STRATEGIC CHOICES

FOR MANAGING THE TRANSITION

FROM PEAK OIL

TO A REDUCED PETROLEUM ECONOMY

BY

SARAH K. ODLAND

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PREFACE

The topic of Peak Oil – the idea that the world is approaching a geologically constrained maximum rate of oil production - has consumed me for the past two years. After Peak Oil is reached, it will be impossible to maintain, much less increase, the world's daily oil production rate, no matter how much money and effort are thrown at the problem. Any growth in oil demand in one region will have to be met by a reduction in consumption someplace else. The consequences for our economic health and security will be profound at all levels – individual, business, national and global. Business as usual will not be an option. Peak Oil signals the beginning of a revolution to whatever Age is going to follow the Industrial Age. Interesting times.

My interest in Peak Oil management is the logical outgrowth of more than 20 years working as a geologist and project manager, followed by 10 years as a business manager and university administrator. The more deeply I looked, the more I became convinced that the whole Peak Oil issue needs to be framed as a strategic management problem. Here we are, facing a situation where the decisions we make now, whether by informed choice or default, will determine the kind of life available to us and our children 30 years down the road. Yet, there is very little reliable public data on which to base decisions, almost no public discourse, and no viable long-term national energy policy or planning. A manager's job is to plan a course of action and allocate available resources to achieve a desired outcome, often in the face of incomplete or contradictory information. By that definition, Peak Oil is a quintessential management problem.

The exact timing of Peak Oil is extremely difficult to predict because the publicly available data on remaining oil reserves is astoundingly poor. Much of the "data" is crafted specifically to meet political and financial requirements. Essentially, companies and countries keep two sets of books. There is no data transparency or verification. Knowing any data I used would be suspect and immediately obsolete, I decided to generate all my graphs and tables from a single, commonly cited source – the Annual Statistical Review of World Energy, published in July 2005 by British Petroleum (BP).

For this paper I consider only oil production, not natural gas, which has it's own very significant peak issues. That means this paper concentrates on energy use for transportation, not for electric power generation. For alternative energy, it means only considering those forms that can substitute for oil as a mobile fuel – no wind, hydro, solar, or nuclear power, which provide stationary energy.

I've drawn heavily on the assessments of retired petroleum geologists Kenneth Deffeyes, Colin Campbell and Jean Laherrere, energy investment banker Matthew Simmons, and former government analyst Tom Whipple. From a management perspective, three U.S. Government reports were particularly useful: the "Hirsch Report" for DOE on mitigating risks from Peak Oil, the Pentagon-funded "Oil Endgame" report by Amory Lovins, and a recent report on energy trends and implications by the Army Corps of Engineers. There are now numerous energy observers writing about the depletion of world supplies.

I owe thanks to many geophysicists at Lamont-Doherty Earth Observatory where I work: Roger Anderson, Karen Goodfellow, Garry Karner, Kim Kastens, Alberto Malinverno, Greg Mountain, Bill Ryan, Maya Tolstoy and Jeff Weissel offered encouragement and shared articles,

insights and concerns. I'm especially grateful to Walter Pitman and Chris Small, who waded through very rough drafts of the manuscript, offered sound advice on improving it, and never ducked when they saw me coming. Thanks to my father, Ben, my tireless energy correspondent, and my mother, Betsy, an inspiration in living simply with class. Profound thanks to Mary-Ann for helping haul me out of the hole I dug myself into halfway through this undertaking. Finally, love and gratitude to my family - Bruce, Mike, Xandra, and Max- who cut me slack and gave me more time and space than they'd ever bargained for.

As I write this, nine months after hurricanes Katrina and Rita, U.S. Gulf of Mexico oil production has still not returned to its prior rate. Last year we saw how quickly the human situation can become desperate and how rapidly civil order can break down when the infrastructure is destroyed. New Orleans is far from rebuilt, and we have not yet felt the full impact of the lost production. We enter the 2006 hurricane season with damaged infrastructure and less spare capacity than in 2005.

