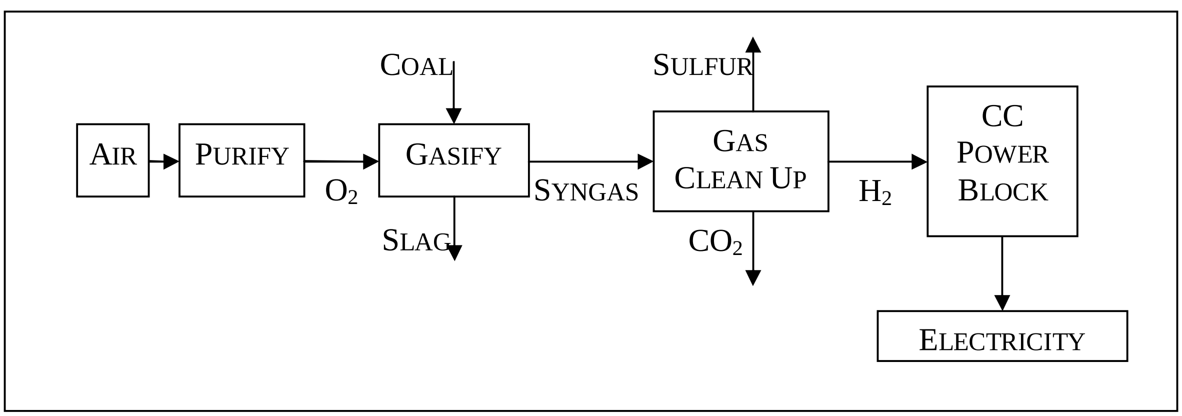


Figure 5-8 Schematic diagram of coal IGCC process

In a combined cycle process that burns natural gas, less carbon dioxide is generated than in an IGCC process burning coal. With gas, however, the carbon dioxide is emitted as exhaust diluted with water vapor and nitrogen making removal of the carbon dioxide difficult. In the coal IGCC process, the carbon dioxide is mixed with hydrogen in the syngas and removal is less technically challenging.

Experts estimate that adding the carbon dioxide removal process to a coal IGCC power plant would add about 1.3 cents per kilowatt of electricity, compared to about 1.8 cents/kwh for a gas-fired combined cycle plant or a conventional coal plant.[16] The additional cost of transporting and sequestering the captured carbon dioxide from a coal IGCC plant has been estimated at about one cent/kwh, approximately the same as the current cost of fuel. These costs should be considered preliminary estimates, however, until functioning commercial power plants using these technologies are in operation. The actual cost of permanent carbon dioxide sequestration may be considerably higher.

Clean air advocates are generally supportive of using the IGCC process for coal-fired power plants because they are significantly less polluting than conventional plants.[17] They also allow at least the potential for carbon dioxide capture; even if the coal IGCC plant were built without carbon dioxide capture initially, this technology could be added later. To date, there are no commercial coal IGCC power plants in operation, although the Ohio utility company Cinergy announced in late 2004 that construction of such a plant was under study.[18] 15 of the proposed plants identified in Figure 5-7 are identified as using IGCC technology.

In 2003, President Bush announced “FutureGen” with considerable fanfare, a 10-year “clean coal” IGCC project with carbon sequestration under the supervision of the U.S. Department of Energy.[19] Cynics suspect that this government demonstration project is in reality an effort to postpone the widespread use of this new technology; the recent Cinergy announcement gives some credence to this belief. Meanwhile, many conventional power plants are being proposed and built.

Liquid fuels from coal

Fuels for transportation vehicles are now virtually all in liquid form – gasoline, diesel, oil and jet fuel. Solid coal that once fueled ships and railroads has been replaced by oil or diesel. Some short-haul buses use compressed natural gas, but it is difficult to store as much energy in gaseous fuels for longer range travel. Liquid fuels made from petroleum now dominate the transportation sector, but with the impending shortage of oil, interest in liquid fuels made from coal is being rekindled.

