LONG TERM CRUDE OIL SUPPLY AND PRICES

CONSULTANT REPORT

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EXECUTIVE SUMMARY

Background

Recent energy forecasts have predicted a substantial increase in crude oil demand. The Energy Information Administration (EIA), the International Energy Agency (IEA), the Organization of Petroleum Exporting Countries (OPEC), and the European Commission project global growth in demand will range from 1.6 to 1.9 percent annually with demand reaching as much as 120 million barrels per day (mmb/d) in 2030.

These forecasts assume that petroleum supplies will be available at reasonable prices to meet this demand and that global investments in petroleum infrastructure (including exploration, production, refining, and transportation) increase during the same period to $3.1 trillion. These forecasts also raise concerns about global oil reserves and resources, the timing to peak oil production, the future distribution of global oil production, as well as questions about optimal investment levels and world refinery capacity. Gaps, inconsistencies, and lack of transparency in world petroleum demand and supply data have heightened these concerns.

The West Coast has historically been relatively self sufficient in petroleum supplies. During the last decade, however, California's reliance on imported crude oil has grown, reflecting declining state oil production, population increases, and rising demand for petroleum products, particularly transportation fuels. The California Energy Commission's (Energy Commission) forecasts project a steady growth in demand for petroleum based transportation fuels.

Under current conditions and technology, California will consume more petroleum and become more reliant on imports of crude oil and products. World oil markets and the ongoing debate over the volume, availability, and future of conventional crude oil are of concern to the state.

Two contrasting views have emerged about future conventional crude oil supplies:

- **Low Production Outlook.** In this view, global conventional crude oil production is at peak or near peak production and discovery of new conventional oil reserves cannot keep pace with high rates of production decline in existing fields. While substantial worldwide oil resources remain to be developed, future oil field discoveries will be smaller, more costly to find and produce, and subject to rapid production decline.

- **High Production Outlook.** In this more optimistic view of world oil supply, a substantially larger undiscovered resource base and new and emerging technology allow the discovery and development of new oil reserves to exceed production decline in established fields. The distinction between conventional and non-conventional oil becomes less important as new technology expands production in challenging environments.

Both viewpoints agree that world oil resources are finite and, in the face of rising global demand, world production is likely to peak in this century. The distinction between the two viewpoints results from different outlooks on the global resource base, the role of technology development, and the cost of future oil exploration and development. This report addresses both the Low and High outlooks for future oil production.

The Report

The Energy Commission retained ICF Consulting LLC (ICF) to examine world crude oil supplies and prices, the timing of peak oil production and the likelihood of supply constraints in the period from the present to 2050. ICF also reviewed other factors (geopolitical events, spare production capacity, hedge fund activity, etc.) for possible impacts on prices.

This report examines the estimates of remaining conventional and unconventional crude oil resources. The analysis compares the outcomes of a range of resource base and supply cost assumptions, which reflect a variety of possibilities from the low oil production outlook to the most optimistic high oil production outlook. The report also examines the impact of constraints on future greenhouse gas (GHG) emissions. This report does not attempt to predict future world oil supply. Rather, the report allows the Energy Commission to assess the potential impacts of various resource, production and demand assumptions on the availability and price of crude oil supplies. Throughout this report all prices represent the OPEC basket (calculated from a volume-weighted basket of OPEC's main export crude oils) and are quoted in year 2000 dollars.

The model used for this study is an adaptation of the Climate Change Risk Assessment Framework (CCRAF) developed for the U.S. Environmental Protection Agency (EPA) by ICF. The CCRAF model is a long term stochastic world energy model that was adapted for this study for the current time period to 2050.

Modeling Future Uncertainty

Modeling future energy supply is marked with many uncertainties. The main strength of the CCRAF is that it acknowledges these uncertainties; stochastic models like the CCRAF are designed to test the impact of uncertainty. Because many of the inputs are subjective and uncertain, the flexible structure of the CCRAF model allows inputs to be changed by the analyst to compare alternative possibilities (cases). Results are reported in ranges and probabilities, allowing the analyst to examine a suite of possible outcomes.

The uncertain input variables for CCRAF include parameters such as energy resources, energy extraction costs, population and economic growth rates, and greenhouse gas emission targets. Many of the key input variables are defined not as single numbers but as random variables with probability distributions that define the probability that the variable will fall within a certain range of values. For practical purposes, some “fixed” assumptions about the future are necessary. For example, this analysis assumes that Gross Domestic Product (GDP) will grow steadily, and that geopolitical tensions in the oil producing countries will be resolved over the long run so there are no catastrophic disruptions in production.

The output from the CCRAF model includes energy consumption, production, and prices, greenhouse gas emissions, emission allowance charges, and global temperature change. Typically, more than one thousand simulations are executed where key input variables (such as resources, costs, population, etc.) take on different values. The outputs (such as energy consumption, prices, and production) are produced for each simulation, which means that there are more than a thousand sets of results for each output parameter. Consequently, the key results can be presented as averages or frequency ranges. For example, instead of reporting one number, results may be presented as ranges of output values and the percentage of output values in each range. This approach allows examination of a range of outcomes.

World Oil Resources and Peak Production

ICF relied on various sources to estimate world oil and natural gas resources including the United States Geological Survey (USGS) *2000 World Petroleum Assessment,* current USGS and U.S. Minerals Management Service (MMS) assessments of the United States’ conventional crude oil and natural gas resources, and British Petroleum’s (BP) annual assessment of proved reserves.

Conventional Crude Oil, Natural Gas, and Natural Gas Liquids

The definitions of conventional oil and natural gas assumed for this analysis correspond to conventional oil and natural gas resources included in the USGS assessments and BP’s annual assessment of worldwide proved reserves. Conventional crude oil and natural gas liquids are defined as oil produced from underground reservoirs by means of conventional wells. Included in the conventional category are oil produced from offshore deepwater fields, heavy oil reserves in Venezuela under active development, and oil currently produced from Arctic regions. Although not typically considered conventional crude oil, most current world assessments of crude oil reserves also include 11 billion barrels of Canadian oil sands under active development. Non-conventional oil includes oil shale, extra heavy oil deposits not under active development, oil sands or shallow bitumen (tar sands) not under active development, and synthetic crude products derived from oil sands.

Conventional natural gas resources are defined in the USGS assessments based on the characteristics of a reservoir. Non-conventional natural gas includes coal bed methane and continuous accumulations of natural gas in low permeability sandstone, chalk, and shale deposits (tight gas and gas shale). The CCRAF model inputs for non-conventional natural gas also include estimated resources from two extremely large, but highly speculative natural gas resource types – methane hydrates and natural gas dissolved in deep, geopressured aquifers.

Table 1 summarizes estimated world conventional crude oil and natural gas reserves and resources. The CCRAF model results discussed in this report show that the estimated size of the conventional oil resource base has a large influence on future primary energy use.[1]

Table 1: Estimated World Conventional Crude Oil and Natural Gas Resource Base

	Crude Oil			**Natural Gas**			**Natural Gas Liquids**		
	Billion Barrels			**Trillion Cubic Feet**			**Billion Barrels**		
	F95	**Mean**	**F5**	**F95**	**Mean**	**F5**	**F95**	**Mean**	**F5**
Undiscovered Resources – non U.S. *(includes estimated reserves growth)*	369	1,253	2,299	2,278	7,939	14,938	69	249	516
Undiscovered Resources-Total U.S. *(includes estimated reserves growth)*	139	171	211	812	982	1,215	19	21	23
Proved Reserves Year end 2003	1,148			6,205			NGL included in crude oil reserves		
Totals	**1,656**	**2,572**	**3,658**	**9,295**	**15,126**	**22,358**	**88**	**270**	**539**

Notes: F95 represents a 95 percent probability of at least the amount shown. F5 represents a 5 percent probability that undiscovered resources will at least equal the amount shown.

Peak Oil Production

The concept of peak oil production developed as a result of observations of the lifetime production histories of oil fields and oil producing regions. After oil production begins in a field or an oil-producing basin or region, production will increase annually to some maximum capacity, after which production from the field, basin, or region begins an irreversible decline. While the concept of peak oil production acknowledges the ultimate depletion of a finite resource, the observation and timing of peak oil production is a dynamic process that depends on such factors as demand, the size of the resource base, technology, and economic factors such as oil price and production costs.

For example, on a regional or basin scale, the size of the resource base is relevant to the concept of peak production because after peak production is reached, the remaining resources, while still substantial, cannot be converted to reserves in sufficient quantity to sustain the peak production rate. Fewer resources are discovered in smaller and smaller accumulations. The application of new technologies may expand the resource base, leading to more reserves, or new technology may lower the cost of producing the remaining reserves. In either case, the application of new technology is generally observed to increase ultimate recoverable resources, which may or may not have a discernible impact on the level and timing of peak production.

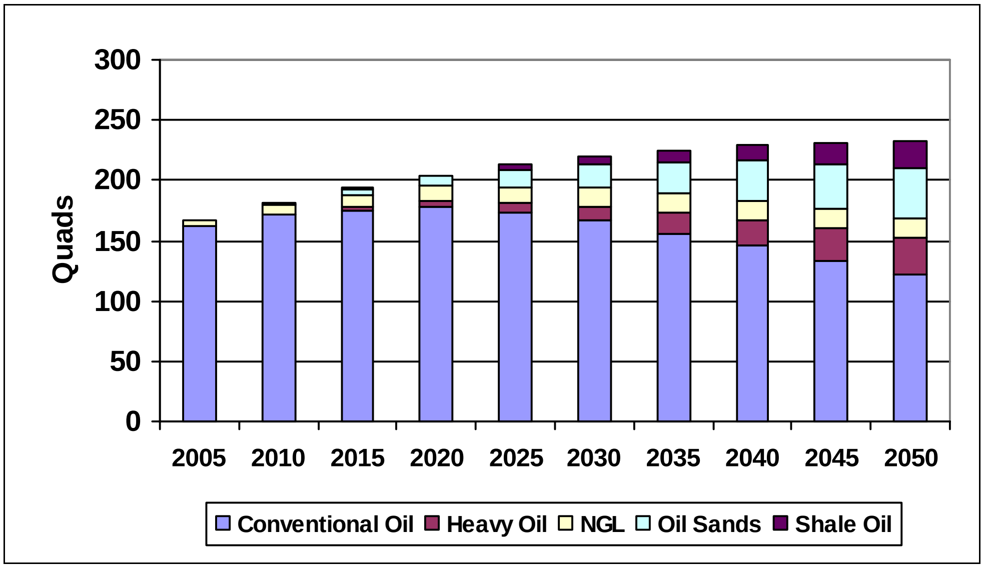
The concept of peak oil production depends on the scale of the observation. For example, new technologies for exploration and production of deepwater areas have resulted in oil production from a new category of offshore petroleum resources, which will have its own production profile and timing of peak production. When viewed on a global scale as just one part of the total world petroleum resource base, the deepwater oil and gas resources exploited using these new technologies expand the world's recoverable resources and contribute to pushing the timing of global peak production further out to the future.

The timing of global peak oil production is of growing concern worldwide, as historic oil producing regions throughout the world are increasingly recognized as being at or past peak production for conventional crude oil. For example, onshore oil production in the lower 48 United States is widely acknowledged to have reached peak production in the early 1970's. Post-peak oil production in mature producing regions is characterized by steadily declining production. Although large volumes of oil still remain to be produced, more effort is required to locate and produce ever-smaller oil accumulations. New producing zones and enhanced oil recovery technologies may boost reserves in existing fields and slow the rate of production decline, but do not reverse the production decline.

Crude Oil Production – Selected Model Results

Figure 1 shows that for the model Reference Case, conventional oil production peaks in the 2020 time frame and then slowly declines. Following the peak of conventional oil production, total world oil production is increasingly supplemented by non-conventional oil resources such as extra heavy oil, oil sands, and shale oil. The model Reference Case assumes no GHG emission controls but increasing limits on sulfur dioxide (SO_2) and nitrogen oxides (NO_x). The Reference Case also assumes a conventional crude oil resource base corresponding to the mean U.S. Geological Survey assessment of world crude oil resources.

Figure 1: Average Crude Oil Production by Resource Type, Reference Case



If either higher or lower conventional crude oil resource cases are assumed, the crude oil production story will be different. Figure 2 and Figure 3 show crude oil production for low and high estimates, respectively, of world crude oil resources.

Figure 2: Crude Oil Production by Resource Type, Low Conventional Oil Resources

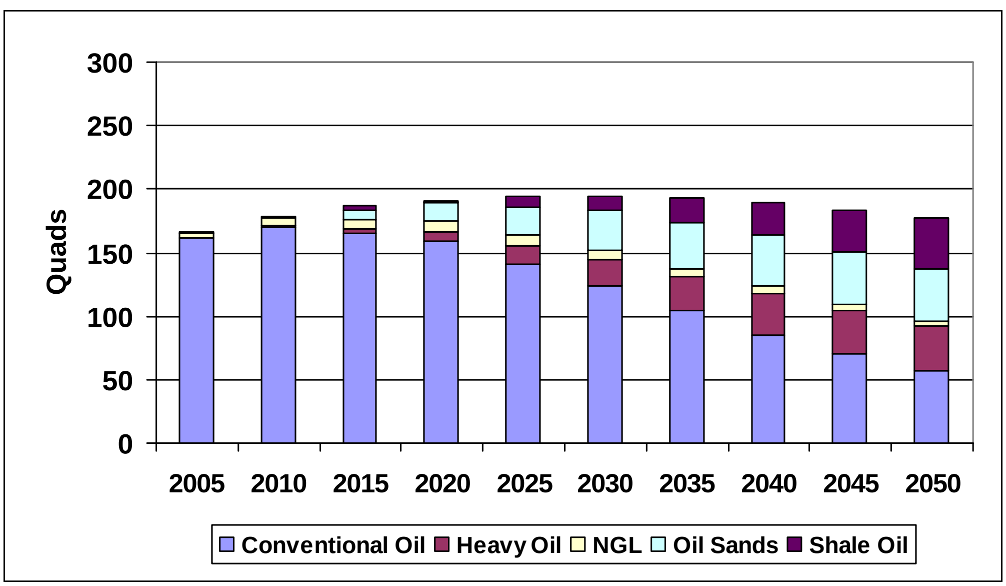
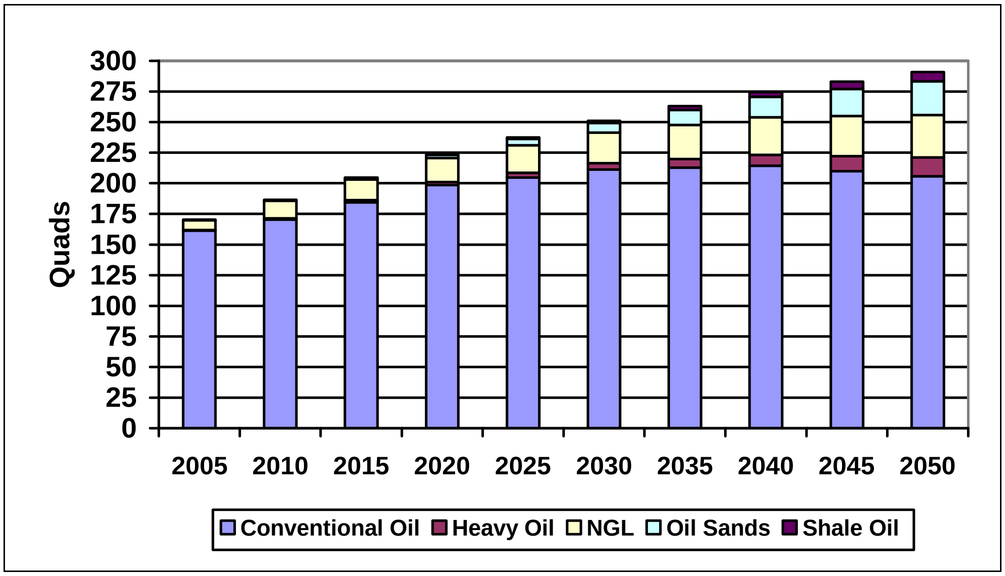


Figure 3: Crude Oil Production by Resource Type, High Conventional Oil Resources



For the low resources case, conventional oil production peaks around 2010 and total crude oil production peaks around 2030. With high conventional oil resources, conventional oil production does not peak until 2040.

Figure 4 assesses the effects of alternate assumptions of conventional oil resources on crude oil production in 2050. In the low conventional resource case, the production of non-conventional oil increases (e.g., heavy oil, oil sands, and shale oil). Expected higher prices also lead to lower overall demand for oil. As the estimated size of the conventional resource base increases, total oil production and conventional oil production also increase. Note that the CCRAF model does not fully capture potential constraints to future production of non-conventional oil such as restrictions on water, natural gas, and land use; therefore the model output represents an optimistic view of the future availability of non-conventional oil.

While the timing and volume of peak oil production are sensitive to the size of the resource base, Figure 5 shows that the most optimistic assessment of conventional crude oil resources does not extend the timing of peak oil production by more than thirty years past the oil production peak estimated for low resource cases. The size of the resource base, however, has a significant impact on the estimated volume of oil produced at peak production. This in turn has a substantial impact on the outlook for crude oil production at year 2050.

Figure 4: Crude Oil Production at 2050, Reference Case

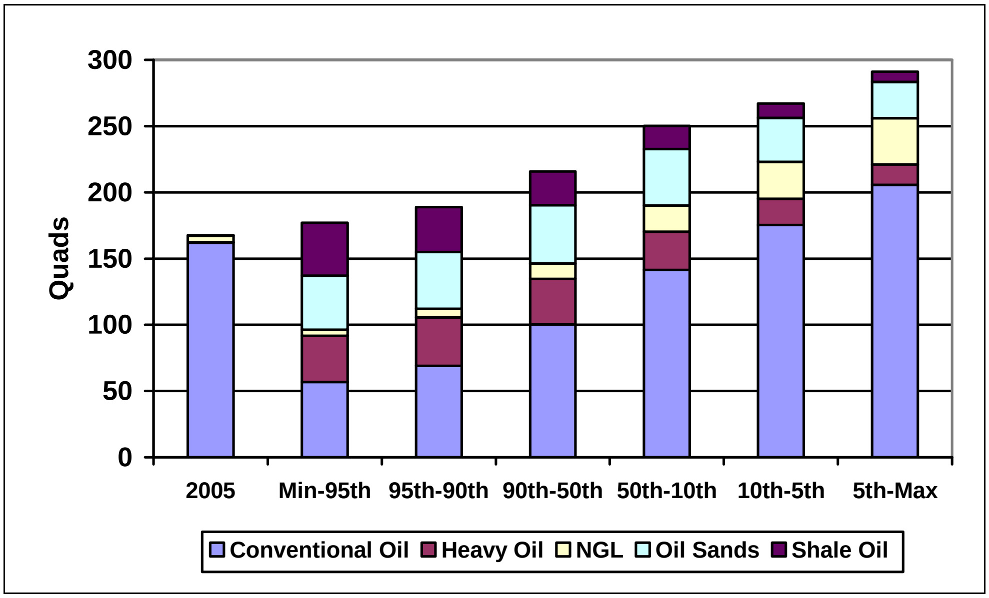
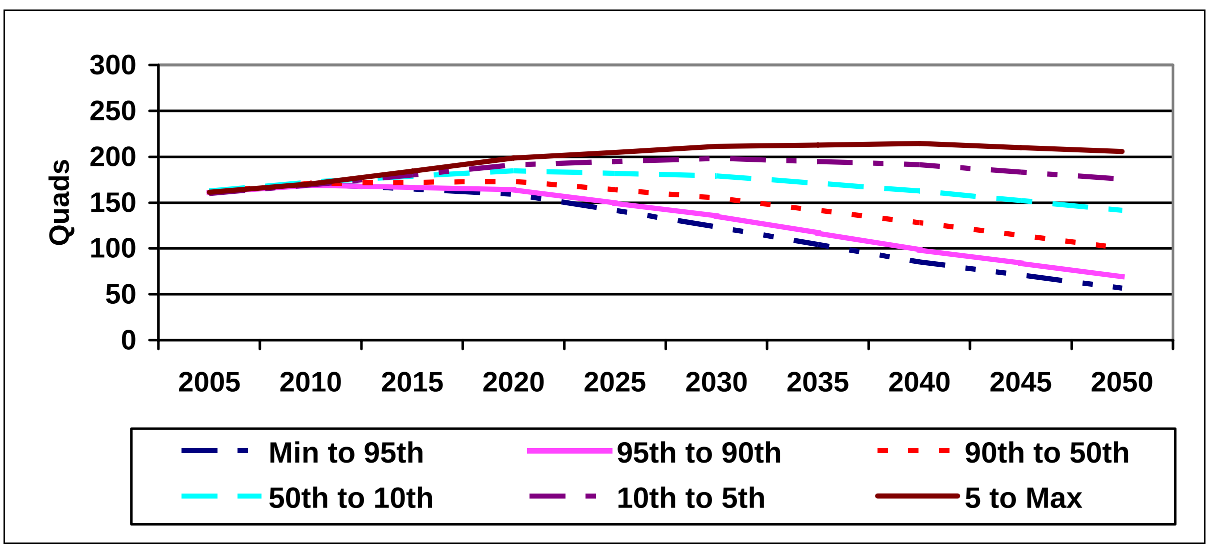


Figure 5: World Conventional Oil Production by Resource Grouping, Reference Case



For the lowest estimated crude oil resources, peak conventional oil production is approximately 169 Quads, or 80 million barrels per day (mmb/d) in 2010.[2] By 2050, conventional oil production declines to 57 Quads (27mmb/d). The 50th to 10th percentile resource case, which brackets the mean USGS resource assessment for conventional oil, has production peaking around 2020 at approximately 185 Quads (87 mmb/d); oil production at 2050 is approximately 141 Quads (67 mmb/d).

Peak oil for the 10th percentile resource grouping is 198 Quads (93.6 mmb/d) at 2030. By 2050, conventional oil production is estimated to be 175 Quads, or 83 mmb/d, which is a conventional oil production scenario comparable to current crude oil production. This CCRAF result suggests that if conventional oil production in 2050 is comparable to current levels, a conventional oil resource base in the range of 3300 billion to 3700 billion barrels is required. Projected conventional oil production at 2050 is estimated to be 206 Quads (97 mmb/d) for the highest estimated resource grouping, which assumes a resource base of more than 3700 billion barrels.

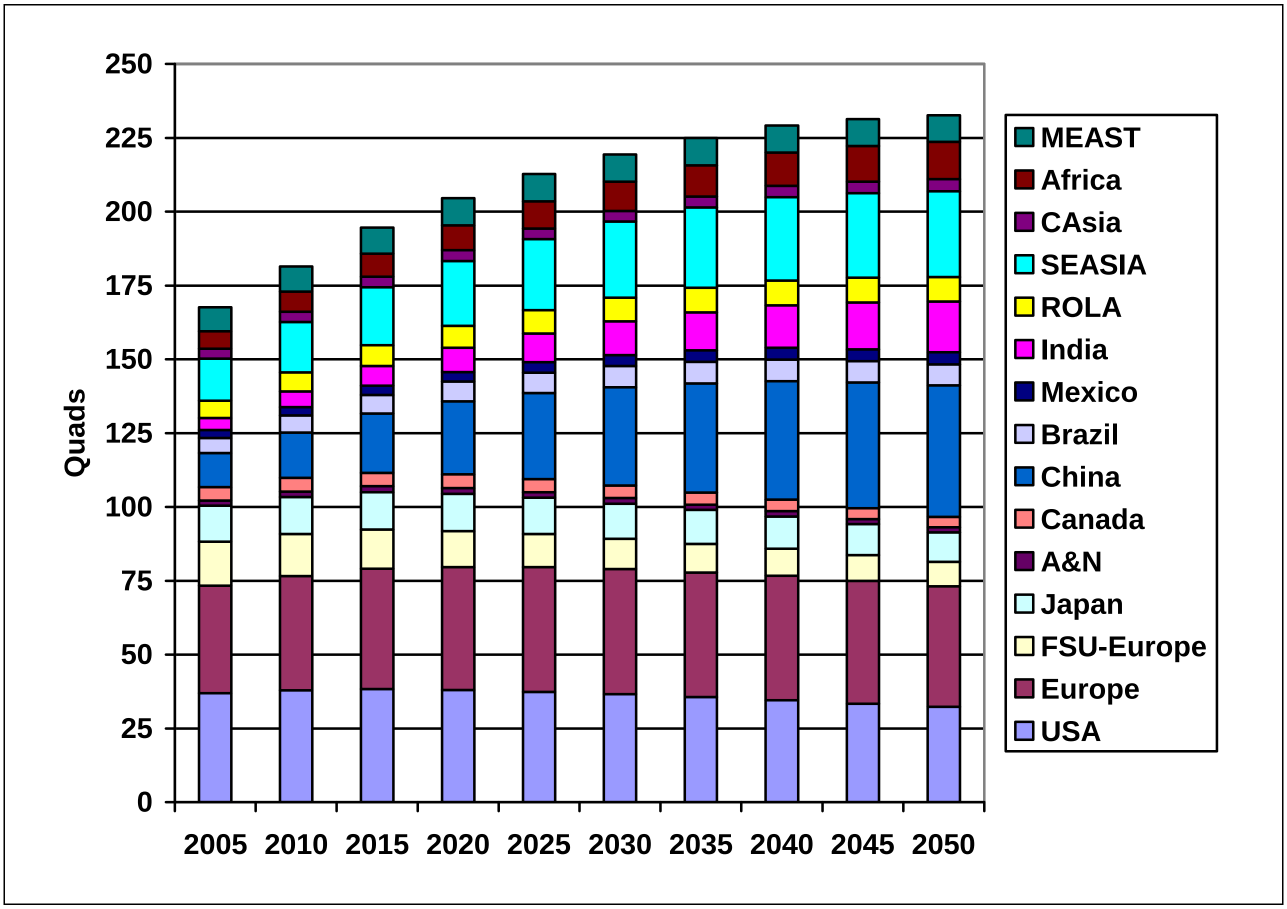
Crude Oil Demand - Potential Impact of Greenhouse Gas Emission Limits

Figure 6 shows projected crude oil demand for the Reference Case.[3] Growth in demand is greatest in developing economies. Growth in production depends on resource endowment and demand, and in the absence of greenhouse gas targets that reduce demand, conventional crude oil production is never sufficient to meet demand, even assuming the maximum resource case.

If the conventional crude oil resource base is assumed to correspond approximately to the USGS mean resource assessment, at peak conventional crude oil production in 2020, the model projects a shortfall of about 20 Quads or 9.4 mmb/d of crude oil demand. The shortfall would presumably be met by non-conventional crude oil.

When greenhouse gas concentration targets are assumed, moderate carbon dioxide (CO_2) emission reduction targets yield significant reductions in coal and oil and some reductions in natural gas demand compared to the Reference Case. Crude oil demand is reduced by 4 percent at 2020 and by 40 percent at 2050. The most stringent CO_2 reduction target yields significant reductions in all fossil fuels. Crude oil demand is reduced 5 percent at 2020 and by 2050 is reduced by two thirds. The minimum reduction in greenhouse gas emissions yields a 4 percent reduction in crude oil demand at 2020 and 12 percent reduction in demand at 2050.

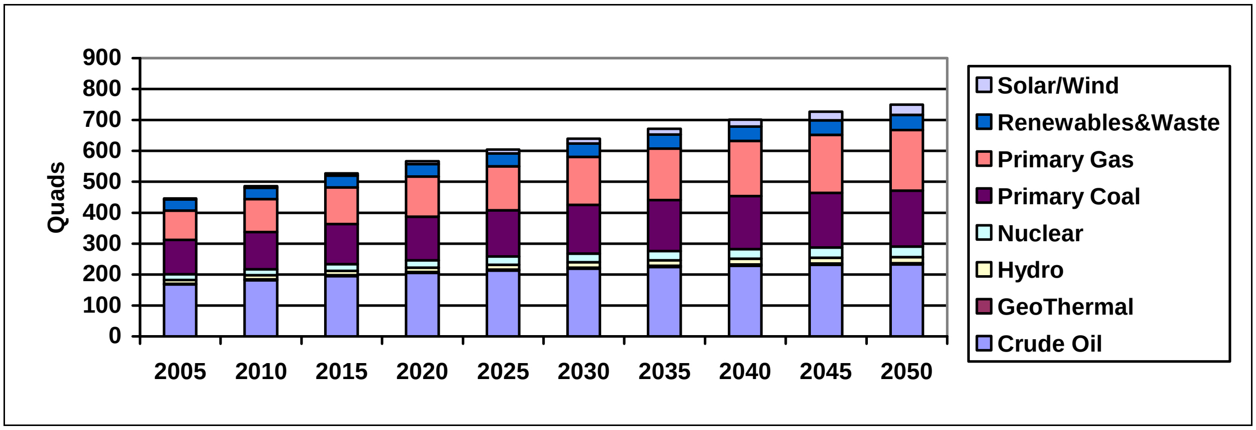
Figure 6: Average Total Crude Oil Demand by Region, Reference Case



Primary Energy Production

Figure 7 illustrates average primary energy production by energy type for the Reference Case. In the absence of greenhouse gas emission control targets, crude oil production from conventional plus non-conventional resources provides 37 percent of world energy needs in 2005 and slightly less than 36 percent at 2020, around the time of projected peak conventional oil production. By 2050 the crude oil contribution to world energy production drops to 31 percent. The contribution from natural gas is 21 percent in 2005, rising to 23 percent in 2020, and 26 percent in 2050. Primary coal provides 25 percent of world energy production in 2005. This remains unchanged throughout most of the model period; coal provides 25 percent of world energy production at 2020 and at 2040. By 2050 the contribution from coal declines slightly to 24 percent.

Figure 7: Average Primary Energy Production by Energy Type, Reference Case



World crude oil production for the Reference Case, including both conventional and non-conventional oil, is projected to be 167 Quads or 28.8 billion barrels (approximately 79 mmb/d) in 2005. At 2020, conventional oil production is expected to peak, and total crude oil production is projected to be 204 Quads or 35 billion barrels (96 mmb/d). Total crude oil production continues to increase, and by 2050 projected total crude oil production is 229 Quads or 40 billion barrels (110 mmb/d).

Effect of Short Term Market Intangibles

Market intangibles are parameters that influence short term prices (24 months or less) and can also have a substantial impact on price volatility. The most important short term market intangibles include:

- Stock levels
- Spare production capacity
- Investment levels
- The decline of the dollar
- The role of hedge funds
- Market structure
- Geopolitical factors
- Strategic petroleum reserves

The impact of market intangibles is often seen in price effects. Some of the parameters have near term effects, some longer term. For example, Hurricane Ivan had an immediate impact on oil supply and prices in the United States. On the other hand, the effects of investment levels can be spread over many years. For example, major expansions at refineries can take up to four years to complete, and ten years or more may be needed to develop major new oil reserves in frontier areas.

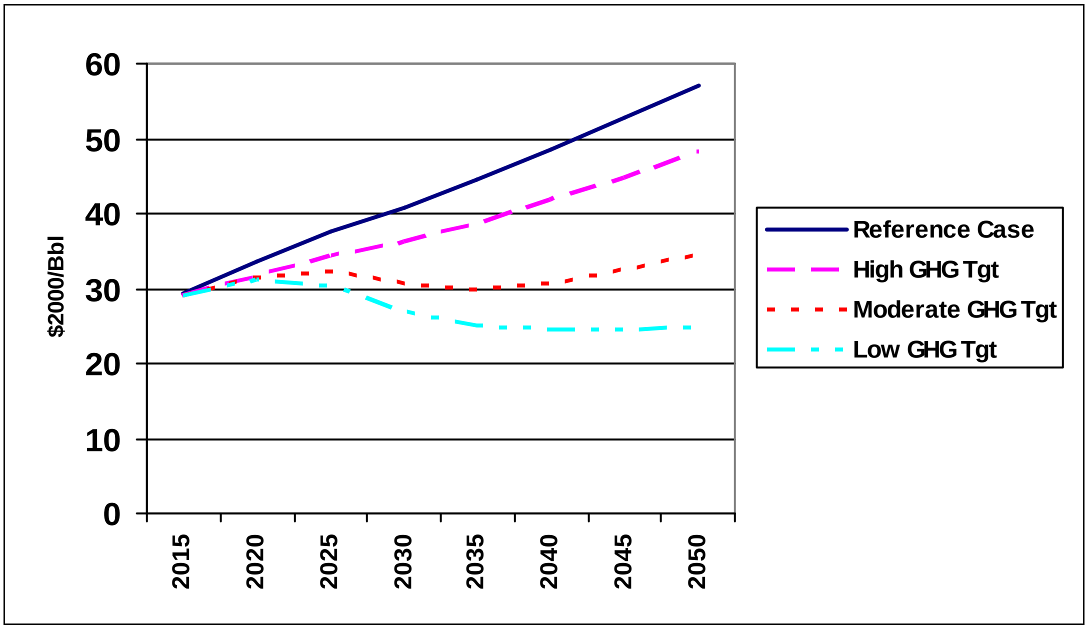
Short term market intangibles contribute to the volatility of the current and near term crude oil market. Over the long term of a decade or more, many of the problems represented by intangible market parameters are expected to be resolved and equilibrium restored to the market. Nevertheless, oil demand is expected to grow rapidly during the next decade and markets are expected to remain tight resulting in high and volatile prices. An example of the impact of a key short term market parameter is Saudi Arabia's announced expansion of production capacity to12 mmb/d, which is not expected to come on line until after 2009. In the meantime, spare production capacity is not expected to expand during this period beyond the 1.5 mmb/d to 2 mmb/d already announced by Saudi Arabia. This will likely keep the market volatile, as geopolitical tensions in the Middle East are not expected to be resolved during the next decade. While the high oil prices of the last few years have stimulated increased investment in petroleum infrastructure, the levels of investment to expand oil production capacity have not been as much as expected. For example, some companies are instead buying back stock and increasing stock dividends[4], and the refining sector is making investments to meet the tightening sulfur restrictions rather than to expand capacity.

Crude Oil Pricing

ICF expects that very high oil prices will continue for several years before current market and geopolitical events resolve themselves and prices decline to long term equilibrium prices. The CCRAF results suggest that while the low oil prices of the 1990s are indeed possible, they are not likely. However, by 2015 crude oil prices are expected to decline as production increases and demand dampens in response to short term high prices. After 2015, oil prices again increase through 2050. If no greenhouse gas emission targets are assumed, crude oil prices in 2050 vary from $34/bbl for the highest resource case to $87/bbl for the lowest resource case, with a median of $50/bbl ($2000). The crude oil price at 2050 is $57/bbl for the Reference Case (assumes no GHG emission targets and conventional oil resources corresponding to the USGS mean resource assessment.)

The high prices correspond to a combination of several factors including low conventional oil resources, higher than expected extraction costs, high demand for petroleum products, and high costs for competing energy sources. Low prices correspond to a combination of high conventional oil resources, lower extraction costs, lower demand for petroleum products in relation to supply, and lower costs for competing energy sources. Figure 8 shows the possible impact of GHG policy options on crude oil prices. Stringent greenhouse gas emission targets result in significant reductions in demand for crude oil compared to the Reference Case, which lowers the market price over time. Reduced crude oil demand results in lower prices and less production from non-conventional crude oil sources such as oil shale.

Figure 8: Average Crude Oil Prices for the Reference and Environmental Cases



Implications for California

The Reference Case presents a world in which the average demand for fossil fuels is high, and meeting this demand requires increasing production of non-conventional oil resources. The greenhouse gas policy cases present a world in which average demand for fossil fuels slowly declines as a function of the stringency of the greenhouse gas emission controls.

The two cases are extreme: either no greenhouse gas emission controls or global greenhouse gas emission controls. A more likely case would be some mix of the two. Actual long term equilibrium oil prices are likely to be less than forecast in the Reference Case but somewhat higher than prices under the global greenhouse gas control cases.

The model analysis assumes that resources exist to support the Reference Case. In fact, the level of investment necessary to meet the requirements of the Reference Case may not be made, either by the international oil companies (IOCs) or by the OPEC countries because of major geopolitical barriers and the price volatility of the market. Both of these factors are examined in Chapter 4. This is not to say that demand could not be met, but it would be difficult and probably at a higher price.

Reference Case Impact

In the Reference Case, crude oil prices are assumed to stabilize between 2010 and 2015 in the range of $30 per barrel. Crude oil prices are then expected to increase gradually from 2015 onwards. Although the industrialized economies such as the United States and California have essentially retooled their economies so that oil does not have as large an impact as in the past, consistently higher prices will exert downward pressure on demand in all sectors excluding transportation. Consequently, growing demand for hybrid vehicles and/or other new transportation technologies is expected. Transportation demand for petroleum continues to increase but the rate of increase is expected to be lower, driven by the price elasticity of demand.

California imports crude oil from many countries, with the largest volumes coming from Saudi Arabia, Ecuador, and Iraq. In the Reference Case, imports are expected to continue but with a shift towards domestic and Canadian non-conventional crude oils. The planned pipeline in Canada to its western coast would facilitate the movement of Canadian syncrude to California.

Substantial untapped non-conventional oil resources in the western United States theoretically should also benefit California. While the resources are known, however, there may be other environmental and land use constraints on production. For example, restricted water availability in the Rocky Mountain region may ultimately limit production of shale oil. When these additional constraints are considered and combined with the concern that global oil prices may not stabilize because geopolitical issues are not resolved, there likely will be constraints on the availability of crude oil. High prices, of course, will ultimately depress demand.

Impact of Greenhouse Gas Emission Controls

Under a moderate restriction on greenhouse gas emissions, world crude oil use by 2050 (including conventional and non-conventional resources) is reduced to 141 Quads (67 mmb/d) compared to the 233 Quads (110 mmb/d) in the Reference Case. This is predominantly driven by global limits on CO_2 through emission allowance charges, which increase the cost to consumers and reduce prices to producers. By 2050, average crude oil prices are forecast to decline from more than $50/barrel ($2000) in the Reference Case to $34.70/barrel for the moderate GHG target. Although fossil fuels are more constrained under the moderate GHG policy scenario, oil prices do not retreat to the historic level of $20/barrel. Crude oil prices fall to the low twenties only under the most stringent greenhouse gas emissions target.

Under this combination of cases, California will (1) consume less primary energy in general, (2) consume less oil and gas, but consume more solar/wind/renewables, and (3) become increasingly dependent on the Middle East for its imported crude oil. Compared to the Reference Case crude oil prices will fall about 39 percent on average by 2050, although they will still be above $30/barrel in year 2000 dollars. If the GHG targets are not adopted globally, crude oil prices will likely drift up towards those of the Reference Case.

California is facing both long term and short term petroleum supply challenges. While finding sufficient crude oil for its refineries is a long term concern, demand for transportation fuel will grow over the next decade and the availability and sources of petroleum products of the right specifications will be an increasing challenge. More products will be imported from new and/or expanded refineries in Asia and the Middle East and increased product imports will bring pressure on California’s petroleum infrastructure. If California’s product specifications continue to be more stringent than elsewhere, constraints on the availability of these products can be expected. If California’s import volume is large enough, overseas refineries may make the investment to supply California product specifications and long term product contracts may emerge. Until that happens, continued supply vulnerability and price volatility are to be expected in the California product market.

CHAPTER 1: INTRODUCTION AND BACKGROUND

Introduction

Recent energy forecasts have predicted a substantial increase in oil demand. The current *Annual Energy Outlook 2005* (*AEO05*) from the Energy Information Administration (EIA) has projected an annualized worldwide growth in petroleum consumption of 1.9 percent between 2003 and 2025. This projection assumes a growth in world supplies from 77.58 million barrels per day (mmb/d) in 2003 to 120 mmb/d in 2025. Even the sensitivity cases which assume much higher prices in the outer years ($39.24/barrel and $48.00/barrel) estimate production at 115 mmb/d and 112 mmb/d respectively.[5]

The International Energy Agency (IEA) has published a similar projection assuming a global annualized growth rate of 1.6 percent between 2002 and 2030.[6] Concerned about current high prices, the IEA has also examined a high oil price projection and has concluded that demand growth would be reduced from 1.6 percent annually to 1.0 percent. Likewise the European Commission assumes petroleum supplies of 120 mmb/d in 2030 at a world price of $38/barrel.[7]

The agencies that generate the most widely used forecasts are therefore assuming that petroleum supplies, at whatever mix of conventional and unconventional crude oil, will be available at a reasonable price. The other universal assumption is that in the outer years much of the incremental crude oil will come from Saudi Arabia.[8] This comes at a time when there is escalating debate over global supplies, prices, investment levels, and refinery capacity, a debate that is driven in part by the lack of transparency in some critical data and the very clear realization that world demand data, and to some extent supply data, have serious gaps and flaws.

California and the West Coast have historically been relatively self sufficient in petroleum supplies. California has relied on its own indigenous production, production from Alaska, and some imports. During the last decade production has steadily declined in both California and Alaska. Consequently, California's reliance on imported crude oil has grown steadily. Table 2 shows recent imports of crude by source.[9]

Population has also grown steadily in California and with it has come increased demand for petroleum products, particularly transportation fuels. The California Energy Commission's (Energy Commission) own projections estimate a steady growth in demand for petroleum based transportation fuels.[10] This will place increasing pressure on California refineries and will lead to increasing imports of products.

Under current conditions and technology, it is clear that California's consumption of petroleum will increase, even if the rate of the increase slows. That being the case, California will become increasingly reliant on imports of both crude oil and products. Therefore, the events and discussions that are roiling the world oil market are of increasing concern to the state.