I hope this paper will stimulate thought and discussion about the issues surrounding Peak Oil amongst people of different backgrounds and viewpoints. The problems presented here will not be solved in isolation.

Sally Odland
June 2006

INTRODUCTION

- ELEPHANT IN THE ROOM -

If you don't know where you're going, you're gonna end up someplace else.
– Yogi Berra

The imminent (or current) peaking of the rate of world oil production is barely discussed publicly in government, business and policy circles. Peak Oil, as this transition is called, will irreversibly alter the delivery rate of liquid fossil energy to fuel economic growth.[1] As demand outstrips the rate at which oil can be supplied, we can expect higher prices, volatile markets, physical fuel and power shortages, international geopolitical strife and wars. The magnitude of the problems will increase as supply rates decline. The implications are profound, both for our ability to maintain our standard of living in the developed countries and for the chance of economic growth at all in the developing ones. There is a cognitive disconnect between the actual situation and public awareness, resulting in a dangerous policy and preparation gap.

That world oil production must peak one day is fact, not theory. All finite resources face an extraction/production curve. The rate of production increases as high quality, easy-to-access resources are exploited first and extraction technologies improve. Marginal production diminishes to zero at the point of maximum extraction, after which the rate declines. As production continues, the remaining, lower quality, resource becomes increasingly more difficult, and expensive, to reach and extract. Figure 1 depicts projected world oil consumption on a millennial timescale.

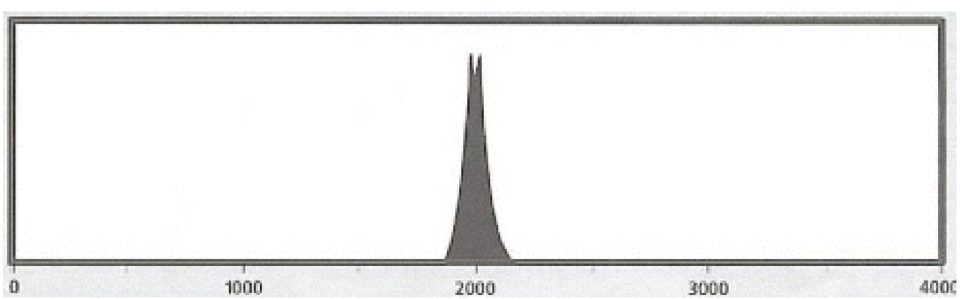

Figure 1. "The Flame in the Darkness". The consumption of the world's accessible oil endowment will occur over a two-century span of human history. Source: Community Solution, modified from Hubbert, 1956.

[1] There is also a natural gas production crisis looming, especially in North America. But this paper is limited to examining the liquid petroleum problem.

The real debate is exactly when Peak Oil will occur and whether technology, substitute fuels and conservation can satisfy demand for the lost oil production. A production peak cannot be pinpointed until several years after the fact – it is recognized "in the rear view mirror". However, the most reliable publicly available evidence suggests that the peaking of world oil production will occur sometime between 2004 and 2017. Since 1998, a growing number of geologists, engineers, social thinkers, bankers and economists have been writing and speaking publicly about Peak Oil. By 2005, awareness and concern had grown to a level capable of supporting international conferences and the initiation of a Peak Oil caucus in Congress. [2] By 2006, President Bush felt obliged to include the subject of oil dependency in his State of the Union Address.[3]

Many in the U.S. government are well informed of the problem[4]. The major oil companies briefed Vice President Cheney's 2001 Energy Task Force on the state of world oil supplies, and energy merchant banker and Peak Oil spokesman Matthew Simmons advises both Bush and the White House. However, the government has been reluctant to make official statements alluding to future declines in petroleum availability or to introduce policy to prepare for it. Until the Fall of 2005, Representative Roscoe Bartlett was the lone voice in Congress urging action to prepare for the upcoming oil shortages. Consequently, the average citizen does not realize that there is any fuel crisis on the horizon. Though acutely aware of higher prices for gasoline, heating and electric power, the general public attributes these symptoms of the coming crisis solely to short-term supply disruptions and price gouging by the oil and power companies.