During the second world war, Germany was cut off from oil supplies and ran its military with coal-derived liquid fuels. More recently, South Africa turned to these fuels when oil imports were restricted in response to apartheid. Processes for making liquid fuels from coal, such as the Fischer-Tropsch process, are well-known. It is estimated that these fuels become economically competitive with petroleum-based fuels at prices about equal to today’s oil prices.[20]

The F-T process begins with the gasification of coal as in the IGCC process discussed above. The resulting syngas, a mixture of hydrogen and carbon monoxide, is then catalyzed to form hydrocarbon products that are further refined into fuels. Coal can therefore be considered as an unconventional source of liquid fuels, together with tar sands and shale.

However, the scale and speed at which coal-to-liquid technology would have to be developed to replace petroleum is daunting. As we saw in Chapter 3, difference between projected oil demand and supply from conventional sources by the year 2025 may be as large as 10 billion barrels per year and perhaps even greater. Developing coal-to-liquid capacity sufficient to produce 10 billion barrels of fuel annually would require enormous amounts of capital, and efforts would have to begin immediately. But as long as official agencies like USEIA and the International Energy Agency persist in projecting adequate petroleum supplies, there will be no such investment.

Outlook for the future

Coal is the most abundant of the major fossil fuel resources, and consumption is likely to continue to grow for several decades. The rate of increase will rise if coal is used to replace energy currently obtained from oil and gas as these resources are further depleted. Coal resources are limited as well, however, and half the remaining coal is likely to be burned in this century unless diligent efforts are made to improve efficiency and expand the use of non-fossil fuels.

Currently more carbon dioxide is created by the burning of oil than of coal. As the most carbon-intensive and abundant fossil fuel, coal is likely to replace oil as the major single cause of global warming. Fortunately, most coal is burned in stationary facilities making carbon dioxide capture and sequestration feasible. Efforts to minimize climate change must necessarily focus on reducing the use of coal and limiting the emission of carbon dioxide into the atmosphere.

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[1] USEIA, International Energy Outlook 2004, Table A.2.

2 USEIA, Figure 14.

[3] Coal is shipped to the Mohave power plant in Nevada via pipeline as a powder in a slurry of water.

[4] One metric tonne = 1.1023 "short" tons, the unit used in the U.S.

[5] Data are from USEIA, IEO 2002.

[6] USEIA, IEO 2004, Table A2.

[7] U.S. coal data are given in "short" tons. One short ton = 0.9072 metric tonne.

[8] USEIA projects an average annual increase of 1.5% through 2025, but also projects low prices for natural gas. Given the current gas price outlook, it appears reasonable to assume that coal consumption will increase at least at the historical rate of 2% annually.

[9] Refer to the discussion of heat rates in Chapter 4.

[10] From data reported by USEIA, Electric Power Monthly.

[11] From data reported by USEIA, Natural Gas Monthly. See also Chapter 3.

[12] USEIA, Electric Power Monthly, March 2005. Data are for first 11 months of 2004.

[13] DOE-NETL, "Tracking New Coal-Fired Power Plants", March 30, 2005. Available at http://www.netl.doe.gov/coal/refshelf.

[14] "Survey of Energy Resources", World Energy Council. Available at http://www.worldenergy.org/wec-geis/publications/reports/ser/coal/coal.asp.

[15] USEIA, Annual Energy Outlook 2005, Tables A2 and A18.

[16] Neville Holt, Electric Power Research Institute (EPRI), "Clean Coal Technologies (with particular reference to Coal Gasification) – Status and Overview", presentation at the Canadian Clean Coal Technology Roadmap Workshop, March 2003.

[17] John Barth, “Coal-Fired Power Production”, Energy Foundation Publication, April 2004. Available at http://www.ef.org/documents/CoalFiredPowerProduction.pdf.

[18] Cinergy press release, available at http://www.cinergy.com/News/default_corporate_news.asp?news_id=467.

[19] Press release available at http://www.fe.doe.gov/programs/powersystems/futuregen/.

[20] Wikipedia, available at http://en.wikipedia.org/wiki/Coal.

Chapter 6 Global Energy and Global Warming

Introduction

Earlier chapters have discussed the likely future of the world's primary sources of conventional fossil energy – oil, natural gas, and coal. Each of these resources is being depleted, albeit at different rates, so total fossil fuel production and consumption must eventually begin to decline. Replacing conventional fuels with unconventional fossil resources or sustainable sources of energy will be the major challenge of the 21st century. As if this challenge were not difficult enough, carbon dioxide from fossil fuel combustion must be reduced if catastrophic climate changes are to be avoided.