Table 2: Imports of Crude Oil into California by Source 2000-2004
(Thousand Barrels)

SOURCE	2000	2001	2002	2003	2004	Grand Total
ANGOLA		3127	17552	8414	6014	35107
ARGENTINA	6993	7030	12834	7504	8119	42480
AUSTRALIA	5557	8248	5841	7646	4360	31652
BOLIVIA					260	260
BRAZIL				953	1893	2846
BRUNEI	651	1613	392	1778	725	5159
CANADA		1977	3559	4421	2826	12783
CHAD					2293	2293
CHINA, PEOPLE'S REP	835	664				1499
COLOMBIA	1237	1988	2190	1828	4062	11305
CONGO (BRAZZAVILLE)		399				399
ECUADOR	36862	23871	27410	39318	50250	177711
EQUATORIAL GUINEA			1958	583		2541
GABON			1973			1973
INDONESIA	4110	2401	5222	2959	2792	17484
IRAQ	51249	54307	39512	37371	51119	233558
KUWAIT	5766	1728	3808	3343	277	14922
MALAYSIA	2910	118	1194			4222
MEXICO	14858	18288	18533	16469	14284	82432
NIGERIA		312		1084		1396
NORWAY		37	385			422
OMAN		5444	6060	2835	321	14660
PERU	1494	2524	1128	2447	383	7976
QATAR			3194			3194
SAUDI ARABIA	30544	42726	36256	83477	86051	279054
UNITED ARAB EMIRATES	477	4723	3505	3645	639	12989
VENEZUELA	3014	5183	321	1725	711	10954
VIETNAM	2367	974		291		3632
YEMEN	9802	8702	7884	2000		28388
Grand Total	178726	196384	200711	230091	237379	1043291

There is extensive debate over the volume, availability, and future of conventional crude oil. This is not a new debate, but it has come to the fore again recently. Its current prominence is driven by the large, unanticipated growth in demand in recent years from the developing countries (such as China, India and Brazil) and by the unexpectedly strong growth in demand in the United States. This has been combined with a general tightness in supply, as seen in very high prices, and concern expressed about the likely future rapid growth in dependence on the Middle East, particularly Saudi Arabia. There is also apprehension that the international energy agencies have been slow to grasp the dimensions of global demand growth, as well as apprehension about the lack of transparency in Saudi Arabia's supply data.

Two views have emerged about conventional crude oil supplies. On one side are those who believe that global conventional crude oil production is at peak or near peak production, and that due to high rates of production decline in existing fields, discovery of new reserves cannot keep pace with the global production decline. This so-called 'depletionist' view defines conventional oil resources somewhat conservatively and considers the United States Geological Survey (USGS) 2000 assessment of mean world undiscovered oil and gas resources to be too optimistic due to the inclusion of estimates of reserves growth in existing fields, hypothetical resources in untested geologic basins, and estimated resources for high cost operating regions and extreme environments such as ultra-deep water and the Arctic. In this "low resource" outlook, a substantial worldwide hydrocarbon resource base remains; however, the remaining oil and gas accumulations will be smaller, subject to high rates of decline, and be more costly to discover and produce.

On the other side is a more optimistic view of world hydrocarbon supply, which considers a substantially larger undiscovered resource base, concedes a major role to new and emerging technology to discover and develop new oil and gas reserves in challenging environments, and places less importance on the distinction between conventional and non-conventional oil. The more optimistic view acknowledges that world oil production will eventually peak, but estimates the timing and production rate of peak oil to be substantially later and higher than the depletionist view. The debate between the oil supply optimists and the oil supply pessimists is sometimes complicated by confusion over terms and definitions and, at times, has been marked by rancor on both sides. Nevertheless, the debate is drawing increasing attention in recent years as oil prices have soared.

Both the supply optimist and depletionist outlooks agree that world oil resources are finite and that, in the face of rising global demand, world production is likely to peak in the 21st century. The distinction between the two viewpoints regarding peak oil production results from two different outlooks on the global resource base and the likely future cost to find and produce oil and gas in various supply regions. Given that petroleum is likely to be the dominant transportation fuel over the next two decades, the Energy Commission is concerned with the long term availability of crude oil and the price at which it will available. This report, therefore, examines in some detail the estimates of remaining conventional crude oil and the estimates of unconventional crude oil, and discusses the validity of the ongoing supply debate. This analysis compares the outcomes of a range of resource base and supply cost assumptions, which in turn represent the spectrum of viewpoints from low conventional oil production and supply outlook through the most optimistic oil supply outlook. This report does not attempt to predict future world oil supply; rather, the report allows the Energy Commission to consider the potential impacts of a range of oil supply assumptions.

Chapter 2 lays out the methodology for the modeling. The model used for this study is an adaptation of the Climate Change Risk Assessment Framework (CCRAF) developed for the U.S. Environmental Protection Agency (EPA) by ICF Consulting. The CCRAF model is a long term global stochastic model that has been adapted for the time period out to 2050 for this study. The particular approach used by stochastic models is explained in the following section.

Chapter 2 discusses and explains the development of a Reference Case. Three overarching environmental cases are also developed off the Reference Case to perform sensitivity analysis. Within these environmental cases there are further iterations of resource cases, population cases, and GDP cases. These are explained in detail in Chapter 2. The section on the resource cases discusses estimates of world oil resources and attempts to compare the various projects on a unified base. To clarify understanding of the resource issues the section below explains the terminology used in resource evaluation and also explains the debate over the future of conventional oil.

Chapter 3 presents what are known as market intangibles. These are events such as geopolitical threats or speculators' activities that are not explicitly represented in the model but which affect the price of, and ultimately the demand for, crude oil. Market intangibles and their impacts influence how the output of the model should be evaluated.

Finally, the results of the modeling runs are presented in summarized form in Chapter 4. Included in this chapter is a discussion on oil prices. These results are also examined to determine their likely impact on California. The full details of the runs are in Appendix A.

Background

This section provides an overview of stochastic models and a discussion of the terms and concepts *reserves*, *resources*, and *peak production.* The purpose of this section is to provide background information and a useful context for the later discussion of model methodology and results.

Stochastic Models

Stochastic models like the CCRAF are designed to test the impact of uncertainty on the behavior of the system being modeled. Typically, over a thousand simulations are executed where key variables can take on different values. Key results can then be presented in a number of ways: as averages and as frequency ranges. In CCRAF, many of the key input variables are defined not as single numbers but as random variables with distributions. For example, the distribution for conventional oil resources in the Middle East is defined by a low estimate, a median estimate, and a high estimate, which allow us to apply a set shape for the probability distribution function (pdf). This pdf defines the probability that the resources will fall within certain ranges. During the simulation, a value referred to as a *pseudo-random value* is selected based on these probabilities so that the frequency of the selection within a range is consistent with the probability that the resource is in that range. If the probability that the resource level is between 5,687 and 6,161 Quadrillion BTUs (Quads) is 30 percent, then close to 30 percent of the selections will occur in this range.

With the multiple simulations, a wide range of results are produced, reflecting the selection of pseudo-random values, and defining the uncertainty of the key results of the model. For CCRAF, the uncertain input variables include parameters such as energy resources, energy extraction costs, population and economic growth rates, and climate sensitivity. The output from CCRAF includes such things as energy consumption, energy production, energy prices, emissions of greenhouse gases, emission allowance charges, and global temperature change. These outputs are produced for each simulation, which means there are over a thousand sets of results for each output parameter.

The amount of output available to report on provides a wide range of opportunities to present these results. Typically, it is not useful to present results for each simulation so several options for providing results are provided:

- Averaging.
- Showing results by fractile.
- Showing average results where key output parameters fall within certain ranges.

Averaging reports the mean of the simulations. We would take primary crude oil consumption for the United States for a specified year and average it over all simulations and report this value.

The average or mean value provides good information on what is expected but not how the results can vary. For example, one output variable can have values from 4.6 to 16.7 with an average of 7.2. The output of results by fractile provides information on how the results vary from the mean. In this example, the fractiles were as follows:

95th	5.4
90th	5.5
50th	6.9
10th	9.2
5th	10.6

The 95^{th} fractile indicates that 95 percent of the simulations had results at or above 5.4 and the 90^{th} fractile indicates that 90 percent of the simulations had results at or above 5.5. Only 5 percent of the simulations had results at or above 10.6.

Often, the relationship of variables is important. In this report, the dependence of the crude oil prices, consumption, and production on conventional oil resources was important to explain. In this case, we provided an alternative approach to presenting results. We defined ranges for resources where we wanted to show the average results of the simulations when the conventional oil resources fell within this range. To take a simple example, we had the following ten simulations:

Simulation	Variable 1 (dependent variable)	Variable 2 (independent variable)	Group
1	50	7.6	1
2	175	21.9	2
3	40	6.3	1
4	130	16.9	2
5	145	18.9	2
6	95	9.8	1
7	60	6.3	1
8	110	14.8	1
9	85	13.0	1
10	150	17.2	2

The grouping for variable 1 is defined as 0 to 110 for group 1 and 110 and above for group 2. The average of the results for variable 2 in group 1 is 9.6 and the average of the results in group 2 is 18.7. From this one can see a very strong relationship between variable 1 and variable 2, as variable 2 increases as variable 1 increases.

Resources and Reserves, Resource Types and Peak Oil Production

Definitions of the terms reserves and resources have been an ongoing source of confusion and inconsistency in discussions about future world oil supply. The Society of Petroleum Engineers and the World Petroleum Council have proposed a single set of definitions for reserves, an excerpt of which is provided in the side box.[11] Under this definition, reserves are the part of the known petroleum resource base that has the potential to be produced under current economic conditions using current or foreseeable technology. Consequently, production comes from reserves; reserves must be replenished from the petroleum resource base through exploration and discovery of new fields or the expansion of current producing zones in existing fields, or the discovery of new producing zones in existing fields. Unproved reserves are converted to proved reserves as known accumulations become economically producible

"Reserves are quantities of petroleum which are anticipated to be commercially recoverable from known accumulation from a given date forward. All reserve estimates involve some degree of uncertainty… depending upon the amount of reliable geologic and engineering data. The relative degree of uncertainty may be conveyed by placing reserves into one of two principal classifications, either proved or unproved. Proved reserves are estimated with reasonable certainty to be commercially recoverable and may be categorized as developed and undeveloped. Unproved reserves are based on geologic and engineering data similar to that used in estimates of proved reserves, but technical, economic, or regulatory conditions preclude such reserves as being classified as proved. For example, unproved reserves may be estimated assuming future economic conditions different from those at the time of the estimate."

by either the application of new technology, more favorable market conditions, or improved access to the hydrocarbon accumulation.

The total endowment of recoverable petroleum resources includes all quantities of petroleum that are estimated to be initially-in-place in naturally occurring accumulations and are estimated to have the potential to be recovered at some point. Discovered recoverable resources include cumulative and current production plus reserves. Undiscovered recoverable resources are the estimated quantity of petroleum in yet-to-be-discovered accumulations, which is technically recoverable using known or foreseeable technology. Undiscovered technically recoverable resources may or may not be commercially recoverable. Estimated ultimate recoverable resources are the total of current production, remaining reserves, cumulative oil and natural gas production to date, plus estimated recoverable undiscovered resources.

Reserves growth*,* also called reserves appreciation, is an estimate of future increases in reserves in existing fields, which is based on the historic tendency for the proved reserves in discovered fields to increase during the lifetime of the field. Such reserves revisions in existing fields can result from improved knowledge about the subsurface hydrocarbon accumulation, testing of a new pay horizon, or the application of new production technology and practices that improve reservoir recovery. The concept of reserves growth can be controversial because some oil and gas industry stakeholders contend that such growth does not represent new hydrocarbons, but is instead an artifact of under-reporting or overly conservative assessment of reserves early in the life of a field. In this view, reserves growth is often the result of the tendency for initial proved reserves estimates to be conservative, frequently representing a 90^{th} percentile or higher certainty. Initial reserves estimates with a lower level of certainty, often described as “possible” reserves may not be reported initially as “proved”. As the field is produced over time and the initial reservoir parameters are confirmed or improved, total proved reserves might grow to be closer to an initial high case estimate of possible reserves. Estimates of reserves appreciation in existing fields are typically added to estimates of undiscovered recoverable resources to estimate the future recoverable resource base.

Global proved petroleum reserves data are official reserves reported by individual countries. There is significant uncertainty in reported reserves because many oil and gas producing countries do not report reserves updates on an annual basis. Of 97 countries reporting oil reserves for 2003, reserves were unchanged since 1998 for 38 countries and 13 countries’ reserves were unchanged since 1993. There are also differences among the public sources of reserves data as to what resources are included as crude oil reserves. Table 3 summarizes current world oil reserves reported by various sources.[12]

Table 3: Estimates of Crude Oil and NGL Reserves at Year End 2003

Source	Proved Reserves (Billion barrels)	Comments
Oil and Gas Journal	1,266	Includes all proven oil-sands reserves estimated at 174 billion barrels
IHS Energy Group (formerly Petroconsultants)	1,266	"Proven plus Probable" Technically Recoverable Reserves. Includes developed oil sands reserves in Canada and developed Venezuelan extra-heavy oil in the Orinoco
BP *Statistical Review of World Energy*	1,148	Includes 11 billion barrels of Canadian oil sands reserves under active development
World Oil	1,051	Excludes natural gas liquids and Canadian oil sands

Reserves are an indicator of the capability to produce oil in the short term. Estimated recoverable undiscovered resources indicate medium to long term production potential. Peak petroleum production (either crude oil or natural gas) is the point in the life of a petroleum producing asset (either a producing field, a basin, a geographic region or the entire world) when the maximum unconstrained rate of production is achieved. After peak production is passed, production from the petroleum asset enters a stage of steady decline. Peak oil production was first described by Shell geophysicist M.K. Hubbert in 1956, who observed that production from a cluster of fields in a sedimentary basin peaks long before supply is exhausted. Hubbert observed that in the absence of external constraints or controls on production rates, peak production occurs when approximately half of the total ultimately recoverable resource has been produced. The date of peak production in historic oil and gas producing basins or regions has been observed to occur 20 to 30 years after the peak in the annual number of new discoveries in a producing region. Because the largest accumulations are generally discovered and produced first in a petroleum-producing region, once peak production is reached, the production decline in the early large fields cannot be overcome by new output from smaller later fields or from reserves additions in existing fields.

Peak production is a dynamic concept which depends on such factors as demand, the size of the resource base, technology, and economic factors such as oil price and production costs. For example, the size of the resource base is relevant to the concept of peak production because after peak production is reached, fewer resources located in smaller and smaller accumulations cannot be converted to reserves in sufficient quantity to sustain the peak production rate. The application of new technologies in an existing petroleum-producing region can expand the resource base, leading to more reserves, or new technology can lower the cost of producing the remaining reserves. In either case, the application of new technology is generally observed to increase ultimate recoverable resources, which may or may not have a discernible impact on the level and timing of peak production. The concept of peak oil production also depends on the scale of the observation. New technologies for exploration and production of deepwater areas have resulted in oil production from a new category of offshore petroleum resources, which will have its own production profile and timing of peak production. When viewed on a global scale as just one part of the total world petroleum resource base, deepwater oil and gas resources exploited using these new technologies expand the world's recoverable oil resources and contribute to pushing the timing of global peak oil production further out to the future.

The timing of global peak oil production is of growing concern worldwide, as historic oil producing regions throughout the world are increasingly recognized as being at or past peak production for conventional crude oil. For example, onshore oil production in the lower 48 United States is widely acknowledged to have reached peak production in the early 1970's. Post-peak oil production in mature producing regions is characterized by steadily declining production. Although large volumes of oil still remain to be produced, more effort is required to locate and drill ever-smaller oil accumulations. New producing zones and enhanced oil recovery technologies boost reserves appreciation in existing fields and slow the rate of production decline, but have not succeeded in reversing the production decline.

CHAPTER 2: METHODOLOGICAL APPROACH

The analysis assesses global energy markets utilizing the Climate Change Risk Assessment Framework (CCRAF), which was developed for the U.S. EPA primarily by ICF with input from others[13] on climate and impact modeling. The CCRAF is a stochastic integrated assessment model with integrated models of population growth, economic growth, energy production and use, emissions of greenhouse gases and pollutants, climate change, and the impacts of climate change. The primary focus of this analysis is the population, economic, and energy models; the emissions models are key to assessing the impact of multi-pollutant and greenhouse gas policies on the energy markets.

In CCRAF, key parameters such as total resources and resource extraction costs, conversion cost and efficiencies, population, economic growth, change in energy use over time, and technological improvement in resource extraction costs, conversion costs and efficiencies, and energy use are all modeled as uncertain, random variables. Different values of these parameters are selected and modeled within the Monte-Carlo process and in these runs thousands of potential combinations of parameters are tested. Each Monte-Carlo loop, or combination of parameters, is referred to as a variant in the CCRAF.

Cases within CCRAF are used to look at alternative policies, primarily constraints on NO_x, SO_2, and greenhouse gases, and to address structural uncertainties in the modeling process such as elasticities, feedbacks, and alternative modeling approaches. In this assessment, CCRAF cases include evaluation of alternative greenhouse gas control scenarios. CCRAF is structured so that the variants can be reproduced under these different emission policies to ensure consistency of the analyses. The variants are reported and analyzed in a manner to address key concerns and the conditional impact of ranges of key assumptions consistent to a case type of analysis.

The types of outputs and analysis produced are:

- Distributions for key input and output variables such as population, GDP, energy resources, technological change, energy production, and energy prices.

- The variation of energy production and prices within and between specified ranges of global population growth, GDP growth, and energy resource levels.

- Input parameters that have the greatest impact on energy production and prices.

- The impact of CCRAF emission cases on energy production and prices.

Other issues such as the impact of trade liberalization, speculative trading, competition for capital, processing and transportation constraints, geopolitical risk, and the effects of growing strategic petroleum reserves on energy production and prices are addressed outside of the models in Chapter 3.

Input Parameters

The key inputs to the CCRAF and to the variant analysis described above include:

- Population and GDP.
- Demand models.
- Resource and resource extraction cost estimates.
- Conversion technologies and cost estimates.
- Technological improvements in the resource exploration and development.
- Reduced cost of producing these resources.
- Technological improvements in energy consumption technologies.
- Technological improvements in energy conversion technologies including improved efficiency and reduced costs.

The following sections discuss how these inputs are assessed.

Population and GDP

CCRAF models population and GDP growth endogenously using auto-regressive formulations with annual random variance and random decaying time trends. The coefficients in this formulation are based on regressions using 1960 to 1999 population and GDP data from the World Bank.[14] The model of population and GDP does not represent a general equilibrium approach to measuring economic growth but a simulation based approach where GDP growth reacts to other factors in the economy. GDP growth and population growth are structurally correlated where population growth rates decline with increasing GDP per capita and GDP per capita growth rates increase with decreasing population growth rates.

The population growth rate (dP_t) is a function of population growth rates in the previous two years, literacy rates (Lit_t), GDP per capita in the previous year ($GDPc_{t-1}$), a random decaying time factor, and annual random variations. The strength of the year-to-year correlation is provided by the auto-regressive coefficients b1 and c1 in the equation below, which combined are greater than 0.94. Increased literacy reduces population growth rates and literacy improvements are modeled to increase over time to a maximum of 100 percent. Annual rates of improvements in literacy start at up to 2 percent for some developing economies and decline as literacy increases. The random decaying time factor captures declines in population growth rates that exist in the historic data but can not be explained by GDP or literacy. The formulation for population growth rate follows:

$$dP_t = e^{a1} * dP_{t-1}^{b1} * dP_{t-2}^{c1} * Lit_t^{d1} * GDPc_{t-1}^{e1} * e^{(f1 * (1/(t-1945))} + x * SDP$$

Where *a1, b1, c1, d1, e1, f1* are coefficients determined by regression analysis against historic data, *t* is the year (e.g., 2005). The variable *x* is a pseudo-random value with a normal distribution with mean zero and standard deviation *1* and the variable *SDP* is the annual standard deviation of the regression estimating the coefficients. The coefficient *f1* is also a pseudo-random variable representing the decaying time trend and derived during the regression analysis. Table 4 summarizes the coefficients for this equation. Since CCRAF starts simulations in 1990, variance in historic population data from the above formulation is captured and utilized to calibrate the model through 1999.

GDP per capita ($GDPc_t$) is modeled as a function of GDP per capita in the previous year, the previous year growth rate for GDP per capita, this year's population growth rate, a decaying time trend, and annual random variations. As population growth rates decline, GDP per capita growth rates increase. The strength of the year-to-year correlation is provided by the coefficient *b2*, which is over 0.99. The decaying time trend captures historic reductions in GDP per capita growth rates in the historic data not explained by the above factors. The formulation follows:

$$GDPc_t = e^{a2} * GDPc_{t-1}^{b2} * dGDPc_{t-1}^{c2} * dP_t^{d2} * e^{(f2 * 1/(t - 1945))} + y * SDG$$

Where *a2, b2, c2, d2, f2* are coefficients. The variable *y* is a pseudo-random value with a normal distribution with mean zero and standard deviation *1* and the variable *SDG* is the annual standard deviation of the regression estimating the coefficients. The coefficient *f2* is also a pseudo-random variable representing the decaying time trend and derived during the regression analysis. Table 4 summarizes the coefficients for this equation.

Since CCRAF starts simulations in 1990, variance in historic GDP data from the above formulation is captured and utilized to calibrate the model through 1999. After 1999, population growth is random based on the above formulation. The random factor is adjusted by the average variance in historic data from 1994 to 1999 but declines quickly and is eliminated completely by 2030. This allows for smooth extension of recent trends within the random framework.

Other factors that impact population and GDP include migration and secondary effects of environmental policies and climate impacts. The population model includes regional migration that is a function of the relative income per capita of different regions and population growth rates and is calibrated to migration patterns during the 1990s. The GDP model includes secondary effects due to environmental costs of climate change impacts and due to emission allowance charges from environmental policies. In this time frame, except for very stringent carbon dioxide (CO_2) constraints, these secondary effects on GDP are minor.

Table 4: Population and GDPc Model Coefficients

Population		GDPc	
	Coefficient		Coefficient
a1	0.0003	a2	0.0275
b1	0.7782	b2	0.9975
c1	0.1652	c2	0.4749
d1	-0.0011	d2	-0.5208
e1	-0.0001		
f1 (mean)	0.0251	f2 (mean)	0.5318
f1 standard deviation	0.000100 + 0.000003 * (t-1990)	f2 standard deviation	0.001273 + 0.000043 * (t-1990)
SDP		SDG	

Demand

In CCRAF, demand for energy is modeled through three processes:

- Secondary (or direct) energy use
- Power and heat generation
- Energy use in production and processing/refining

Secondary Energy Use

Secondary energy use in CCRAF is modeled using one sector competing for the following energy types:

- Petroleum products
- Natural gas
- Coal
- Renewables (e.g., biofuels)
- Electricity

The estimation of the coefficients and starting energy values are based on data from the International Energy Agency.[15]

The formulation for total secondary energy use is autoregressive and includes a decaying time trend. It can be thought of as a standard demand equation with price and income elasticities and a decaying time component, combined with an autoregressive component and random variations. Income elasticities are provided for two ranges of GDP per capita: $0 to $7,500 and greater than $7,500. The model uses an average cost of energy for secondary energy use converted to an equivalent crude oil price using relative fuel efficiencies and non-fuel costs.

The price elasticity is small (-0.024) in the short run due to the strength of the autoregressive coefficients but larger in the long run (-0.92). The short run income elasticities are small (0.011 for income less than $7,500 and 0.010 for incomes above $7,500) and the long run income elasticities are 0.423 for the income range to $7,500 and 0.385 for income above $7,500.

Other factors in the demand equation include a decaying time trend, annual random variations, and elasticities to adjust from changes in heating degree days and cooling degree days due to increased global warming. The decaying time trend captures reductions in secondary energy use per capita in the historic data not explained by price and GDP per capita. The annual variations capture annual variance in the historic data and also impact overall long term trends through the auto-regressive components.

Note that technology for secondary energy use is not modeled explicitly but through the total energy use equations and variance in them.

The formulation for total secondary energy use follows:

$$\mathbf{SEc_{t,r} = e^{a} * SEc_{t-1,r}^{\,b} * Min(GDPc_{t,r}\,,TRS)^{c} * GDPc_{t,r}^{\,d} * e^{(g*(1/(t-1945)))} * (PrcA_{t,r})^{PEavg} * (HDD_{t,r}\text{-}HDD_{1990,r})^{HC} * (CDD_{t,r}\text{-}CDD_{1990,r})^{CC} * e^{X*StDev}}$$

Where *t* is the year, *r* is the region, $SEc_{t,r}$ is the secondary energy, $GDPc_{t,r}$ is the GDP per capita, $PrcA_{t,r}$ is the average price of secondary energy, $HDD_{t,r}$ is the average daily heating degree days for the year, and $CDD_{t,r}$ is the average daily cooling degree days for the year. The value TRS = $7,500 is an income threshold for the income elasticities. The coefficients a, b, c, *d, g,* PEAvg, HC, and CC are determined in the regression model. X represents a pseudo-random variable with a N(0,1) distribution, and StDev is the standard deviation from the regression model. Table 5 provides the coefficients for this equation.

Table 5: Total Secondary Energy Use Coefficients

Coefficient	Coefficient Description	Coefficient Value
A	Intercept	0.047
B	ln(Fet-1)	0.974
C	ln(min(GDPc,7500))	0.001
D	ln(GDPc)	0.010
PEavg	ln(Average Price)	-0.024
E	1/(Year-1945)	0.555
StDev	X	0.035
HC	$Ln(HDD_{t,r}-HDD_{1990,r})$	0.876
CC	$Ln(CDD_{t,r}-CDD_{1990,r})$	2.043

The equation for the share of secondary energy use by energy type takes a similar form to that above but includes a price elasticity based on the average cost of energy for secondary energy use. This price elasticity for the average cost of energy for secondary energy use effectively provides for cross price elasticities.

The equation follows:

$$\mathbf{SES_{t,r,k} = e^{a(k)} * SES_{t-1,r,k}{}^{b(k)} * Min(GDPc_{t,r},TRS)^{c(k)} * (GDPc_{t,r}/Min(GDPc_{t,r},TRS))^{d(k)} * (PrcA_{t,r})^{PEavg(k)} * (PrcO_{t,r,k})^{PEown(k)} * e^{X*StDev(k)}}$$

Where $SES_{t,r,k}$ represents the share of secondary energy use for secondary energy type *k*, the additional variable *PEOwn(k)* represents the own price elasticity. The coefficients for this equation are in Table 6.

Table 6: Coefficients for Secondary Energy Use Fuel Share Equations

Coefficient	Coefficient Description	Electricity and Heat	Renewables And Waste	Natural Gas	Petroleum Products	Coal
R^2	R Square	0.867	0.935	0.989	0.970	0.990
Coefficient						
a_k	Intercept	-0.369	0.467	-0.126	-0.152	-0.067
b_k	$\ln(SES_{t-1,r,k})$	0.889	0.905	0.968	0.956	0.988
c_k	$\ln(\min(GDPc_{tr},7500))$	-0.018	-0.057	0.027	0.029	0.003
d_k	$\ln(GDPc_{t,r})$	0.031	-0.035	-0.018	-0.012	-0.006
$PEOwn_{k,}$	$\ln(PrcO_k)$	-0.104	-0.089	-0.030	-0.041	-0.011
$PEAvg_k$	$\ln(PrcA_k)$	0.140	0.114	0.037	0.030	0.046
PEO_k	$\ln(OilP_t)$	0.035	0.026	0.007	-0.012	0.036
$StDev_k$	X	0.047	0.118	0.080	0.041	0.071
Coefficients in Equilibrium State						
a_k	Intercept	-3.323	4.934	-3.884	-3.468	*-5.776*
b_k	$\ln(\min(GDPc_{tr},7500))$	-0.163	-0.606	0.847	0.656	*0.229*
c_k	$\ln(GDPc_{t,r})$	0.276	-0.374	-0.554	-0.273	*-0.558*
$PEOwn_{k,}$	$\ln(PrcO_k)$	-0.937	-0.937	-0.937	-0.937	*-0.937*
$PEAvg_k$	*$\ln(PrcA_k)$*	*1.257*	*1.207*	*1.153*	*0.675*	*3.998*

Power and Heat Generation

Power and heat generation are modeled utilizing physical capacity and using logic equations to allocate shares of new capacity to energy types. Power and heat generation utilize the following energy types:

- Petroleum products
- Natural gas
- Coal
- Hydro
- Nuclear

- Solar and Wind
- Biofuels
- Geothermal

New capacity comes online with the maximum effective efficiency available in the year for the fuel type. The maximum effective efficiency is a random variable in CCRAF and can take values between a specified input range defined by the current maximum efficiency and maximum possible efficiency, current average efficiencies, and the rate at which the maximum possible efficiency is achieved.

The current efficiency of power and heat generation technologies varies considerably regionally, by technology, and by input energy type. For example, current average global efficiencies of natural gas power and heat generation are around 30 percent while the efficiency of new combined cycle and cogeneration facilities is above 48 percent. Potential improvements in efficiency within the next 10 to 20 years could increase the efficiency of new capacity to over 60 percent and potentially up to 70 or 80 percent. Integrated coal gasification and combined cycle power generation units are under development and could increase coal efficiencies and reduce emissions of NO_x and SO_2.

CCRAF inputs include:

- Current regional efficiencies of power and heat production by energy type.
- Current effective efficiency of new capacity by energy type.
- Possible ranges of efficiency improvements in new capacity by energy type.
- Changes in the cost of reducing NO_x and SO_2 emissions over time.

The current effective efficiency of new capacity by energy type and the maximum improvement assumed in the analysis are shown in Table 7.

Table 7: Power and Heat Generation Efficiency Assumptions

Fuel	Current Effective Efficiency of New Capacity	Maximum Possible Efficiency
Renewable	0.08	0.2
Gas	0.46	0.8
Petroleum	0.46	0.75
Coal	0.4	0.6

Current efficiencies of coal pressurized fluidized bed combustion are close to 40 percent and test plants for integrated coal gasification combined cycle units are over 40 percent without providing additional cogeneration benefits. Future efficiencies without cogeneration are expected to exceed 50 percent[16] and with fuel cells and micro-turbines could reach 60 percent. Current integrated gasification combined cycle with cogeneration could reach over 60 percent. Current efficiencies of gas and petroleum combined cycle units exceed 46 percent. The commercialization of combined fuel cells and micro-turbines is expected to increase efficiency to 70 percent or higher from levels on test systems that now exceed 50 percent.[17]

Production and Processing/Refining Energy Use

Energy use in production and refining are constant in the model at 11.9 percent for natural gas, 5.6 percent for crude oil, and 2.9 percent for coal.

Fixed Resource Energy Sources

Fixed resource energy sources include conventional and unconventional crude oil and natural gas, natural gas liquids, and coal. Other energy sources such as wind, solar, biofuels, hydroelectricity, geothermal, and nuclear are treated as annual supplies dependant on price and described later in this document. The fixed resource energy sources are all modeled similarly in CCRAF but include important differences both in the development of the input resource and cost estimates and how the resource is exploited over time. For each resource type, crude oil, natural gas, natural gas liquids, and coal, the assessment estimates the following:

- Current estimates of energy resources within resource categories for each resource type. Resource categories include conventional oil and conventional natural gas and the various unconventional resources such as oil shale, oil sands, coal bed methane, gas hydrates, etc.

- High, median, and low estimates of potential resources within a resource category, which can be subjectively converted to probability distribution functions.

- Current costs for extracting energy resources by resource category plus transportation to the nearest market center.

- Ultimate cost of extracting fixed energy resources plus transport to the nearest market center, and the variance around these cost estimates. The ultimate cost assumes an estimate of potential technology improvements.

- Other constraints to exploiting the resource including production to reserve ratios, time required to develop large basins, and different regional or country resource extraction strategies.

High and low estimates of potential fixed energy resources are estimated for each CCRAF region and resource category. These high and low resource estimates are the starting point for developing probability distribution functions and resource price–supply relationships. The CCRAF supply regions are defined in Table 8.

Table 8: CCRAF Fixed Resource Supply Regions

	Region (Identifier)	Countries in the Region
1	**United States (USA)**	United States
2	**Europe (Europe)**	Western and Eastern Europe
3	**Former Soviet Union – Europe (FSU-Europe)**	Belarus, Moldova, Russian Federation, Ukraine
4	**Japan (Japan)**	Japan
5	**Australia and New Zealand (A&N)**	Australia, New Zealand
6	**Canada (Canada)**	Canada
7	**China (China)**	China, including Hong Kong
8	**Brazil (Brazil)**	Brazil
9	**Mexico (Mexico)**	Mexico
10	**India (India)**	India
11	**Rest of Latin America (ROLA)**	Other South and Central American countries
12	**South and East Asia (SEASIA)**	Other South Asian countries
13	**Central Asia (CAsia)**	Afghanistan, Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyz Republic, Mongolia, Pakistan, Tajikistan, Turkmenistan, Uzbekistan
14	**Africa (Africa)**	All African countries, including Egypt
15	**Middle East (MEAST)**	Bahrain, Islamic Rep. of Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates, West Bank and Gaza, Yemen

Conventional Crude Oil, Natural Gas, and Natural Gas Liquids

Conventional crude oil and natural gas, natural gas liquids, and coal are modeled similarly as “fixed resource” types. The primary sources for model inputs of world reserves and resources of conventional crude oil, natural gas, and natural gas liquids are the United States Geological Survey (USGS) *2000 World Petroleum Assessment,* current USGS and U.S. Minerals Management Service (MMS) assessments of the United States’ conventional crude oil and natural gas resources, and British Petroleum’s

(BP) annual assessment of proved reserves.[18] Consequently, the definitions of conventional oil and natural gas assumed for this analysis correspond to conventional oil and natural gas resources included in the USGS assessments and BP's work.[19]

Conventional crude oil and natural gas liquids are defined as oil produced from underground reservoirs by means of conventional wells. Included in the conventional category is oil produced from offshore deepwater fields, heavy oil reserves in Venezuela under active development, and oil currently produced from Arctic regions. Although not typically considered conventional crude oil, most current world assessment of crude oil reserves also includes 11 billion barrels of Canadian oil sands under active development. Non-conventional oil includes oil shale, extra heavy oil deposits not under active development, oil sands or shallow bitumen (tar sands) not under active development, and oil sands-derived synthetic crude products. Non-conventional crude oil also does not include gas-to-liquids (GTL) and biofuels.

Conventional natural gas resources are defined in the USGS assessments based on the characteristics of a reservoir. Conventional oil and gas reservoirs are generally sandstone or carbonate reservoirs with distinct structural and stratigraphic boundaries, a well-defined gas/water contact, and sufficient permeability for gas production without induced fracture stimulation or other production interventions. By this definition, non-conventional natural gas includes coal bed methane and continuous accumulations of natural gas in low permeability sandstone, chalk, and shale deposits (tight gas and gas shale). The CCRAF model inputs for non-conventional natural gas also include estimated resources from two extremely large, but highly speculative natural gas resource types – methane hydrates and natural gas dissolved in deep, geopressured aquifers.

Model inputs for each conventional and non-conventional resource category include the following:

- Current estimates of global reserves for crude oil, natural gas, and natural gas liquids.

- High, median, and low estimates of the technically recoverable resources for each resource category, which are converted to probability distribution functions.

- Estimated current and ultimate extraction costs plus transportation to the nearest market center, and the variance around these cost estimates. The ultimate extraction cost qualitatively assumes that technology advancement will occur and the resources will be developed using current, emerging, and foreseeable technology improvements. The model does explicitly examine a high technology scenario.

- Estimated constraints on oil and natural gas exploration and development including production to reserve ratios, the time and infrastructure required to develop large basins, and timing constraints due to different regional or national resource extraction strategies.

Table 9 summarizes total world conventional crude oil and natural gas reserves and resources incorporated into the CCRAF fixed resource energy supply.[20]

Table 9: Summary of Total World Conventional Crude Oil and Natural Gas Reserves and Undiscovered Resources

	Crude Oil			Natural Gas			Natural Gas Liquids		
	Billion Barrels			Trillion Cubic Feet			Billion Barrels		
	F95	Mean	F5	F95	Mean	F5	F95	Mean	F5
Undiscovered Resources – non U.S. *(includes estimated reserves growth)*	369	1,253	2,299	2,278	7,939	14,938	69	249	516
Undiscovered Resources- Total U.S. (includes estimated reserves growth)	139	171	211	812	982	1,215	19	21	23
Proved Reserves Year end 2003	1,148			6,205			NGL included in crude oil reserves		
Totals	**1,656**	**2,572**	**3,658**	**9,295**	**15,126**	**22,358**	**88**	**270**	**539**

Notes: F95 represents a 95 percent probability of at least the amount shown. F5 represents a 5 percent probability that undiscovered resources will equal the amount shown.

Details showing conventional oil and natural gas resources in the model for each CCRAF region are found in Table 11. The low, mean, and high resource categories each include total proved reserves for year-end 2003 plus estimated low, mean, or high undiscovered resources for each CCRAF region. The low resource category corresponds to the USGS estimated undiscovered resources and reserves growth for the F95 case, representing a 95 percent probability that the estimated quantity exists. The high resource category represents the USGS estimated undiscovered resources and reserves for the F5 case, representing a 5 percent probability that the estimated quantity is present. The mean resource category includes the USGS estimated mean undiscovered resources and reserves growth. The estimates of low, high, and median resources for each resource type provide the basis for estimating probability distributions for regional resources and production costs, which are input directly to the CCRAF model. Regional resource estimates and regional production cost estimates are distributed across two standard deviations for each of five cost steps. Distributions of regional resource estimates into five cost steps are discussed in more detail later in this chapter.

CCRAF is a Monte Carlo model that produces multiple simulations of variants for a reference case and three environmental cases. In order to understand the distribution of results and the impact on the results of key parameters such as hydrocarbon resources, the CCRAF model outputs are aggregated into categories defined according to the following ranges for the key parameter, hydrocarbon resources in this case:

- Minimum Estimated Resource to 95th Percentile Resource.
- 95th Percentile to 90th Percentile Resource.
- 90th Percentile to 50th Percentile Resource.
- 50th Percentile to 10th Percentile Resource.
- 10th Percentile to 5th Percentile Resource.
- 5th Percentile to Maximum Estimated Resource.

For example, Table 10 illustrates the range of conventional oil resources (including both reserves, estimated reserves appreciation in existing fields, and undiscovered technically recoverable resources) assumed for each model output aggregation category. Similar tables are input to the CCRAF model showing ranges in other key parameters such as population and GDP.

Table 10: Ranges of Conventional Oil Resources for Model Aggregation Category

Resource Range Category	Low end of range	Upper end of range
	Conventional Oil Resources (includes NGL) billion barrels	
1. Minimum Resource to 95th Percentile	Less than 1700	
2. 95th to 90th Percentile	1700	1800
3. 90th to 50th Percentile	1800	2600
4. 50th to 10th Percentile	2600	3300
5. 10th to 5th Percentile	3300	3700
6. 5th Percentile to Maximum Resource	Greater than 3700	

Resource Range Category 4 (50th to 10th Percentile) corresponds approximately to the USGS estimate of mean undiscovered resources in the United States and rest of the world plus current world reserves reported by BP. Resource range Category 2 (95th to 90th Percentile) corresponds approximately to the USGS 95th percentile (F95) assessment of undiscovered resources in the United States and rest of the world plus current world reserves. Resource Range Category 6 (5th Percentile to Maximum Resource) corresponds to a maximum resource category equivalent to world reserves plus estimated undiscovered world resources that equal or exceed the USGS 5th percentile estimate in the world and U.S. petroleum resource assessments. Resource Range Category 3 and Category 5 represent estimated crude oil resources intermediate between the USGS F95 and F50 assessed volumes and F50 and F5 assessed volumes. Finally, Resource Range Category 1 represents an outlook for very constrained crude oil resources in which current world reserves are substantially lower than official country reports, the USGS estimates of future reserves growth in existing fields is strongly discounted, and USGS estimates of undiscovered resources in unexplored Arctic and ultra deepwater basins are not included. Resource Category 1 corresponds most closely to the conservative estimates of global conventional oil resources assumed by proponents of early global peak oil production.

Table 11 shows the low, high, and median resources that were estimated for conventional crude oil and natural gas resource categories. These estimates were converted to a resource probability distribution for each resource category.

Table 11: Conventional Crude Oil and Natural Gas Resources by Resource Category and CCRAF Region
(includes proved reserves)

Model Region	Crude Oil (Billion Barrels)			Natural Gas (Trillion Cubic Feet)			Natural Gas Liquids-NGL (Billion Barrels)		
	Low	Mean	High	Low	Mean	High	Low	Mean	High
USA	170	201	242	996	1,167	1,400	20	21	23
Canada	19	22	27	75	239	452	0	9	23
Mexico	28	56	89	37	99	183	1	3	7
Brazil	27	102	193	72	342	692	2	10	22
ROLA	117	206	327	360	747	1,290	3	14	33
Europe	29	139	272	263	623	1,142	1	13	32
Former Soviet Union	122	223	343	2,289	3,748	5,541	12	47	97
Central Asia	39	90	154	529	1,069	1,729	5	20	42
Middle East	866	1,135	1,437	3,279	4,736	6,403	29	93	179
Africa	171	286	409	701	1,102	1,595	7	20	39
India	7	11	14	45	82	126	0	1	2
South & East Asia	22	40	61	396	684	1,031	2	7	15
Japan	-	-	-	-	-	-	-	-	-
China	31	47	68	103	211	352	1	5	12
Australia & NZ	8	14	22	150	277	422	2	7	13
Totals	**1,656**	**2,572**	**3,658**	**9,295**	**15,126**	**22,358**	**85**	**270**	**539**

Unconventional Oil and Natural Gas Resources

A low resource category and a high resource category are defined for unconventional oil and unconventional natural gas resources in each CCRAF region. The unconventional resources specified in the model include:

- Unconventional Oil
    - Heavy Oil
    - Oil Sand/ Natural Bitumen
    - Oil Shale

- Unconventional Natural Gas
  - Low Permeability Reservoirs; Tight Gas
  - Coal bed Methane
  - Shale Gas
  - Methane Hydrates
  - Geopressured Aquifers

Primary sources for the estimates of fixed unconventional oil and gas resources are the United Nations, the World Energy Council, and *Energy and Environment, Annual Reviews*. [21] These primary sources were supplemented with resource estimates for unconventional oil and natural gas resources from other sources. Table 12 and Table 13 summarize the fixed unconventional resources for each CCRAF region. The low and high resource estimates for each unconventional oil resource are converted to a resource probability distribution for each resource type. Table 14 summarizes the fixed resources for coal for each CCRAF region.