Peak Oil is essentially a matter of energy flows. The world economy in 2006 will require around 84 million barrels per day (30 billion bbl/year) of petroleum just to function at its 2005 level. To sustain that rate requires 1 billion barrels of oil – the equivalent of two megafields – be produced every 12 days. Therefore, what is more significant than the actual production peak date is the onset of a demand gap – when oil demand exceeds the capacity of the system to supply it. At that point, the world tips from a long-term buyers' to a sellers' market for petroleum.

This paper presents the world oil demand/supply situation from a physical constraints perspective, then takes a strategic decision management/game theory approach to look at our options for action. The paper consists of two distinct parts:

Part I – The Big Rollover: Onset of a Petroleum Demand Gap and the Switch to a Sellers' Market[5] - examines the world's demand for cheap energy, estimates of future oil availability and potential supply constraints. Chapter 1 reviews current and projected oil demand and discusses the energy requirement for economic growth. Chapter 2 briefly inventories world oil supply,

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[2] Representative Roscoe Bartlett (Republican, Maryland) gave four peak oil presentations to Congress in 2005 and in November started a Peak Oil caucus with16 members. From his website: In the 109th Congress, Bartlett serves as Chairman of the Projection Forces Subcommittee of the Armed Services Committee. One of three scientists in the Congress, Dr. Bartlett is also a senior member of the Science Committee. Due to his ten years of experience as a small business owner, he also serves on the Small Business Committee and is its Vice Chairman.

[3] "America is addicted to oil". President Bush, State of the Union Address, January 2006.

[4] The intelligence agencies have tracked and gamed the oil issue since the 1970s and the Bush Administration is studded with former energy industry insiders.

[5] The term "Big Rollover" was coined by USGS geologist Les Magoon. It describes the point when world demand for oil outstrips the capacity to produce it. *Are We Running Out of Oil?* (U.S. Geological Survey: Open File Report 00-320, 2000).

concentrating on the uncertainty of reported reserves, potential rate-limits to production, and the likely timing of the onset of an oil demand/supply gap. Chapter 3 summarizes the potential to fill that gap using substitute fossil and renewable fuel alternatives, technological innovation and conservation.

Part II - Transition Endgame: Gambling for Our Energy Future - uses the strategic management tactic of gaming to present possible scenarios for transitioning to a world of reduced petroleum supply. Chapter 4 defines the game, identifying the players, the rules, the underlying states of nature and their probabilities, and the stakes. It presents a matrix of speculative, but plausible societal outcomes, depending on whether the transition is abrupt or gradual, and whether we prepare for it or not. Chapter 5 identifies potential strategic actions (tactics) that might be undertaken by the markets, governments, the private sector, and/or social groups to balance demand with reduced supply. Chapter 6 integrates the options and risks into a management decision framework. Four likely strategic approaches are considered, the potential outcomes and risks evaluated, and an optimal approach selected. Chapter 7 considers business and behavioral impediments to achieving a managed transition. The conclusion, Chapter 8, calls for immediate actions to avert the worst potential outcomes.

PART I

THE BIG ROLLOVER: ONSET OF A PETROLEUM DEMAND GAP AND SWITCH TO A SELLERS' MARKET

As we approach the limits of our easy access to energy, the defining economic currency will be dominated by availability of energy units rather than by an artificial currency, be that gold or dollars.

-Paul B. Weisz (2004)

A dispassionate observer from outer space may watch with amazement how an incredibly complex and resourceful society of Homo economicus, armed with the most advanced technology and all of the knowledge amassed through their entire history, is voluntarily, with determination, even enthusiastically painting itself into a corner and reduces its future options to what in the game of chess is termed zugzwang (compulsed move) - by deferring the recognition of the Universe's challenge until the crisis that is currently clearly visible on the horizon becomes detectible through economic and monetary mechanisms, signals which in this particular peculiar civilization apparently take precedence over the other six senses.