The Intergovernmental Panel on Climate Change (IPCC) is the international scientific organization studying the contribution of carbon dioxide emissions to global warming. The panel has developed several different scenarios based on differences in population changes, technology development, economic activity, concern for the environment, and so forth. The IPCC does not assign a greater likelihood to any one. Energy consumption is quite different across the scenarios, of course, requiring different amounts of fossil fuels. This chapter compares the fossil resource assumptions made by the IPCC scenarios with data from earlier chapters, and the projected impact of resource consumption on global temperatures.

Global fossil fuel consumption

The Hubbert-type analyses for each fuel can be combined into a single chart based on current estimates of the resources remaining to be exploited. Figure 6-1 is a chart showing the history and projections of all three energy sources together from the Hubbert-type analyses discussed in earlier chapters:

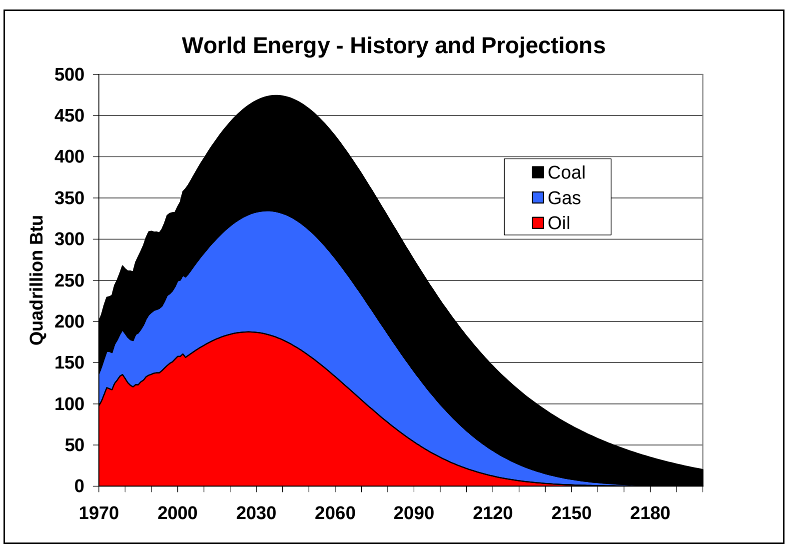

Figure 6-1 World energy consumption by resource, history and Hubbert-type projections

Based on data for conventional oil and gas resources, Figure 6-1 indicates a peak in total fossil energy consumption can be expected around 2040, beyond the USEIA planning horizon. These Hubbert-type analyses require an estimate of available conventional resources remaining and assume that production (and therefore consumption) follows a symmetrical bell-curve pattern.

Although the Hubbert peak does not occur until about 2040, the impact of depletion is expected to be noticed much earlier, as seen from a comparison of the USEIA business-as-usual scenario through 2025[1] with the corresponding years from Figure 6-1.

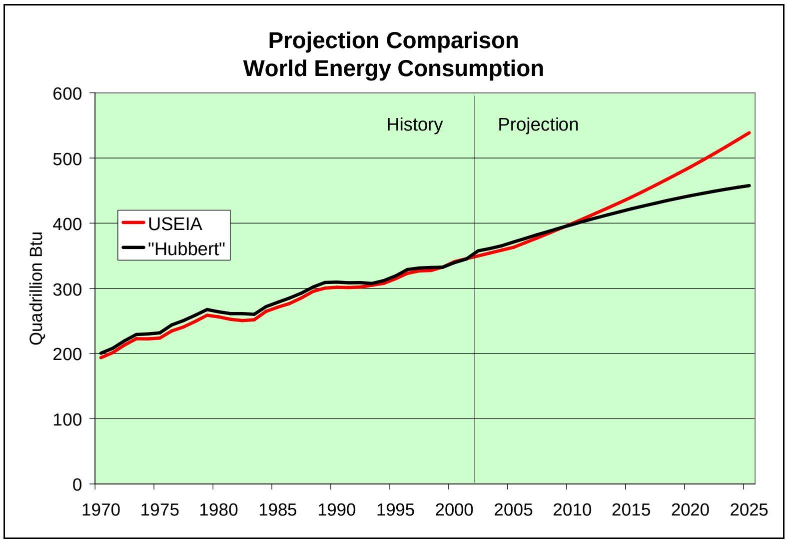

Figure 6-2 Comparison of USEIA projections with Hubbert-type projections through 2025

The "Hubbert" projection in Figure 6-2 shows total energy consumption increasing less every year after 2010, while the USEIA projection increases every year.[2] By 2025, USEIA projects 20% more energy consumption annually than can be supported by the Hubbert model. Figure 6-2 should serve as a note of warning that the effects of energy resource depletion will be felt in global markets several decades before consumption reaches its peak value.