Unconventional Oil

The low resource category for shale oil represents the estimated total recoverable reserves (including proved reserves plus estimated additional and speculative reserves) compiled from the World Energy Council, H-H. Rogner, and other regional evaluations.[22] The high resource category for shale oil assumes that approximately two thirds of the total estimated resource-in-place represents technically recoverable resource assumed to be available during the model period.

Discovered resource-in-place for extra heavy oil is estimated to be 2,064 billion barrels. The low resource category for extra heavy oil represents 20 percent of the resource-in-place, which is approximately equal to reserves plus contingent resources.[23] The high resource category for extra heavy oil assumes that approximately 50 percent of the total estimated resource-in place represents technically recoverable resource available during the model period.

For oil sands or natural bitumen, the low resource category represents total proved reserves, possible reserves, and estimated additional reserves, which are approximately equal to 25 percent of discovered oil-in-place.[24] The high resource category for oil sands assumes that approximately 55 percent of the total discovered resource-in-place represents technically recoverable resource that will be available during the model period.

Unconventional Natural Gas

Tables 12 and 13 summarize the CCRAF inputs for fixed natural gas resources for tight gas, coal bed methane, and fractured shale gas. The low and high resource estimates for each unconventional gas resource are converted to a resource probability distribution for each resource type. The estimates shown are for technically recoverable resources.

Only one estimate of global tight gas resources has been published in which regional estimates of tight formation gas-in-place are based on the worldwide distribution of onshore conventional gas resource-in-place. Total world tight gas-in-place is estimated to be approximately 8,600 trillion cubic feet (Tcf).[25] This may be a conservative total when compared to a recent estimate of tight formation gas-in-place in the United States of as much as 15,000 Tcf, of which 500 Tcf is technically recoverable. [26] This analysis assumes that the tight gas technically recoverable resource in the low case is approximately 40 percent of the tight gas resource-in-place estimated by Rogner,[27] while the high case estimate is assumed to be 65 percent of the tight gas resource-in-place.

Recent estimates of world coal bed methane resources-in-place are wide-ranging, from approximately 3,000 Tcf to more than 9,900 Tcf. Global coal bed methane resource estimates are growing as more is learned about the resource characteristics and effective production techniques for lower rank coals. For this analysis, several published estimates were used to bracket the world coal bed methane resources-in-place at approximately 3,000 Tcf on the low side and 9,900 Tcf on the high side. Next, a distribution of coal bed methane resources by CCRAF region was estimated. For the low resource category for this analysis, 65 percent of the low case coal bed methane resource-in-place is assumed to be technically recoverable and available during the model time period. For the high coal bed methane resource category for this analysis, 65 percent of the high coal bed methane resource-in-place is assumed to be technically recoverable and available during the model period.

For fractured shale gas, a recent estimate of potential shale gas-in-place was calculated by first multiplying the U.S. ratio of shale gas-in-place to total shale-in-place by the total worldwide estimated shale-in-place volumes.[28] For this analysis, the resulting estimated shale-gas-in-place volume was reduced by 75 percent to estimate a high case for shale gas resources. The low case shale gas resource was estimated as 50 percent of the high case resource, or approximately 12 percent of the estimated shale gas-in-place resource. The low and high case shale gas resource estimated for this analysis is speculative and may be quite optimistic because no gas-productive shale formations are known outside the United States. Only 10 percent or less of the total shale gas resource-in-place in the United States is estimated to be recoverable.[29]

A mean global resource in place of 770,000 Tcf is assumed for methane hydrates. This total is allocated to various CCRAF regions according to the known extent of methane hydrates or inferred potential for onshore or offshore methane hydrate deposits. The low resource category assumes that only 1 percent of the methane hydrate resource in place is technically recoverable during the model period. The high resource category assumes that 2.2 percent of the methane hydrate resource is technically recoverable during the model period.

The primary source for gas resources from geopressured aquifers is provided by Rogner.[30] Assessments of low, medium, and high geopressured aquifer gas resources are provided. For CCRAF model input, 2 percent of the geopressured aquifer gas-in-place is assumed to be technically recoverable and available during the model period.

Coal Resources

Table 14 summarizes the CCRAF input for fixed resources from coal. The low and high resource estimates are converted to a resource probability distribution for each resource type.

The primary sources for coal are Rogner and the *WEC2004*. The low resource category includes proved coal recoverable reserves of bituminous (including anthracite) and sub-bituminous coal and lignite. The high resource category includes proved recoverable reserves plus estimated additional recoverable reserves plus estimated recoverable speculative coal resources (where provided).

Table 12: Unconventional Resources by Resource Category and CCRAF Region – Low Estimate

(includes proved reserves where applicable)

Region	Unconventional Oil – Low Resource Estimate (Billion Barrels)			Unconventional Natural Gas – Low Resource Estimate (Trillion Cubic Feet)					
	Extra Heavy Oil	Oil Sand/ Bitumen	Oil Shale	'Tight' Gas	Shale Gas	Coalbed Methane	Methane Hydrate	Aquifer Gas - Low	Aquifer Gas - Mean
USA	0.6	11	1,031	494	215	260	779	136	897
Canada	-	408	5	172	215	130	779	136	897
Mexico	0.1	-	-	17	-	-	32	11	75
Brazil	-	-	27	54	-	-	565	109	789
ROLA	406	0.3	0.1	82	260	-	1,414	164	1,184
Europe	1.4	0.4	37	74	67	169	390	115	658
Former Soviet Union	-	51	86	335	77	228	1,494	138	1,026
Central Asia	-	63	6	124	-	228	1,495	51	380
Middle East	4.6	0.1	13	362	313	-	63	207	1,183
Africa	0.1	107.1	52	101	34	20	126	196	1,326
India	-	-	-	8	-	20	94	58	333
South & East Asia	-	2.2	3	67	39	-	-	151	861
Japan		-	-	-	-	-	47	53	68
China	0.3	0.4	5	24	433	689	-	93	531
Australia & NZ	-	-	11	31	284	195	423	150	1,019
Total World	**413**	**643**	**1,276**	**1,945**	**1,937**	**1,939**	**7,701**	**1,768**	**11,227**

Table 13: Unconventional Resources by Resource Category and CCRAF Region – High Estimate

(Includes proved reserves where applicable)

Region	Unconventional Oil – High Resource Estimate (Billion Barrels)			Unconventional Natural Gas – High Resource Estimate (Trillion Cubic Feet)				
	Heavy Oil	Tar Sand/ Bitumen	Oil Shale	'Tight' Gas	Coalbed Methane	Shale Gas	Methane Hydrate	Geo-pressure Aquifer Gas
USA	1.4	23	2,092	803	487	783	1,947	1,007
Canada	-	908	10	280	600	783	1,947	1,007
Mexico	0	-	-	27	-	-	80	84
Brazil	-	-	55	88	-	-	1,412	1,368
ROLA	1,015	1	0.3	133	-	519	1,414	2,053
Europe	4	1	74	120	169	135	976	1,437
Former Soviet Union	0	106	174	544	1,333	154	3,735	1,726
Central Asia	0	127	13	202	1,333	-	3,736	638
Middle East	11	0.2	26	589	-	625	157	2,590
Africa	0.3	217	106	163	20	67	314	2,231
India	-	-	-	14	20	-	235	728
South & East Asia	-	5	5	109	-	77	-	1,885
Japan	-	-	-	-	-	-	119	99
China	1	1	11	39	806	866	-	964
Australia & NZ	-	-	21	50	325	567	1,058	1,675
Total World	**1,032**	**1,389**	**2,587**	**3,161**	**5,093**	**4,576**	**17,130**	**19,492**

Table 14: Coal Resources by Resource Category and CCRAF Region
(Includes proved reserves)

Region	Coal Resources (Million Tonnes)	
	Low	**High**
USA	249,994	1,820,258
Canada	6,761	135,492
Mexico	1,211	1,211
Brazil	11,929	36,640
ROLA	9,899	26,372
Europe	125,212	362,375
Former Soviet Union	191,163	242,444
Central Asia	41,143	149,023
Middle East	1,710	1,710
Africa	55,367	171,899
India	87,396	87,396
South & East Asia	7,807	10,739
Japan	773	9,038
China	114,500	114,500
Australia & New Zealand	82,664	639,332
Total World	**987,529**	**3,808,429**

Estimated Resource Extraction Costs and Timing

As Tables 11 through 14 show, the regional distribution of hydrocarbon resources varies considerably. For example, conventional crude oil and natural gas resources are primarily in the Middle East, Russia, Central Asia, and Africa; while heavy oil and shale oil resources are predominantly in North and South America. The majority of the coal resources are found in North America, China, India, Russia, and Australia.

The technology to extract and transport the energy to markets also varies considerably. Conventional crude oil, natural gas, and coal extraction technologies are well known and mature although improvements continue. Heavy oil extraction is becoming mature but shale oil extraction technology is not and requires considerable research and development before the resource can be extracted commercially. Deepwater oil and gas extraction technologies are advancing and are likely to see considerable improvements over time.

The resources estimated for each region that are shown in Tables 11 through 14 were further distributed into cost step categories. The cost step categories include both the estimated extraction cost for the resource plus an estimated transportation cost to the nearest market center. For example, a quantity of a conventional resource in a remote area might be placed in the same higher cost step category as an unconventional resource type. In the former case, transportation cost might be the greater contributor to the higher cost. In the latter case, extraction costs are likely to be higher than transportation cost.

Each energy type must be placed on a consistent basis for evaluation in the model. Crude oil resource extraction costs are converted to an equivalent West Texas Intermediate (WTI) cost basis for use in CCRAF and reporting. This means minor increases or decreases in extraction costs are applied to put the crude on an equivalent basis to WTI as a refinery feedstock. For natural gas, a U.S. average extraction cost, net of processing to dry natural gas is used. For coal, all coal values are converted to an equivalent price based on relative efficiency and non-fuel costs of the dominant processes (e.g., power generation) using the coal.

The costs for each of the resource categories described above are represented through continuous cost curves ranging from $9/bbl of oil equivalent and up to $140/bbl of oil equivalent. Some conventional crude oil, natural gas, and coal resources can go as high as $70/bbl equivalent due to the field size, resource characteristics, accessibility, location, and environment. Non-conventional resources start at higher prices depending on the resource type. Table 15 summarizes the cost step categories for each resource type.

Table 15: Cost Step Categories for Hydrocarbon Resource Production

$2000	Cost Step 1		Cost Step 2		Cost Step 3		Cost Step 4		Cost Step 5	
	Low	High	Low	High	Low	High	Low	High	Low	High
$/boe	9.00	18.99	19.00	36.99	37.00	55.99	56.00	92.99	93.00	140.00
$/Mcf	1.61	3.38	3.39	6.60	6.61	9.99	10.00	16.59	16.60	25.00
$ tonne/coal	9..00	18.64	19.00	36.99	37.00	55.99	≥ 56.00			

The estimated undiscovered technically recoverable resources for each CCRAF region shown in Table 11 through 14 were distributed into the cost categories provided in Table 15. The estimated distribution of undiscovered resources into the cost steps are shown in Tables 16 through 18. The resources shown for each cost step represent incremental technically recoverable undiscovered resources estimated to be recoverable in the region at the range of costs represented by the cost step. All the resources are assumed to be available for recovery and conversion to reserves during the model period of 2000 to 2050 within the assumed cost range from $9.00/barrel of oil equivalent (boe) to $140/boe ($2000). In other words, the total resources estimated for each region are distributed 100 percent across the cost steps. The resource distributions by cost step for each region are the basis from which continuous cost curves are developed.

The distributions of regional resources into cost steps were estimated using information and estimates from a variety of sources including the United States Department of Interior economic assessments of U.S. onshore and offshore oil and gas resources, Chapter 5, *Energy Resources* in the United Nations Development Programme *World Energy Assessment, the Challenge of Sustainability* (2000), and H-H. Rogner's

Assessment of World Energy Resources in the *Annual Review of Energy and the Environment* (1997). Also, the USGS *World Petroleum Assessment* provides an assessment of discovery maturity or exploration maturity of the world hydrocarbon basins, as well as a ranking of each assessed basin by expected future oil and gas volumes. This was a key input to the estimated distribution of conventional oil and natural gas resources into the various cost steps. Several recent papers and other analyses of specific unconventional resource categories were helpful as well in estimating reasonable cost distributions for undiscovered resources.

After the undiscovered resources for each CCRAF region are distributed into cost steps, additional constraints are needed on the timing and conversion of resources into reserves. Timing and resource conversion or “discovery and production” constraints are provided for each region and cost step category to prevent the CCRAF model from converting all the undiscovered resources to reserves once a price threshold is reached. For each region and resource category, the relevant factors considered to estimate timing and constraints on the conversion of resources to reserves include current and likely production infrastructure, discovery maturity, remoteness, technical challenges, transportation considerations, potential environmental constraints. Informed, albeit subjective, estimates must be made regarding reasonable constraints on the timing and likely exploration and production success for each region, resource category, and cost step. For example, estimated tight gas resources in regions other than the United States and Canada will have stringent constraints on timing and the estimated percentage of resource that might be converted each year to reserves, whereas coal bed methane resources have less stringent production and timing constraints. Similarly, unconventional oil resources such as oil sands and extra heavy oil have less stringent constraints on timing and conversion of resources to reserves in Latin American regions and Canada than in the United States. Although these resource categories are present in the United States, they are in a higher cost category and have more stringent timing and resource conversion constraints to reflect environmental and technological concerns. Some resource categories such as coal have almost no timing constraints, whereas resource categories such as methane hydrates and aquifer gas clearly must have significant timing constraints applied.

Tables 16 through 18 show the estimated distribution of technically recoverable undiscovered resources by cost step. Tables 19 and 20 summarize the estimated timing and resource conversion constraints estimated for each resource category, region, and cost step. The resource conversion constraint is the maximum percentage of resource that can be converted annually to reserves for the region, resource category and cost step. The constraints do not mean that the CCRAF model converts that volume of resource to reserves annually; rather, it is a cap on the amount of resource that can be moved to reserves, depending on other parameters in the model.

Table 16: Estimated Distribution of Undiscovered Conventional Resources into Cost Steps

		Low Resource Estimate			Mean Resource Estimate			High Resource Estimate		
Region	**Cost Step**	**Crude Oil Bbbls**	**Natural Gas Tcf**	**NGL Bbbls**	**Crude Oil Bbbls**	**Natural Gas Tcf**	**NGL Bbbls**	**Crude Oil Bbbls**	**Natural Gas Tcf**	**NGL Bbbls**
United States	**1**	28	162	9	34	197	9	42	243	10
	2	70	487	9	85	589	9	106	729	10
	3	14	146	1	17	177	2	21	219	3
	4	28	16	1	34	20	1	42	24	1
	5	-	-	-	-	-	-	-	-	-
Canada	**1**	1	5	0.1	2	72	4	3	158	9
	2	0.5	6	0.1	1	54	3	3	118	7
	3	0.3	4	0.1	2	45	2	3	98	6
	4	0.2	1	<0.1	1	9	0.5	1	20	1
	5	-	-	-	-	-	-	-	-	-
Mexico	**1**	5	9	0.3	16	34	1	29	67	3
	2	4	7	0.3	12	25	1	22	51	2
	3	2	3	0.1	6	13	0.5	11	25	1
	4	2	3	0.1	6	13	0.5	11	25	1
	5	-	-	-	-	-	-	-	-	-
Brazil	**1**	2	6	0.2	9	33	1	18	68	2
	2	7	35	1	36	183	5	73	376	12
	3	10	13	0.3	255	67	2	110	137	4
	4	2	10	0.2	9	50	1.5	18	103	3
	5	-	-	-	-	-	-	-	-	-
Rest of Latin America	**1**	7	35	1	34	150	4	71	314	10
	2	10	46	1	46	201	6	94	418	13
	3	2	7	0.2	7	30	1	14	63	2
	4	2	11	0.3	11	50	1.5	24	105	3
	5	-	-	-	-	-	-	-	-	-
Europe	**1**	2	27	0.7	25	243	8	53	555	14
	2	0.1	5	0.1	1	41	1	3	92	3
	3	1	5	0.1	12	41	1	25	92	3
	4	7	9	0.2	81	81	3	172	185	6
	5	-	-	-	-	-	-	-	-	-
Former Soviet Union	**1**	8	236	4	25	820	16	44	1537	34
	2	24	177	4	69	615	16	123	1153	34
	3	20	171	3.5	56	594	14	104	1114	28
	4	1	6	0.1	2	21	15	3	38	1
	5	-	-	-	-	-	-	-	-	-
Central Asia	**1**	5	55	1	18	190	5	34	355	11
	2	5	120	3	18	418	11	34	781	23
	3	10	22	0.5	33	76	2	61	142	4
	4	1	22	0.5	2	76	2	3	142	4
	5	-	-	-	-	-	-	-	-	-

Table 16: Estimated Distribution of Undiscovered Conventional Resources into Cost Steps (continued)

		Low Resource Estimate			Mean Resource Estimate			High Resource Estimate		
Region	Cost Step	Crude Oil Bbbls	Natural Gas Tcf	NGL Bbbls	Crude Oil Bbbls	Natural Gas Tcf	NGL Bbbls	Crude Oil Bbbls	Natural Gas Tcf	NGL Bbbls
Middle East	1	105	560	21	307	1653	70	533	2903	134
	2	28	149	6	82	441	19	142	774	36
	3	7	37	1	20	110	5	36	194	9
	4									
	5	-	-	-	-	-	-	-	-	-
Africa	1	18	66	2	48	191	6	80	344	12
	2	18	66	2	48	191	6	80	344	12
	3	26	47	1.5	70	135	4	117	244	9
	4	7	34	1	18	98	3	31	177	6
	5	-	-	-	-	-	-	-	-	-
India	1	0.4	6	0.1	1	21	0.3	2	39	1
	2	1	4	0.1	2	13	0.2	3	24	0.4
	3	0.4	4	0.1	1	13	0.2	2	24	0.4
	4	0.2	2		1	5	0.1	1	10	0.2
	5	-	-	-	-	-	-	-	-	-
South and East Asia	1	2	59	0.5	7	105	2	12	192	4
	2	3	39	0.8	10	168	3	19	306	6
	3	2	26	0.5	7	105	2	12	192	4
	4	1	7	0.2	3	42	1	5	77	1.5
	5	-	-	-	-	-	-	-	-	-
Japan	1									
	2									
	3									
	4									
	5									
China	1	2	12	0.4	6	44	2	11	86	3
	2	3	15	0.5	9	39	2	18	115	5
	3	2	10	0.3	6	37	1	11	72	3
	4	1	2	0.1	2	7	0.3	5	14	0.6
	5	-	-	-	-	-	-	-	-	-
Australia & New Zealand	1	1	15	0.5	2	47	2	4	83	3
	2	1	24	1.0	4	75	3	7	133	5
	3	1	15	0.5	2	47	2	4	83	3
	4	0.3	6	0.2	1	19	1	2	33	1
	5	-	-	-	-	-	-	-	-	-

Table 17: Estimated Distribution of Unconventional and Coal Resources into Cost Steps – Low Resource Estimate

Region	Cost Step	Oil Shale Bbbls	Heavy Oil Bbbls	Oil Sands Bbbls	Tight Gas Tcf	Coal Bed Methane Tcf	Shale Gas Tcf	Hydrates Tcf	Aquifer Gas Tcf	Coal MMt
United States	**1**		0.1		74	52	11		7	49,999
	2	52	0.1	1	74	130	86	8	34	74,998
	3	361	0.3	6	148	52	108	78	54	99,998
	4	516	0.1	3	173	26	11	304	34	24,999
	5	103			25			304	7	
Canada	**1**			20	26	13	2		7	1,352
	2	0.5	0.5	245	26	65	86	8	34	2,208
	3	2	2	143	52	39	107	78	54	2,704
	4	2	2		60	13	19	304	34	676
	5	0.5	0.5		9			304	7	
Mexico	**1**				3				1	242
	2				3				3	363
	3				5			3	4	484
	4				6			13	3	121
	5				1			16	1	
Brazil	**1**	0.3			8				5	2,386
	2	2			8			6	27	3,579
	3	11			16			56	44	4,772
	4	11			19			220	27	1,193
	5	3			3			282	5	
Rest of Latin America	**1**		41		12		3		8	1,980
	2		81		12		104	14	41	2,970
	3		203	0.2	25		130	141	66	3,960
	4		81	0.1	29		23	551	41	990
	5				4			707	8	
Europe	**1**	0.4	0.1		11	17	1		6	25,042
	2	3	0.3		11	85	27	4	29	37,564
	3	15	0.7	0.2	22	51	34	39	46	50,085
	4	15	0.3	0.2	26	17	6	152	29	12,521
	5	4			4			195	6	
Former Soviet Union	**1**		-	0.5	50	23	1		7	38,223
	2	9	-	5	50	114	31	30	35	38,223
	3	34	-	30	100	68	38	298	55	95,582
	4	34	-	15	117	23	7	1166	34	19,116
	5	9			17			1494	7	
Central Asia	**1**		-	0.6	19	23			3	8,229
	2	1	-	6	19	114			13	12,343
	3	2	-	38	37	68			20	16,457
	4	2	-	19	43	23			13	4,114
	5	1			6				3	

Table 17: Estimated Distribution of Unconventional and Coal Resources into Cost Steps – Low Resource Estimate (continued)

Region	Cost Step	Oil Shale Bbbls	Heavy Oil Bbbls	Oil Sands Bbbls	Tight Gas Tcf	Coal Bed Methane Tcf	Shale Gas Tcf	Hydrates Tcf	Aquifer Gas Tcf	Coal MMt
Middle East	1		0.5		54		3		10	342
	2		0.9		54		125	1	52	342
	3		2	0.1	109		156	6	83	855
	4		0.9	<0.1	127		28	24	52	171
	5				18			31	10	
Africa	1		<0.1	1	15	2			10	11,073
	2	5	<0.1	11	15	10	14	1	49	16,610
	3	5	0.1	64	30	4	17	13	78	22,147
	4	5		32	35	4	3	49	49	5,537
	5	4			5			63	10	
India	1				1	2			3	17,479
	2				1	10		1	14	26,219
	3				3	4		9	23	34,958
	4				3	4		37	14	8,740
	5							47	3	
South and East Asia	1				10				8	1,561
	2	0.3			10		16		38	2,342
	3	21		1	20		20		60	3,123
	4	21		1	23		4		38	781
	5	5			3				8	
Japan	1								3	155
	2								13	155
	3							5	21	387
	4							18	13	77
	5							24	3	
China	1	0.1	<0.1		4	69	433		5	22,900
	2	0.5	0.1		4	345	173		23	34,350
	3	2	0.2	0.2	7	267	217		37	45,800
	4	2	0.1	0.2	8	69	39		23	11,450
	5	0.5			1				5	
Australia & New Zealand	1	0.1			5	20	284		8	16,533
	2	1			5	98	114	4	38	24,799
	3	4			9	58	142	42	60	33,066
	4	4			11	20	26	165	37	8,266
	5	1			2			212	7	

Table 18: Estimated Distribution of Unconventional and Coal Resources into Cost Steps – High Resource Estimate

Region	Cost Step	Oil Shale Bbbls	Heavy Oil Bbbls	Oil Sands Bbbls	Tight Gas Tcf	Coal Bed Methane Tcf	Shale Gas Tcf	Hydrates Tcf	Aquifer Gas Tcf	Coal MMt
United States	**1**	-	0.3	-	121	97	16	-	20	364,05
	2	105	0.7	2	121	244	274	18	201	546,07
	3	732	0.3	14	241	97	392	195	403	728,10
	4	1046	-	7	281	49	78	759	282	182,02
	5	209	-	-	40	-	6	973	101	-
Canada	**1**	-	-	45	42	60	8		20	27,098
	2	1	-	545	42	300	274	18	201	40,648
	3	4	-	318	84	180	392	195	403	54,197
	4	4	-	-	98	60	78	759	282	13,549
	5	1	-	-	14	-	9	973	101	-
Mexico	**1**	-	-	-	4	-	-	-	2	242
	2	-	<0.1	-	4	-	-	1	17	363
	3	-	<0.1	-	8	-	-	8	34	484
	4	-	-	-	10	-	-	31	24	121
	5	-	-	-	1	-	-	40	8	-
Brazil	**1**	0.6	-	-	13	-	-		27	7,328
	2	5	-	-	13	-	-	14	274	10,992
	3	22	-	-	27	-	-	141	547	14,656
	4	22	-	-	31	-	-	551	383	3,664
	5	6	-	-	4	-	-	706	137	
Rest of Latin America	**1**	-	102		20	-	5		41	5,274
	2	-	203		20	-	182	14	411	7,912
	3	-	507	0.4	40	-	260	141	821	10,549
	4	-	203	0.3	47	-	52	551	575	2,637
	5	-			7		10	707	205	
Europe	**1**	0.7	0.4		18	17	1		29	72,475
	2	7	0.7		18	85	47	10	287	108,71
	3	30	2	0.5	36	51	68	98	575	144,95
	4	30	0.7	0.3	42	17	14	381	402	36,238
	5	7			6		3	488	144	
Former Soviet Union	**1**		-	1	82	133	2		35	48,489
	2	17	-	11	82	667	54	74	345	48,489
	3	70	-	64	163	400	77	746	690	121,22
	4	70	-	32	190	133	15	2914	483	24,244
	5	17	-		27		3	3734	173	
Central Asia	**1**		-	1	30	133	-	-	13	29,805
	2	1	-	13	30	667	-	-	128	44,707
	3	5	-	76	61	400	-	-	255	59,609
	4	5	-	38	71	133	-	-	179	14,902
	5	1	-		10		-	-	64	

Table 18: Estimated Distribution of Undiscovered Resources into Cost Steps – High Resource Estimate (continued)

Region	Cost Step	Oil Shale Bbbls	Heavy Oil Bbbls	Oil Sands Bbbls	Tight Gas Tcf	Coal Bed Methane Tcf	Shale Gas Tcf	Hydrates Tcf	Aquifer Gas Tcf	Coal MMt
Middle East	**1**	-	1	-	88	-	6	-	52	342
	2	3	2	-	88	-	219	2	518	342
	3	10	6	0.1	177	-	313	16	1036	855
	4	10	2	0.1	206	-	63	61	725	171
	5	3	-	-	29	-	13	78	259	-
Africa	**1**	-	<0.1	2	25	2	1	-	45	34,380
	2	11	0.1	22	25	10	23	3	446	51,570
	3	43	0.2	130	49	4	34	31	892	68,670
	4	43	0.1	65	57	4	7	122	625	17,190
	5	11	-	-	8	-	1	157	223	-
India	**1**	-	-	-	2	2	-	-	15	17,479
	2	-	-	-	2	10	-	2	146	26,219
	3	-	-	-	4	4	-	24	291	34,958
	4	-	-	-	5	4	-	92	204	8,740
	5	-	-	-	1	-	-	118	73	-
South and East Asia	**1**		-		16	-	1	-	38	2,148
	2	0.5	-		16	-	27	-	377	3,222
	3	2	-	3	33	-	39	-	754	4,296
	4	2	-	2	38	-	8	-	528	1,074
	5	0.5	-		5	-	2	-	189	-
Japan	**1**	-	-	-	-	-	-	-	2	1808
	2	-	-	-	-	-	-	1	20	1808
	3	-	-	-	-	-	-	12	40	4519
	4	-	-	-	-	-	-	46	28	904
	5	-	-	-	-	-	-	59	10	-
China	**1**	0.1	0.1	-	6	81	9	-	19	22,900
	2	1	0.1	-	6	403	303	-	193	34,350
	3	4	0.4	0.5	12	242	433	-	386	45,800
	4	4	0.1	0.3	14	81	87	-	270	11,450
	5	1	-	-	2	-	17	-	96	-
Australia & New Zealand	**1**	0.2	-	-	7	33	6		33	127,86
	2	2	-	-	7	163	198	11	335	191,80
	3	8	-	-	15	98	284	106	670	255,73
	4	8	-	-	17	33	57	413	469	63,933
	5	2	-	-	2	-	11	529	168	-

Table 19: Estimated Timing and Resource Conversion Constraints - Conventional Resources

(timing constraint & maximum resource converted annually to reserves)

		Low Resource Estimate			Mean Resource Estimate			High Resource Estimate		
Region	**Cost Step**	**Crude Oil Bbbls**	**Natural Gas Tcf**	**NGL Bbbls**	**Crude Oil Bbbls**	**Natural Gas Tcf**	**NGL Bbbls**	**Crude Oil Bbbls**	**Natural Gas Tcf**	**NGL Bbbls**
All (Timing & % Converted Varies by Region)	**1**	Current/ 5% - 20%	Current/ 2% - 30%	Current/ 1%- 5%	Current/ 5% - 20%	Current/ 1 – 10%	Current/ 5%, 10%	Current/ 2% - 10%	Current/ .5% - 10%	Current/ 5%, 10%
	2	Current/ 5% - 20%	Current/ 5%- 30%	Current/ 5%,10%	Current/ 5% - 20%	Current/ 1 – 10%	Current/ 10%	Current/ 5%- 20%	Current/ 1% - 20%	Current/ 5%, 10%
	3	Current/ 10% - 20%	2020/ 15% - 20%	2020/ 20%	Current/ 15%	2020/ 5% - 20%	2020/ 20%	Current/ 15%	2020/ 1% - 20%	2020/ 10%
	4	2020/ 20%	2025/ 20%	2025/ 20%	2020/ 20%	2025-30/ 10% - 20%	2025/ 20%	2020/ 20%	2030/ 5% - 20%	2030/ 10%, 20%

Table 20: Estimated Timing and Resource Conversion Constraints - Unconventional Resources and Coal

(timing constraint & maximum resource converted annually to reserves)

Region	**Cost Step**	**Oil Shale Bbbls**	**Heavy Oil Bbbls**	**Oil Sands Bbbls**	**Tight Gas Tcf**	**Coal Bed Methane Tcf**	**Shale Gas Tcf**	**Hydrates Tcf**	**Aquifer Gas Tcf**	**Coal MMt**
Low Resource Estimate										
All (Timing & % Converted Varies by Region)	**1**	Current 1%, 5%	2000-10/ 1%, 5%	Current/ 1%	2000 – 30/ 5% -10%	2000 – 10/ 1% - 10%	2000 – 30/ 5%	-	2010/ 1%, 5%	Current/ 10%
	2	2005 -15/ 1% - 5%	2005 – 10/ 1% - 5%	2005 -10/ 1% - 5%	2000 – 30/ 5% -10%	2000 – 10/ 1% - 10%	2000 – 30/ 1%, 10%	2010-20/ 5%, 10%	2010/ 2%, 5%	Current/ 5%
	3	2010 – 20/ 1% - 10%	2010 – 15 5%	2010 – 15/ 5%	2010 – 30/ 5% - 10%	2010 – 20/ 2% - 10%	2010-40/ 1%, 5%, 10%	2010-20/ 1%, 5%, 10%	2015/ 3%, 5%	Current/ 2%
	4	2015-25/ 1%-10%	2020 -25/ 10%	2020/ 10%	2015 – 30/ 5% - 10%	2010-25/ 5% - 10%	2015 – 40/ 5%, 10%	2010-40/ 1%, 10%	2020/ 1%, 5%	Current/ 2%
	5	2030/ 5%	-	-	2015 – 30/ 10%	-	-	2015-40/ 1%, 10%	2025/ 10%	-
High Resource Estimate										
All (Timing & % Converted Varies by Region)	**1**	Current 1%, 5%	2005 – 10/ 1%, 5%	Current/ 1%	2000 – 30/ 3% -10%	2000 – 10/ 5% - 10%	2000 – 30/ 5%	-	2010/ 0.5%, 5%	Current/ 5%
	2	2005 -15/ 1% - 5%	2005 – 10/ 5%	2005 -10/ 5% - 10%	2000 – 30/ 3% -10%	2000 – 10/ 5% - 10%	2000 – 30/ 1% - 10%	2010-20/ 5%	2010/ 0.5%, 5%	Current/ 2%
	3	2010 – 20/ 1% - 10%	2010 – 15/ 1% - 10%	2010 – 15/ 5%	2010 – 30/ 5% - 10%	2010 – 20/ 10%	2010-40/ 1% - 10%	2010-20/ 1%, 10%	2015/ 0.5%, 5%	Current/ 1%
	4	2015-25/ 1%-10%	2020 – 25/ 10%	2020 10%	2015 – 30/ 5% - 10%	2010-25/ 10%	2015 – 40/ 5% - 10%	2010-40/ 0.5% -10%	2020/ 0.5%, 5%	Current/ 1%
	5	2030/ 5%	-	-	2015 – 30/ 10%	-	2015 -40/ 10%	2015-40/ 0.5% -10%	2025/ 5%, 10%	-

Other Energy Sources

Other energy sources, including solar, wind, biofuels, hydroelectricity, geothermal, and nuclear energy are modeled utilizing a framework that focuses on price that varies over time due to technological development and annual availability constrained regionally, if appropriate. Costs for intermittent energy sources such as wind and solar photovoltaic (PV) can increase as their share of electricity production increases.

The availability and cost of all these energy sources, with the possible exception of hydroelectricity, is highly uncertain in the time frame of this analysis. For example, wind turbine technology has matured tremendously in the past 15 years but the cost of transporting the energy to market may be costly and the impact on the power grids, especially increased reserve requirements, is more difficult to assess. Solar PV costs have been declining 5 percent annually, and technology programs are predicting costs competitive with peak power production in many places within 5 to 10 years. The key issues with solar will be how fast and far do costs decline, and how quickly can manufacturing capacity increase and the technology penetrate the market. Geothermal technologies are currently economic in many areas and the key questions have to do with how quickly market imperfections such as consumer knowledge and high consumer discount rates can be resolved.

Solar and Wind Resources

Solar and wind are combined in CCRAF and the assumptions about future prices and availability of these resources need to reflect a mix of these sources. Due to the greater abundance of solar PV and better access to the resource, we will use solar PV as a proxy for the combined resource in the out years but due to greater wind power generation, we will use current wind costs in the near term. At the start of 2002, there were approximately 24,500 megawatts (MW) of wind power globally[31] and around 1,000 cumulative MW of solar PV produced, estimated by the *National Renewable Energy Lab, 2003 Margolis Presentation*.

The assumptions for solar generation costs are based on[32] work performed by the U.S. Department of Energy (DOE) in 2004*.* The baseline estimates for solar PV costs for commercial customers start at $0.18/kilowatt hour (kwh) in 2004 and decline to $0.068/kwh by 2050 and provide the basis for the median cost estimates. The 95^{th} percentile estimate for commercial customers is based on the roadmap estimate from this source, which has electricity prices declining to $0.037/kwh by 2050. The 5^{th} percentile estimate assumes a price reduction to only $0.10/kwh by 2050.

The economics of wind power are regional and depend heavily on the wind resource but even in good wind resource areas, the cost of generation is currently competitive as distributed generation depending on the location of the resource. Estimates for final wind power costs are based on data from the U.S. Department of Energy*, Energy Efficiency and Renewable Energy, Wind and HydroPower Technologies Program, 2004* and for fair wind resources are comparable to the estimated cost reductions for solar PV. The DOE goal of reducing wind power cost is to reduce from current costs of $0.10 to $0.15/kwh to around $0.03/kwh by 2007 (the solar PV roadmap is for $0.037/kwh in 2050). Additional cost reductions should be expected after that. Note that these costs represent the cost to the consumer and must be adjusted for use in CCRAF to compete with wholesale power. The base line starting costs are $0.12/kwh and decline by 2050 to $0.052/kwh in the low case (95th percentile), $0.068/kwh in the median case, and $0.095 in the high case (5th percentile).

HydroPower

Hydropower is cost competitive and has been exploited to various degrees in different regions. Currently, hydropower produces 2650 Terawatt hours/year (Twh/year) of electricity.[33] The ultimate potential that is both economically and technically feasible is 8000 Twh/year (however, environmental and other constraints may limit the exploitation of these resources.) For purposes of this analysis, we assume that only a small percentage 3100 Twh/year are available with a 98 percent probability, 4900 Twh/year are available at a 50 percent probability, and 6600 Twh/year are available at 2 percent probability with the distribution of cost ranging from $0.035/kwh up to $0.07/kwh for the last step (2 percent probability).

Geothermal and Renewables and Waste

Geothermal energy and renewables and waste will continue to play an increasing but minor role in the world energy market. For this analysis we assumes that on average we get a 10 percent reduction in costs by 2050 and an over 20 percent increase in resource availability from 1990 levels. Note that geothermal energy focuses on power generation using geothermal resources. Geothermal energy use such as geothermal heat pumps and central heating are modeled as efficiency gains in the energy use module.

Model Cases

The analysis examines a Reference Case with no greenhouse gas limits and three environmental policy cases where greenhouse gases are constrained. For each case, output is provided in different ways: as averages or means, as percentiles, and as conditional on global population, global GDP, or global conventional crude oil resources. Each case can be represented by all of these output types but typically, if not otherwise specified, if a value is referenced and not clarified, it will represent the mean value from the variants in the simulation.

Reference Case

The Reference Case represents a world without greenhouse gas controls but where limits on SO_2 and NO_x increase over time, both in developed economies and developing economies. The SO_2 and NO_x limits are defined based on the EPA proposed Interstate Air Quality Rule (IAQR) and tightened past 2020. In the EPA analysis of the proposed IAQR, the limits for the 28 states for NO_x and SO_2 are extended to the lower 48 states. The limits used in the Reference Case reflect these limits, which are tightened past 2020. The proposed IAQR only covers emissions from power generation, so the U.S. regional SO_2 and NO_x emission targets for the period through 2050 were increased using 1990 emissions from other sectors such as transportation and agriculture.

Emission targets for other regions were developed using a pollution density approach. The U.S. target was divided by the area in the United States with population above 25 per square kilometer. This ratio was then applied to each region based on the area in the region with population above 25 per square kilometer. This target was then adjusted to allow other regions to shift gradually from current emissions to the target using population growth and growth in GDP per capita.

The Reference Case, as well as each environmental policy case, includes a thousand variants where income growth, population growth, energy resources, energy demand, and climate variables vary. Subsequently, the Reference Case is defined by both the average results from the simulation but also the distribution of these results.

Environmental Cases

The analysis included three environmental cases that explore the impact of alternative limits on GHG but use the same pollution density targets for NO_x and SO_2 as the reference case. They include constraints on CO_2 emissions to achieve the following CO_2 concentrations by 2100:

- High Target: 650 parts per million (ppm) (408 ppm in 2015, and 436 ppm in 2025)
- Medium Target: 550 ppm (408 ppm in 2015, and 425 ppm in 2025)
- Low Target: 450 ppm (408 ppm in 2015, and 413 ppm in 2025)

These targets are achieved by setting a regional CO_2 emissions target for developed economies at the 1990 emissions level starting in 2015 and setting a regional CO_2 emissions target for developing economies at the 2020 emission levels starting in 2025. The regional emission targets are then adjusted if the emissions over or under-achieve the concentration target. Global trading of emission allowances is allowed and the model solves for a CO_2 emission allowance charge that achieves the emission targets. CH4 and NO_x emissions are controlled through emission allowance charges that are tied to the CO_2 emission allowance charge. These charges are based on 100-year global warming potentials for these gases. The results of the model runs are presented in Chapter 4.

CHAPTER 3: MARKET INTANGIBLES

The prior chapters have dealt with the fundamentals underlying the oil market: that is largely supply and demand, and with the population and GDP projections that drive demand. There are a number of other parameters that affect the market, but that are difficult to model explicitly. In many cases price is used as a surrogate to represent these various factors, as the market's perception of their importance can have a substantial impact on price. In addition, these market intangibles, as they are called, can be a major contributor towards market price volatility.

This chapter will address a number of parameters that are not explicitly modeled in CCRAF but will have to be implicitly accounted for in the cases and in assessing the implications for California. These parameters are:

- Stock levels
- Spare production capacity
- Investment levels
- The decline of the dollar
- The role of the hedge funds
- Market structure
- Geopolitical factors
- Strategic petroleum reserves

Stock Levels

Just-in-time inventory management has become the mantra of inventory management over the last decade. Management of petroleum inventories is somewhat different. Unlike the manufacture of widgets where the Federal Express van draws up each morning with the necessary inventory, management of petroleum inventories still demands stocks, and sometimes substantial stocks. Inventory assures stable supply and allows for the seasonality of demand for certain products, but it is also a cost of doing business.

Nevertheless, over the past decade there have been substantial efficiency advances in the management of liquid inventories. This has application to all aspects of the supply chain from large terminals to small product tanks in residential housing. The advance in electronics and software management systems allows industry to monitor stock levels much more effectively and in real time, allowing a more optimal use of stocks. This, combined with similar efficiencies and advances in shipping technology, has allowed the petroleum industry to adopt a version of the just-in-time inventory approach.

Figure 9 shows U.S. national stocks for crude oil, gasoline, and distillates from 1990 to the present. The trend line is also shown. The decline in crude oil stocks is particularly marked. Gasoline stocks have declined slightly and distillate[34] stocks have remained flat. The graphs also reflect the changing demand for products. Demand for gasoline and distillates, particularly diesel, has grown steadily and this growth in demand has been matched by a growth in stocks that offsets the overall decline. A better reflection of trends is the forward day coverage.