- Dimtry Podborits (2005)

CHAPTER 1

WHAT'S OIL EVER DONE FOR YOU?
(AND WHAT WOULD HAPPEN IF IT STOPPED DOING IT?)

Oil is unique in that it is so strategic in nature. We are not talking about soapflakes or leisurewear here. Energy is truly fundamental to the world's economy. The Gulf War was a reflection of that reality. The degree of government involvement also makes oil a unique commodity. This is true in both the overwhelming control of oil resources by national oil companies and governments as well as in the consuming nations where oil products are heavily taxed and regulated.... It is the basic, fundamental building block of the world's economy. It is unlike any other commodity.

- Dick Cheney, CEO Halliburton[6]

Oil: Cheap Energy on Demand

Oil is Not Just a Commodity[7]

Oil is the world's single largest traded commodity, accounting for over half the total value of all commodity transactions[8]. The U.S. Department of Energy's Energy Information Administration (EIA) estimates that U.S. expenditures on oil in 2005 were $1 trillion, representing 8.7% of gross domestic product (GDP).[9] With the U.S. currently importing about 60% of its oil, over 12 million barrels per day (mbd), the daily cash exodus from the U.S. at $70/barrel is more than $840 million. Fortunately, the major world oil exchanges[10] and the Organization of Petroleum Exporting Countries (OPEC) all still denominate oil sales in dollars.

Oil, however, is much more than a commodity. The capacity to produce oil is a capital

[6] Speaking to the London Institute of Petroleum in 1999. Full speech is available at http://www.energybulletin.net/559.html.

[7] With apologies to Matthew Simmons, "Oil is Not Just Another Commodity" in *Twilight in the Desert: the Coming Saudi Oil Shock and the World Economy*, (John Wiley & Sons, 2005) and Yergin, "Just Another Commodity?" in *The Prize: the Epic Quest for Oil, Money and Power*, (New York Free Press, 1991), who have treated the topic in much greater depth in their chapters of similar name.

[8] Per the U.K. Oil Depletion Analysis Centre (ODAC). www.odac-info.org

[9] U.S. Dept. of Energy, Energy Information Administration (EIA), *Short-Term Energy Outlook and Winter Fuels Outlook*, October 2005. www.eia.doe.gov/pub/forecasting/steo/oldsteos/oct05.pdf

[10] New York Mercantile Exchange (NYMEX), the London International Petroleum Exchange (IPE), and the Singapore and Tokyo exchanges.

asset, like land, buildings and equipment. Yet oil removed from the ground is neither depreciated nor replaced. Simultaneously, oil could be considered a form of labor, since its principal attribute is its ability to do work and its energy replaces labor formerly provided by traction animals or people. As Rep. Bartlett describes it:

> One barrel of oil, 42 gallons of oil, equals the productivity of 25,000 manhours. That is the equivalent of having 60 dedicated servants that do nothing but work for someone. We can get a little better real-life example of this. A gallon of gas will drive a 3-ton SUV...20 miles at 60 miles an hour down the road. That is just one little gallon of gas, which, by the way, is still cheaper than water.[11]

The large increases in productivity in the developed world over the past three centuries are the result of workers controlling ever-increasing supplies of cheap energy with ever-greater efficiency. Technology is the enabler, but oil does the work. In short, oil is:

- the densest, portable form of energy known to man[12]
- the current basis of economic wealth
- the factor of productivity underlying economic growth, and
- the major daily cash/debt flow in the world economy

Oil is a blessing and a curse. It brings easy wealth and confers power. But it also brings war. Some even make a convincing case that oil functions like the gold standard formerly did, to anchor the value of currencies; they argue it would be more accurate to view our wealth denominated in oil rather than dollars.[13]

Heavy Users

It is difficult to find anything in the industrial world that does not depend on cheap oil in some way for its production and distribution. The global economy is built around cheap transportation for just-in-time manufacturing and inventory management. The U.S. has only 5% of the world's population, but it consumes 25% (almost 21 mbd) of the 84 million barrels per day that the world produces (Figure 2).[14] The U.S. and countries of the Organization for Economic Cooperation and Development (OECD) are all heavy users, as is Japan, and increasingly, China and India. In general, the higher the level of development and GDP, the more oil per capita a