Carbon dioxide emissions and global warming

Each fossil fuel contains carbon in different amounts. For the same amount of energy released, coal produces the most carbon dioxide, followed by oil and natural gas. The figures above can thus be converted into annual emissions of carbon dioxide, which are customarily presented in metric tonnes of carbon.[3]

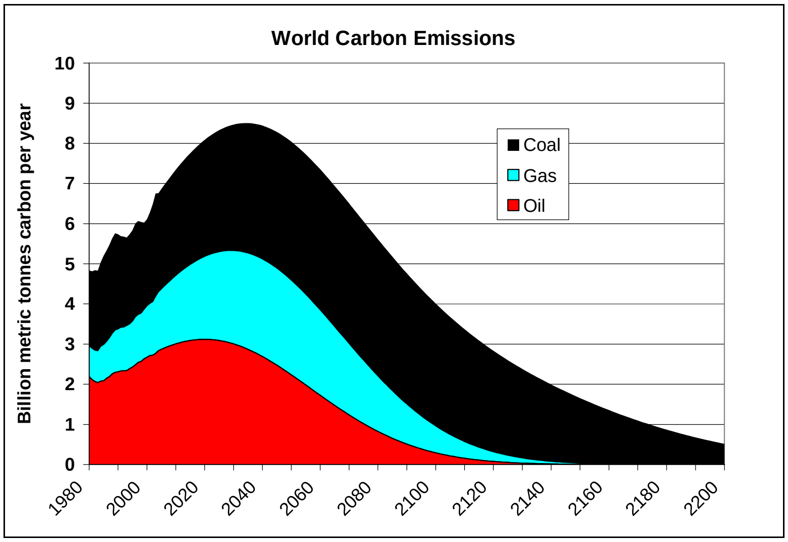

Figure 6-3 Carbon emissions from fossil fuel burning projected by Hubbert-type analysis

As expected, the Hubbert-type analysis projects that emissions of carbon dioxide will be lower than EIA projections.[4]

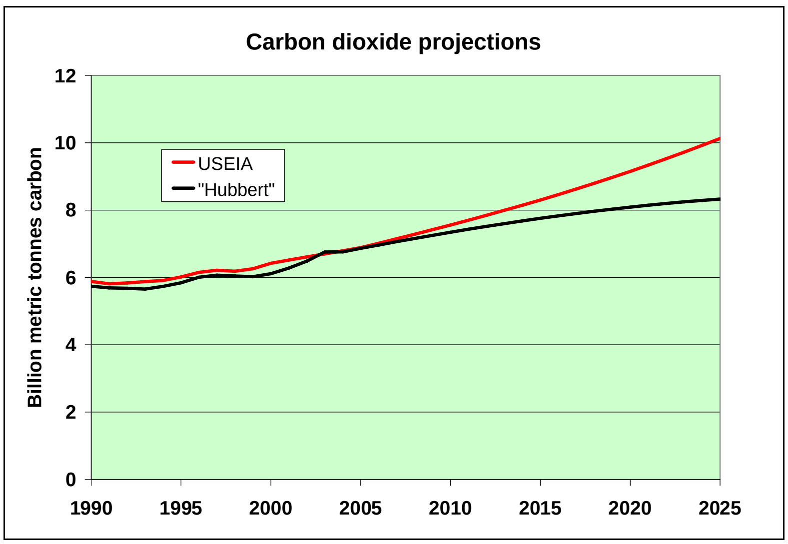

Figure 6-4 Comparison of carbon dioxide emission projections

Accurate measurements of carbon dioxide in the atmosphere have been made since 1959 and there is no doubt that the concentration is increasing, as shown in Figure 6-5.[5]