Figure 9: U.S. Stocks 1990-2004
(Thousand Barrels)

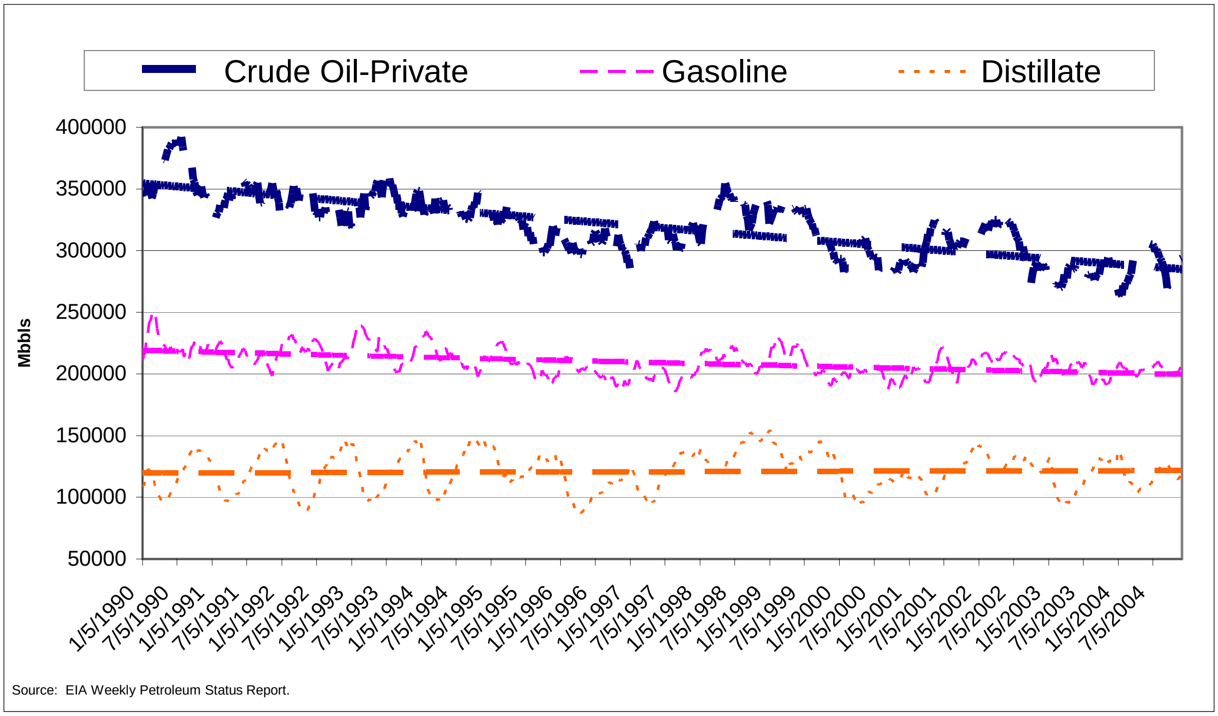


Figure 10 shows the trend in forward day coverage for the same products and for the same time period. Figure 11 shows the trend in forward day coverage for total petroleum within the entire Organization for Economic Cooperation and Development (OECD) region. Both graphs show a steady decline in the forward day coverage.

Figure 10: U.S. Crude Oil, Gasoline and Distillates – Days of Forward Cover

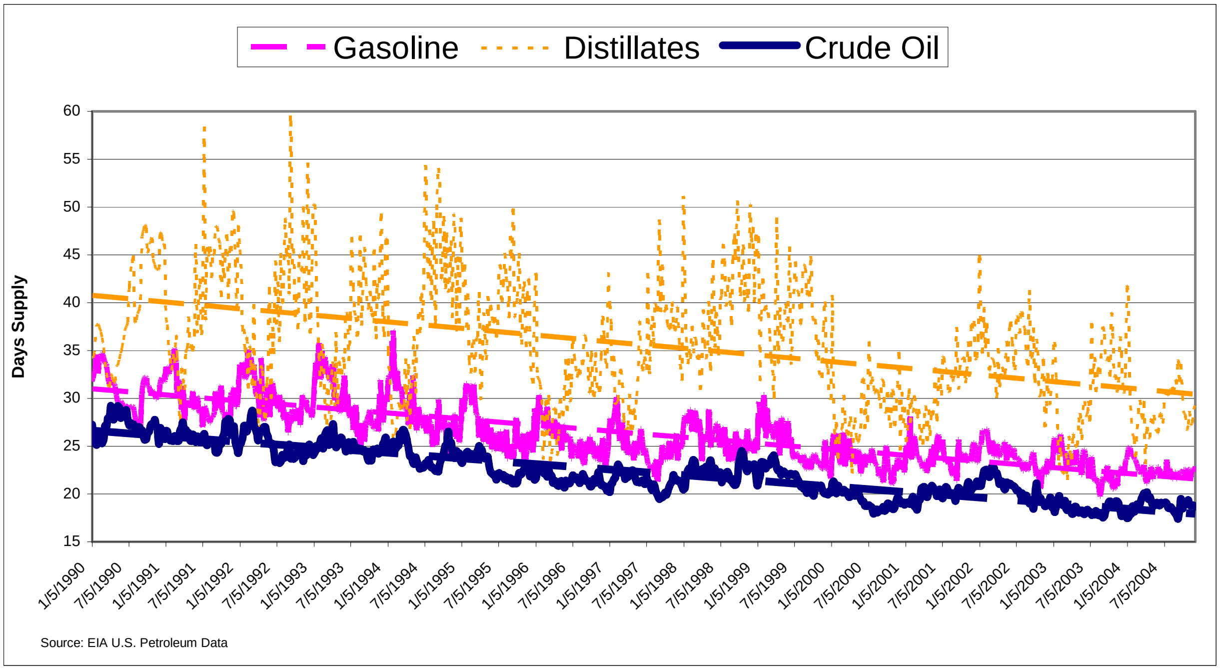
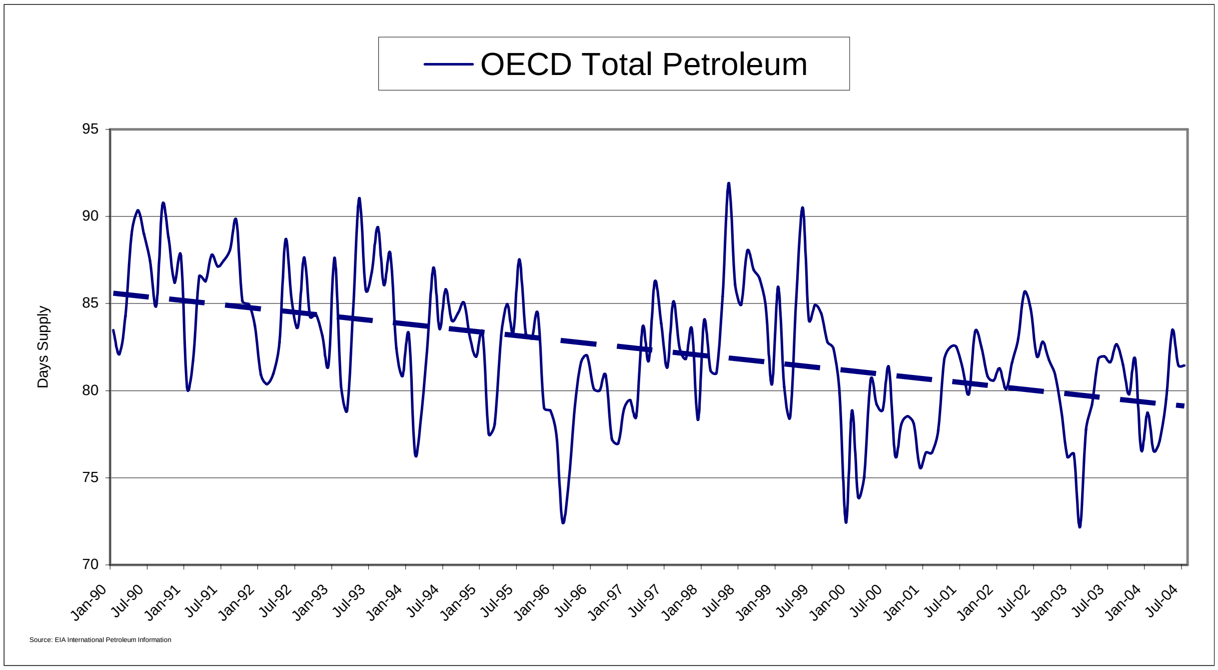


Figure 11: OECD Total Petroleum - Days of Forward Cover



Since inventories are considered working capital and a cost of doing business, the trend is to minimize inventory levels unless there is a financial incentive to carrying larger volumes. The decision whether or not to reduce or increase inventory levels is based in large part on the futures market. If the out months prices are higher than the current price, the future profits may cover the current carrying cost and the risk. However, the market recently has been largely backwardated[35] which has reinforced the decline in the inventory levels.

A company carrying more inventory than necessary faces increased costs, unless they have some other financial incentive to do so. Consequently, companies aim to minimize working capital or costs while at the same time maintaining an adequate inventory for customers. ICF envisages that these trends will continue. Stock buildup for specific products will continue on a seasonal basis (e.g., heating oil stocks will be built up during the late summer and early fall), but the general trend will be to minimize any excess stocks.

There is another force at work in minimizing inventories. One of the driving parameters behind the setting of OPEC quotas is the prevention of a large stock build, which will mitigate against price spikes and act as a buffer. However, current prices are such that OPEC has decided to maintain and increase production levels so that inventories can increase and calm the market. This decision has resulted in a small stock build. The increase has translated into slightly contango markets, which in turn will increase stocks.[36]

The history of the past decade shows that the industry can supply product even when stock levels are much lower than in the past.[37] However, lower levels of stocks cut the cushion that is available to protect against unforeseen events, whether they be accidents or weather events. The outcome of this will be that random price spikes may become the norm and general volatility increases.

Spare Production Capacity

Historically, OPEC has always maintained between 3 and 5 mmb/d of spare production capacity, much of it concentrated in Saudi Arabia.[38] This excess capacity, or idle capital equipment, has provided the mechanism by which OPEC, and in particular Saudi Arabia, has controlled the oil market. Implicit in the spare capacity is the ability to flood the market and depress prices. After the shock of the oil price collapse in the mid 1980s, OPEC has displayed surprising discipline in its production and pricing approach and the cartel's spare capacity has played a role in this.

The last few years have seen the unexpected surge in demand from the developing world, particularly China, India, and Brazil, as well as from the United States. There has been a clear underestimation of demand by the energy data agencies. The resulting surge in supply to meet this demand has essentially used up the excess production capacity in both the non-OPEC and OPEC producers. Table 21 shows the recent history of OPEC's spare production capacity. Historically, OPEC has always maintained that spare capacity needs to be approximately 4 percent of world demand to regulate the market.[39] Data from 2004 show that spare capacity fell to approximately 1 percent of world demand. Major producers, including Saudi Arabia, have embarked on projects to bring additional production capacity on line more quickly than originally planned. Saudi Arabia's plans, in particular are important as much of the world's spare capacity is to be found in Saudi Arabia, and to a lesser extent, in the United Arab Emirates.

In the past, the benefits accruing from having spare capacity have outweighed the capital costs of maintaining it. Whether this position will continue going forward remains to be seen. Saudi Arabia is planning to bring forward new production that will raise the kingdom's output to 12 mmb/d by 2009 and has stated that it is examining the feasibility of 15 mmb/d.[40] However, Saudi officials have stated that spare capacity will be between 1.5 and 2 mmb/d.[41] As demand for petroleum grows, the size of spare capacity (if the 4 percent rule is to be maintained) must also grow. This raises some questions as to Saudi Arabia's willingness to make the necessary investments given the internal problems of 14 percent plus unemployment and one of the world's highest population growths (2.4 percent per year).[42]

The question of spare production capacity is a major parameter when considering price drivers. Much of the current nervousness of the market is based on the realization that little spare capacity exists should a major supply crisis erupt. This worry has been magnified by the fact that commercial stocks have also been low. There are reports that the International Monetary Fund (IMF) will recommend that OPEC double its spare capacity back to between 3 and 5 mmb/d. The IMF is concerned that the market is exposed to "significant upside price risk" and is likely to remain tight until 2010.[43]

As long as a high percentage of crude oil supplies originate in an unstable part of the world and spare production capacity is largely concentrated in one country and is perceived to be low, the market is likely to be subject to nervousness and volatility. To some extent this volatility can be offset by the buildup of commercial stocks. However, excessive buildup of stocks brings its own costs.

Table 21: Spare Production Capacity
(Thousand Barrels per Day)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	Mar-04
Algeria	44.0	29.0	20.0	64.7	35.0	28.2	6.9	-37.7	-2.4	106.7	41.1	100.3	260.0	0.0	0.0
Indonesia	14.0	34.9	85.8	62.6	19.8	81.3	75.5	98.0	97.9	44.2	63.6	34.5	-70.4	0.0	-10.0
Iran	65.0	51.0	103.9	230.0	222.0	191.8	142.3	153.8	179.2	256.0	316.3	311.3	353.8	157.2	0.0
Iraq	126.0	-5.0	24.9	-14.7	2.5	-10.0	0.2	424.0	634.0	176.1	434.3	522.6	911.0	0.0	200.0
Kuwait	555.0	237.0	328.8	455.9	425.0	538.6	449.3	479.9	395.7	583.3	173.5	402.5	311.9	122.2	0.0
Libya	190.0	39.8	83.3	123.0	21.4	60.0	50.2	-5.9	50.0	121.0	-10.0	33.5	84.4	0.0	0.0
Nigeria	10.0	28.2	58.0	226.0	264.1	202.2	194.5	62.5	41.5	65.1	166.0	132.6	340.1	0.0	50.0
Qatar	53.0	23.0	-17.2	32.0	60.0	38.0	38.5	-21.0	-181.6	223.1	47.8	100.8	213.4	123.1	100.0
Saudi Arabia	1554.9	541.0	833.3	1284.7	1780.1	1763.4	1670.2	1811.0	1741.1	2385.8	1596.2	1968.9	2403.8	1156.9	1300.0
United Arab Emirates	245.0	133.4	261.9	351.0	247.0	247.0	159.4	220.6	181.7	468.0	132.2	323.6	524.6	251.9	200.0
Venezuela	332.0	61.0	50.0	39.0	1.0	-48.9	95.0	-40.0	71.0	587.2	151.4	169.7	302.9	0.0	0.0
Total	3188.9	1173.3	1832.7	2854.2	3077.8	3091.7	2881.9	3145.1	3208.0	5016.7	3112.4	4100.3	5635.4	1811.2	1840.0
Source: EIA contact, Erik Kreil (Ekreil@eia.doe.gov), provided spare production capacity spreadsheet.															

Note: Columns may not add due to independent rounding.

Investment Levels

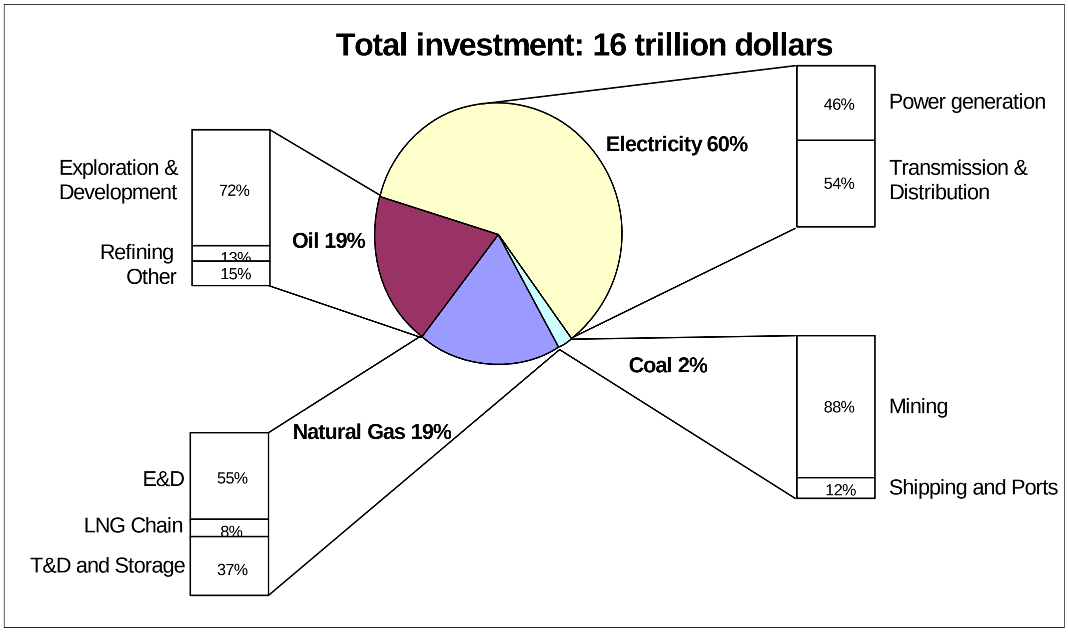
While there may be some disagreement over the details EIA, IEA, and OPEC all agree that, assuming average GDP growth in the world, oil demand will continue to grow throughout the next two decades. Demand for oil in transportation is expected to grow everywhere but particularly in the developing countries as a result of the growing wealth effect and the burgeoning demand for private cars. Despite the possible constraints of infrastructure and policies there is a huge potential in the developing countries, particularly India and China.

EIA's reference case assumes petroleum consumption of 120 mmb/d by 2025, IEA's reference case assumes oil demand of 121.3 mmb/d by 2030, and OPEC assumes oil demand of 114.6 mmb/d by 2025.[44] All parties concerned agree that this growing demand will call for enormous investments to be made throughout the supply chain.

The IEA recently completed a detailed study of energy investment requirements out to 2030. Total estimated investment requirements total $16 trillion, or 1 percent of world GDP.[45] Figure 12 shows the percentage distribution of the $16 trillion by energy type. Oil accounts for 19 percent, or $3.1 trillion, with conventional oil production accounting for the bulk of the investment at $2.2 trillion, and an additional $205 billion needed for non-conventional oil. The investment needs of tankers and pipelines amount to $260 billion while $410 billion is needed for refineries, predominantly in the Middle East, Africa, and Asia.

There is considerable uncertainty as to whether or not these investment dollars will be available. In large part there is concern over macroeconomic issues; that is, will the world's economies, particularly in the developing countries, continue to grow strongly. Lower economic growth would lead to a slowing down in demand for energy. The macroeconomic issues are important, as the energy investment distribution is not uniform. The investment total of 1 percent of GDP is a world average. The impact is much higher in the developing countries. In India and China it is estimated to equal between 2 and 3 percent of GDP, in the Middle East over 3 percent, and in Russia over 5 percent.

Figure 12: Total Energy Investment Requirements Through 2030



Source: International Energy Agency, *World Energy Investment Outlook*, 2003

OPEC itself believes that there is considerable uncertainty after 2010 in the level of non-OPEC oil production.[46] For example, they believe that the present level of production in Russia is not sustainable, especially due to infrastructure constraints. Current events in Russia would seem to bear these concerns out. Russian production has slowed. In addition, the Russian government has taken various steps to tighten its control over the natural resources industry. The latest step is to impose restrictions on foreign companies bidding on the development of a number of big fields. This reversal potentially could undercut Russia's efforts to raise the large investment sums in the international markets necessary for both the development of the fields and the expansion of the crude oil transportation infrastructure.[47]

This uncertainty about the projections of non-OPEC oil production after 2010 is found among many analysts. Only EIA has a robust view of likely increasing growth. OPEC itself sees a small growth, while the IEA and other forecasters see a decline. This generates great uncertainty as to the level and timing of OPEC investments if they are to provide the marginal barrel and balance the market. Current projections show a range of almost $100 billion in the investment requirements for OPEC depending on the assumptions of non-OPEC oil production. The decision facing OPEC is whether they should make the investments and then run the risk of maintaining substantial spare capacity if demand does not grow as projected. As mentioned before, Saudi Arabia is planning to rapidly boost their production from the current 10.5 mmb/d to 12 mmb/d. Saudi Aramco has a long term development scenario of 15 mmb/d; a level they believe they can sustain for half a century.[48]

The downstream sector of the industry is also faced with considerable uncertainties. On a worldwide basis there is a continual push for more stringent product specifications, which will be challenging for many of the refiners in the developing world. At the same time more stringent environmental restrictions are being placed on refinery operations. This is also true of the tanker industry, which is being pushed towards more stringent environmental and safety specifications. The implementation of Annex VI of the MARPOL Convention in May 2005 will also require the production of low sulfur marine fuels, both distillate and residual.

The result of refinery inflexibility in a world of changing specifications can be seen in the widening margin between light sweet crude oils and the heavier sour crude oils, which is at a historic high. The margin between distillate and residual fuel is also at a historic high. Refiners in China and India are now facing lower sulfur requirements for transportation fuels. Starting April 1, 2005, Indian gasoline and diesel sulfur levels are reduced to 500 ppm, with 11 major cities requiring diesel with a 350 ppm level and gasoline with a 150 ppm level. China will require the sulfur content of diesel and gasoline to be reduced to 500 ppm on July 1, 2005.[49]

There are reports that the upgrading of Indian domestic refineries will not be completed until the end of 2006, while the Chinese refineries are estimated to have very low hydrotreating capacity. The solution being pursued is to seek greater volumes of light, sweet crude oil and essentially bidding up the price of crude oils such as Brent and WTI. The risk is that if a sufficient level of investment is not forthcoming for refineries to expand and adapt, and the same can be said for distribution facilities, then there will be considerable risk that the downstream sector in the industry will become the prime source of oil price volatility in both the crude oil and the products markets.

There are reports in the trade journals that the major oil companies are pursuing a conservative investment policy and making their decisions on projected $20 per barrel oil.[50] Certainly the high short term price volatility increases risk and the internal investment hurdle rate for companies. The low real oil prices of the past 20 years have restrained substantial investment and companies are leery of making investments only to have prices crash.[51] Work that the IEA has performed in the past shows that there is a strong inverse relationship between investment levels and price volatility.

Companies are factoring in a conservative price assumption for many reasons. They are concerned about:

- Macroeconomic trends and the effect on demand.
- Environmental policies, whether applicable to the upstream or downstream sectors.
- Geopolitical problems that increase the perception of risk.

- Access to reserves: 35 percent of the world's reserves are completely restricted to national oil companies and another 22 percent are under the control of national oil companies and only allow limited access.

- Technological problems.

- Pressure from shareholders who resist risk and demand high investment returns.[52]

- A fall in demand resulting in a return to low prices.[53]

- Aging of the work force and a potential future lack of technical experts.

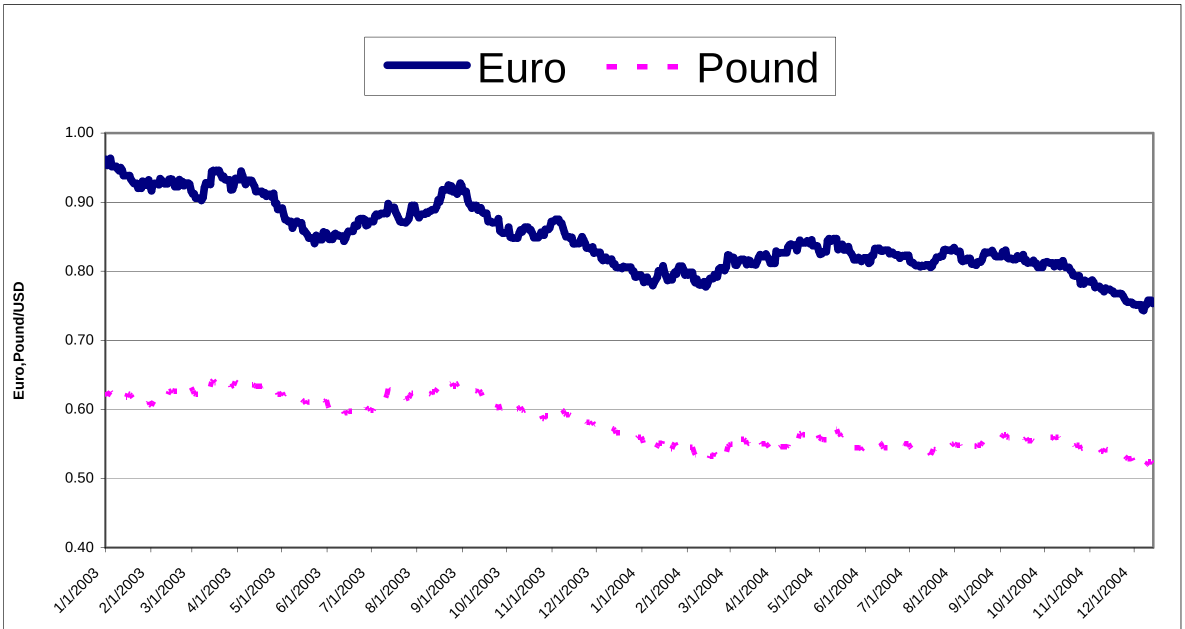
The national oil companies have also under invested. Many of the Middle Eastern countries are largely dependent on oil revenues and are faced with high public debt and social and infrastructure demands from a rapidly growing population.[54] The usual assumption among analysts is that the investment dollars for energy will be there. There is some concern about this assumption. There are many and varied demands on the world's investment dollars and energy is only one of the sectors facing the need to expand and replace infrastructure, adapt to changing environmental policies, and push the edge of technologies. Failure to make the necessary investments, or to make them in a timely fashion, will result in inflexibility and tightness in the market that will translate into higher volatility and prices.

Decline of the Dollar

Over the last few years, as the U.S. deficit has grown the dollar has become weaker. Figures 13 and 14 track the dollar against the pound, euro, and the yen. The graphs show a steady decline in the value of the dollar against the other major currencies. Oil is denominated in dollars in the international market. The oil producing countries are concerned that with the value of the dollar declining their ability to purchase on the world market also declines. The value of the dollar falling has effectively cut the value of payments to OPEC producers. Taking into account dollar devaluation, the OPEC old price range of $22 to $28 translates into $29.26 to $37.24 in Euro adjusted dollars.[55] At the same time, because of the strength of the other major currencies, the high price of oil does not have quite as negative an impact as might be expected if the economies using other major currencies were growing to begin with.

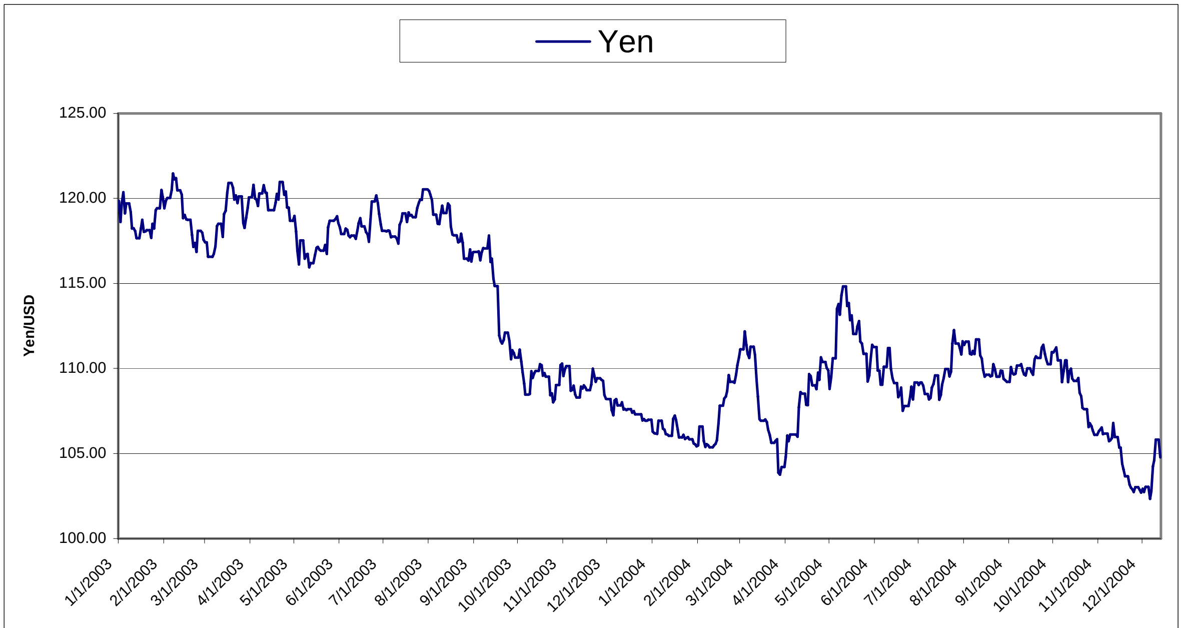
As long as the dollar is declining, the incentive of the producing countries is to try and keep their prices high to compensate for the loss of buying power. OPEC countries are now discussing a price floor rather than a price band. The number most commonly cited is $30 per barrel,[56] although the more radical elements in OPEC such as Iran and Venezuela are talking about higher numbers. Given the U.S. budget deficit, which does not take into account the cost of the war in Iraq and plans to change Social Security, the dollar is most likely to continue weak. Efforts to decrease the deficit will likely take a number of years to show any effect. As long as the dollar remains weak, the tendency will be for the oil producing countries to try to maintain a high price to compensate for lost purchasing power.

Figure 13: Value of the Dollar versus the Euro and the Pound



Source: www.fxtop.com Currency Converter.

Figure 14: Value of the Dollar versus the Yen



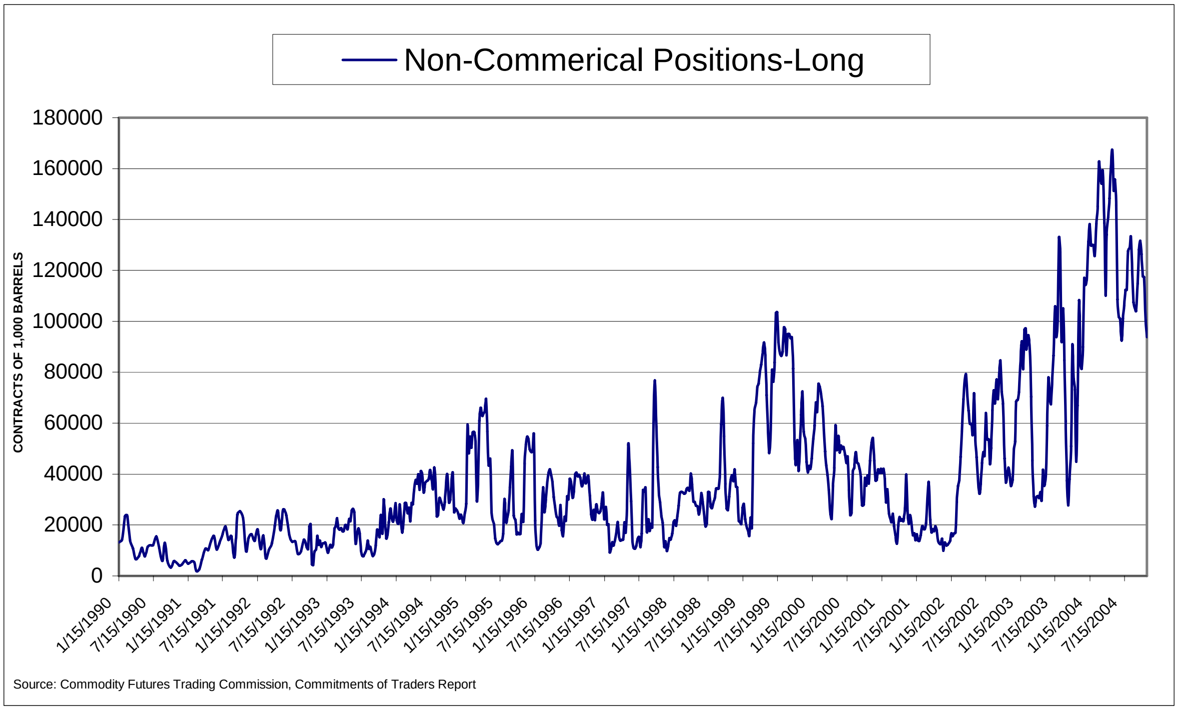
Source: www.fxtop.com Currency Converter.

Hedge Funds

There has been considerable discussion over the last year on the role of the hedge funds in the futures market and whether or not they are responsible for driving up the price of oil. Certainly it is true that that there are more players in the market today. Figure 15 shows the net long positions of the hedge funds in oil futures from 1990 onwards. Although the *Commitment of Traders Report* does not fully represent the activity in the market, the graph clearly shows that participation has substantially increased. There is a sustained bull market across the entire energy spectrum and prices are extremely volatile. Volatility attracts speculators who in turn bring greater liquidity to the market. Energy is seen as a commodity that offers the potential for greater returns.

Nevertheless there is considerable argument as to what role large traders do play, if any, in bidding up the price of oil. Opinions have ranged from no effect to a belief that speculation is what is driving the market. Premiums of $5 to $7 a barrel have been estimated at various points of time. EIA has been looking into the question of whether speculators are driving the price of oil. EIA has concluded that the role of speculators is minor; they exacerbate a situation that preexists rather than being the driving force.[57] ICF's view is that speculators are not major drivers, but tend to follow the market. Price movements appear to be related to changing fundamentals rather than to the action of speculators. Volatility must preexist to attract speculators, although once they enter the market, they may exacerbate preexisting trends.

Figure 15: Non-Commercial Positions – Long



Market Structure

In the 1990s, particularly with the fall of the Soviet Union, there appeared to be a growing trend towards market liberalization and globalization, trends in which the oil market participated. A characteristic of these trends was the lessening role of states or state entities in the markets. Problems of supply and demand are resolved by the open market and free trade, with prices determined by the fundamentals. Another critical aspect of this emerging global market structure was the realization that commercial law and commercial agreements must be transparent and not subject to political whims. The first four years of the 21st century have seen some retreats from these trends with increasing involvement in the market by states, often with the enthusiastic support of large sections of the population. Rather than evolving towards a global free market, the world appears to be evolving into several markets, ranging from a free market to a restricted government controlled market and everything in between. [58]

Thirty-five percent of the world's reserves are under the total control of national oil companies, with another 22 percent largely under the control of the national oil companies. The latter countries may also have investment agreements that are not attractive to outside investors.[59] Consequently, investment activities of the international oil companies may be constrained by these restrictions. One of the main drivers of the changes in the market observed in the last two years is the surge in demand in the developing countries, particularly China, India, and Brazil. Both Chinese and Indian national oil companies are scouring the world for oil and gas supplies. They have a different approach from the international oil companies:

- They are willing to work in countries that are dangerous.
- They are willing to accept much greater risk as they do not have investors who are demanding high returns.
- They are willing to accept less favorable commercial terms.

These national oil companies are in some sense extensions of their governments and act as such, essentially entering into government to government bilateral deals in which foreign aid is offered in return for access to oil and gas. Examples are interest free loans to develop communications systems and the Chinese loan to Russia to help finance the nationalization of Yukos Oil Company. Other actions are the changing of the oil tax rules in Venezuela with retroactive impacts on existing contracts. This may indicate one of the future trends of moving away from open markets to government to government bilateral deals. In the future, large oil producing countries may enter directly into bilateral deals with large oil consuming countries.[60]

Geopolitical Events

Crude oil is unique in that a substantial percentage of the crude oil on the market today, and in the future, comes from the Middle East, a politically unstable part of the world. Since the 1973 oil embargo analysts have always been concerned about the viability of the region and the likelihood of a major supply disruption there. This was further reinforced when the Shah was overthrown and Iranian oil was cut off from the market place for five months.

This concern over the Middle East continues and has grown with the invasion of Iraq and the upsurge in Islamic terrorism, but this has been joined by concern over other major producers, such as Venezuela,[61] Nigeria,[62] and Russia. There have been other events such as a major strike in Norway closing down production in part of the North Sea. In addition, some of the major new finds, such as that in Khazakhstan, are far from markets and must be transported over pipelines running through some of the most politically unstable parts of the world.

Events that affect the market and the world economy can take numerous forms:

- Supplies can be cut off by either political or natural events (witness the impact of Hurricane Ivan).

- Transportation can be disrupted.

    - Pipelines can be bombed, as is happening in Iraq currently. There is an increasing reliance on long distance transnational pipelines, which are vulnerable to attack.

    - Tankers can be attacked, as happens in the Straits of Malacca, or critical tanker “chokepoints” could be disrupted either by attacks or blockades. Approximately 11 mmb/d passes through the Straits of Malacca and 15 mmb/d through the Straits of Hormuz.

The possibility of geopolitical events is always there looming in the background to a greater or lesser extent depending on cultural, social and political events. The effects on the world market, however, vary depending on the state of the oil market. Currently the oil market is tight and relatively inflexible. In such circumstances even small events are magnified and have an effect out of proportion to the event. In the current environment even one refinery going down unexpectedly makes product prices soar. Combinations of events can also impact the market. In 2003 some Nigerian production was lost. In the overall scheme of things it would not have had an appreciable impact except that it happened at the same time as the labor strike in Venezuela and the loss of Iraqi production.

Other events in the oil markets can also magnify the effects of geopolitical upsets. More stringent product specifications, particularly lower sulfur in gasoline and diesel, are spreading around the world. These regulations are going into effect in China and India within the next few months despite their refineries not yet being completely upgraded to produce these products. Consequently both countries are buying up sweet crude oil. Bonny Light from Nigeria is one of the more valuable crude oils in the world for making low sulfur gasoline and diesel. The possibility that the Niger Delta will be disrupted again because of the upcoming Nigerian presidential elections is driving up the price of light sweet crude oils everywhere.

ICF believes that the oil market will continue to be tight at least until 2010, and even beyond that if demand in the developing countries and the United States continues to grow rapidly. Markets that are tight tend to be inflexible in their response to crises and are marked by price spikes and volatility. We therefore expect that geopolitical events will continue to exercise a large impact on the oil market.

Strategic Petroleum Reserves

There is considerable controversy over the different aspects of energy policy, but there appear to be two actions upon which most countries agree. These two actions are the maintenance of surge production capacity that can be brought on in times of supply disruptions, and strategic stocks that can also be brought on in emergencies.

The 26 industrialized member states of the IEA have built up strategic reserves largely as a response to the 1973 oil embargo. The reserves vary considerably from the British Industrial Reserve where industry maintains additional stocks as a cost of doing business, through European reserves that are partially industrial and partially government, to the U.S. Strategic Reserve, which is wholly government owned. What is stored also varies. Until the establishment of the Northeast Heating Oil Reserve, the U.S. reserve was exclusively crude oil. Other members of the IEA store a mix of crude oil and products or only products. Storing products is more complicated as the problem of shelf life necessitates the regular turnover of the product. The IEA recommends that reserves be equal to 90 days of net oil imports.

The European Union (EU) also requires that its members maintain strategic stocks. Over the last four to five years the EU has become more concerned about the possibility of supply disruptions of both crude oil and products. Unlike the United States, the EU is much more dependent on imported refined products, particularly from Kuwait, and in the Iraqi invasion of Kuwait the EU was as much affected by the cutoff of Kuwaiti refineries as it was by the loss of crude oil. Currently, the EU is discussing the possibility of extending the reserve requirements beyond the 90 days to 120 days with the requirement that the government own the incremental 30 days supply.

Concern over the volatility of the oil market and the real possibility of disruptions has raised the interest of other countries outside those of the IEA and the EU. Both China and India are considering the establishment of strategic reserves, as is Thailand and possibly the Philippines. Russia is known to have the concept under consideration.

Since 1993 China has become a net importer of petroleum. Imports jumped 31.29 percent in 2003 and 34.66 percent in 2004.[63] Demand is expected to slow somewhat in 2005 and early estimates for 2005 import growth are for 14 percent, raising the imports to 2.3 mmb/d. China is currently talking about a reserve of approximately 150 million barrels, which would cover refinery demand for 20 to 30 days. Construction of the reserve is expected to begin in August 2005 with tentative plans to fill it at the rate of 110 mb/d until 2008, and then, possibly, 250 mb/d until 2015. Indian plans are much smaller with the current discussion focused on a reserve of about two weeks. There are rumors that the Chinese are seriously considering using their reserve to manipulate oil prices as well as providing backup in a possible supply disruption.

There has been considerable controversy over the U.S. Administration's determination to fill completely the Strategic Reserve. The amount of crude oil going into the U.S. Strategic Reserve is equal to less than a tenth of 1 percent of the world market. An impact on the market would be expected, however, if there are a number of countries attempting to fill their reserves during a tight market with high and volatile prices.

Short Term Impacts of Intangible Market Factors

As mentioned in the introduction to this chapter, the impact of market intangibles is often played out in price effects. Some of the parameters have short term effects, some long term. For example, Hurricane Ivan had an immediate impact on supply and prices in the United States. Although the impact lasted longer than initially expected (the hurricane did more damage underwater than expected) nevertheless the period of impact has been finite. On the other hand, the effects of investment levels can be spread over many years: major expansions at refineries can take up to four years, and it can take up to ten years to find major new reserves in frontier locations. Looking forward, ICF sees three periods related to prices: the present to about 2010, 2010 to 2015, and post 2015. The impact from market intangibles varies depending on the period with their greatest impact coming in the short term.

Present to 2010

This is a period in which demand continues to grow but markets generally remain tight resulting in high and volatile prices. ICF sees short term prices for both the refiner's acquisition cost and WTI being higher than $37 per barrel in real terms ($2000). Saudi Arabia's announced production expansion to 12 mmb/d is not expected to be on line until 2009. Nor is there expected to be any substantial expansion of spare capacity during this period until right at the end. Saudi Arabia's target spare capacity of 1.5 to 2 mmb/d may not be enough to calm the market if demand continues to grow. This is likely to keep the market volatile, as geopolitical tensions in the Middle East are not expected to be resolved during this period.

The high prices of the last few years have stimulated increased investment, but not as much as expected. Companies are buying back stock and increasing stock dividends,[64] while the refining sector is making investments to meet the tightening sulfur restrictions, particularly the on road diesel regulations that go into effect next year. Refinery downstream capacity is highly utilized and forms a bottleneck. Saudi Arabia is currently producing 9.5 mmb/d. The additional barrels they can produce have no market as it is all heavy and sour and global downstream upgrading equipment is fully utilized.[65] Given estimates of future demand, the level of investment needs to be increased – if not, the impact further out will be increasing tightness in the markets. ICF sees the impact of all these events increasing volatility and uncertainty in the market and contributing to high oil prices.

2010-2015

During this period additional production resulting from current investments is expected to come on line. Prices start to come down towards the long term equilibrium prices. In addition, around 2012 the impact of GHG controls starts to appear in those countries that have implemented the Kyoto Accord. Nevertheless there are still uncertainties in the market. A major uncertainty is whether or not Saudi Arabia will return to maintaining its historical level of spare capacity. This will depend on Saudi Arabia's evaluation of their optimal investment level, which may not coincide with what the global oil market perceives as optimal. Lack of sufficient spare capacity will maintain the volatility in the market. Another unknown is what geopolitical events may occur in the oil producing nations. If resolution of the problems in these countries has not occurred by this point, the volatility and uncertainty in the market is likely to continue with attendant price spikes.

Post 2015

By 2015, all things being equal, prices will have reached the long term equilibrium prices in CCRAF. From this point they start to climb again slowly in real terms other than in the extreme GHG control target case. The real point of concern is whether or not the optimal level of investment has been made by both the International Oil Companies (IOCs) and the National Oil Companies (NOCs). If not, then volatility will return to prices.