[11] The Fourth Special Order speech on Peak Oil to the US Congress by Rep. Roscoe Bartlett, accompanied by Rep.'s Ehlers, Gilchrest, Inglis, and Wamp, May 11, 2005. Archived 12 May 2005, US Congressional Record. Partial transcript available at www.energybulletin.net/6082.html

[12] While uranium atoms have a higher energy density, they are neither easily transported nor used.

[13] J.R. Fibonacci, *Navigating the New Economy, Lesson 1: Worth Its Weight in Oil.* (Published online at www.321energy.com, Sept. 9, 2005); Greg Croft, *The End of the Oil Standard*, (Published online at www.energybulletin.net, Feb. 7, 2005).

[14] The U.S. military is the biggest consumer of liquid petroleum in U.S. and the biggest purchaser of imported oil in the world. (Amory Lovins, et al, *Winning the Oil Endgame: Innovation for Profits, Jobs, and Security*, Rocky Mountain Institute, 2005); Sohbet Karbuz, *The U.S. Military Oil Consumption*, (www.energybulletin.net, Feb 27, 2006).

country consumes. Per capita oil use in the U.S. was over 3 tons per year in 2004, triple that of China and India.[15]
The world uses oil to meet two types of energy needs: mobile and stationary. Mobile use (cars, planes, ships) consumes the lion's share, more than 50% of oil consumption worldwide, but 70% in the highly mobile U.S. (Figure 3). About 22% of U.S. oil is used for industry and agriculture[16], including the production of petrochemicals and plastics. Stationary energy use is for heat and electricity. Combined residential, commercial, and electric utility use of oil in the U.S. is only about 8% of total oil used.[17] As oil is such a minor player in the stationary fuel mix, this paper will focus on mobile fuel use, and will not discuss further any energy use for heating or electric power generation.

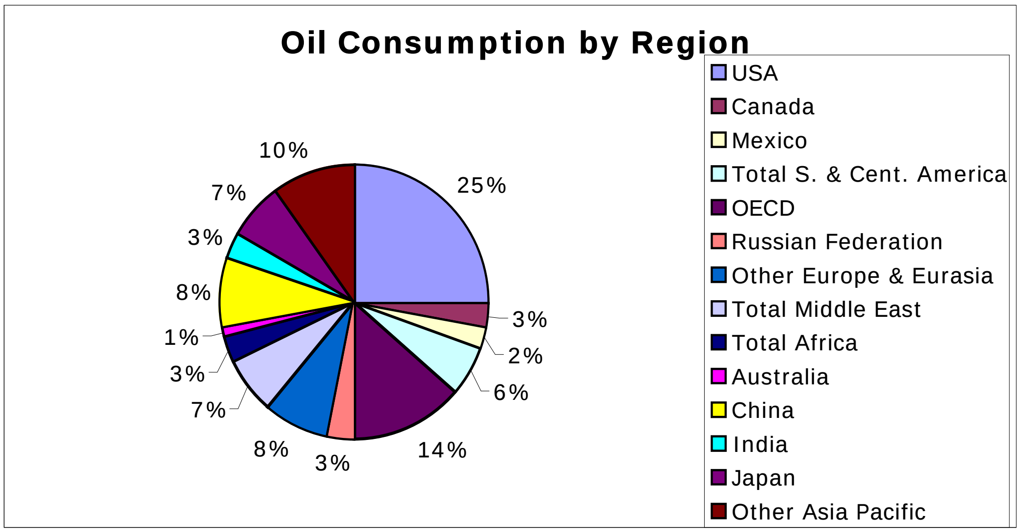

Figure 2. Percentage of total oil production consumed by the major oil-using countries and regions in 2004. Data from BP Statistical Review World Energy 2005.

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[15] BP Statistical Review of World Energy, 2005.