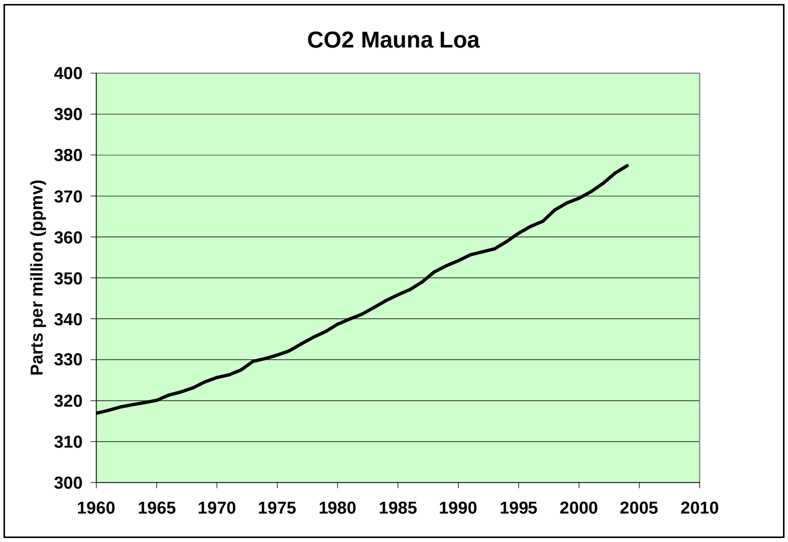

Figure 6-5 Atmospheric CO2 concentrations measured at Mauna Loa, Hawaii

There is also no doubt that the increasing amount of carbon dioxide in the atmosphere is due primarily to human consumption of fossil fuels. There is also no *scientific* doubt that these increases have already raised the temperature of Earth's surface and will continue to do so.

The IPCC has constructed a series of fossil fuel consumption scenarios which are used to examine potential impacts on global climate in this century as shown in Figure 6-6.[6]

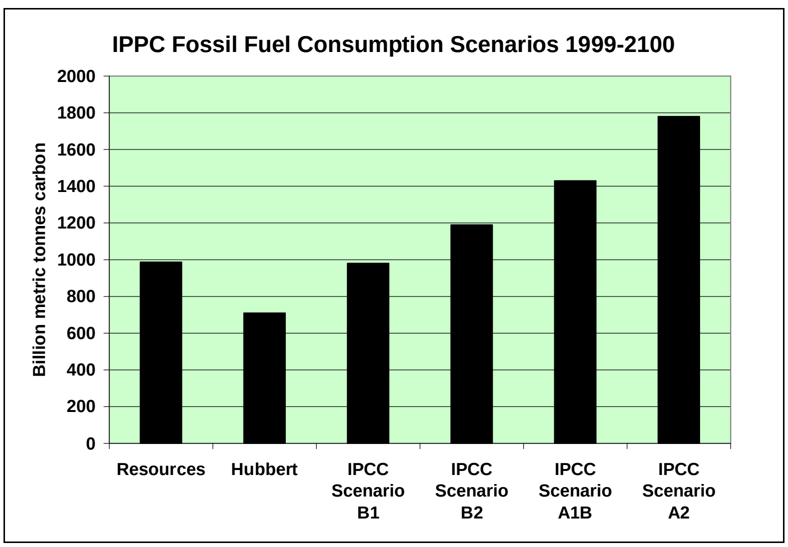

Figure 6-6 Remaining fossil energy resources and consumption scenarios

"Resources" in Figure 6-6 represent all the remaining conventional resources identified in previous chapters converted into metric tonnes of carbon.[7] "Hubbert" represents the sum of emissions shown in Figure 6-3 between 1999 and 2100.

Note that each of the IPCC scenarios shown would require *all* of the currently remaining, available, conventional global fossil resources to be consumed in this century.[8] In addition, the IPCC scenarios assume that additional oil and gas resources, including unconventional resources, will become available during the 21st century.[9] Moreover, IPCC assumes that coal resources available during the century will be more than 7 times existing reserves.

As we have seen, there are three mechanisms by which additional resources become available:

1. Known resources may be increased if reserve growth is greater than currently assumed due to better technology and higher levels of investment;
2. More undiscovered resource may be found; and
3. Unconventional resources may be developed.