CHAPTER 4: RESULTS

Crude oil prices and production are results of a number of factors that include population, GDP, energy use, energy resources, energy production, technological change, and environmental policy. This section will address these factors individually and then address the crude oil story in much more detail. Data tables for graphs shown in this chapter can be found in Appendix A.

Aggregation of Results

CCRAF is a Monte Carlo model that produces multiple simulations of variants for the Reference Case and for each environmental case. In order to understand the distribution of results and the impact of key parameters on the results, the CCRAF output is provided in several forms:

- CCRAF output shows the distribution of key output variables over time. The 5th, 10th, 50th, 90th, and 95th fractiles (percentile) for an output variable are provided for five-year increments from 2005 to 2050. An example of this output form is Exhibit 4-9, which shows distribution of primary energy use for the reference case; the 5th, 10th, 50th, 90th, and 95th percentiles of primary energy use (Quads) are displayed.

- CCRAF output shows the impact of key parameters. Key parameters (or comparison variables) include global population, global GDP, and global resources of conventional oil, all in 2050. The ranges of key parameters (comparison variables) such as population or global GDP are aggregated into groups. These aggregation groups contain the following ranges of the key parameter or comparison variable:

    - Minimum to 95th percentile
    - 95th percentile to 90th percentile
    - 90th percentile to 50th percentile
    - 50th percentile to 10th percentile
    - 10th percentile to 5th percentile
    - 5th percentile to Maximum

For output variables, CCRAF provides the average output value for variants that fall into each aggregation group. An example is provided in Figure 27 which shows average primary energy use at 2050 (an output variable) for the 5th percentile aggregation group of population, GDP, and conventional oil resources, the 10th percentile aggregation, the 50th percentile, and so on.

Table 22 shows the range of values for each aggregation group of the comparison variables - population, GDP, and conventional oil resources - used in the discussion and graphs that follow. For each variant, the global population, global GDP, and global conventional oil resources in 2050 are used to classify the variant into population, GDP, and conventional oil resources groupings. Then, the variant results are averaged and reported for each group and displayed on selected graphs and tables.

For example, the "minimum to 95th percentile" means there is a 95 percent chance that the value of the key parameter or comparison variable will exceed the minimum range. In the case of the key parameter GDP, the "minimum to 95th percentile" range is 73.1 trillion, which means that there is a 95 percent chance that global GDP will be at least 73.1 trillion. The "5th percentile to maximum" range is 133.1 trillion, which means that 5 percent chance is given that global GDP will reach a maximum of 133.1 trillion in 2050.

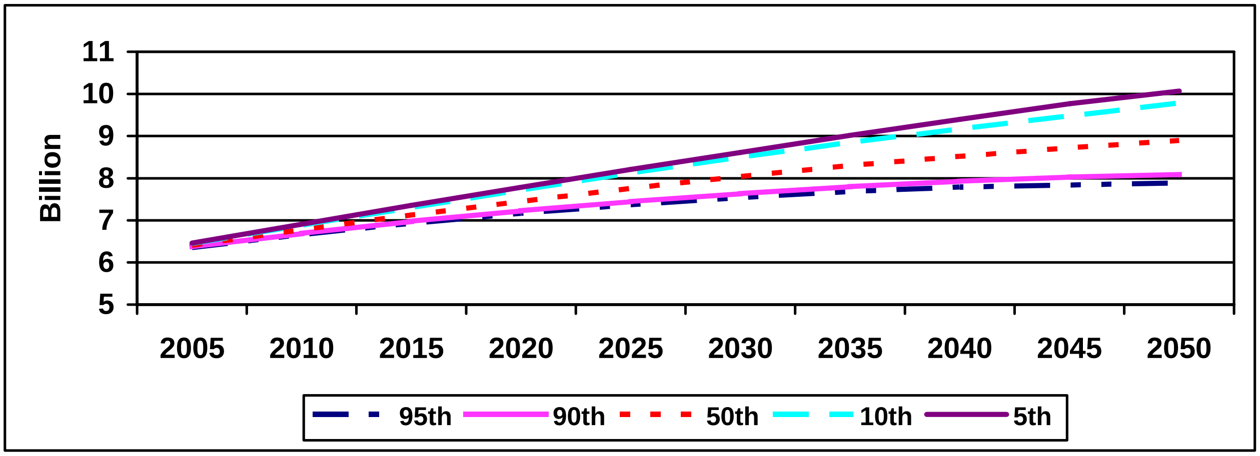
Table 22: Ranges of Comparison Variables for Aggregation Groups

Aggregation Group	Lower End of Range	Upper End of Range
	GDP (trillion $2000)	
Minimum to 95th Percentile	Min	73.1
95th to 90th Percentile	73.1	78.8
90th to 50th Percentile	78.8	97.6
50th to 10th Percentile	97.6	124.1
10th to 5th Percentile	124.1	133.1
5th Percentile to Maximum	133.1	max
	Population (billion)	
Minimum to 95th Percentile	Min	7.9
95th to 90th Percentile	7.9	8.1
90th to 50th Percentile	8.1	8.9
50th to 10th Percentile	8.9	9.8
10th to 5th Percentile	9.8	10.1
5th Percentile to Maximum	10.1	max
	Conventional Oil Resources (billion barrels)	
Minimum to 95th Percentile	Less than 1700	
95th to 90th Percentile	1700	1800
90th to 50th Percentile	1800	2600
50th to 10th Percentile	2600	3300
10th to 5th Percentile	3300	3700
5th Percentile to Maximum	Greater than 3700	

Population

Global population is expected to grow from 6.4 billion people in 2005 to 7 billion (low estimate) to 11.1 billion (high estimate) by 2050. Figure 16 provides the annual global population estimates by percentile. By 2050, the uncertainty above the 50th percentile is somewhat greater than the uncertainty below the 50th percentile but not dramatically so.

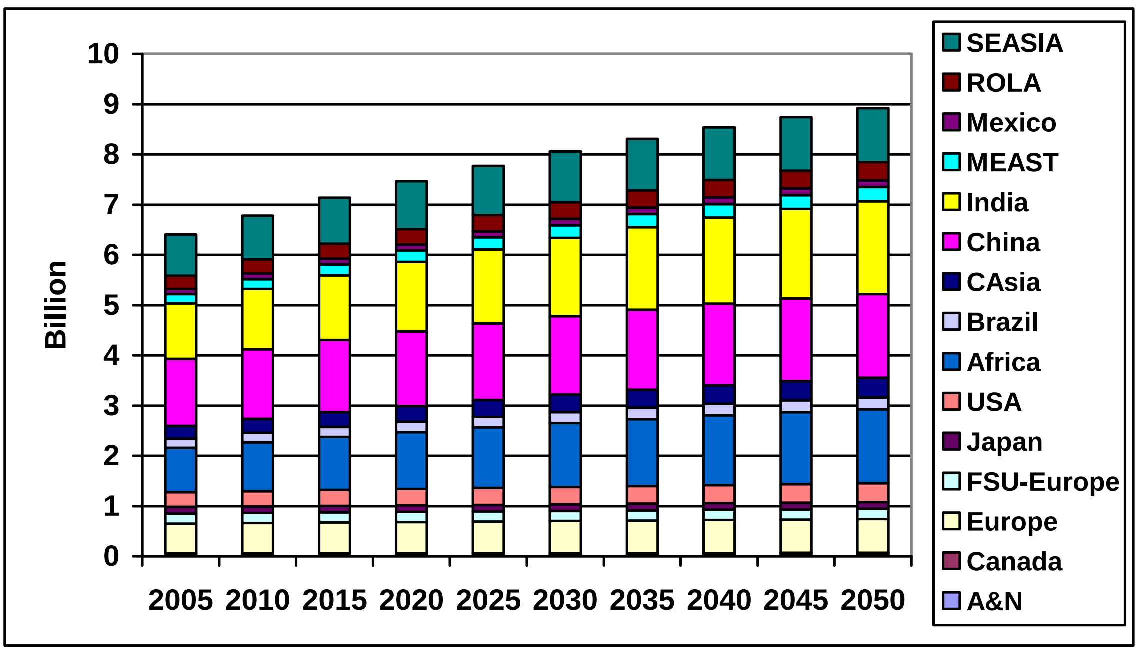
Figure 16: Global Population by Percentile, Reference Case



Data for this graphic is in Table 29.

The majority of the population growth occurs in developing countries (93 percent on average) as shown in Figure 17.

Figure 17: Mean Population Growth by Region, Reference Case

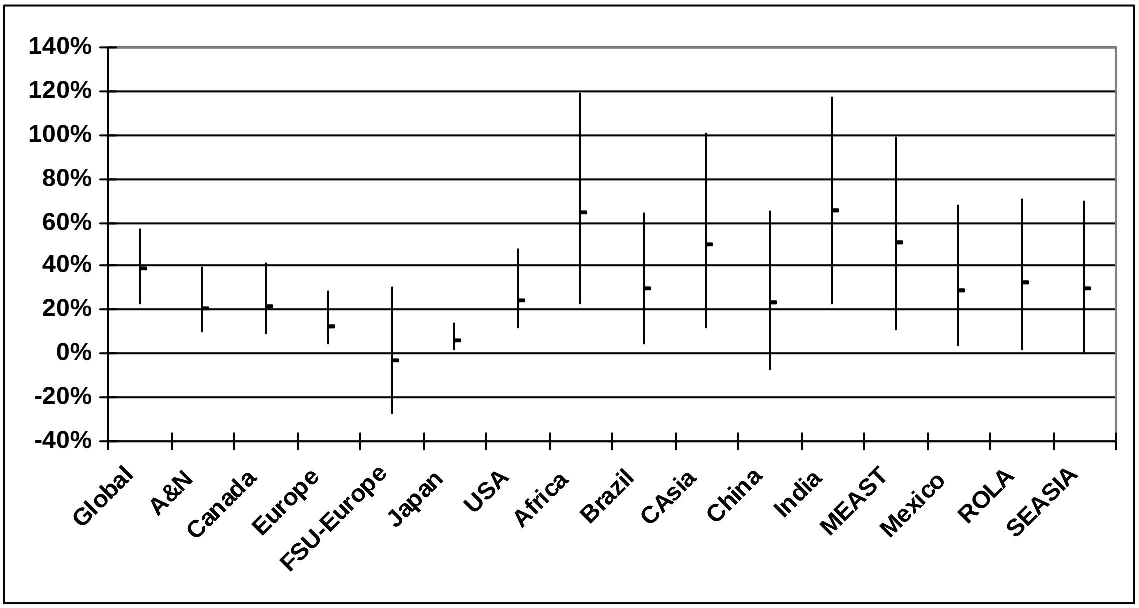


Data for this graphic is in Table 30.

Regional population shows more uncertainty proportional to 2005 population levels than global population. This is due to two key factors: (1) high estimates in one region are often offset by low estimates in another region and (2) population growth is impacted by migration, which regionally adds uncertainty but globally nets out.

Figure 18 shows the range of regional and global population growth for the reference case from 2005 to 2050. Global population growth ranges from 23 percent to 56 percent from the 95th to the 5th percentile while population growth in Africa ranges from 23 percent to 119 percent.

Figure 18: 2005 to 2010 Population Growth Uncertainty, Reference Case

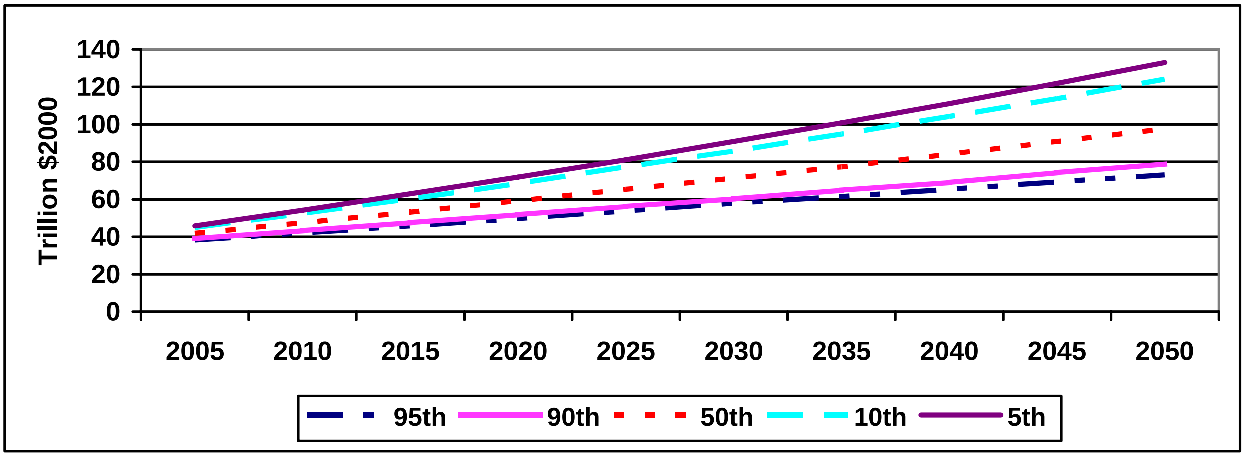


Data for this graphic is in Table 31.

GDP

GDP is expected to grow considerably in all regions with higher growth rates in developing countries, but most of the growth in total GDP is in developed economies. Figure 19 provides the global GDP within the uncertainty ranges. Uncertainty in 2005 is due to the model structure, which starts in 1990. Global GDP varies by a factor of two from the 95th percentile to the 5th percentile.

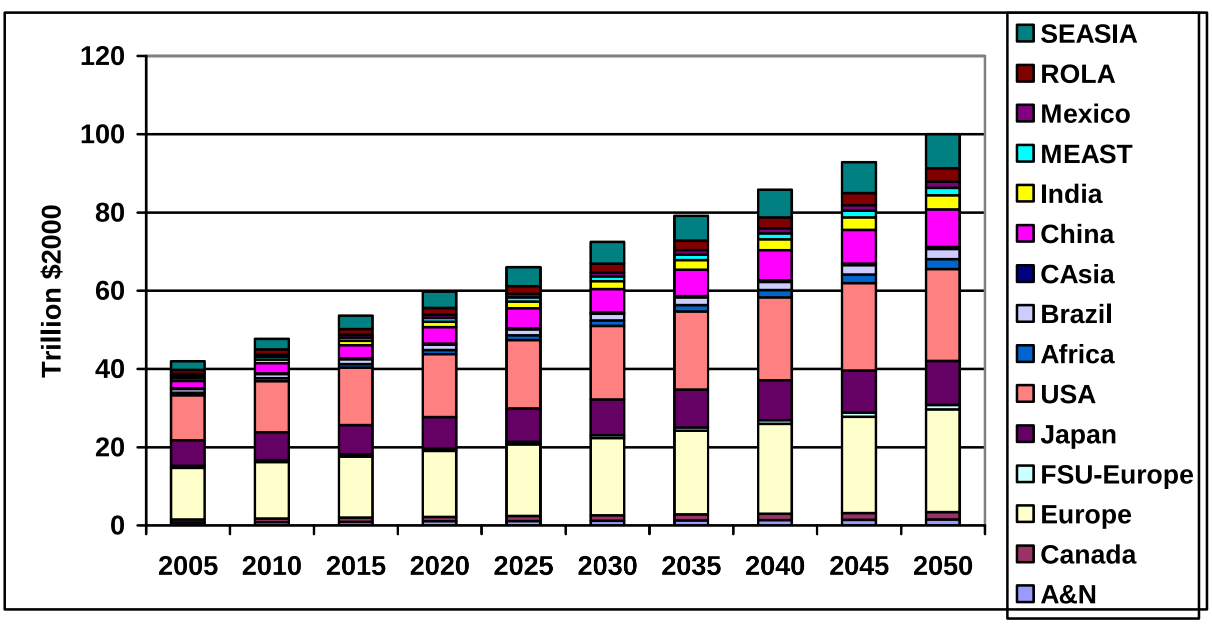
Figure 19: Global GDP by Percentile, Reference Case



Data for this graphic is in Table 32.

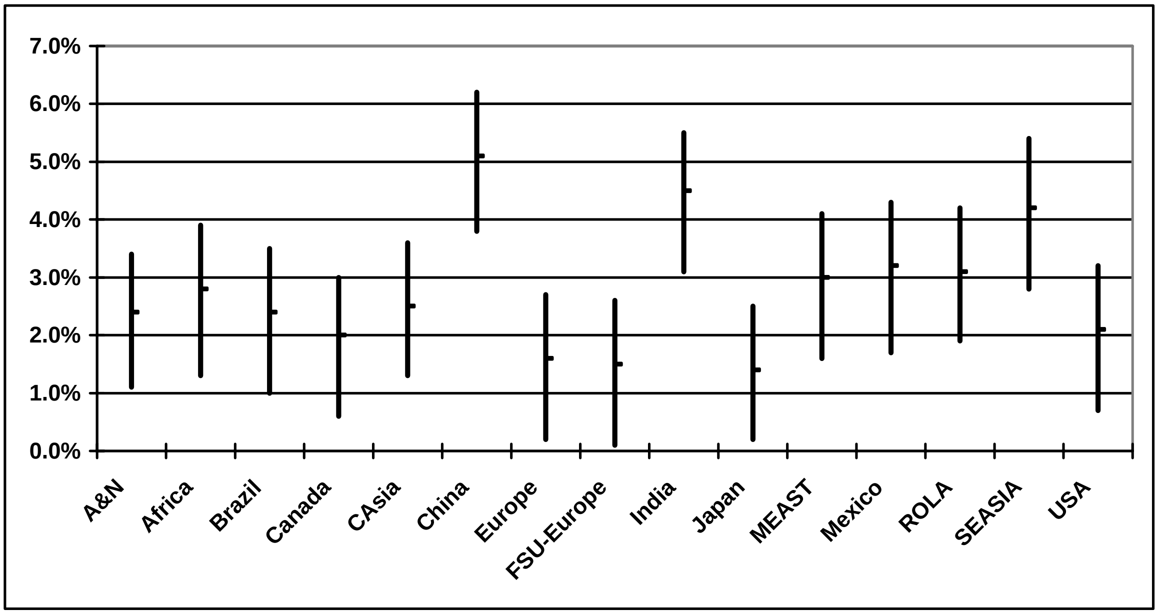
Figure 20 shows the mean regional GDP through 2050. The developed economies represent 79 percent of the global GDP in 2005 with their share declining to 66 percent by 2050. Figures 21a and 21b show the average and range of growth rates for each region for the periods 2000 to 2025 and 2000 to 2050. GDP growth rates are high for China, India, South and Southeast Asia, Mexico, and the rest of Latin America. Growth rates for developed economies are lower with the lowest in FSU-Europe and Japan. The low rates for FSU-Europe and Japan reflect a continuation of existing trends combined with very low population growth rates. Growth rates decline over time in all regions.

Figure 20: Mean GDP Growth by Region, Reference Case



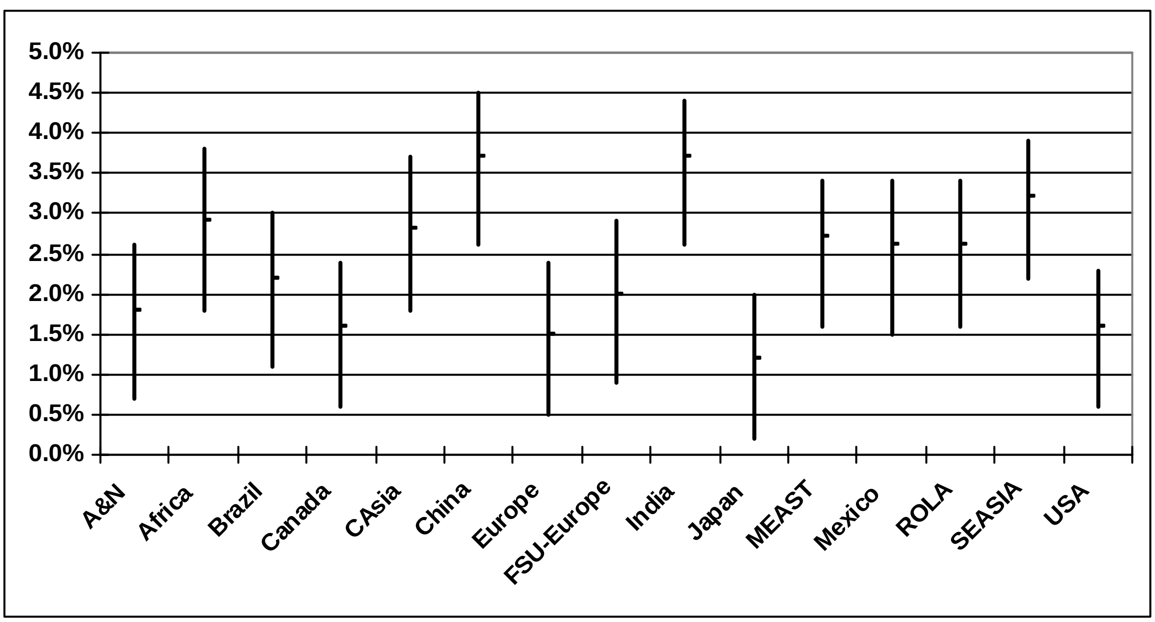
Data for this graphic is in Table 33.

Figure 21a: Average Annual GDP Growth by Region (2000 to 2025), Reference Case



Data for this graphic is in Table 34.

Figure 21b: Average Annual GDP Growth by Region (2000 to 2050), Reference Case



Data for this graphic is in Table 34.

CCRAF GDP growth results diverge from other studies for some regions. In the United States, historic growth in real GDP has averaged 2.9 percent for the past 20 years and EIA[66] projects 3.1 percent from 2005 to 2025. In the CCRAF results, the average starts at 2.9 percent but declines through 2050 yielding an average annual real growth rate of 2.1 percent through 2025 and 1.6 percent through 2050. The key drivers are declines in population growth rates and declines in improvements in GDP per capita. Population growth rates in the U.S. averaged 1.2 percent through the 1990s but in CCRAF decline to 0.5 percent by 2025 and to 0.04 percent by 2050. Growth in GDP per capita which averaged 2.0 percent annually through the 1990s starts at 2.0 percent but declines to 1.1 percent by 2025 and 0.6 percent by 2050. By 2025, aging of the population yields a labor force that has a smaller share of the total population contributing to 0.6 percent (or two thirds) of the decline in growth in GDP per capita.

In China and India, economic growth has been averaging 9.4 percent and 5.3 percent respectively, since 1976 to 1999 and EIA's reference case[67] has 6.1 percent and 5.2 percent, respectively, average annual growth for 2001 to 2025. CCRAF average results show average annual growth of 5.1 percent for China and 4.5 percent for India from 2005 to 2025. Overall, the results from CCRAF suggest that the growth rates statistically are unlikely to continue at historic rates, especially for China, as the size of the Chinese economy grows. Even as the percentage growth declines for China, the absolute growth in terms of $US continues to grow. We would expect the EIA's annual growth rates for these regions to decline in the *International Energy Outlook 2005* (*IEO 2005)*[68] due to EIA increasing oil prices. EIA's forecast growth in real GDP for the United States in the *International Energy Outlook 2004* (*IEO 2004)* from 2001 to 2005 was 3.4 percent and was reduced by 0.3 percent in their *Annual Energy Outlook 2005* (*AEO 2005)* reference case.

Average annual growth in global GDP from CCRAF from 2005 to 2025 is 2.3 percent, lower than the 3.0 percent for the EIA reference case. Again, the CCRAF results suggest slower growth than EIA in most regions and in particular, the United States, Europe, China, and India.

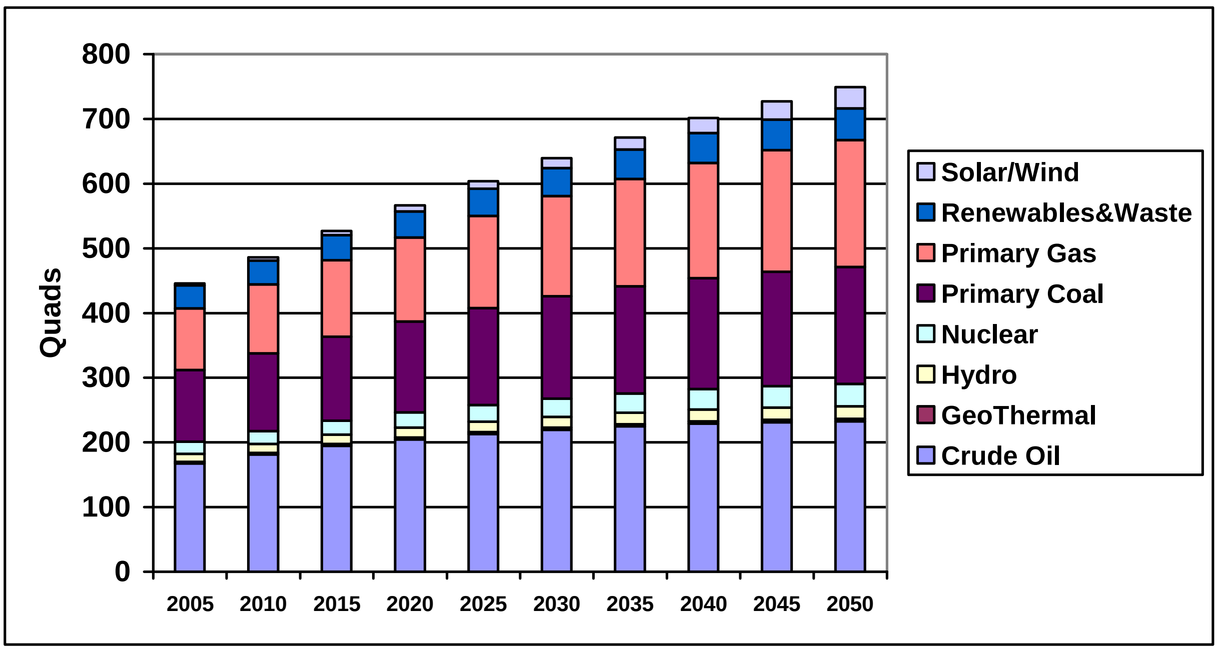
Primary Energy Use, Reference Case

The reference and environmental case energy use results will be presented as primary energy. Primary energy use represents the total amount of energy used in the economy and includes energy used for production and energy conversion (e.g., power generation and refining). Electric power is not considered primary energy; however, the energy used to produce electric power is considered primary energy use.

In CCRAF, the primary energy used to produce electricity for wind, solar, nuclear, and hydro energy sources is set equal to the amount of electric power produced. For example, if 1 kwh of power is produced from solar, then this is represented as 1 kwh of solar energy. This approach is not consistent with the way other data sources represent this data. For example, the Energy Information Administration assumes that 3.06 kwh of nuclear energy is consumed on average for each 1 kwh of electricity produced. This means that some care is required in comparing CCRAF results to EIA results.

Figure 22 shows the average global primary energy use from CCRAF for the Reference Case. Primary energy use grows from 445 Quads in 2005 to 750 Quads in 2050.[69] Without greenhouse gas controls the growth is balanced between fossil fuels and non-fossil energy sources, with the fossil fuel share declining by 3 percent in this time frame. Conventional and unconventional crude oil use declines as a share of total energy use from 38 percent in 2005 to 31 percent in 2050 while the share provided by natural gas increases by 5 percent. Conversely, crude oil use in absolute terms increases by close to 40 percent in this time frame and natural gas use increases by 106 percent.

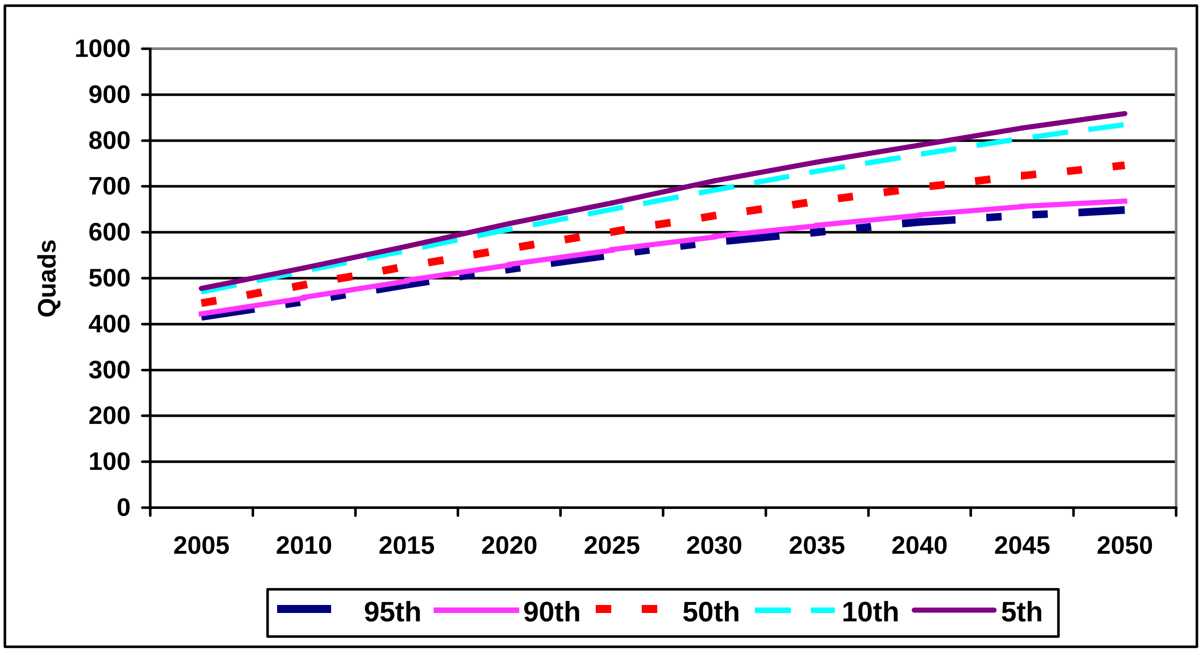
Figure 22: Average Global Primary Energy Use, Reference Case



Data for this graphic is in Table 35.

The CCRAF Reference Case results show average annual growth of 1.5 percent from 2005 to 2025 while the EIA Reference Case (in *IEO 2004*) has 1.8 percent annual growth. The differences are in large part due to differences in economic growth rates. The uncertainty surrounding primary energy use in the Reference Case is considerable. Figure 23 shows primary energy use varying plus or minus 15 percent from the median case by 2050 from the 95th to the 5th percentile. Variance shown for 2005 is primarily the result of the CCRAF starting year of 1990.

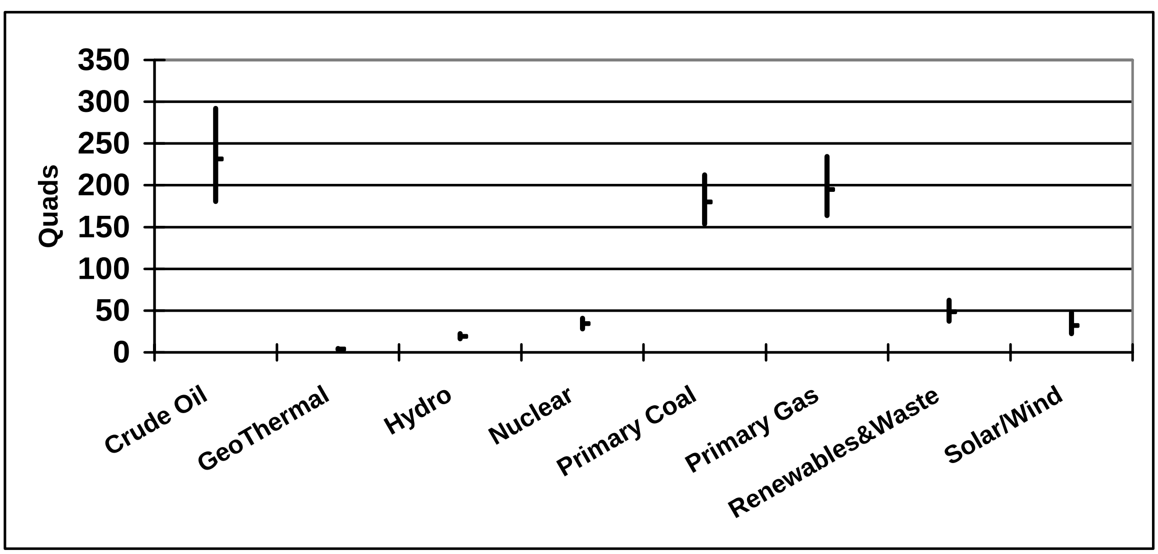
Figure 23: Primary Energy Use by Percentile, Reference Case



Data for this graphic is in Table 36.

The variance for each energy type is considerable and reflects the uncertainty surrounding the energy resources and costs. Crude oil consumed in the Reference Case varies by -22 percent to +26 percent from the 95th and 5th fractal to the 50th fractal while solar and wind energy consumed varies by -30 percent to +49 percent. This is shown in Figure 24.

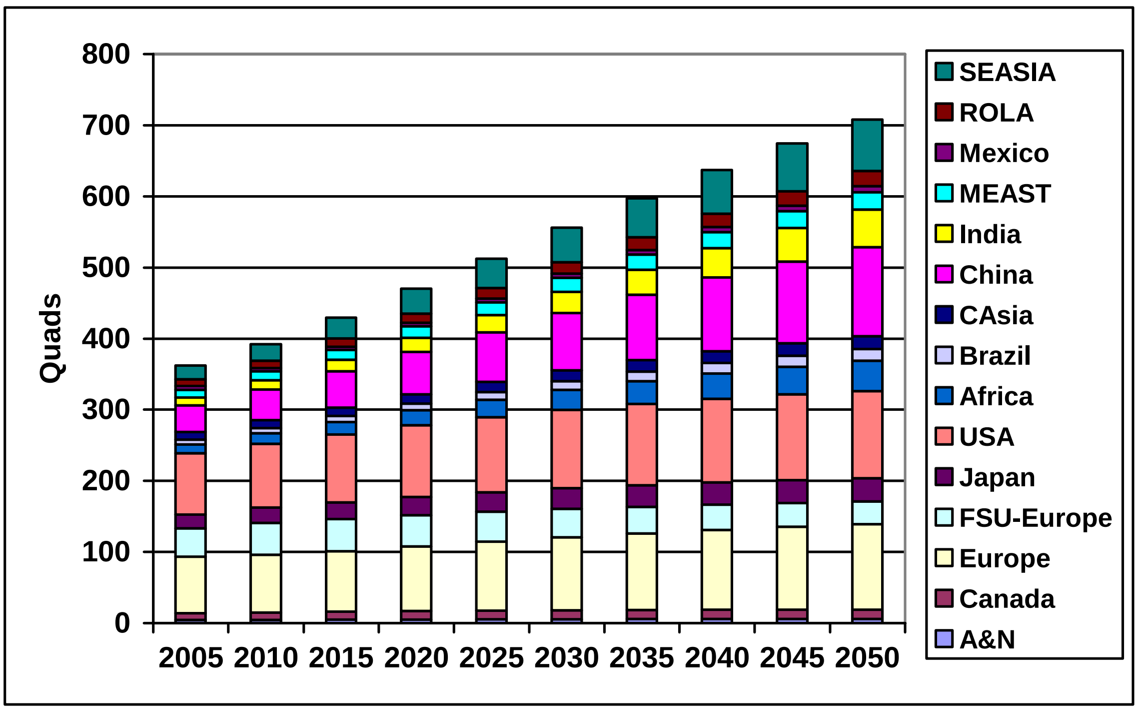
Figure 24: Uncertainty in Primary Energy Use, Reference Case



Data for this graphic is in Table 37.

In the Reference Case, developing economies account for more than 75 percent of the growth in primary energy use on average. China alone represents 25 percent of the growth in primary energy use on average and India represents 13 percent of the growth on average. The regional stories are very different as shown in Figure 25. While both China and India have primary energy use per capita doubling on average from 2005 to 2050, higher population growth rates in India result in a greater overall proportional increase in primary energy use. Primary energy use in China grows by a factor of 3.3 and in India by a factor of over five. Energy intensity (primary energy use per dollar GDP) declines by nearly 50 percent on average for China and 25 percent for India in the period 2005 to 2050.

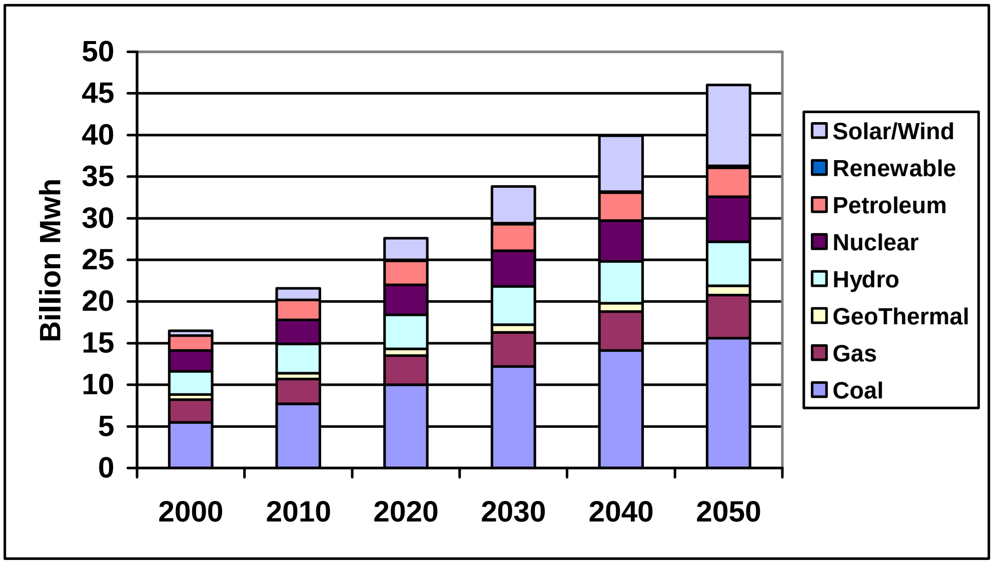
Figure 25: Mean Primary Energy Use by Region, Reference Case



Data for this graphic is in Table 38.

Figure 26 shows average global power generation by energy source in the Reference Case. The share of power and heat produced by coal stays relatively constant through 2050 but the share produced by natural gas and petroleum products declines. Solar/wind generation increases its share from around 4 percent in 2000 to over 20 percent on average in 2050.

Figure 26: Average Power and Heat Generation by Fuel Type, Reference Case

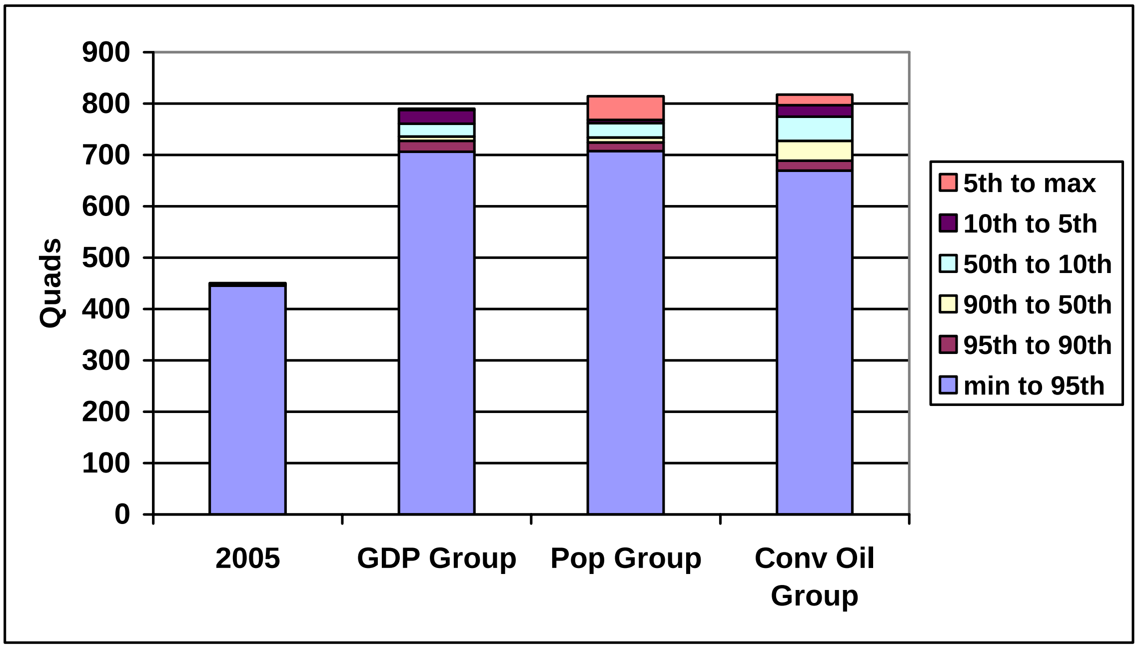


Data for this graphic is in Table 39.

The sensitivity of the primary energy use to changes in economic, population, and conventional oil resources is shown in Figure 27. Primary energy use and GDP are highly related but despite there being nearly a difference of two between the 5th to maximum GDP group and the minimum to 95th GDP group, the difference in primary energy use in the groups is only 12 percent. Similarly, average population in the 5th to maximum population group is 35 percent greater than population in the minimum to 95th population group, but primary energy use only varies 15 percent between these groups. This behavior is explained by a number of factors. First, the energy systems contain a number of feedbacks that tend to dampen the influence of varying GDP and population on energy use. Increased population leads to reductions in the increase in GDP per capita and vice versa. Increased energy use requires additional supply, which will increase prices and have a negative impact on energy use.

Conventional oil resources have a large impact on primary energy use. Low resources mean that more expensive energy sources are exploited in order to meet energy demand resulting in higher energy prices, putting downward pressure on crude oil demand and energy use in total. High resources provide the opposite impact.

Figure 27: 2050 Average Primary Energy Use, Reference Case



Data for this graphic is in Table 40.