[16] Modern agriculture is extremely oil-intensive, consuming 7 to10 Kilocalories of oil/gas in fertilizers, pesticides, machinery fuel and transportation for every 1 Kcal (Cal) food brought to market (before cooking). See Richard Manning *"The Oil We Eat: Following the Food Chain Back to Iraq"* (Harper's Magazine, February 2004); and Dale Allen Pfeiffer, *"Eating Fossil Fuels"* (From the Wilderness, March 2004).

[17] Nationally, fuel oil provides only about 8% of total residential energy used. However, 78% of U.S. heating oil is used in the Northeast, where 33% of the homes are heated by oil. *Residential Heating Prices: What Consumers Should Know*, EIA brochure, September 2004. Available at http://www.eia.doe.gov/neic/brochure/heatoil04/Chapter1.htm

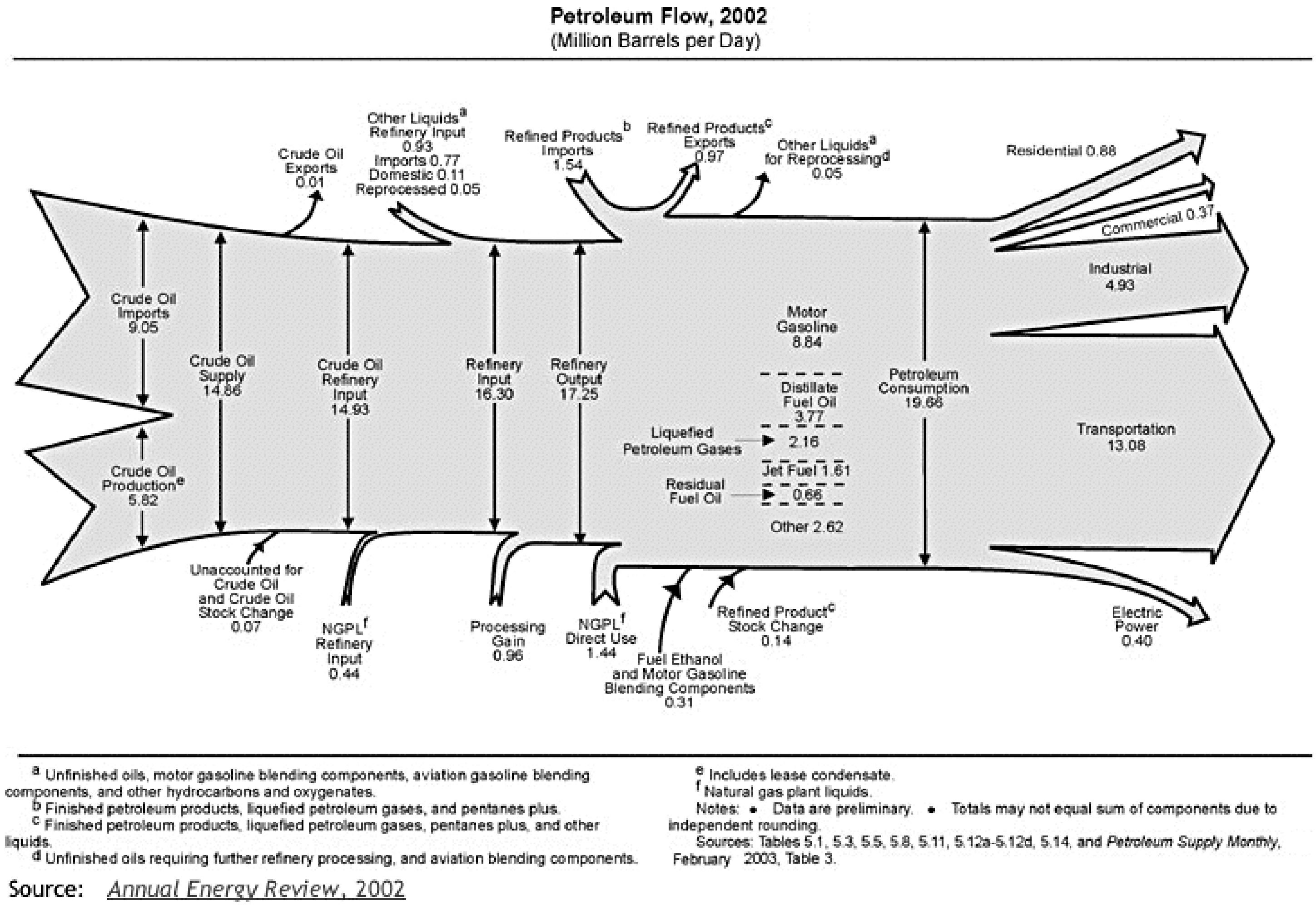

Figure 3. U.S. refined oil sources and end uses. Source: DOE/EIA

Projected Demand Growth for Liquid Petroleum

Demand growth projections depend on assumptions about future rates of economic growth in the various countries. In June 2005, the EIA projected world oil demand would grow to 119 million barrels/day by 2025[18], representing an average demand growth of 2% per year. Demand growth is expected to be highest in the developing world, especially China and India, as they invest in industry and adopt automobile lifestyles. Between 2003 and 2004, U.S. demand grew 2.4%, while Chinese demand grew by 15%. However, the U.S. increase (484,000 bbl/day) was more than half the Chinese increase (893,000 bbl/day) in terms of volume.[19]

As of December 2005, the world had consumed just over 1 trillion barrels of oil.[20] At a projected growth rate of 2%, the world will require another 1 trillion barrels of oil over the next 35 years, as much as it has consumed in its entire history to date. Figure 4 illustrates the exponentially increasing volume of oil that would be needed to sustain a 2% annual growth rate. Oil required beyond 2040 has not been discovered – its existence is hypothetical to purely speculative.

<table>
<tr><td colspan="3">QUANTITY OF OIL NEEDED TO SUSTAIN 2% DEMAND GROWTH