The IPCC evidently believes these measures will produce vast quantities of additional fossil fuels in the next century in order to satisfy even the least demanding of the scenarios, Scenario B1.[10] Addition of unconventional fossil resources would expand Figure 6-3 and move the peak to later years.

IPCC participants use carbon dioxide emission scenarios as input to computer models which estimate the rate at which the greenhouse effect increases global temperatures. A thorough discussion of the IPCC assessment process is beyond the scope of this report.[11] A wide variety of different computer models are in use, and all indicate that increasing amounts of carbon dioxide in the atmosphere will increase Earth's temperature. However, the rate of increase varies from model to model, so an average of the results is thought to be more reliable than any single one.[12]

The average global temperature increases in this century projected by IPCC emission scenarios A2 and B2 are approximately 3.1 and 1.6 degrees Celsius (5.6 and 2.9 °F) respectively. Such changes are unprecedented in human history. Moreover, even if atmospheric concentrations of carbon dioxide were to stabilize in 2100, temperatures would continue upward in the next century due to Earth's thermal inertia. The impact on human societies of the climate changes associated with these temperature increases such as sea level rise, precipitation, etc., is impossible to quantify but will certainly be disruptive.

Long term resource scenarios are necessarily only rough estimates. The Hubbert-type scenarios err on the low side, since they are based on estimates of resources thought to be available at approximately current prices using current technologies. The IPCC scenarios appear to err on the high side by assuming that vast new fossil fuel resources will become available at low prices. If the IPCC resource assumption is too high, global warming may be less severe than projected simply because depletion of fossil fuel resources and rising prices will limit the amounts consumed.

Responding to depletion and global warming

The appropriate response to both the threat of global warming and the rapid depletion of fossil energy resources is the same – transition away from reliance on fossil fuels by improving efficiency and developing non-fossil energy resources as quickly as possible. Fortunately, many governments have announced their intentions to make this transition by participating in the Kyoto Protocol. Progress to date has been negligible, however.

Energy resource depletion happens gradually, as indicated in the above analyses. Associated increases in energy costs may happen suddenly, however. In response to limited production of natural gas in North America, prices have quadrupled in the last five years, for example. Average global temperatures are also expected to rise gradually, but regional temperatures may not. There is scientific concern that climate changes may weaken the Gulf Stream over a period of a few years which would sharply *lower* temperatures in Europe. The future of both energy prices and global climate are uncertain.

The uncertainty of future events, even though potentially sudden and catastrophic, makes it difficult for governments to respond aggressively. The costs of inaction are unknown, as are the benefits of action. The cost of any particular action *is* known, however. Politically it is easy to say that something must be done, although the U.S. has yet to admit even that. A commitment to invest huge amounts of money to revamp the world's energy system while energy remains inexpensive is politically very difficult.

Moreover, the enormity of the task ahead is seldom acknowledged. Modern society is tremendously dependent on energy from the fossil fuels consumed, and monumental changes will be required to reduce this dependency significantly. The lack of progress toward the Kyoto Protocol goals provides some inkling of the magnitude of the changes required.

Signatories to the Kyoto agreement pledge to reduce greenhouse gas emissions by an average of 5.2% below 1990 levels by the 2008-2012 time frame, but global emissions of carbon dioxide from fossil fuel consumption have increased more than 15% from 1990 to 2004. By 2010 emissions are projected to have increased by more than 28%.[13]

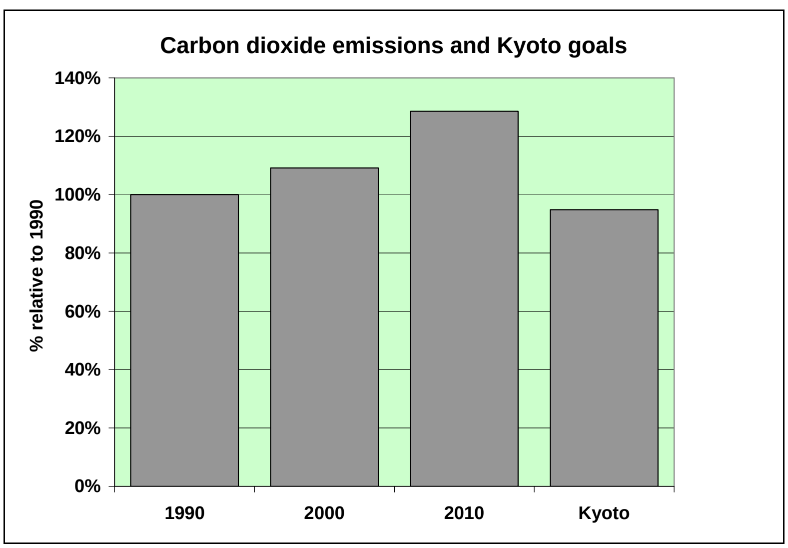

Figure 6-7 Historical and projected emissions of carbon dioxide and Kyoto Protocol goals