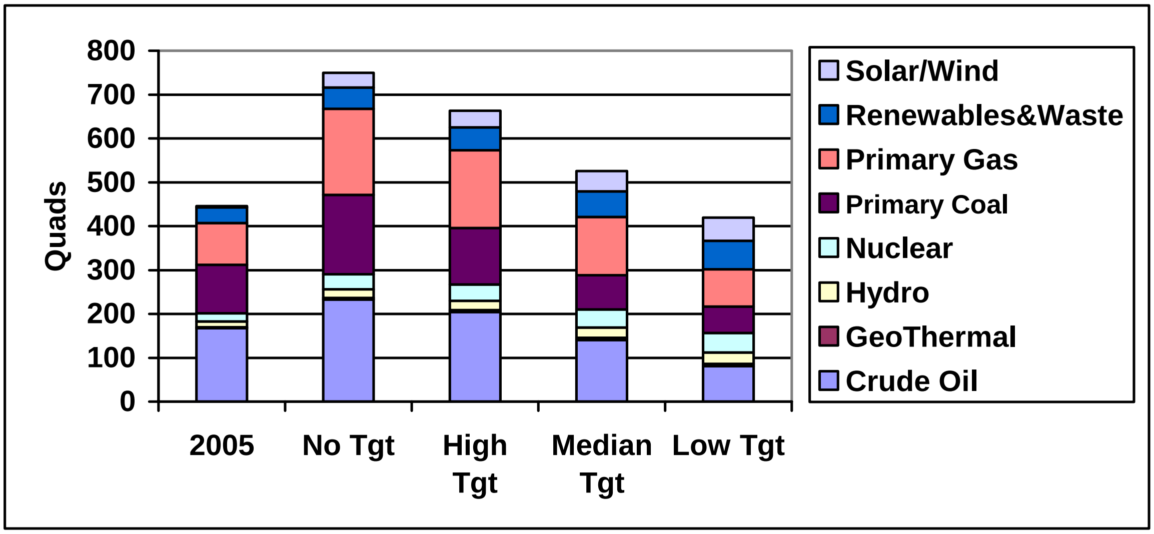
Summary for Reference Case Primary Energy Use

In summary, energy use absent of greenhouse gas controls, is expected to grow from 445 Quads in 2005 to anywhere from 650 to 860 Quads by 2050. Seventy-five percent of this growth will occur in developing economies. Primary energy use shares by energy type do change somewhat over this period with natural gas use increasing the most during this time frame with its share increasing by 5 percent by 2050. The share of primary energy supplied by crude oil declines by 7 percent and the share supplied by solar and wind energy increases by 4 percent.

Primary Energy Use and Greenhouse Gas Policy

GHG emission limits have a significant impact on primary energy use so the impact of greenhouse gas emission limits was modeled in three policy cases. Figure 28 shows the average primary energy use by energy source in 2005 and in 2050 for the Reference Case and the three greenhouse gas policy scenarios. In the policy scenarios, primary energy use in 2050 declines compared to the Reference Case. On average, a 45 percent reduction in primary energy use is needed to achieve the low CO_2 concentration target but a 65 percent reduction in coal and crude oil use and a 55 percent reduction in natural gas use is required to achieve this target. Non-fossil energy sources increase in the GHG policy cases and much of the emission reductions are through efficiency gains.

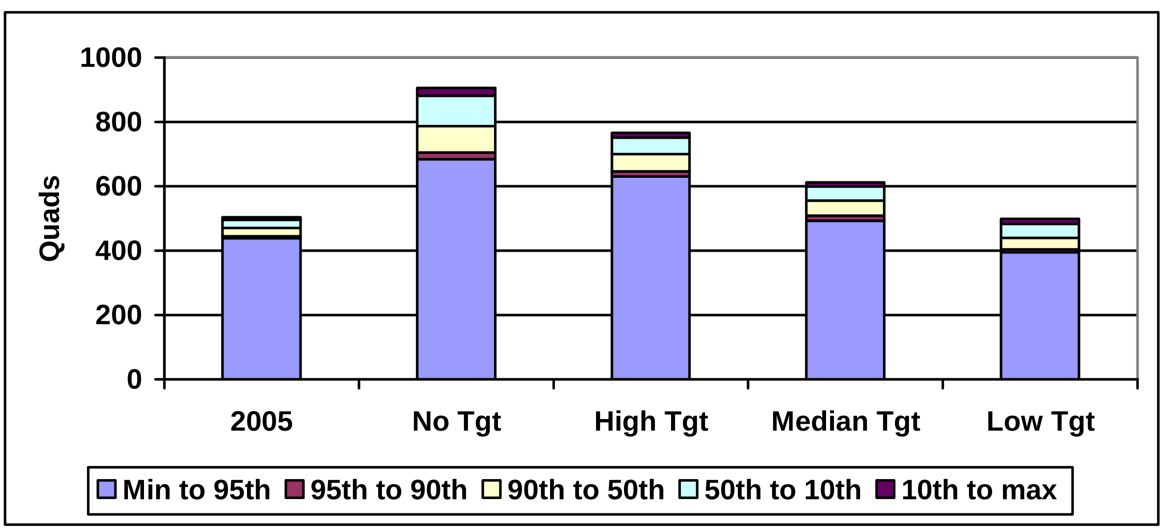
Figure 28: 2050 Average Primary Energy Use, GHG Policy Cases



Data for this graphic is in Table 41.

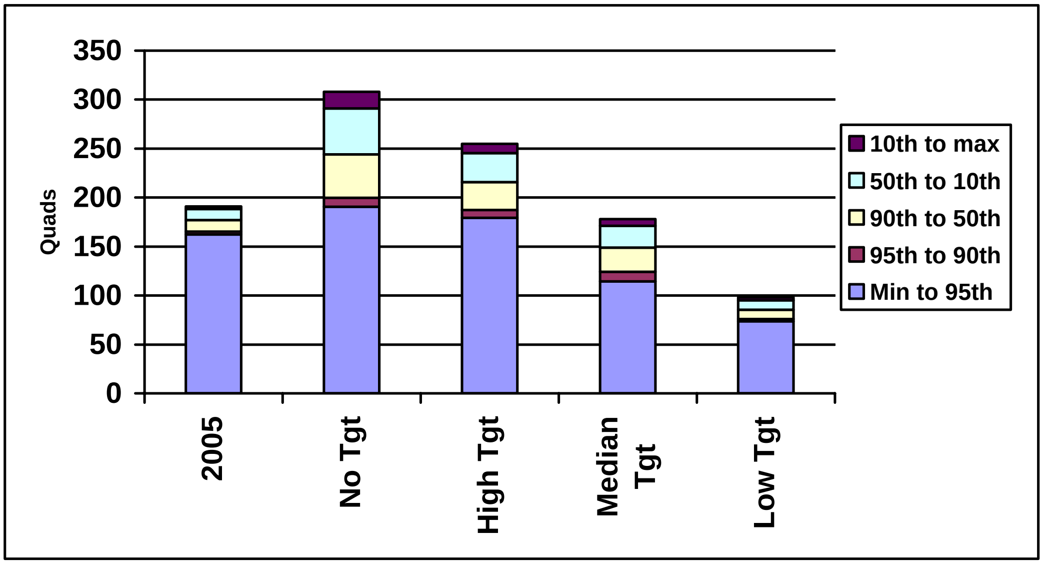
The GHG emission targets impact average results in the different cases but also the uncertainty in the results. The GHG policies impact the higher energy use variants the most since they require the greatest emission reductions. The impact of GHG policies can be seen in Figures 29 and 30. Figure 29 shows primary energy use in 2050 about 45 percent less in the Low GHG Policy Case than in the Reference Case. The impact on crude oil and coal is much greater. Figure 30 shows 2050 primary crude oil use, which is 70 percent less in the Low GHG Policy Case than in the Reference Case.

Figure 29: 2050 Primary Energy Use, GHG Policy Cases



Data for this graphic is in Table 42.

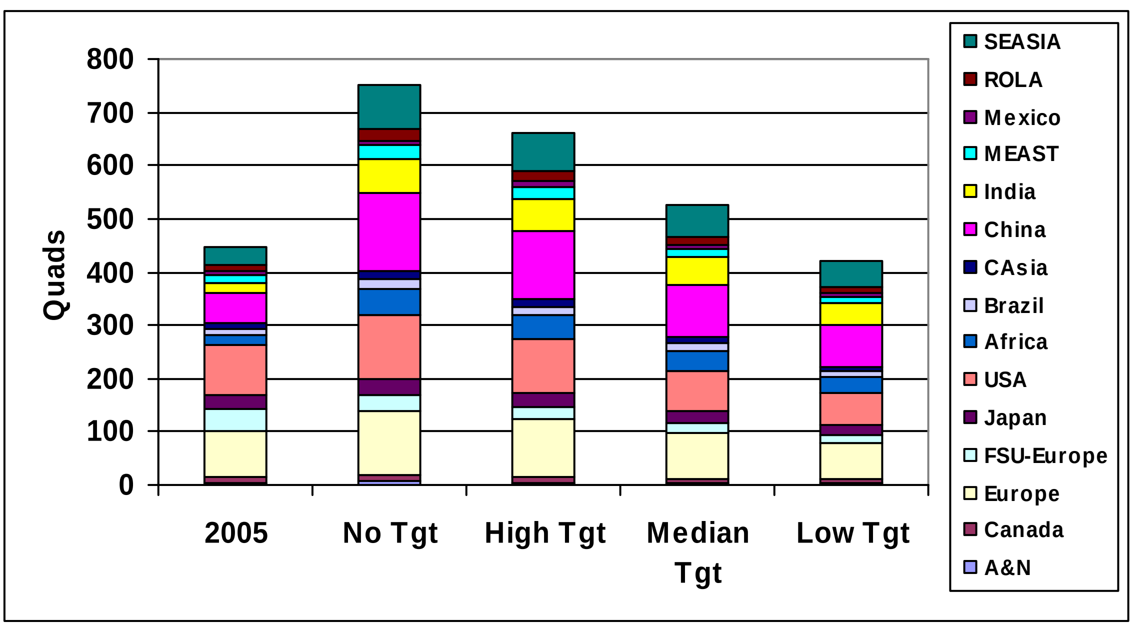
Figure 30: 2050 Crude Oil Use, GHG Policy Cases



Data for this graphic is in Table 43.

Regionally, the impact of greenhouse gas controls is different. Developed economies experience declines in primary energy use leading to an overall reduction in energy use by 2050, as targets get more restrictive. Figure 31 shows that primary energy use in developing economies continues to grow, just not as much with tighter greenhouse gas controls.

Figure 31: Average 2050 Regional Primary Energy Use, GHG Policy Cases



Data for this graphic is in Table 44.

Summary Environmental Policy Cases

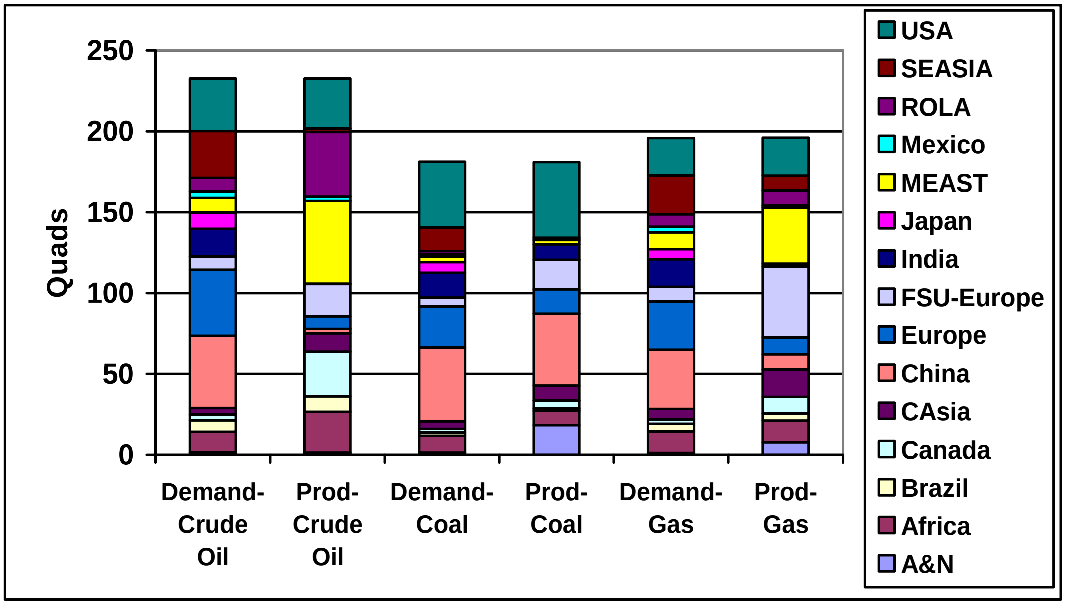
In summary, the environmental cases illustrate the importance of future greenhouse gas policy on global energy use and crude oil markets. High targets for CO_2 concentrations result in relatively small changes in primary energy use and moderate reductions in crude oil use. More stringent reductions in allowed CO_2 concentrations can result in significant (70 percent on average) reductions in crude oil use.

Energy Production

Energy production will match primary energy use globally for each type of energy but fossil fuels follow much different regional patterns. Figure 32 shows average primary energy use and production for coal, crude oil, and natural gas for 2050 in the Reference Case. For crude oil, China and Europe are major importers in 2050 while Canada, FSU-Europe, and the Middle East are major exporters. The United States is close to producing its needs. These results, especially for the United States and Canada may appear inconsistent with conventional logic but actually represent an increase in heavy oil and shale oil within this time frame.

The United States, Australia, and FSU-Europe become net exporters of coal while Asia and Europe become large importers. Natural gas is concentrated in the Middle East, FSU-Europe, and Africa and exports from these regions are significant and flow to Europe, Asia (including China and India). Again, the United States and Canada tend to balance out representing the increased utilization of higher cost natural gas resources in these regions such as tight gas and shale gas.

Figure 32: Average 2050 Regional Primary Energy Production and Use, Reference Case

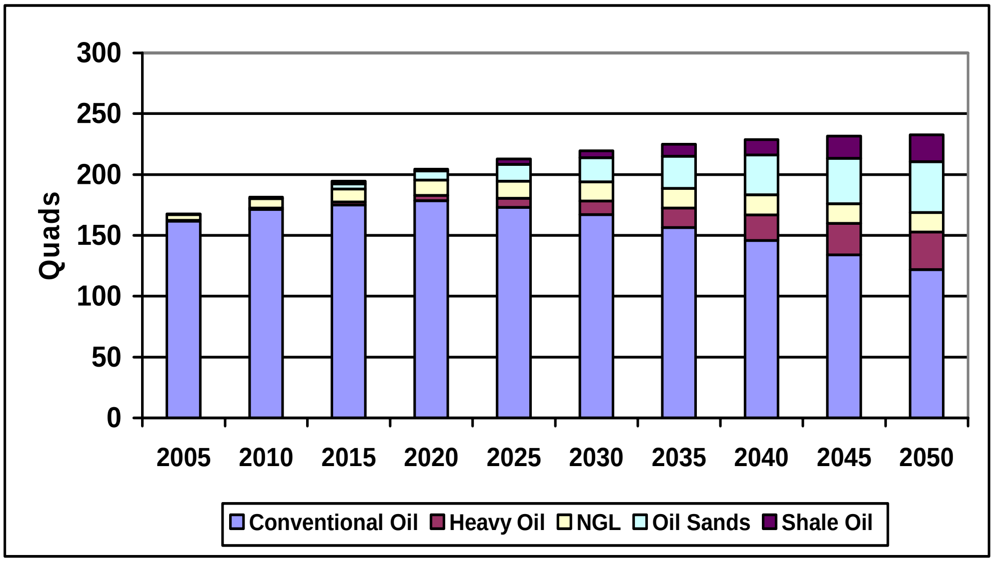


Data for this graphic is in Table 45.

Crude oil production is comprised of conventional oil, heavy oil, natural gas liquids (NGLs), oil sands, and shale oil. In the reference case on average, conventional oil peaks in the 2020 time frame and then slowly declines (see Figure 33). Crude oil production is then supplemented by more expensive resources such as heavy oil, oil sands, and shale oil.

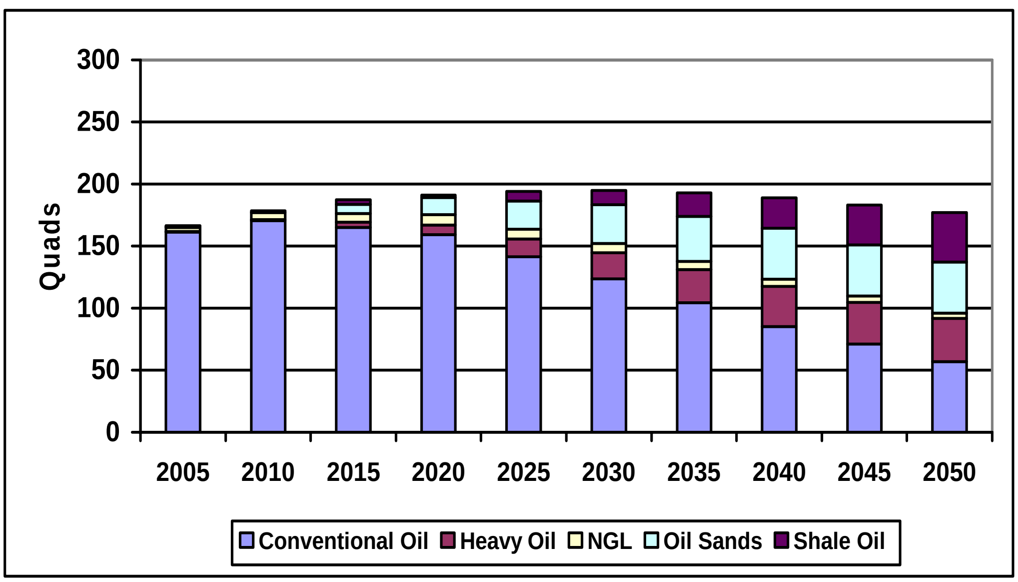
With high and low conventional oil resource estimates, the story will be different. Figures 34 and 35 show crude oil production for the minimum to 95th resource grouping and the 5th to maximum resource grouping, respectively. With low resources, conventional oil production peaks around 2010 and total crude oil production peaks around 2030. With high conventional oil resources, conventional oil production does not peak until 2040.

Figure 33: Average Crude Oil Production by Resource Type Reference Case



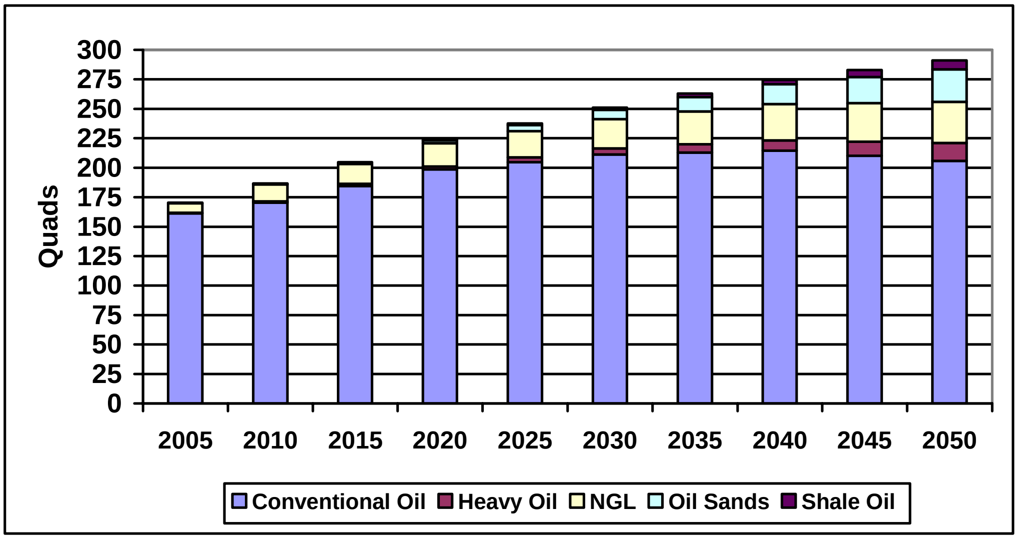
Data for this graphic is in Table 46.

Figure 34: Crude Oil Production by Resource Type, Lowest Resource Grouping, Reference Case



Data for this graphic is in Table 47.

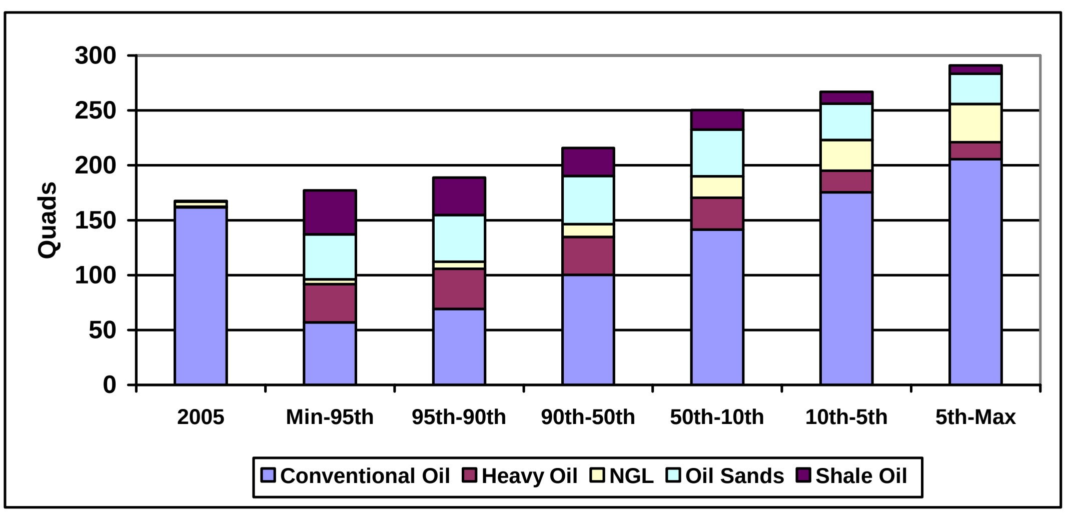
Figure 35: Crude Oil Production by Resource Type, Highest Resource Grouping, Reference Case



Data for this graphic is in Table 48.

Figure 36 shows the impact of alternate assumptions of conventional oil resources on crude oil production in 2050. In the low resource case, oil prices increase the utilization of more expensive oil including heavy oil, oil sands, and shale oil. Higher prices also lead to less overall demand for oil. As the resource estimate increases, total oil and conventional oil production will increase and heavy oil, oil sands, and shale oil production will decline along with oil prices. NGL resources are closely correlated to conventional oil resources and tend to follow the oil production pattern.

Figure 36: 2050 Crude Oil Production by Resource Type and Resource Grouping, Reference Case

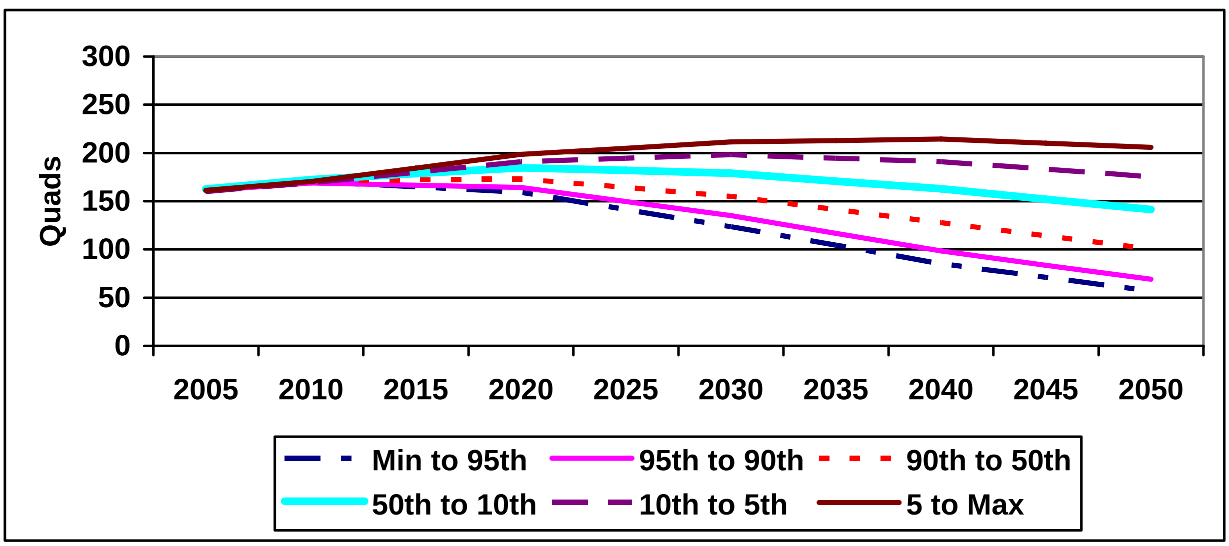


Data for this graphic is in Table 49.

Impact of Conventional Crude Oil Resource Base on Production

Figure 37 shows the potential impact of the conventional crude oil resource base on conventional crude oil production. While the timing and volume of peak oil production are sensitive to the size of the resource base, the most optimistic assessment of conventional crude oil resources does not extend the timing of peak oil production by more than 30 years past the peak oil production in the low resource cases. Peak oil production occurs at 2010 in the low conventional oil resource groupings (minimum to 95th and 95th to 90th percentile groupings), which assumes a total conventional oil resource base of less than 1800 billion barrels. For resource range grouping of 50th to 10th percentile, which corresponds to the mean USGS assessment of world oil resources, conventional crude oil production peaks at 2020 at approximately 184.7 Quads or 87 million barrels per day (mmb/d). For the highest resource grouping, 5th percentile to maximum, representing crude oil resources that are 42 percent greater than assumed for the 50th percentile grouping, peak oil production is delayed by only 20 years to 2040.

Figure 37: World Conventional Oil Production by Resource Range, Reference Case



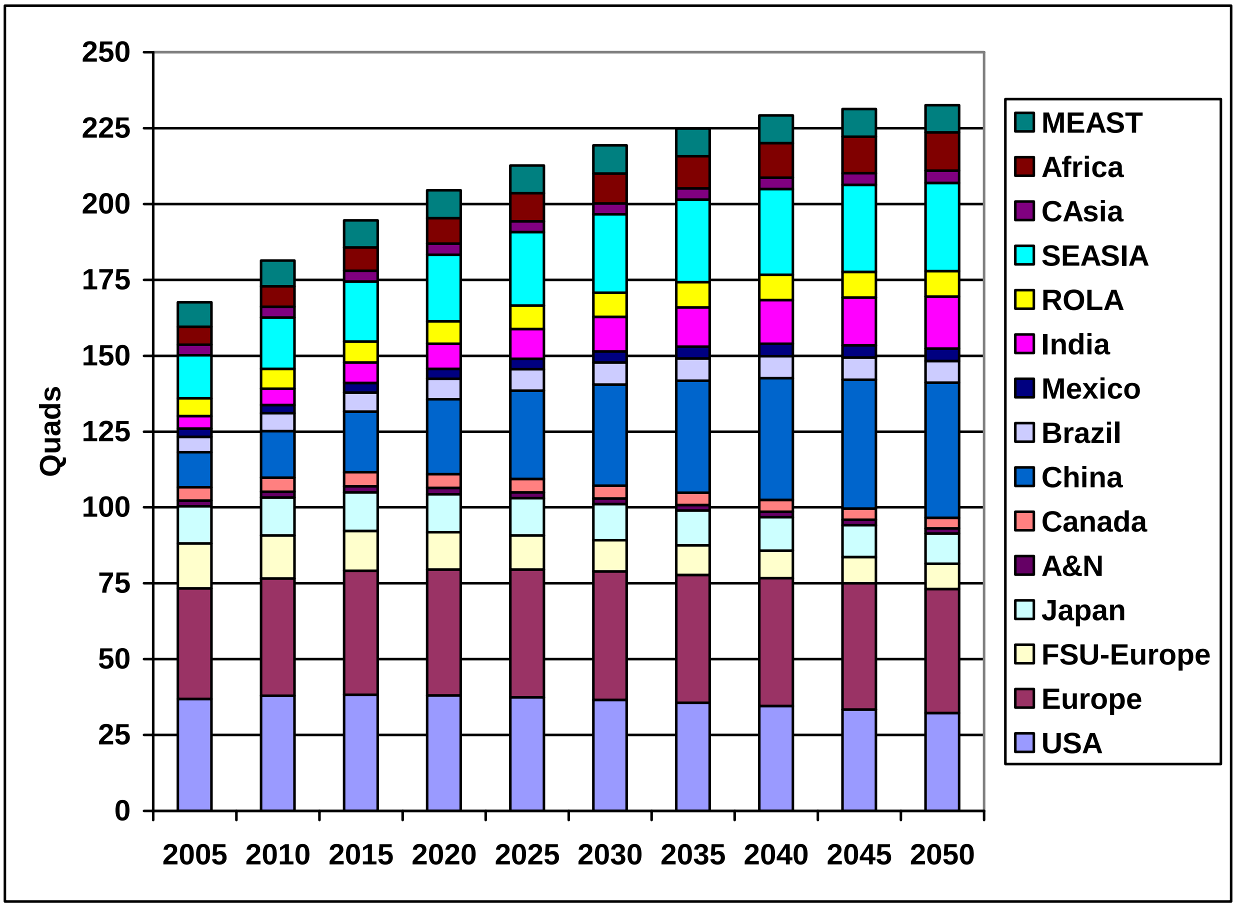
Data for this graphic is in Table 50.

The size of the resource base has the greatest impact on the estimated volume of oil produced at peak production, which in turn has a substantial impact on the outlook for crude oil production by 2050. For lowest resource categories representing the most pessimistic outlook for conventional crude oil resources, peak production occurs at 2010 at 80 mmb/d. By 2050, conventional oil production has declined to 56.8 Quads or less than 27 mmb/d in the lowest resource case. For the 95th to 90th resource grouping, which assumes resources in the range of 1700 billion barrels to 1800 billion barrels, conventional oil production at 2050 is slightly higher at 69 Quads or 32.6 mmb/d. The 50th percentile resource group, representing the USGS mean resource estimate for conventional oil has production at 2050 of 141.4 Quads or 66.8 mmb/d. Peak oil for the 10^{th} percentile resource grouping is 198.2 Quads or 93.6 mmb/d at 2030. By 2050, conventional oil production is estimated to be 175.3 Quads or 82.8 mmb/d, a conventional oil production scenario slightly higher but comparable to current crude oil production. This CCRAF result shows that for conventional oil production in 2050 to be comparable to current levels, conventional oil resources need to be in the range of 3300 billion to 3700 billion barrels. Projected conventional oil production at 2050 is estimated to be 205.8 Quads or 97.2 mmb/d for the highest estimated resource grouping, which assumes a resource base of more than 3700 billion barrels.

The CCRAF results suggest that variance in outlook for conventional crude oil resources of 2 trillion barrels or more only shifts the timing of peak production by 30 years; production rate at peak production varies by more than 25 percent from approximately 169.4 Quads or 80 mmb/d to more than 211.7 Quads or 100 mmb/d. The most significant impact of the different resource assumptions is on conventional oil production at 2050, due to the combined effect of peak production timing and production decline rates. In the lowest resource cases, conventional oil production at 2050 declines by two thirds from the production rate at peak, representing a rate of production decline of approximately 2 percent per year. In the mean resource grouping (50^{th} percentile), conventional oil production at 2050 declines by 23 percent from the peak production rate at an annual decline rate of 0.8 percent. For the highest resource case, production at 2050 is 10 years past peak but has declined by only 4 percent.

Figure 38 shows projected crude oil demand for the Reference Case. Growth in demand is greatest in developing economies. Growth in production depends on resource endowment and demand, and in the absence of environmental targets that reduce demand, conventional crude oil production is never sufficient to meet demand, even assuming the maximum resource case. For the maximum oil resource grouping, some of the crude oil demand must be met by non-conventional crude oil sources. If the 50^{th} to 10^{th} percentile conventional crude oil resources are assumed (corresponds to USGS mean assessment), at peak conventional crude oil production in 2020, a shortfall of 19.8 Quads or 9.4 mmb/d of crude oil demand must be met by non-conventional crude oil.

Figure 38: Average Crude Oil Demand by Region, Reference Case



Data for this graphic is in Table 51.

In the highest resource grouping, a shortfall of 5.9 Quads or 2.8 mmb/d of crude oil demand at 2020 must be met by non-conventional crude oil, and at peak oil production in 2040, 14.6 Quads or 6.9 mmb/d must be supplied by non-conventional oil. If the 95th percentile conventional crude oil resources are assumed (corresponds to USGS F95 assessment), at peak oil production in 2010, there is a conventional oil shortfall of 12.5 Quads or 5.9 mmb/d. By 2020, 40.2 Quads or 19 mmb/d must be supplied by non-conventional crude oil or other sources, nearly 20 percent of crude oil demand. If no greenhouse gas targets are assumed, by 2050 26.9 Quads or 12.7 mmb/d are supplied by non-conventional oil in the high resource category; 91.2 Quads or 43.1 mmb/d in the mean resource category (50th percentile grouping); and 163 Quads or 77 mmb/d in the low resource category. These are levels of non-conventional crude oil production that may not be attainable due to limits on other resources required to produce large volumes of non-conventional oil, such as water for oil shale and heavy oil processing and recovery and natural gas for oil sands production. Degradation of surface lands to recover oil shale and shallow bitumen deposits may be unacceptable as well.

When greenhouse gas concentration targets are assumed, the high GHG concentration target yields a 4 percent reduction in crude oil demand at 2020 and 12 percent reduction in demand at 2050. The moderate GHG target yields significant reductions in coal and oil and some reductions in natural gas demand. Crude oil demand is reduced by 4 percent at 2020 and by 40 percent at 2050. The low GHG target yields significant reductions in all fossil fuels. Crude oil demand is reduced 5 percent at 2020 and by 2050; crude oil demand is reduced by two-thirds.

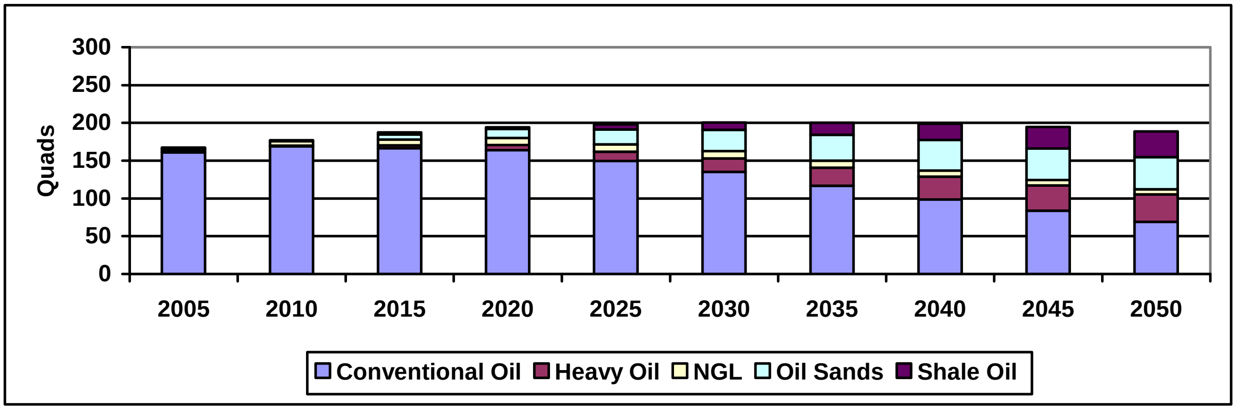
Table 23: Average World Crude Oil Demand, GHG Policy Scenarios

Average World Crude Oil Demand Under GHG Target Cases										
GHG Concentration Target	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
No GHG Target, Quads	167	181	195	204	213	219	225	229	231	233
No GHG Target, mmb/d	79	85	92	96	100	103	106	108	109	110
High GHG Target, Quads	167	181	194	196	197	193	194	197	201	205
High GHG Target, mmb/d	79	85	91	92	93	91	91	93	95	97
Moderate Target, Quads	167	181	194	195	188	162	142	133	134	140
Moderate Target, mm/d	79	85	91	92	89	76	67	63	63	66
Low GHG Target, Quads	167	181	194	193	178	139	112	96	86	81
Low GHG Target, mmb/d	79	85	91	91	84	65	53	45	41	38

Comparing Figure 37 and Table 23 suggests that conventional crude oil production projected for the 90th to 50th percentile resource grouping could meet projected crude oil demand under the low GHG concentration target for years 2030 to 2050. The conventional oil resource base assumed for the 50th to 10th resource group is required for projected conventional oil production to meet projected demand for 2030 to 2050 under the moderate GHG target. Under the high GHG target, only the highest resource category (Category 6) can provide enough conventional oil production to meet projected oil demand for years 2020 to 2050.

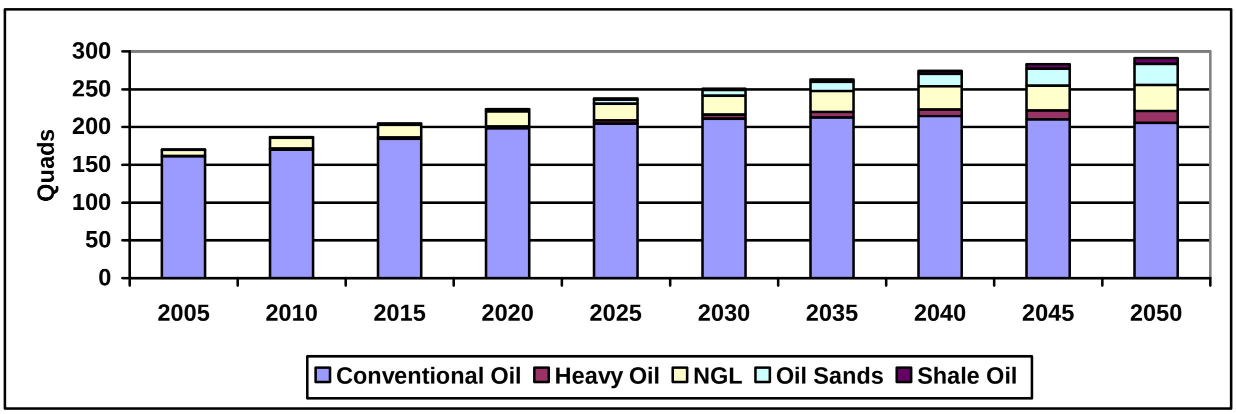
Non-conventional resources increase over time depending on price levels, but conventional oil resources impact the overall level of consumption and exploitation of non-conventional resources. This is illustrated by Figures 39 and 40, which compare crude oil production by resource type for conventional crude oil in the 95th percentile resource group and the 5th percentile resource group for the Reference Case (assumes no GHG targets). These two exhibits illustrate that the future contribution of non-conventional crude oil production is strikingly different depending upon assumptions about the conventional crude oil resource base.

Figure 39: Global Crude Oil Production by Resource Type, Reference Case and 95th Percentile Crude Oil Resource Group



Data for this graphic is in Table 52.

Figure 40: Global Crude Oil Production by Resource Type, Reference Case and 5th Percentile Conventional Oil Resource Group



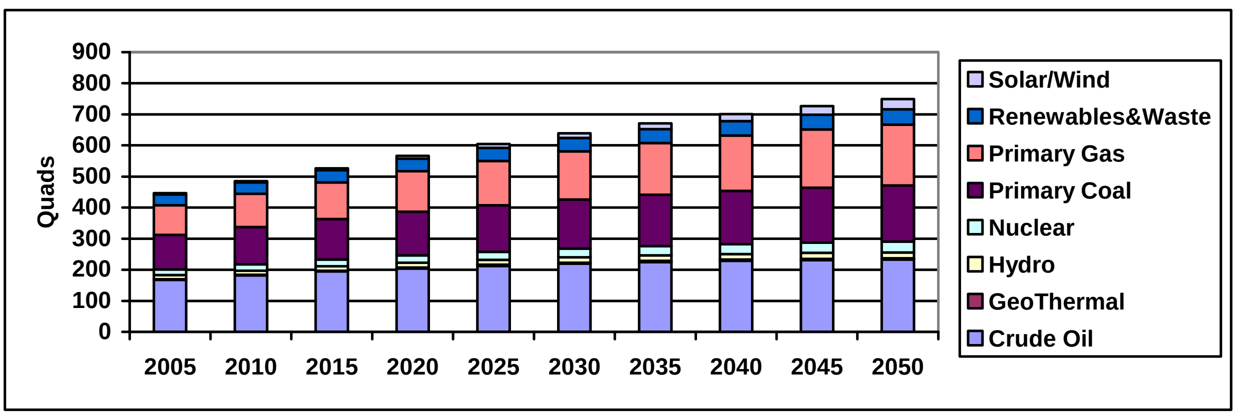
Data for this graphic is in Table 53.

For the high conventional resource category illustrated by Figure 40, oil sands are the main contributor to non-conventional oil production,[70] but production does not exceed one billion barrels per year (5.8 Quads per year) until 2025. By 2050, oil sands provide 27.5 Quads or 13 mmb/d; heavy oil provides 15.3 Quads or 7 mmb/d and oil shale provides 7.6 Quads or 4 mmb/d. Contrast this with Figure 39, which illustrates non-conventional crude oil production for the 95th percentile conventional crude oil resource group. At 2050, oil sands are projected to provide 42.8 Quads or 20 mmb/d, followed by 36.3 Quads or 17 mmb/d of heavy oil and 34 Quads or 16 mmb/d from oil shale. It is unlikely that this level of non-conventional oil production can be attained if there are severe limits on the availability of other resources needed for non-conventional oil production including water, natural gas as a diluent and fuel, as well as limits on land access and surface disturbance. In addition, some of the processes for extracting oil sands, extra heavy oil deposits, and oil shale may be constrained in order to control greenhouse gas and other air emissions.

Crude Oil Production Outlook for 2005 – 2050

Figure 41 and Table 24 illustrate average primary energy production by energy type for the Reference Case. The conventional crude oil resource base assumed for the Reference Case corresponds approximately to the 50th percentile resource group. Crude oil production from conventional plus non-conventional resources provides over 37 percent of world energy needs in 2005 and slightly less than 36 percent at 2020, around the time of projected peak conventional oil production. By 2050 crude oil contribution to world energy production drops to 31 percent. The contribution from natural gas is 21 percent in 2005, rising to 23 percent in 2020 and 26 percent in 2050. Primary coal provides 25 percent of world energy production in 2005. This remains unchanged throughout most of the model period; coal provides 25 percent of world energy production at 2020 and at 2040. By 2050 the contribution from coal declines slightly to 24 percent.