If the entire world were to meet the goals agreed to by the Kyoto signatories, by 2010 emissions of carbon dioxide would have to reduced by about one-third from projected levels.[14] In other words, the world would have cut fossil fuel use by one-third in the next five years,[15] an obvious impossibility. Even most Kyoto signatories appear unlikely to meet their goals.

The Kyoto Protocol may have erred by focusing on greenhouse gases in general and not on fossil energy use, giving the mistaken the emission reductions would be easy to make.[16] A more modest and more achievable initial goal would be to stabilize global fossil fuel use at current levels by investing in more efficient energy infrastructure and non-fossil energy resources. Accomplishing even this goal would be difficult and require large amounts of capital.

Investing in energy efficiency and renewable energy resources

A number of exotic technologies have been suggested for reducing carbon dioxide emission, such as nuclear fusion and solar arrays in space. Since these technologies have not been developed, it would be foolish to count on them. Rapid deployment of existing technologies should be considered instead.

An excellent paper published in Science magazine by Stephen Pacala and Raboert Socolow describes a portfolio of 15 existing technologies which could be deployed in various combinations to reduce carbon dioxide emissions.[17] They range from reducing the use of cars to carbon sequestration to expanding nuclear power. Most of the most feasible technologies involve improving energy efficiency and expanding the use of renewable energy resources.

Many energy efficiency improvements are “cost effective” since the capital cost of the efficiency measure is repaid over the measure lifetime by reducing energy costs. Nevertheless, large amounts of capital are required to make the improvements. For example, California now invests nearly one-half billion dollars annually in cost-effective electric energy efficiency measures. The capital cost of efficiency improvements worldwide in all energy sectors sufficient to stabilize fossil fuel consumption is unknown. A reasonable “guesstimate” would be global investment on the order of one-half trillion dollars annually, comparable to supply-side investment in the energy sector, about 2% of total world economic output.[18]

Investment in facilities to generate electricity from wind energy now is also cost-effective compared to generation from fossil fuels, but as with efficiency, the capital costs of massive development are not trivial.[19] An estimated $100 billion annually would be required merely to avoid the anticipated global growth in fossil fuel consumption used for electric generation.[20]

The only currently available, sustainable energy resource with long term potential to replace all fossil fuels is the sun. While there are many applications in which solar heating is currently cost-effective, the “holy grail” of solar energy technology is inexpensively generated electricity. Solar electricity could be used to extract hydrogen from water which could then provide the basis for a variety of fuels to replace fossil fuels in all applications.[21] Unfortunately, solar electricity is also capital intensive and is likely to remain so. Global investments in solar power on the order of one-half trillion dollars annually would be required merely to offset growth in fossil consumption for electric generation.

Approximately one-quarter of global fossil fuel consumption is for electric generation[22]. The rough estimates above indicate that stabilizing fossil fuel use at current levels will require investments on the order of a trillion dollars annually. To make significant *reductions* in global fossil fuel use will require much more, perhaps as much as several trillion dollars annually.

Investments in efficiency and renewable energy resource development would offset some, but not all, investment in fossil energy resources. Nevertheless, the amount of capital that will be required to significantly reduce fossil fuel consumption is staggering, perhaps 10% of global economic output.

Conclusion

The growing global dependence on fossil energy in the last century is unprecedented in human history. Now for the first time we are faced with the prospect of dwindling fossil resources. The effort to reduce reliance on fossil fuels and to minimize global warming also will be unprecedented. Fortunately, decreasing the combustion of fossil fuels can solve both problems.