Figure 41: Average Primary Energy Production by Energy Type, Reference Case



Data for this graphic is in Table 54.

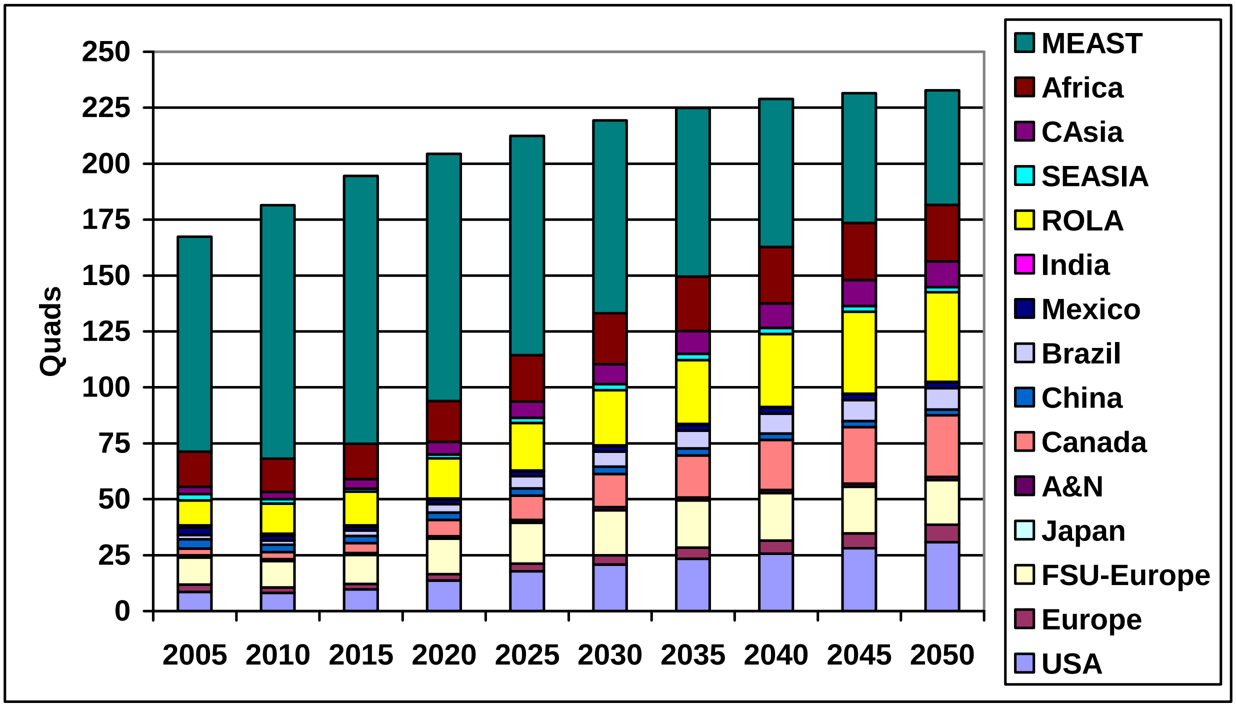
World crude oil production for the Reference Case, including both conventional and non-conventional oil, is projected to be 28.8 billion barrels in 2005 (79 mmb/d or 167 Quads). At 2020, the approximate date of peak conventional oil production for the Reference Case, total crude oil production is projected to be 35 billion barrels (96 mmb/d or 204 Quads). By 2050, projected crude oil production grows to 40 billion barrels (approximately 110 mmb/d or 233 Quads).

Table 24: Average Primary Energy Production by Energy Type, Reference Case - Data

Average Primary Energy Production by Energy Type For the Reference Case (Quads)										
	2005	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Crude Oil	167	181	195	204	213	219	225	229	231	233
GeoThermal	2	3	3	3	3	3	4	4	4	4
Hydro	12	13	14	15	16	17	18	18	19	19
Nuclear	19	20	22	24	26	28	30	31	33	34
Primary Coal	111	120	130	140	150	158	165	172	177	181
Primary Gas	95	106	118	130	143	155	167	178	188	196
Renewables & Waste	35	37	39	40	42	44	45	46	48	49
Solar/Wind	3	5	7	9	12	15	19	23	28	33
Total	444	485	528	565	605	639	673	701	728	749
Average Primary Energy Production by Energy Type for the Reference Case (million barrels of oil per day)										
Crude Oil	79	85	92	96	100	103	106	108	109	110
Primary Gas	45	50	56	61	67	73	78	84	88	92

Figure 42 provides projected average crude oil production by region for the Reference Case. Total world crude oil production increases during the model period. The Middle East remains the dominant producing region throughout the model period providing 58 percent of world oil production in 2005, 61 percent in 2015 and declining after 2015 to 22 percent of world production in 2050. Conventional crude oil production from the Middle East peaks around 2015 and afterward declines at approximately 2 percent to 2.5 percent annually. Few non-conventional oil resources are identified for the Middle East region (see Chapter 3) so no significant non-conventional oil production is expected from the region to offset declining conventional crude production.

Figure 42: Average Crude Oil Production by Region (Includes Non-Conventional Oil), Reference Case

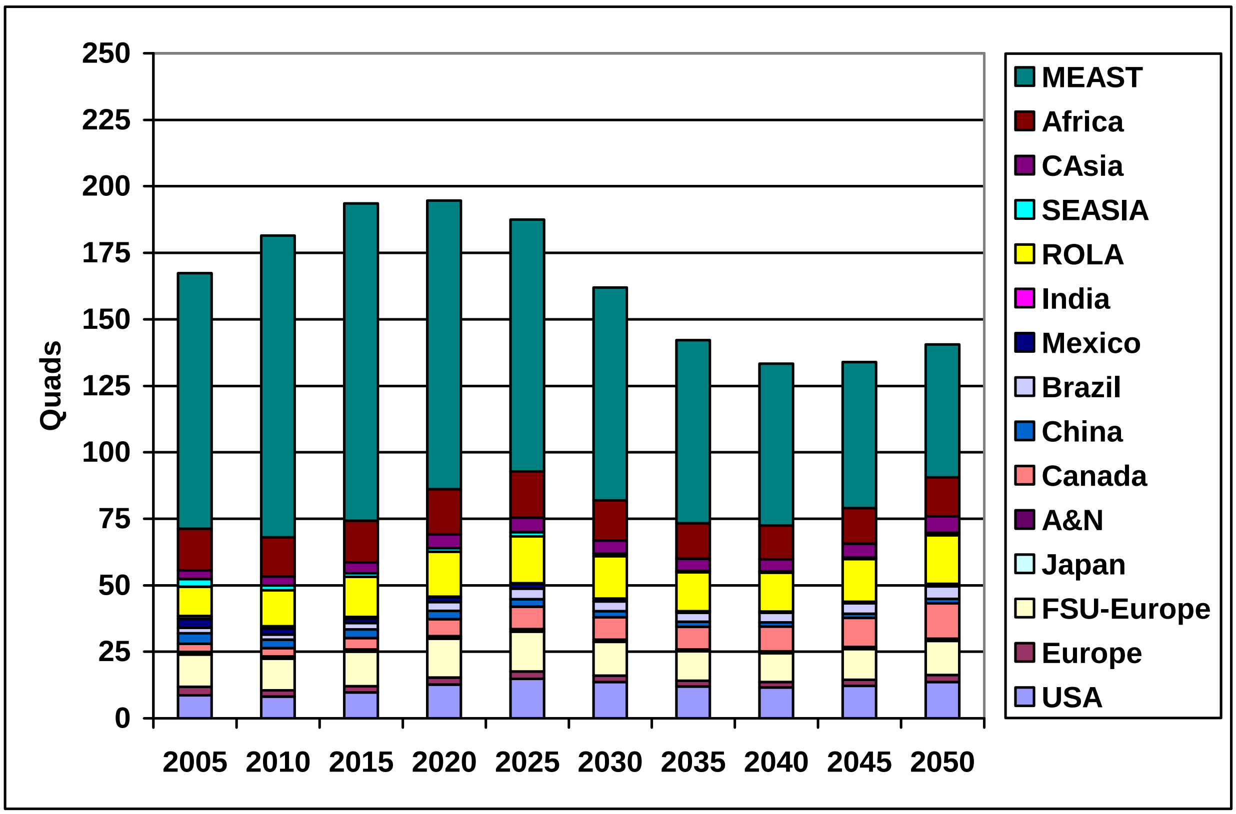


Data for this graphic is in Table 55.

Crude oil production increases in the United States and Canada after 2015 represent increasing production from Arctic, offshore and non-conventional oil resources, mainly oil shale and heavy oil in the United States and oil sands in Canada. Projected oil production in the United States grows from 9.7 Quads or 4.6 mmb/d in 2015 to 30.7 Quads or 14.5 mmb/d in 2050. Canadian oil production grows from 4.4 Quads or 2.1 mmb/d in 2015 to 27.5 Quads or 13 mmb/d in 2050. Other regions showing significant increases in oil production to offset declining Middle East production include ROLA (Rest of Latin America), FSU-Europe (Russia), and Africa. Oil production from Latin America grows from 15.2 Quads or 7.2 mmb/d in 2015 to 40.2 Quads or 19 mmb/d. FSU-Europe production increases from 13.1 Quads or 6.2 mmb/d in 2015 to 20.1 Quads or 9.5 mmb/d in 2035 and remains fairly constant at approximately 21.2 Quads or 10 mmb/d to 2050. Oil production in Africa grows from 15.9 Quads or 7.5 mmb/d in 2015 to 24.4 Quads or 12 mmb/d in 2040 and remains at 24.4 Quads or 12 mmb/d through 2050.

The projected oil production illustrated in Figure 42 represents a production case with constraints on NO_x and SO_2 emissions, but no greenhouse gas emissions targets or other potential environmental constraints such as limits on water use, land use, or surface and water discharges. It is questionable whether such substantial oil production increases can be attained in North America, where production of non-conventional oil resources may be constrained by water availability, land use restrictions, and the price and availability of natural gas for diluent and process fuel, in addition to future restrictions on greenhouse gas emissions and hazardous air pollutants. To illustrate the potential impact of greenhouse gas targets, Figure 43 shows projected regional crude oil production for the Moderate GHG concentration target case. It is possible that other moderate environmental targets, as yet unidentified and unquantified, might have similar impacts on future production of non-conventional oil.

Figure 43: Average Crude Oil Production by Region (Includes Non-Conventional Oil), Moderate GHG Concentration Target



Data for this graphic is in Table 56.

Total world crude oil production increases to 2015 at which point Middle East oil production peaks. Middle East production declines at 2 percent to 2.5 percent annually through the remainder of the model period. The Middle East remains the dominant producing region throughout the model period providing 58 percent of world oil production in 2005, 62 percent in 2015 and declining after 2015 to 38 percent of world production in 2050.

Non-conventional crude oil production increases slightly in the United States and Canada from 2015 through 2025, but does not offset declining Middle East production. U.S. and Canadian oil production decline until 2040, at which point oil production increases during the next ten years for North America, South America, Africa, and FSU-

Europe (Russia) in response to relaxation of production constraints when greenhouse gas targets are attained. A comparison of the moderate GHG target case with the Reference Case shows that environmental constraints, particularly GHG targets could have a substantial impact on future production of non-conventional oil resources, as well as remaining conventional oil resources.

Projected oil production in the United States increases to 14.8 Quads or 7 mmb/d in 2025 and then declines to 11.6 Quads or 5.5 mmb/d by 2040. U.S. crude oil production rebounds by 2050 to 13.5 Quads or 6.4 mmb/d, which is significantly lower than the 30.9 Quads or 14.6 mmb/d projected in the Reference Case. Canadian oil production grows from 4.2 Quads or 2 mmb/d to around 8.5 Quads or 4 mmb/d from 2015 to 2040. Canadian oil production then jumps to 13.3 Quads or 6.3 mmb/d by 2050, less than half of the 27.5 Quads or 13 mmb/d projected for 2050 in the Reference Case. Similarly, crude oil production from other key regions declines very slightly or remains flat overall between 2015 and 2050. At 2050, production from ROLA is 18.2 Quads or 8.6 mmb/d compared to 40.2 Quads or 19 mmb/d in the Reference Case. FSU-Europe (Russia) oil production is 12.7 Quads or 6 mmb/d at 2050 in the moderate GHG target case compared to 21.2 Quads or 10 mmb/d in the Reference Case. Oil production in Africa is 14.8 Quads or 7 mmb/d at 2050 compared to 25.4 Quads or 12 mmb/d at 2050 in the Reference Case.

Comparison with Other World Energy Forecasts

Recent published forecasts of world oil resources and production represent one of two divergent views on crude oil resources. The first view recognizes the USGS *Assessment of World Petroleum Resources* as the most comprehensive and authoritative assessment of world petroleum resources published to date and generally incorporates the USGS estimated mean undiscovered resources into a base case or reference case. The source for reserves data is usually one of the primary public sources for reserves; typically such production forecasts assume that current world oil reserves are in the range of 1000 to 1200 billion barrels. This first view is largely represented by the forecasts of world resources and production published by the International Energy Agency in the *World Energy Outlook* and the U.S. Energy Information Administration in the *Annual Energy Outlook* and *International Energy Outlook.*

Proponents of the second viewpoint on crude oil resources criticize the USGS mean estimate of undiscovered resources as too optimistic and object to the USGS estimate of reserves appreciation in existing fields, as well as USGS estimates of hypothetical resources in unexplored basins. Current published reserves data are also challenged as being inaccurate and out of date at best, and inflated at worst. A growing number of prominent petroleum geologists and engineers are agitating for more transparency and opportunities to inspect and verify reported reserves. Proponents of the second view are alarmed by the rapid individual well and field depletion rates observed in mature producing areas that are at or past peak oil production. Representatives of this view maintain that rapid depletion in mature producing regions is not adequately accounted for in most published crude oil production forecasts. Vocal representatives of this second viewpoint include Colin J. Campbell (Hubbert Center for the Study of Peak Oil at the Colorado School of Mines), Jean Laherrere, and Matthew Simmons (Simmons and Company). This second viewpoint is often referred to as the "depletionist" view because of the concern for rapid depletion of world oil supplies once peak world oil production is past.

The so-called depletionists have tended to define conventional oil narrowly, contending that oil produced from Polar Regions and deepwater offshore regions is unconventional oil because of high production costs. Similarly, heavy oil and current oil sands production should be excluded from current reserves reporting for conventional oil. The main points of this outlook can be summarized as the following:

- Proved reserves as currently reported are uncertain. International reporting of reserves should be reformed, but in the meantime uncertainty around published reserves should be considered.

- Production forecasts do not adequately take into account the rapid rates of production decline that have been observed in mature producing regions that are widely recognized to be at "peak" or "past peak" production.

- The USGS World Petroleum Assessment is too optimistic and cannot be achieved assuming current rates of exploration success and reserves addition. Only the USGS F95 (low resource) estimate is likely to be achieved based on projections of recent worldwide exploration success.

- The rate and timing of peak oil production is very sensitive to the size of the petroleum resource base. The world is nearing peak oil production, which is projected to occur around 2010.

- The shortfall between rising world demand for crude oil and declining conventional crude oil production will not be easily made up by non-conventional resources, resulting in soaring prices and shortages.

The lowest resource group of minimum to 95th percentile is comparable to the depletionist outlook on world crude oil resources. The CCRAF results allow one to analyze the future impacts and implications of a very low crude oil resource case and compare the implications of a low resource outlook with the more conventional outlook on global resources. The remainder of this chapter will briefly compare CCRAF results with recent conventional projections of crude oil production. Published crude oil production forecasts representing the extreme low resource outlook are difficult to find; this chapter provides a comparison of CCRAF results for the resource grouping minimum to 95th and the 95th percentile with a recent crude oil forecast published by Colin Campbell.

Comparison of CCRAF Forecast with World Energy Outlook 2004 and International Energy Outlook 2004

The Reference Scenario in the *World Energy Outlook 2004* is derived from the USGS mean resource estimates from which a low resource case and a high resource case were developed. Table 25 shows the impact of different oil resource assumptions on the *WEO* Production Outlook and compares key results with the CCRAF model results. Tables 26 and 27 compare total world supply estimates and prices between the *WEO* and CCRAF and between the *IEO* and CCRAF.

Table 25: Impact of Oil Resource Base Assumptions – Comparison of *2004 World Energy Outlook* with CCRAF Results

WEO 2004 Production Outlook[71]	**Reference Scenario**	**Low Resource Case**	**High Resource Case**
Remaining Ultimate Recoverable Resources (billion barrels)	2,626	1,700	3,200
Peak Period of Conventional Oil Production	2028 – 2032	2013 – 2017	2033-2037
Global Demand for Conventional Oil at Peak (mmb/d)	121	96	142
Non –Conventional Oil Production in 2030 (mmb/d)	10	37	8
CCRAF Production Outlook	**50^{th} – 10^{th} Percentile Resource Group**	**95^{th} Percentile Resource Group**	**5^{th} Percentile Resource Group**
Remaining Ultimate Recoverable Conventional Oil Resource	2,600 – 3,300	1,700 - 1,800	3,300 – 3,700
Peak Period – Conventional Oil Production	2020	2010	2030
Global Demand for Conventional Crude Oil at Peak (mmb/d) – Reference Case	87.2	79.8	93.6
Total Crude Oil Production at Peak (mmb/d) - Reference Case	97	83	110

Table 26: Comparison of Total World Oil Supply from *2004 World Energy Outlook* with CCRAF Results

World Energy Forecast[72]	2010	2020	2030
World Energy Outlook 2004 – Reference Scenario (million barrels per day)	90.4	106.7	121.3
WEO Oil Price- Reference Scenario ($2000/bbl)	$22	$26	$29
CCRAF Analysis – Reference Case (million barrels per day)	86	97	104
CCRAF Analysis Oil Price Reference Case ($2000/bbl)	$23	$30	$37

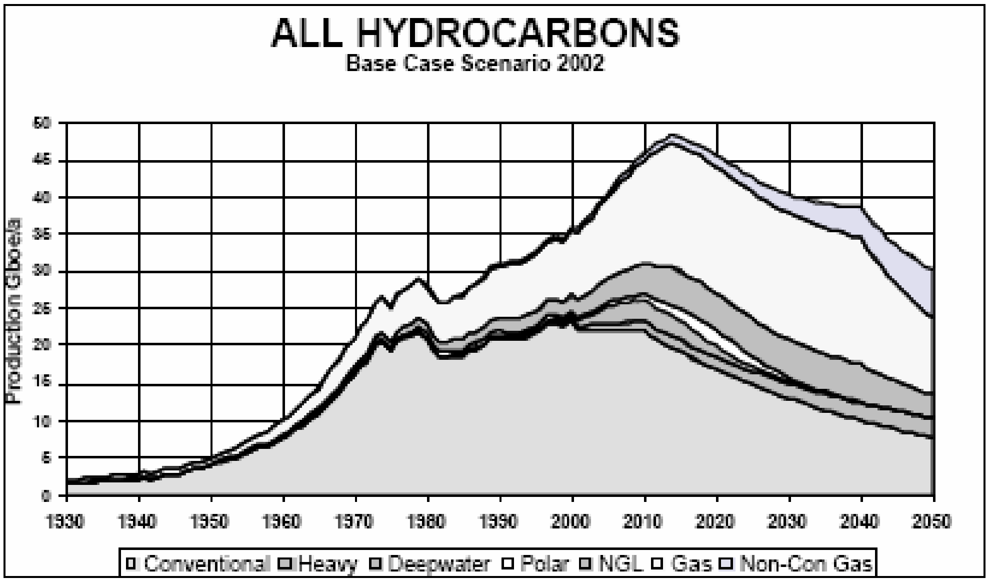
Table 27: Comparison of Total World Oil Supply from CCRAF and *International Energy Outlook 2004*

World Energy Forecast	2010	2015	2020	2025
EIA International Energy Outlook 2004 – Reference Case (million barrels per day)	91.4	100.5	110.3	120.9
EIA International Energy Outlook 2004 – Reference Scenario ($2000/bbl)[73]	$21	$22	$24	$26
CCRAF Analysis – Reference Case (million barrels per day)	86	92	97	100
CCRAF Analysis Oil Price Reference Case ($2000/bbl)	$23	$30	$33	$37

Comparison With a Hubbert Center Base Case

Figure 44 shows a forecast of hydrocarbon production to 2050 published recently by Colin Campbell of the Hubbert Center for Petroleum Studies.[74] Table 28 provides a table of data approximated from the chart in Figure 44. The total hydrocarbon resource base assumed in this forecast is unclear, although based on various publications by Colin Campbell and others, estimated global resources do not exceed the USGS estimated resources for the F95 case in the 2000 *World Petroleum Assessment*. Campbell estimated world conventional oil reserves to be approximately 884 billion barrels, or approximately 300 billion barrels less than most published reserves estimates.

Figure 44: Hubbert Center Base Case Forecast of Hydrocarbon Production to 2050



With the exception of the heavy oil depicted in Figure 44, all of the other liquid hydrocarbon categories are considered conventional oil production in the CCRAF analysis. Figure 44 shows total liquid hydrocarbon production [crude oil plus natural gas liquid (NGL) production] peaking at 2010 at approximately 31 billion barrels per year or 85 mmb/d. If the approximatedly one billion barrels of heavy oil is excluded from the total, peak production of conventional oil projected in Figure 44 becomes approximately 82 mmb/d, which is directly comparable to the conventional oil production forecast from CCRAF. After 2010, total crude oil plus NGL production declines at an average annual rate of approximately 1.5 percent. At 2050, total crude oil production is estimated to be 14 billion barrels per year or 38 mmb/d. By 2050 the contibution from deepwater and polar resources is miniscule. The contribution from heavy oil is two billion barrels per year or approximately 5.5 mmb/d or 14 percent of total crude oil production.

Table 28: Tabular Data Estimated from Exhibit 4-35, Hydrocarbon Production Forecast to 2050

Oil and Gas Production (billion barrels of oil equivalent per year) – *approximate values from graph in Exhibit 4-35*										
	2005	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Conventional Oil	22	22	20	17	15	13	12	11	10	9
Heavy	1	1	1.5	1.5	1.5	2	2	2	2	2
Deepwater	2	3	2	1.5	1					
Polar	1	1	2	2	1.5	1				
NGL	3	4	4.5	5	5	5	5	5	4	3
Total Crude Oil & NGL	**29**	**31**	**30**	**27**	**24**	**21**	**19**	**18**	**16**	**14**
Conventional Gas	10	14	17	17	17	17	17	17	12	9
Non-Conventional Gas	1	1	2	2	2	2	3	4	5	7
Total Natural Gas	**11**	**15**	**19**	**19**	**19**	**19**	**20**	**21**	**17**	**16**
Total Oil and Gas	**40**	**46**	**49**	**46**	**43**	**40**	**39**	**39**	**33**	**30**

The low resource groupings of CCRAF output offer analytical framework that adequately represents the low conventional petroleum resource outlook proposed by Colin Campbell and colleagues. To illustrate, the lowest resource ranges for conventional crude oil resources in CCRAF are resource groups 1 and 2 corresponding to the greater than 95th percentile and the 95th – 90th percentile resource groups. Resource Category 2 (the 95th percentile resource grouping) is comparable to the USGS F95 resource estimate. Resource Category 1 is the lowest resource grouping and corresponds to an extreme low crude oil resource outlook of less than 1700 billion barrels. For both low resource categories in CCRAF (Resource Categories 1 and 2), conventional crude oil production peaks at 2010 at approximately 80 mmb/d. At 2030, conventional crude oil production in CCRAF is 58.3 mmb/d for Resource Category 1 and 63.8 mmb/d for Resource Category 2. At 2030, total crude oil production for the Hubbert Center Base Case forecast is 21 billion barrels or 58 mmb/d; projected crude oil production without two billion barrels of heavy oil production is 52 mmb/d. At 2050, the CCRAF Reference Case forecasts 27 mmb/d conventional oil production for the lowest resource group and 33 mmb/d for the second resource group, 95th – 90th percentile. The Hubbert Center forecast estimates 33 mmb/d of conventional oil production and 38 mmb/d of total production.

As observed in Figures 39 and 40, a significant difference of the CCRAF analysis is the outlook for non-conventional oil production. For example, by 2050 the Hubbert Center forecast produces only 2 billion barrels per year of heavy oil representing only 5 mmb/d of non-conventional oil production. However, for CCRAF 95th percentile resource grouping, estimated non-conventional oil production in the Reference Case is 53 mmb/d total from oil shale, oil sands, and heavy oil and exceeds conventional oil production.

Crude Oil Prices

Crude oil prices[75] have increased significantly over the past five years with current prices well above $45/bbl. These high oil prices reflect a combination of factors:

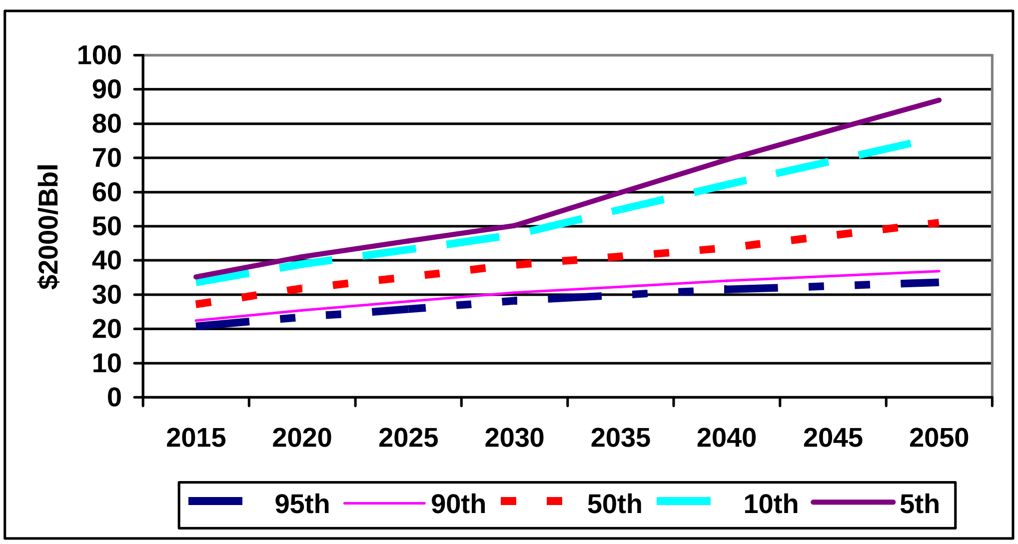
- Greater than expected growth in demand of oil.
- Geopolitical events constraining oil exports from some regions.

Very high oil prices are expected to continue for several years before current market and geopolitical events resolve themselves and prices decline to long term equilibrium prices as modeled in CCRAF. The CCRAF results suggest that while the low oil prices of the 1990s are indeed possible, they are not likely. Oil prices are likely to fall again as production increases and demand dampens in response to higher prices. After 2015, oil prices again increase through 2050. In 2050, crude oil prices ($2000) vary from $34/bbl to $87/bbl from the 95th to the 5th resource fractile, with a median of $50/bbl. Figure 45 shows crude oil prices from the Reference Case through 2050 by fractile.

The high prices correspond to a combination of low conventional oil resources, higher than expected extraction costs, high demand for petroleum products, and high costs for competing energy sources. The low prices correspond to a combination of high conventional oil resources, lower extraction costs, lower demand for petroleum products in relation to supply, and/or lower costs for competing energy sources. All of these factors contribute to the distribution of prices in Figure 45.

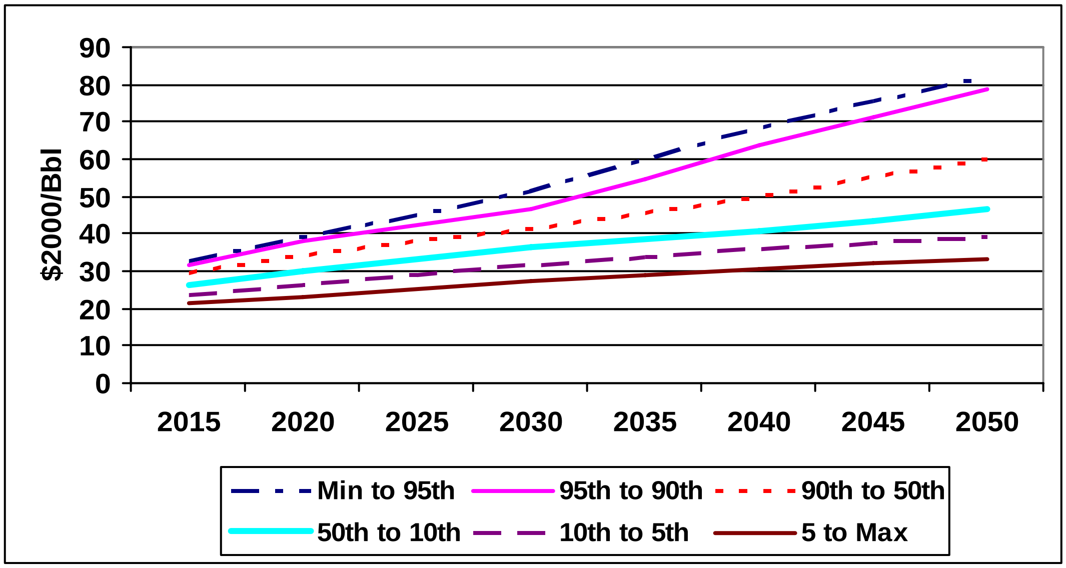
Figure 46 shows the impact of conventional oil resource estimates only on crude oil prices and indicates that while the other factors are important, the conventional oil resources are the dominant reason for the price variance.

Figure 45: Crude Oil Price Uncertainty, Reference Case



Data for this graphic is in Table 57.

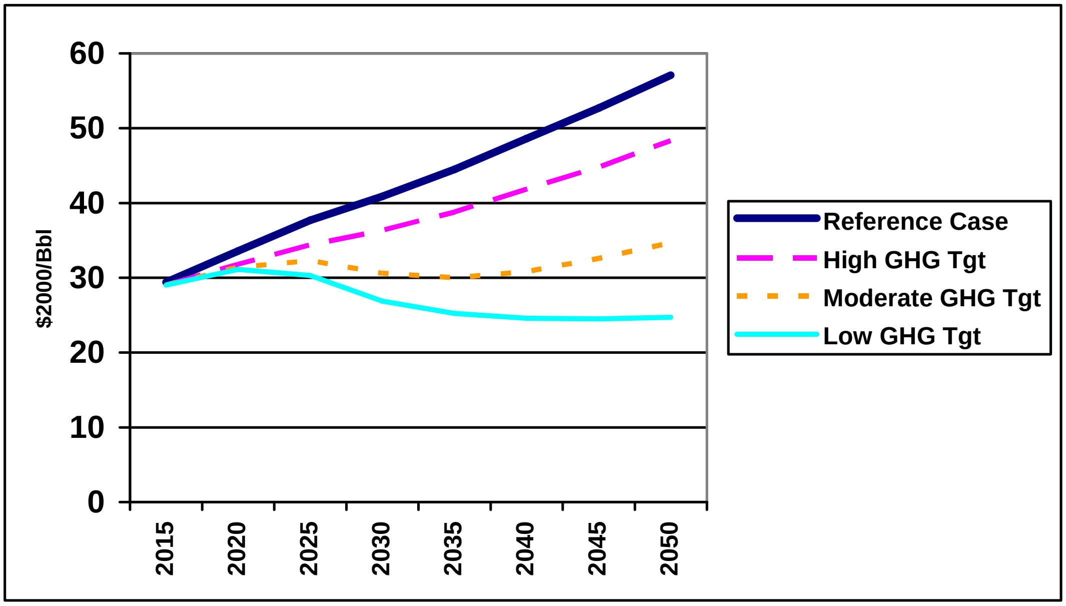
Figure 46: Crude Oil Price by Conventional Oil Resource Group, Reference Case



Data for this graphic is in Table 58.

Figure 47 shows the impact of the GHG policy on crude oil prices. Low GHG targets result in significant reductions in demand for crude oil from the Reference Case, which results in lowering the market price over time. In this case, demand for crude oil is lower resulting in lower prices and reductions in production from unconventional crude oil sources such as heavy oil and shale oil. The reductions in crude oil prices are less as the GHG target increases. The high GHG target results in only a 15 percent reduction in crude oil prices on average by 2050, while the low GHG target results in a 57 percent reduction on average.

Figure 47: Average Crude Oil Prices for the Reference and Environmental Cases



Data for this graphic is in Table 59.

Implications for California

The normal approach in impact analysis is to evaluate the likely impacts from the Reference Case and then consider the changes that might arise from the sensitivity cases. The Reference Case portrays a world with SO_x and NO_x constraints but without a greenhouse gas policy and with expected behavior by energy producers. The environmental policy cases, whether high or low target, reflect a world where restraints on CO2 are accepted globally. The Reference Case presents a world in which the average demand for fossil fuels is high and to meet this demand growing volumes of more expensive unconventional oils are called for. The environmental policy cases present a world in which average demand for fossil fuels slowly falls with the attendant fall in the price of these fuels. The fall in price is a function of the stringency of the regulations.

The underlying assumption in the price trajectory shown in this chapter is that current prices are high and volatile and that long term equilibrium prices will only be restored in 2015. In addition, there is the assumption that the impact of the GHG control mechanisms would start showing in 2012. The two cases in a sense are extreme: either no GHG controls, or global GHG controls. The more likely scenario would be some mix of the two. That being the case, prices are likely to be less than the Reference Case but higher than a global GHG control case. The other factor to consider is that even if California and other states were to implement GHG controls, the oil market is a global market where prices are set globally despite the actions of individual entities.

We have, nevertheless, chosen to examine the impact on California of the Reference Case and one of the environmental policy cases. This would be a case with moderate GHG targets to reflect both Kyoto and growing concern over climate change, but also the fact that there is resistance to the imposition of GHG controls. This is combined with median resource estimates to reflect recent investment trends by international oil companies (IOCs) and OPEC. Thus in this last section ICF considers the impact on California from the Reference Case (no climate policy and average over all resource estimates) and from the alternate case (moderate GHG targets and constrained investments in energy resource extraction simulated through median conventional crude oil resources).

ICF believes that the resources exist to support the Reference Case. However, we also believe that the level of investment that is necessary to meet the requirements of the Reference Case may not be made, either by the IOCs or by the OPEC countries. This conservative attitude towards investment arises from many causes, some geopolitical, and some structural. Both IOCs and OPEC countries remember the collapse of oil prices and the impact on the companies and countries, and so they tend to be leery about the current high level of prices. In recent months both OPEC ministers and the CEO of an IOC have made statements to the effect that they believe high oil prices are here to stay. Nevertheless, both groups are moving slowly as major investments are costly and have a long lead time. In addition, Saudi Arabia has been saying for several years that its long term sustainable production level is 15 mmb/d, which is lower than would be needed to meet some of the projected demand targets.

There are also major geopolitical barriers in the way of investment, as well as the extreme volatility of the market. Both of these factors were examined in Chapter 3. In addition, to meet the Reference Case growing volumes of unconventional oil would be required. With the production of unconventional oils, North America becomes relatively self sufficient. However, what CCRAF does not take into account are some of the constraints of producing unconventional oils such as oil sands and shale oil. In particular, the constraints of natural gas availability and diluent in the case of oil sands and water in the case of oil shale are not considered. This is not to say that demand could not be met but it would be difficult and probably at a higher price.

The reasons for selecting a moderate GHG case is based on observed reactions by governments now that the Kyoto Agreement has been implemented. Faced with actually having to implement the agreement, a number of governments, including some European governments, are taking a hard look at the costs and are concerned about the economic impacts of stringent regulations. High unemployment and stagnant economies are causing a number of governments to revisit various regional or global agreements and amend them to suit the particular circumstances of their economies.

Reference Case Impact

Average global demand for crude oil in the Reference Case reaches 109.9 mmb/d (232.6 Quads) by 2050.[76] This demand is met by a combination of conventional and unconventional crude oils. The main producing areas by then are the United States, the Former Soviet Union (FSU), Canada, Latin America, Africa, and the Middle East. The FSU and the Middle East have both begun declining in their levels of production; the latter having declined from a peak of 56.5 mmb/d (119.7 Quads) in 2015 to 24.1 mmb/d (51.1 Quads) by 2050. The median oil price by 2050 has reached $50 ($2000) or $54 in 2004 dollars.

Prices are assumed to stabilize most likely between 2010 and 2015 and fall from their current high and volatile levels to between $30 and $40 per barrel. They are then expected to increase gradually from 2015 onwards. Although the industrialized countries have essentially retooled their economies so that oil does not have as large an impact as in the past, consistently higher prices will exert downward pressure on demand in all sectors excluding transportation. One would expect to see growing demand for hybrid vehicles and/or other new transportation technologies. Demand for petroleum continues to increase but the rate of increase is expected to be lower driven by the price elasticity of demand.

The mean population growth for the United States is expected to increase gradually over the study period, in large part through immigration. California is expected to remain one of the prime targets for immigration and consequently demand for products, especially transportation fuels, is expected to continue to grow. California imports crude oil from many countries, with the largest volumes coming from Ecuador, Iraq, and Saudi Arabia.[77] One would expect these imports to continue but with a decided shift towards domestic and Canadian non-conventional crude oils. The planned pipeline in Canada to its western coast, if it materializes, would facilitate the movement of Canadian syncrude to California. The substantial non-conventional resources in the western United States theoretically should also benefit California.

As discussed above, while the resources are there, there may be other constraints on production. Water availability in the Rockies is a major problem and may ultimately determine the production of shale oil. The logistics of moving the oil would also have to be solved. When these additional constraints are considered and combined with the concern that global oil prices may not stabilize because the geopolitical problems are not resolved, there likely will be constraints on the availability of crude oil, or at least at a reasonable price. High prices, of course, will ultimately depress demand.

Impact of Greenhouse Gas Emission Controls

Under a moderate restriction of GHGs world crude oil use (conventional and unconventional) by 2050 is reduced to 66.7 mmb/d (141.2 Quads) compared to the 109.9 mmb/d (232.6 Quads) in the Reference Case. This is predominantly driven by global limits of CO_2 through emission allowance charges. These emission allowance charges increase the cost to consumers and reduce prices to producers.

Global crude oil production undergoes a shift in distribution compared to the Reference Case. Crude oil production predominantly shifts to the Middle East by 2050. This is due in large part to the fact that global production and Middle East production have been lower than the Reference Case due to the GHG restrictions. This allows the lower cost resources to be exploited more slowly and regions like the Middle East with large endowments of conventional low-cost oil resources see their production stretched out over a longer period. Higher cost unconventional resources are delayed.

By 2050 average crude oil prices have fallen from over $50/barrel ($2000) in the Reference Case to $34.70/barrel in the moderate GHG target. Even though fossil fuels are more constrained under the moderate GHG target policy scenario, oil prices do not retreat to the historic $20/barrel; they remain reasonably high. Under this combination of cases, California will (1) consume less primary energy in general, (2) consume less oil and gas and other solar/wind/renewables, and (3) become increasingly dependent on the Middle East for its imported crude oil. Compared to the Reference Case crude oil prices will fall about 39 percent on average by 2050, although they will still be above $30/barrel in real terms. However, if the GHG targets are not adopted globally, prices will likely drift up towards those of the Reference Case.

The problems facing California over the next decade as demand continues to grow will be the availability and sources of products of the right specifications rather than crude oil for its refineries, which is a more long term problem. Increasing demand may require an expansion of the infrastructure. U.S. refineries will continue to expand by capacity creep, but increasingly products will be imported from new and/or expanded refineries in Asia and the Middle East. Increased product imports will bring pressure on our already constrained infrastructure. If one also assumes that product specifications in California will continue to be more stringent than elsewhere, there may be constraints on the availability of these products. Once the import volume is large enough it is likely one of the overseas refineries will make the investment and long term product contracts may emerge. However, until that happens one would expect to see volatility and price spikes in the California product market.