No solution is possible until the scope of the problem is acknowledged. The adoption of carbon dioxide reduction goals by a variety of cities, states and nations is an important first step. Even a journey of a thousand miles begins with a first step. The next step is to develop strategies for deploying technologies which will reduce fossil fuel combustion and carbon emissions by the required amounts.

The last, most crucial, and politically most difficult step is to develop mechanisms for shifting adequate amounts of capital from current uses into clean energy technologies. The world's energy problems can be solved with technologies that are available today. What is currently missing is the political will to provide the capital needed to deploy these technologies on a scale sufficient to meaningfully reduce the global dependence on fossil fuels.

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[1] USEIA IEO 2004, figure 14.

[2] The small differences in the two projections prior to 2005 arise from slightly different data formats and should be ignored.

[3] Carbon constitutes 12/44 of the weight of carbon dioxide. One metric tonne equals about 1.1 "short" tons, the customary unit used in the U.S..

[4] USEIA data from IEO 2004, figure 72, converted into metric tonnes of carbon.

[5] Keeling & Whorf, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory. Available at http://cdiac.esd.ornl.gov/trends/co2/sio-mlo.htm.

[6] IPCC scenario data has been taken from Figure 7.5, Climate Change Synthesis Report, available at www.ipcc.ch/present/graphics/htm.

[7] The IPCC chart from which Figure 6-6 scenario data were taken also includes values for conventional and unconventional fossil reserves and resources. The source for these data are found in the "IPCC Special Report on Emission Scenarios", Chapter 3, Section 3.4.3.1. In addition to the resource estimates used in earlier chapters of this report, the IPCC has included resources that may become available over the next century as a result of technological developments. For consistency in this report, we will continue to use the resource estimates identified in previous chapters.

[8] IPCC Third Assessment Report Synthesis.

[9] The IPCC oil and gas resource assumptions have been challenged as unrealistically large. (See "'Too little' oil for global warming", New Scientist, 5 October, 2003.) However, to some extent all

three energy resources are interchangeable. Coal can be converted into gases to fuel combined cycle power plants or can be further liquefied to make transportation fuels, for example. Even though the IPCC assumptions of oil and gas that will be available in this century appear to be unreasonably large, a shortage of oil or gas could conceivably be overcome by burning additional coal if IPCC's assumption of very large coal resources is correct.

[10] As seen in earlier chapters, it is incorrect to assume that all resources will be burned up by 2100 with nothing left for the 22nd century. In order to satisfy any of the IPCC scenarios, resources must be considerably more extensive than what is burned by 2100.

[11] The reader is encouraged to visit the IPCC web site for further details at www.ipcc.ch.

[12] Model outputs can be found at http://www.grida.no/climate/ipcc_tar/wg1/350.htm#9313.

[13] USEIA IEO 2004, Table 72.

[14] The Kyoto signatories set goals for themselves and not for the world as a whole. The U.S. and Australia, two major sources of carbon dioxide have not signed the Protocol. Moreover, the goals apply to all greenhouse gases, not just to carbon dioxide. The discussion here assumes that carbon dioxide is reduced proportionally to other greenhouse gases.

[15] Fossil energy consumption reductions may not exactly equal carbon dioxide reductions if the mix of fuels changes.

[16] It should not be implied that greenhouse gases other than carbon dioxide, such as methane, do not play an important role in global warming and should be ignored. However, emissions from fossil fuel use is the "800 pound gorilla" due to global dependence on fossil energy.

[17] A. Pacala and R. Socolow, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies", *Science,* v.305, pp 968 – 972, 13 August 2004.

[18] The crude estimate is based partly on California's experience with electric efficiency. Although the state invests about one-half billion dollars annually in this sector, electric consumption in the state continues to increase. Efficiency improvements in some energy sectors may be considerably more expensive.

[19] Although the capital costs of efficiency and renewable energy development are high, these costs are offset by the absence of expenses for fuel.

[20] This estimate is based on installed costs of $1000 per kilowatt and ignores the potential cost of transmitting electric from windy areas to urban consumers.

[21] Hydrogen is found only in combinations with other elements, such as oxygen in H_2O. To liberate hydrogen from its chemical bonds requires energy from some primary source. Hydrogen should therefore be thought of as an energy storage mechanism, rather than a primary resource. Much of the current hype about hydrogen ignores this fact.

[22] USEIA IEO 2004, Table 16.