Endnotes

[1] The CCRAF low resource category for conventional oil and natural gas corresponds to the USGS estimated undiscovered resources and reserves growth for the F95 case, representing a 95 percent chance that the estimated quantity exists. The high resource category for conventional oil and gas in CCRAF represents the USGS estimated undiscovered resources and reserves for the F5 case, representing a 5 percent chance that the estimated quantity is present. The mean resource category includes the USGS estimated mean undiscovered resources and reserves growth. The estimates of low, high, and mean resources for each resource type provide the basis for estimating probability distributions for regional resources and production costs, which are input directly to the CCRAF model.
[2] A Quad equals 1 Quadrillion BTU. 1 Billion barrels of oil equals 5.8 Quads. To convert Quads to billion barrels of oil, divide by 5.8.
[3] The Reference Case represents a world without greenhouse gas controls but where limits on SO_2 and NO_x increase over time, both in developed economies and developing economies. The Reference Case also assumes a conventional crude oil resource base corresponding to the mean U.S. Geological Survey assessment of world crude oil resources.
[4] *Oil & Gas Journal*, April 4, 2005.
[5] Energy Information Administration, *Annual Energy Outlook 2005*, February 2005. $2003.
[6] International Energy Agency, *World Energy Outlook 2004.*
[7] European Commission, *World Energy, Technology and Climate Policy Outlook*, 2003.
[8] EIA is forecasting that Saudi oil production could go as high as 18.2 mmb/d by 2020 and even as high as 22.5 mmb/d in 2025. Saudi Arabia has claimed that this is unrealistic and instead talk in terms of 15 mmb/d as a long term sustainable level.
[9] Source: Energy Information Administration, *Company Reports*, various years, [www.eia.doe.gov/oil_gas/petroleum/data_publications/company_level_imports/cli.html], accessed May 2005.
[10] California Energy Commission and California Air Resources Board, *Reducing California's Petroleum Dependence*, P600-03-005F, August 2003.
[11] Society of Petroleum Engineers, 2005, *Petroleum Reserves Definitions,* [www. Spe.org/spe/jsp/basic_pf/]. Access to website by members only.
[12] Figure 3.8, International Energy Agency, *World Energy Outlook 2004*, Paris.
[13] Dr. Tom Wigley who provided MAGICC/SCENGEN and assisted with the integration into CCRAF; Dr. Richard Tol who provided FUND 2.5 and assisted with integration into CCRAF; Stratus Consulting who provided input on integration of climate impacts into CCRAF; and Jane Leggett of EPA who provided oversight and direction.
[14] The World Bank, *2001 World Development Indicators*, 2001.
[15] International Energy Agency, *World Energy Outlook 2000.*
[16] U.S. Department of Energy, Office of Fossil Fuel Information, 2004.
[17] U.S. Department of Energy, National Energy Technology Laboratory, 2004.
[18] United States Geological Survey, *Assessment of World Petroleum Resources*, 2000; U.S. Mineral Management Service, *Five-Year program: Update of Conventional and Economically Recoverable Resources*, 2000, *Assessment of Conventionally Recoverable Hydrocarbon Resource of the Gulf of Mexico and Atlantic Outer Continental Shelf*, 2000, *Oil and Gas Resources in the Pacific Outer Continental Shelf*, 2000; BP, *Statistical Review of World Energy*, various issues.
[19] Sources of reserves data in the *Statistical Review of World Energy* include the OPEC Secretariat, *World Oil, Oil & Gas Journal,* and an independent estimate of Russian reserves based on information in the public domain. Canadian oil reserves include an official estimate of oil reserves from Canadian oil sands "under active development." Gas condensate and natural gas liquids are included as crude oil.
[20] Sources include the 2000 World Petroleum Assessment for non-U.S. resources, the USGS 1995 National Assessment of onshore U.S. resources, and the 2000 Minerals Management Service assessment of offshore U.S. resources.
[21] United Nations Development Program, *World Energy Assessment, the Challenge of Sustainability*, 2000, Chapter 5: The World Energy Council, *Survey of Energy Resources*, 2001: Rogner, "An Assessment of World Hydrocarbon Resources" in *Annual Reviews, Energy and Environment*, 1997.
[22] World Energy Council, *Survey of Energy Resources*, 2004 (*WEC2004*); Rogner, H.H., "Energy Resources" in *World Energy Assessment: Energy and the Challenge of Sustainability*, 2000.
[23] *Ibid.*
[24] *Ibid.*
[25] Rogner, H-H., 1997, "An Assessment of World Hydrocarbon Resources," *Annual Reviews Energy Environment* 22: 217 - 262.
[26] Perry, K., 1998, New Technology for Tight Gas Sand, 17th World Energy Conf., Houston, TX, Sept. 13-18, 1998.
[27] Rogner, H-H, *op cit.*

[28] Bundesanstalt fur Geowissenschaften und Rostoffe (BGR), 1998. Reserve, Resourcen und Verfiigbarkeit von Energierohstoffen. E. Schwiez.-bart'sch Verlagsbuchhandlung, Stuttgart, Hanover, Ger:BGR in Rogner, 2000. Rogner, H.H., 2000, Energy Resources, Chapter 5 in *World Energy Assessment: Energy and the Challenge of Sustainability*, United Nations Development Programme, New York.
[29] Curtis, "Fractured Shale-gas Systems", in *American Association of Petroleum Geologists Bulletin*, Volume 86, 2002.
[30] Rogner, H-H, "Energy Resources" in *World Energy Assessment: Energy and the Challenge of Sustainability*, 2000.
[31] *Wind Power Monthly*, various issues.
[32] U.S. Department of Energy, National Center for Photovoltaic
[33] The World Energy Council, *Survey of Energy Resources*, 2001.
[34] Distillate includes both No. 2 fuel oil and diesel.
[35] If the market is in backwardation, the out month prices are lower than the current prices; conversely if the market is in contango, the out month prices are higher than the current prices.
[36] International Energy Agency, *Oil Market Report*, February 10, 2005; OPEC, *Monthly Oil Market Report*, January 2005.
[37] National Petroleum Council, *Observations on Petroleum Product Supply, 2005.*
[38] The focus is always on OPEC when discussing spare capacity as non-OPEC producers traditionally produce up to capacity.
[39] *Wall Street Journal*, 30 November 2004.
[40] It is estimated that Saudi Arabia needs to bring on 600 mb/d to 800 mb/d annually of new production to offset the normal decline of its producing fields. U.S. Department of Energy, Energy Information Administration, *Country Analysis Briefs: Saudi Arabia*, January 2005.
[41] Public statement by Ali Al-Naimi, Minister of Petroleum and Natural Resources, Saudi Arabia and Abdallah Jum'ah, President and CEO of Saudi Aramco in Washington DC on May 17th, 2005.
[42] *Ibid.*
[43] *Financial Times*, March 10, 2005.
[44] U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook, 2005*, February 2005; International Energy Agency, *World Energy Outlook 2004*; Shihab-Eldin, Dr. Adnan, "Oil Outlook and Investment Prospects", *2nd Joint IEA/OPEC Workshop on Oil Investment Prospects*, 28th April 2004.
[45] International Energy Agency, *World Energy Investment Outlook*, 2003.
[46] Shihab-Eldin, Dr. Adnan, Director of Research, OPEC, *Oil Outlook and Investment Prospects*, 2nd Joint IEA/OPEC Workshop on Oil Investment Prospects, 28 April 2004.
[47] *Wall Street Journal*, 11 February 2005.
[48] Abdallah S. Jum'ah, *Rising to the Challenge: Securing the Energy Future*, presented in Houston at CERA Week, February 16, 2005.
[49] OPEC, *Monthly Oil Market Report*, February 2005.
[50] Deutsche Bank estimates that major E&P companies have cut their exploration budgets by about 27 percent.
[51] *Wall Street Journal*, 13 March 2005; International Monetary Fund, *What Hinders Investment in the Oil Sector*, February 22, 2005.
[52] BP returned $18 billion to shareholders versus a $9.7 billion annual exploration budget.
[53] The years of low prices prior to the recent jump in prices show under-investment by both the oil majors and the OPEC countries.
[54] IMF, *ibid.*
[55] Based on the exchange rate of March 21, 2005.
[56] *Wall Street Journal*, September 4, 2004.
[57] Energy Information Administration, *World Petroleum Market Changes and Import in U.S.*, October 2004.
[58] *Hearings before the U.S. Senate Committee on Energy and Natural Resources*, February 3, 2005.
[59] Joint ventures, production sharing contracts, and service contracts all have their merits and their drawbacks. Under the last two, the international oil companies tend to bear all the risk of the venture.
[60] See the *Wall Street Journal*, various issues and the U.S. Senate Hearings*, op.cit.*
[61] Witness the PDVSA strike and the complete closing down of Venezuelan exports followed by the present attempts by the Venezuelan government to find customers other than the United States.
[62] The constant disruptions of oil facilities in the Delta and the present call by politicians in the Delta to close down the oil as part of their campaign for the presidency.
[63] Platts, *OPR Extra*, Volume 83, No. 16, 25 January 2005.
[64] *Oil & Gas Journal*, April 4, 2005.
[65] Ali Al-Naimi*, U.S.-Saudi Partnership in a Changing Energy World*, Remarks on May 17, 2005 in Washington DC.
[66] Energy Information Administration, *Annual Energy Outlook 2005*, February 2005.
[67] Energy Information Administration, *International Energy Outlook 2004.*
[68] Energy Information Administration*, International Energy Outlook, 2005.*

[69] A Quad equals 1 Quadrillion BTUs, or 172.4 million barrels of crude oil. One billion barrels of crude oil equals 5.8 Quads. To convert Quads to billion barrels of oil, divide by 5.8.
[70] For this discussion we consider NGL to be conventional production. NGL is included with crude oil in estimates of reserves in public data sources on conventional crude oil reserves.
[71] Table 3.4 in the International Energy Agency *World Energy Outlook, 2004.*
[72] Tables 1.3 and Table 3.5 in the *World Energy Outlook 2004.*
[73] Oil prices for the EIA International Energy Outlook 2004 are provided in $2002 per barrel: $22/bbl for 2010; $23/bbl for 2015; $25/bbl for 2020 and $27/bbl for 2025. IEO oil prices are deflated to $2000/bbl in Exhibit II-15.
[74] Campbell, C.J., 2002*, Forecasting Global Oil Supply, 2000 – 2050,* Hubbert Center Newsletter 2002/3. July 2002, M.K. Hubbert Center for Petroleum Supply Studies, Colorado School of Mines, Golden, Colorado.
[75] The oil prices used in the model refer to the OPEC Basket, an aggregation of the main OPEC crude oils.
[76] See Exhibit A-2.
[77] See Exhibit 1-1.

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APPENDIX A: DATA TABLES FOR GRAPHS

(In some tables, columns may not add up to totals due to independent rounding)

Table 29: Global Population by Percentile, Reference Case

(Billions)
(Data for Figure 16)

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
95^{th}	6.4	6.7	6.9	7.2	7.4	7.5	7.7	7.8	7.8	7.9
90^{th}	6.4	6.7	7.0	7.2	7.4	7.6	7.8	7.9	8.0	8.1
50^{th}	6.4	6.8	7.1	7.5	7.8	8.0	8.3	8.5	8.7	8.9
10^{th}	6.5	6.9	7.3	7.7	8.1	8.5	8.9	9.2	9.5	9.8
5^{th}	6.5	6.9	7.4	7.8	8.2	8.6	9.0	9.4	9.8	10.1

Table 30: Mean Population Growth by Region, Reference Case

(Billions)
(Data for Figure 17)

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
A&N	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Canada	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04
Europe	0.59	0.60	0.61	0.62	0.63	0.64	0.65	0.66	0.67	0.67
FSU-Europe	0.21	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Japan	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.14
USA	0.29	0.31	0.32	0.33	0.33	0.34	0.35	0.36	0.37	0.37
Africa	0.88	0.97	1.05	1.13	1.21	1.27	1.33	1.39	1.44	1.48
Brazil	0.18	0.19	0.20	0.20	0.21	0.22	0.22	0.23	0.23	0.24
CAsia	0.26	0.28	0.30	0.32	0.33	0.35	0.36	0.37	0.38	0.39
China	1.33	1.38	1.44	1.48	1.53	1.56	1.59	1.62	1.64	1.66
India	1.11	1.20	1.29	1.38	1.47	1.56	1.64	1.72	1.79	1.85
MEAST	0.18	0.20	0.21	0.23	0.24	0.25	0.26	0.27	0.27	0.28
Mexico	0.10	0.11	0.11	0.12	0.12	0.13	0.13	0.13	0.13	0.14
ROLA	0.27	0.28	0.30	0.31	0.32	0.33	0.34	0.35	0.35	0.36
SEASIA	0.82	0.87	0.91	0.95	0.98	1.01	1.03	1.05	1.07	1.08
Developed	1.28	1.30	1.32	1.34	1.36	1.38	1.40	1.42	1.44	1.45
Developing	5.13	5.48	5.81	6.13	6.41	6.68	6.91	7.12	7.31	7.47
Total	6.41	6.78	7.13	7.47	7.77	8.06	8.31	8.54	8.74	8.92

Table 31: to 2010 Population Growth Uncertainty, Reference Case

(Data for Figure 18)

	5th	95th	50th
Global	56.5%	23.4%	38.9%
A&N	39.4%	9.8%	20.6%
Canada	40.9%	9.5%	21.1%
Europe	28.6%	5.1%	11.7%
FSU-Europe	30.0%	-27.4%	-3.0%
Japan	13.7%	1.7%	5.3%
USA	48.0%	11.8%	24.0%
Africa	118.6%	22.6%	64.1%
Brazil	64.0%	4.6%	29.3%
CAsia	100.4%	12.2%	50.0%
China	64.8%	-6.9%	23.1%
India	117.3%	23.0%	65.0%
MEAST	98.8%	11.6%	50.2%
Mexico	67.8%	3.5%	28.9%
ROLA	71.0%	1.6%	31.8%
SEASIA	70.0%	0.3%	29.0%

Table 32: Global GDP by Percentile, Reference Case

(Trillion $2000)
(Data for Figure 19)

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
95th	38.3	42.0	45.8	49.8	53.9	57.9	61.4	65.4	69.4	73.1
90th	39.0	43.2	47.6	51.8	56.2	60.3	64.9	69.0	74.3	78.8
50th	41.9	47.5	53.2	59.3	65.4	71.3	77.4	84.1	91.0	97.6
10th	45.0	52.5	60.3	68.4	77.3	85.9	94.9	104.2	113.8	124.1
5th	45.9	54.2	63.1	71.8	81.1	91.0	100.9	111.1	121.9	133.0

Table 33: Mean GDP Growth by Region, Reference Case

(Trillion $2000)

(Data for Figure 20)

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
A&N	0.70	0.81	0.92	1.03	1.13	1.23	1.32	1.41	1.50	1.58
Canada	0.88	0.99	1.10	1.19	1.30	1.40	1.51	1.62	1.72	1.82
Europe	13.21	14.46	15.60	16.88	18.26	19.74	21.36	22.96	24.61	26.24
FSU-Europe	0.46	0.49	0.52	0.57	0.63	0.71	0.81	0.91	1.03	1.15
Japan	6.51	7.02	7.53	8.06	8.59	9.13	9.69	10.23	10.74	11.25
USA	11.48	13.08	14.68	16.08	17.46	18.81	20.03	21.15	22.33	23.48
Africa	0.69	0.79	0.90	1.04	1.21	1.40	1.64	1.90	2.21	2.54
Brazil	0.96	1.09	1.23	1.38	1.54	1.73	1.92	2.13	2.35	2.58
CAsia	0.16	0.18	0.20	0.22	0.26	0.30	0.36	0.42	0.48	0.56
China	1.90	2.58	3.39	4.25	5.11	5.93	6.77	7.65	8.60	9.57
India	0.71	0.92	1.16	1.43	1.72	2.03	2.38	2.75	3.16	3.62
MEAST	0.60	0.70	0.82	0.95	1.08	1.23	1.39	1.56	1.74	1.95
Mexico	0.49	0.59	0.69	0.80	0.92	1.03	1.15	1.28	1.41	1.55
ROLA	1.07	1.27	1.49	1.72	1.97	2.22	2.49	2.78	3.07	3.40
SEASIA	2.14	2.75	3.42	4.15	4.88	5.59	6.32	7.08	7.90	8.72
Developed	33.25	36.85	40.36	43.81	47.38	51.02	54.71	58.27	61.92	65.52
Developing	8.71	10.86	13.29	15.94	18.69	21.47	24.42	27.55	30.93	34.49
Total	41.96	47.71	53.65	59.75	66.06	72.49	79.13	85.82	92.86	100.01
Developed Country Share	79%	77%	75%	73%	72%	70%	69%	68%	67%	66%

Table 34: Average Annual GDP Growth by Region (2000 to 2025), Reference Case

(Data for Figures 21a and 21b)

	Average Annual Growth Rate: 2005 to 2025			Average Annual Growth Rate: 2005 to 2050		
	95th Percentile	5th Percentile	Average	95th Percentile	5th Percentile	Average
A&N	1.10%	3.40%	2.40%	0.70%	2.60%	1.80%
Africa	1.30%	3.90%	2.80%	1.80%	3.80%	2.90%
Brazil	1.00%	3.50%	2.40%	1.10%	3.00%	2.20%
Canada	0.60%	3.00%	2.00%	0.60%	2.40%	1.60%
CAsia	1.30%	3.60%	2.50%	1.80%	3.70%	2.80%
China	3.80%	6.20%	5.10%	2.60%	4.50%	3.70%
Europe	0.20%	2.70%	1.60%	0.50%	2.40%	1.50%
FSU-Europe	0.10%	2.60%	1.50%	0.90%	2.90%	2.00%
India	3.10%	5.50%	4.50%	2.60%	4.40%	3.70%
Japan	0.20%	2.50%	1.40%	0.20%	2.00%	1.20%
MEAST	1.60%	4.10%	3.00%	1.60%	3.40%	2.70%
Mexico	1.70%	4.30%	3.20%	1.50%	3.40%	2.60%
ROLA	1.90%	4.20%	3.10%	1.60%	3.40%	2.60%
SEASIA	2.80%	5.40%	4.20%	2.20%	3.90%	3.20%
USA	0.70%	3.20%	2.10%	0.60%	2.30%	1.60%

Table 35: Average Global Primary Energy Use (Quads), Reference Case

(Data for Figure 22)

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Crude Oil	167.39	181.43	194.63	204.46	212.79	219.42	224.76	229.01	231.42	232.61
GeoThermal	2.44	2.65	2.86	3.09	3.28	3.45	3.60	3.75	3.87	3.99
Hydro	12.48	13.42	14.32	15.28	16.13	16.89	17.56	18.19	18.80	19.36
Nuclear	18.88	20.03	21.63	23.72	25.84	27.84	29.64	31.37	32.86	34.24
Primary Coal	110.96	120.36	130.08	140.29	149.68	158.10	165.41	171.71	176.99	181.15
Primary Gas	94.97	106.09	118.06	129.97	142.51	154.84	166.54	177.85	187.61	196.01
Renewables & Waste	35.36	37.18	38.71	40.39	42.00	43.68	45.15	46.47	47.63	48.90
Solar/Wind	3.26	4.70	6.53	8.94	11.76	15.02	18.70	22.93	27.75	33.15

Table 36: Primary Energy Use by Percentile (Quads), Reference Case

(Data for Figure 23)

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
95th	415.59	449.30	485.76	519.26	551.47	579.33	600.08	622.33	636.86	648.80
90th	421.10	457.61	494.39	529.51	561.98	590.07	614.75	637.93	656.50	668.62
50th	445.81	485.53	525.93	564.57	601.12	636.56	667.62	697.61	723.27	746.02
10th	469.99	515.02	560.44	606.26	650.54	692.11	732.84	769.56	804.71	835.02
5th	478.04	522.52	569.87	619.22	664.00	711.96	753.12	789.91	827.41	859.08

Table 37: Uncertainty in Primary Energy Use by Energy Type (Quads), Reference Case

(Data for Figure 24)

	95th	5th	Median
Crude Oil	180.8	292.0	231.3
GeoThermal	3.4	4.6	4.0
Hydro	16.3	22.7	19.3
Nuclear	28.1	40.7	34.2
Primary Coal	153.7	212.4	180.0
Primary Gas	163.8	234.6	194.9
Renewables & Waste	37.3	62.5	48.5
Solar/Wind	22.5	47.8	32.1

Table 38: Mean Primary Energy Use by Region (Quads), Reference Case
(Data for Figure 25)

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
A&N	4.4	4.6	4.8	5.1	5.3	5.5	5.7	5.8	5.9	6.0
Canada	9.4	10.4	11.2	11.9	12.3	12.6	12.8	12.9	12.9	12.9
Europe	79.6	81.0	84.8	90.5	96.6	102.5	107.6	112.5	116.8	120.4
FSU-Europe	39.7	44.9	45.4	44.3	42.2	39.9	37.3	35.2	33.2	31.6
Japan	19.4	21.4	23.6	25.6	27.6	29.2	30.6	31.5	32.3	32.8
USA	86.0	89.9	95.3	100.8	105.6	110.1	114.3	117.7	120.5	122.5
Africa	12.9	14.9	17.7	20.9	24.4	28.1	31.7	35.4	38.9	42.4
Brazil	6.4	7.2	8.4	9.7	11.0	12.3	13.5	14.7	15.7	16.6
CAsia	10.9	10.9	11.7	13.0	14.2	15.3	16.1	16.8	17.4	18.0
China	37.5	43.4	51.1	59.7	69.6	80.6	92.2	103.6	114.7	125.3
India	10.9	13.0	16.0	19.8	24.3	29.5	35.1	40.9	47.0	52.8
MEAST	10.7	12.2	14.1	16.1	18.0	19.9	21.4	22.8	23.8	24.6
Mexico	5.6	4.8	4.6	4.8	5.2	5.8	6.4	7.1	7.8	8.5
ROLA	9.2	10.2	11.6	13.1	14.6	16.2	17.6	18.9	20.1	21.2
SEASIA	19.3	23.5	28.9	35.0	41.7	48.3	54.9	61.4	67.3	72.6

Table 39: Average Power and Heat Generation in 2050, Reference Case
(Billion Mwh)
(Data for Figure 26)

	2000	2010	2020	2030	2040	2050
Coal	5.5	7.7	10.0	12.2	14.1	15.6
Gas	2.7	3.0	3.5	4.1	4.7	5.2
GeoThermal	0.6	0.7	0.8	0.9	1.0	1.1
Hydro	2.8	3.5	4.1	4.6	5.0	5.3
Nuclear	2.5	2.9	3.6	4.3	4.9	5.4
Petroleum	1.8	2.4	2.9	3.2	3.4	3.5
Renewable	0.0	0.0	0.1	0.1	0.1	0.2
Solar/Wind	0.6	1.4	2.6	4.4	6.7	9.7

Table 40: 2050 Average Primary Energy Use (Quads), Reference Case

(Data for Figure 27)

	2005	GDP Group	Pop Group	Conf Oil Group
min to 95th	445.5	706.4	707.3	669.7
95th to 90th	0.9	21.0	17.2	18.9
90th to 50th	-1.5	8.9	9.5	39.0
50th to 10th	0.9	24.4	28.4	46.8
10th to 5th	1.2	27.0	6.2	22.7
5th to max	1.9	2.6	45.9	20.4

Table 41: 2050 Average Primary Energy Use (Quads) GHG Scenarios

(Data for Figure 28)

	2005	No Tgt	High Tgt	Median Tgt	Low Tgt
Crude Oil	167.4	232.6	204.7	140.4	81.0
GeoThermal	2.4	4.0	4.3	4.7	5.1
Hydro	12.5	19.4	20.8	23.3	25.7
Nuclear	18.9	34.2	37.2	41.5	44.5
Primary Coal	111.0	181.2	128.3	78.0	60.2
Primary Gas	95.0	196.0	178.1	133.5	85.1
Renewables & Waste	35.4	48.9	52.0	58.0	65.1
Solar/Wind	3.3	33.2	37.7	46.2	52.6

Table 42: 2050 Primary Energy Use (Quads) GHG Scenarios
(Data for Figure 29)

	2005	No Tgt	High Tgt	Median Tgt	Low Tgt
Min to 95th	438.4	684.5	630.3	493.5	394.7
95th to 90th	5.8	20.9	16.2	15.4	9.2
90th to 50th	26.1	81.7	53.3	46.3	36.0
50th to 10th	25.5	93.9	51.3	43.5	43.4
10th to max	8.5	25.4	15.5	13.5	15.8

Table 43: 2050 Crude Oil Use (Quads) GHG Scenarios
(Data for Figure 30)

	2005	No Tgt	High Tgt	Median Tgt	Low Tgt
Min to 95th	162.2	190.7	179.1	114.5	73.8
95th to 90th	3.0	9.2	8.3	9.7	2.2
90th to 50th	11.7	44.1	28.3	24.8	9.3
50th to 10th	11.3	47.1	29.8	22.2	9.9
10th to max	2.9	17.0	9.4	6.6	2.9

Table 44: Average 2050 Regional Primary Energy Use (Quads) GHG Scenarios

(Data for Figure 31)

	2005	No Tgt	High Tgt	Median Tgt	Low Tgt
A&N	4.8	5.7	4.8	3.8	3.0
Canada	11.3	11.9	10.3	8.3	6.7
Europe	85.8	123.2	108.2	86.5	69.7
FSU-Europe	42.0	26.9	23.1	18.0	14.0
Japan	24.3	31.8	28.0	22.7	18.5
USA	95.5	118.9	98.8	75.8	60.3
Africa	19.8	48.8	44.5	36.3	29.6
Brazil	9.2	17.8	16.4	13.4	10.7
CAsia	12.3	18.6	16.7	13.1	10.4
China	56.6	143.6	127.8	99.5	78.3
India	18.7	65.4	60.0	49.0	39.9
MEAST	15.2	24.7	22.3	17.2	13.1
Mexico	4.5	10.0	9.1	7.3	5.7
ROLA	12.4	22.3	20.4	16.5	13.1
SEASIA	33.2	79.8	72.4	58.1	46.3

Table 45: Average 2050 Regional Primary Energy Production and Use (Quads) Reference Case

(Data for Figure 32)

	Demand-Crude Oil	Prod-Crude Oil	Demand-Coal	Prod-Coal	Demand-Gas	Prod-Gas
A&N	1.7	1.4	1.4	18.5	1.3	7.9
Africa	12.6	25.3	10.3	8.7	13.2	13.4
Brazil	7.2	9.6	2.1	1.7	4.7	4.4
Canada	3.5	27.5	2.3	4.7	2.8	10.1
CAsia	4.1	11.5	4.6	9.2	6.4	17.0
China	44.5	2.6	45.6	44.5	36.6	9.4
Europe	40.8	7.8	25.5	15.1	29.8	10.5
FSU-Europe	8.3	20.0	5.3	18.2	9.0	43.7
India	17.1	0.2	15.5	9.7	17.3	1.8
Japan	10.0	0.0	6.7	0.0	6.1	0.0
MEAST	9.0	51.1	3.3	2.6	10.4	34.6
Mexico	4.1	2.6	1.2	0.0	3.4	1.5
ROLA	8.4	40.0	2.2	1.3	7.8	9.1
SEASIA	29.0	2.3	14.6	0.0	24.0	9.2
USA	32.3	30.8	40.5	46.9	23.1	23.5

Table 46: Average Crude Oil Production by Resource Type (Quads), Reference Case
(Data for Figure 33)

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Conventional Oil	161.9	171.3	175.0	178.7	172.9	167.1	156.4	145.7	133.9	122.0
Heavy Oil	0.5	1.0	2.6	4.1	7.6	11.1	16.1	21.1	25.9	30.7
NGL	4.7	8.1	10.4	12.6	14.2	15.8	16.2	16.6	16.4	16.1
Oil Sands	0.5	1.0	4.3	7.6	13.7	19.9	26.3	32.7	37.3	41.9
Shale Oil	-0.2	0.0	2.4	1.3	4.3	5.6	9.8	12.8	18.0	21.9

Table 47: Crude Oil Production by Resource Type, Lowest Resource Grouping (Quads), Reference Case
(Data for Figure 34)

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Conventional Oil	161.2	170.3	164.8	159.3	141.4	123.5	104.3	85.1	71.0	56.8
Heavy Oil	0.5	1.1	4.3	7.6	14.3	21.0	26.7	32.4	33.7	34.9
NGL	3.4	5.6	7.0	8.4	8.0	7.6	6.7	5.8	5.1	4.4
Oil Sands	0.8	1.5	7.6	13.7	22.6	31.4	36.3	41.1	41.0	40.9
Shale Oil	0.5	0.0	3.7	2.2	7.9	11.3	18.8	24.5	32.4	40.0

Table 48: Crude Oil Production by Resource Type, Highest Resource Grouping (Quads), Reference Case
(Data for Figure 35)

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Conventional Oil	161.2	170.4	184.4	198.5	204.9	211.3	212.8	214.4	210.1	205.8
Heavy Oil	0.6	1.1	1.9	2.6	3.9	5.1	7.0	8.8	12.1	15.3
NGL	8.2	14.3	17.0	19.6	22.3	24.9	27.9	30.8	32.8	34.8
Oil Sands	0.4	0.8	1.6	2.5	5.2	7.9	12.3	16.6	22.1	27.5
Shale Oil	-1.6	0.0	-0.4	0.4	1.4	1.7	3.0	3.8	6.0	7.6

Table 49: 2050 Crude Oil Production by Resource Type and Resource Grouping (Quads), Reference Case

(Data for Figure 36)

	2005	Min-95th	95th-90th	90th-50th	50th-10th	10th-5th	5th-Max
Conventional Oil	161.9	56.8	69.0	100.3	141.4	175.4	205.8
Heavy Oil	0.5	34.9	36.5	34.5	28.9	19.7	15.3
NGL	4.7	4.4	6.5	11.6	19.6	28.0	34.8
Oil Sands	0.5	40.9	42.8	44.0	42.7	33.2	27.5
Shale Oil	-0.2	40.0	33.9	25.5	17.7	10.8	7.6

Table 50: World Conventional Oil Production by Resource Range Reference Case

(Data for Figure 37)

Global Conventional Crude Production by Resource Range - Reference Case (Quads)										
Resource Range	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Category 1: Min to 95th %	161.2	170.3	164.8	159.3	141.4	123.5	104.3	85.1	71.0	56.8
Category 2: 95th to 90th %	160.8	168.8	166.5	164.1	149.6	135.1	116.7	98.4	83.7	69.0
Category 3: 90th to 50th %	161.8	170.9	172.0	173.1	164.1	155.1	141.5	128.0	114.1	100.3
Category 4: 50th to 10th %	162.6	172.5	178.6	184.7	181.9	179.1	170.9	162.8	152.1	141.4
Category 5: 10th to 5th %	159.8	169.2	180.2	191.1	194.6	198.2	194.7	191.1	183.3	175.4
Category 6: 5th % to Max	161.2	170.4	184.4	198.5	204.9	211.3	212.8	214.4	210.1	205.8
World Conventional Crude Production by Resource Range - Reference Case million barrels per day, MMBD)										
Resource Range	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Category 1: Min to 95th %	76.1	80.4	77.8	75.3	66.8	58.3	49.3	40.2	33.5	26.8
Category 2: 95th to 90th %	75.9	79.8	78.6	77.5	70.7	63.8	55.1	46.5	39.5	32.6
Category 3: 90th to 50th %	76.4	80.7	81.2	81.7	77.5	73.3	66.9	60.4	53.9	47.4
Category 4: 50th to 10th %	76.8	81.5	84.4	87.2	85.9	84.6	80.7	76.9	71.8	66.8
Category 5: 10th to 5th %	75.5	79.9	85.1	90.3	91.9	93.6	91.9	90.3	86.6	82.8
Category 6: 5th % to Max	76.2	80.5	87.1	93.8	96.8	99.8	100.5	101.3	99.2	97.2

Table 51: Average Crude Oil Demand by Region Reference Case

(Data for Figure 38)

Crude Oil Demand by Region – Reference Case (Quads)										
	2005	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
USA	36.9	37.9	38.3	38.0	37.4	36.6	35.6	34.6	33.4	32.3
Europe	36.4	38.7	40.8	41.6	42.2	42.3	42.2	42.1	41.6	40.8
FSU-Europe	14.9	14.2	13.2	12.2	11.2	10.3	9.7	9.1	8.7	8.3
Japan	12.2	12.5	12.7	12.6	12.3	11.9	11.5	11.0	10.5	10.0
A&N	1.8	1.9	2.0	2.0	1.9	1.9	1.8	1.8	1.7	1.7
Canada	4.5	4.6	4.6	4.6	4.4	4.2	4.1	3.9	3.7	3.5
China	11.5	15.4	20.0	24.7	29.1	33.3	36.9	40.1	42.5	44.5
Brazil	5.1	5.8	6.3	6.7	7.0	7.2	7.3	7.3	7.3	7.2
Mexico	2.7	2.8	3.1	3.3	3.5	3.7	3.9	4.0	4.0	4.1
India	4.1	5.3	6.7	8.2	9.8	11.4	12.9	14.4	15.8	17.1
ROLA	5.9	6.5	7.0	7.4	7.8	8.0	8.3	8.4	8.4	8.4
SEASIA	14.2	17.0	19.7	22.0	24.1	25.8	27.2	28.2	28.7	29.0
CAsia	3.4	3.5	3.6	3.6	3.6	3.6	3.7	3.8	3.9	4.1
Africa	5.9	6.8	7.7	8.5	9.2	9.9	10.6	11.3	12.0	12.6
MEAST	8.1	8.5	8.9	9.1	9.2	9.2	9.2	9.2	9.1	9.0
Total World, Quads	167.4	181.4	194.6	204.5	212.8	219.4	224.8	229.0	231.4	232.6
Total World, mmb/d	79.1	85.7	91.9	96.6	100.5	103.6	106.2	108.2	109.3	109.9

Table 52: Global Crude Oil Production by Resource Type, Quads and MMBD; Resource Category 2, Reference Case

(Data Table for Figure 39)

Global Crude Oil Production by Resource Type (Quads) Resource Category 2										
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Conventional Oil	160.8	168.8	166.5	164.1	149.6	135.1	116.7	98.4	83.7	69.0
Heavy Oil	0.5	1.0	3.7	6.4	12.1	17.7	24.2	30.7	33.6	36.5
NGL	3.6	6.0	7.8	9.6	9.6	9.7	8.9	8.0	7.2	6.5
Oil Sands	0.7	1.3	6.6	12.0	20.2	28.4	34.4	40.4	41.6	42.8
Shale Oil	1.8	0.0	2.9	2.0	6.6	9.5	15.9	21.5	28.5	33.9
Global Crude Oil Production by Resource Type (MMBD) Resource Category 2										
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Conventional Oil	75.9	79.8	78.6	77.5	70.7	63.8	55.1	46.5	39.5	32.6
Heavy Oil	0.2	0.5	1.8	3.0	5.7	8.4	11.4	14.5	15.9	17.3
NGL	1.7	2.8	3.7	4.5	4.6	4.6	4.2	3.8	3.4	3.1
Oil Sands	0.3	0.6	3.1	5.7	9.5	13.4	16.3	19.1	19.7	20.2
Shale Oil	0.8	0.0	1.4	1.0	3.1	4.5	7.5	10.1	13.4	16.0

Table 53: Global Crude Oil Production by Resource Type, Quads and MMBD; Resource Category 6, Reference Case

(Data Table for Figure 40)

Global Crude Oil Production by Resource Type (Quads) Resource Category 6										
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Conventional Oil	161.2	170.4	184.4	198.5	204.9	211.3	212.8	214.4	210.1	205.8
Heavy Oil	0.6	1.1	1.9	2.6	3.9	5.1	7.0	8.8	12.1	15.3
NGL	8.2	14.3	17.0	19.6	22.3	24.9	27.9	30.8	32.8	34.8
Oil Sands	0.4	0.8	1.6	2.5	5.2	7.9	12.3	16.6	22.1	27.5
Shale Oil	-1.6	0.0	-0.4	0.4	1.4	1.7	3.0	3.8	6.0	7.6
Global Crude Oil Production by Resource Type (MMBD) Resource Category 6										
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Conventional Oil	76.2	80.5	87.1	93.8	96.8	99.8	100.5	101.3	99.2	97.2
Heavy Oil	0.3	0.5	0.9	1.2	1.8	2.4	3.3	4.2	5.7	7.2
NGL	3.9	6.7	8.0	9.3	10.5	11.8	13.2	14.6	15.5	16.5
Oil Sands	0.2	0.4	0.8	1.2	2.5	3.7	5.8	7.9	10.4	13.0
Shale Oil	-0.8	0.0	-0.2	0.2	0.7	0.8	1.4	1.8	2.9	3.6

Table 54: Average Primary Energy Production by Energy Type for Reference Case

(Data Table for Figure 41)

Average Primary Energy Production by Energy Type for Reference Case (Quads)										
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Crude Oil	167.4	181.4	194.6	204.5	212.8	219.4	224.8	229.0	231.4	232.6
GeoThermal	2.4	2.7	2.9	3.1	3.3	3.5	3.6	3.7	3.9	4.0
Hydro	12.5	13.4	14.3	15.3	16.1	16.9	17.6	18.2	18.8	19.4
Nuclear	18.9	20.0	21.6	23.7	25.8	27.8	29.6	31.4	32.9	34.2
Primary Coal	111.0	120.4	130.1	140.3	149.7	158.1	165.4	171.7	177.0	181.2
Primary Gas	95.0	106.1	118.1	130.0	142.5	154.8	166.5	177.8	187.6	196.0
Renewables & Waste	35.4	37.2	38.7	40.4	42.0	43.7	45.1	46.5	47.6	48.9
Solar/Wind	3.3	4.7	6.5	8.9	11.8	15.0	18.7	22.9	27.7	33.2
Average Primary Energy Production by Energy Type for Reference Case (MMBD)										
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Crude Oil	79.1	85.7	91.9	96.6	100.5	103.6	106.2	108.2	109.3	109.9
GeoThermal	1.2	1.3	1.4	1.5	1.6	1.6	1.7	1.8	1.8	1.9
Hydro	5.9	6.3	6.8	7.2	7.6	8.0	8.3	8.6	8.9	9.1
Nuclear	8.9	9.5	10.2	11.2	12.2	13.2	14.0	14.8	15.5	16.2
Primary Coal	52.4	56.9	61.4	66.3	70.7	74.7	78.1	81.1	83.6	85.6
Primary Gas	44.9	50.1	55.8	61.4	67.3	73.1	78.7	84.0	88.6	92.6
Renewables & Waste	16.7	17.6	18.3	19.1	19.8	20.6	21.3	21.9	22.5	23.1
Solar/Wind	1.5	2.2	3.1	4.2	5.6	7.1	8.8	10.8	13.1	15.7

Table 55: Crude Oil Production by Region (Quads)
Reference Case
(Data for Figure 42)

Crude Oil Production by Region (includes conventional and non-conventional production) – Reference Case (Quads)										
Model Region	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
USA	8.6	8.1	9.7	13.7	17.8	20.8	23.4	25.7	28.1	30.8
Europe	3.2	2.5	2.4	2.8	3.4	4.1	4.9	5.8	6.7	7.8
FSU-Europe	12.2	11.8	13.0	15.9	18.3	20.1	21.1	21.3	20.8	20.0
Japan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A&N	0.9	0.8	0.9	1.1	1.2	1.4	1.4	1.4	1.4	1.4
Canada	3.1	3.1	4.4	7.2	10.9	14.9	18.8	22.3	25.3	27.5
China	4.0	3.3	3.2	3.3	3.3	3.2	3.1	2.9	2.7	2.6
Brazil	2.0	1.9	2.4	3.8	5.4	6.8	8.0	8.8	9.3	9.6
Mexico	3.4	2.3	1.7	2.0	2.2	2.4	2.6	2.7	2.7	2.6
India	1.0	0.8	0.6	0.5	0.4	0.4	0.3	0.3	0.2	0.2
ROLA	11.1	13.5	15.2	18.0	21.2	24.7	28.6	32.6	36.6	40.0
SEASIA	2.8	1.9	1.3	1.7	2.3	2.7	2.8	2.7	2.6	2.3
CAsia	3.3	3.3	4.2	5.7	7.3	8.8	10.1	11.0	11.5	11.5
Africa	15.7	14.8	15.8	18.2	20.7	22.8	24.4	25.3	25.5	25.3
MEAST	96.1	113.4	119.7	110.5	98.0	86.2	75.4	66.1	58.0	51.1

Table 56: Crude Oil Production by Region (Quads)
Moderate GHG Concentration Target
(Data for Figure 43)

Table 18 - Crude Oil Production by Region - Moderate GHG Target Scenario (Quads)										
Model Region	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
USA	8.6	8.1	9.7	12.7	14.9	13.6	12.0	11.6	12.2	13.6
Europe	3.2	2.5	2.4	2.6	2.7	2.4	2.1	2.1	2.3	2.7
FSU-Europe	12.2	11.8	12.9	14.6	15.0	12.7	11.0	10.7	11.5	12.8
Japan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A&N	0.9	0.8	0.9	1.0	1.0	0.9	0.8	0.8	0.8	0.9
Canada	3.1	3.1	4.3	6.4	8.3	8.4	8.5	9.3	10.9	13.2
China	4.0	3.3	3.2	3.1	2.9	2.3	1.9	1.6	1.6	1.7
Brazil	2.0	1.9	2.4	3.3	4.0	3.7	3.4	3.5	4.0	4.7
Mexico	3.4	2.3	1.7	1.8	1.8	1.1	0.6	0.5	0.5	0.7
India	1.0	0.8	0.6	0.3	0.2	0.0	0.0	0.0	0.1	0.2
ROLA	11.1	13.5	15.1	16.8	17.6	15.9	14.6	14.6	16.0	18.3
SEASIA	2.8	1.9	1.3	1.4	1.5	0.9	0.5	0.5	0.6	0.9
CAsia	3.3	3.3	4.1	5.1	5.6	5.0	4.6	4.6	5.2	6.2
Africa	15.7	14.8	15.7	17.0	17.3	15.0	13.3	12.7	13.4	14.7
MEAST	96.1	113.4	119.3	108.6	94.7	80.1	68.9	60.8	54.8	49.9
Total World	167.4	181.4	193.7	194.7	187.6	162.0	142.1	133.2	133.8	140.4

Table 57: Crude Oil Price Uncertainty ($2000), Reference Case
(Data for Figure 45)

	2015	2020	2025	2030	2035	2040	2045	2050
95th	20.8	23.5	25.8	28.2	29.9	31.6	32.6	33.6
90th	22.4	25.4	28.0	30.6	32.3	34.1	35.5	36.9
50th	27.2	31.8	35.2	38.7	41.2	43.7	47.4	51.0
10th	33.6	38.9	43.2	47.5	54.8	62.1	69.1	76.1
5th	35.2	41.1	45.7	50.2	59.9	69.5	78.2	86.9

Table 58: Crude Oil Price by Conventional Oil Resource Group ($2000), Reference Case
(Data for Figure 46)

	2015	2020	2025	2030	2035	2040	2045	2050
Min to 95th	32.5	38.9	45.2	51.5	59.9	68.4	75.3	82.1
95th to 90th	31.5	37.8	42.1	46.4	54.9	63.5	71.2	78.9
90th to 50th	29.4	34.3	37.9	41.5	45.7	49.8	55.0	60.1
50th to 10th	26.0	29.8	33.1	36.3	38.5	40.8	43.6	46.5
10th to 5th	23.7	26.5	29.1	31.7	33.9	36.0	37.6	39.1
5 to Max	21.3	23.0	25.0	27.1	28.9	30.6	32.0	33.3

Table 59: Average Crude Oil Prices for the Reference and Environmental Cases ($2000)
(Data for Figure 47)

	2015	2020	2025	2030	2035	2040	2045	2050
Reference Case	29.4	33.6	37.7	40.9	44.5	48.6	52.7	57.1
High GHG Tgt	29.0	31.8	34.4	36.3	38.8	41.8	44.8	48.3
Moderate GHG Tgt	29.0	31.4	32.3	30.6	30.0	30.8	32.6	34.7
Low GHG Tgt	29.0	31.1	30.3	26.9	25.2	24.6	24.5	24.7