(Doubling Time = 35 Years)</td></tr>
<tr><td>1850 – 1969
500 Billion Bbl
(Produced and</td><td>1970 – 2005
500 Billion Bbl
Consumed)</td><td rowspan="2">2041 – 2075
2 Trillion Bbl
Unconventional Oil
+
Undiscovered Oil
(Hypothetical and Speculative)</td></tr>
<tr><td colspan="2">2006 – 2040
1 Trillion Bbl
(Proven and Probable Reserves)</td></tr>
</table>

Figure 4. Quantity of oil needed to sustain 2% demand growth.

---

[18] EIA International Energy Outlook 2005. DOE/EIA-0484(2005). For its Annual Energy Outlook 2006, the EIA downgraded demand projections for 2025 to 111 mbd based on anticipated prices of $54.08 (2004 dollars), $21/bbl higher than it projected in June 2005.

[19] BP Statistical Review, 2005.

[20] Oil & Gas Journal 2005 year-end production numbers.

Where is all this yet-to-be-discovered oil really going to come from? Official projections from the DOE EIA assume that US demand will have to be met from increased imports.[21] IEA projections assume that world demand will be met until at least 2030 by increased production from the Middle East. Chapter 2 will examine whether these are realistic expectations.

Uncertainties affecting Demand

There are many factors that could alter demand growth significantly. Economic growth increases the demand for oil, both for commercial/industrial use and to support a higher standard of living. On the other hand, economic recessions (regional or global) or price spikes could kill discretionary demand or make consumers curtail other spending. War and/or terrorism could inspire conservation efforts to reduce foreign dependency on oil. Finally, global climate change could increase demand for heating oil and gas in European countries facing colder winters, while countries facing warmer summers, like much of the U.S, would demand more electricity for cooling. [22]

Price Elasticity of Oil Demand

Demand for oil has traditionally been considered relatively inelastic with respect to price in the short term, meaning a 10% increase in price is expected to result in a demand drop of only about 2-3%.[23] That's the theory. However, as Figure 5 shows, over the past 7 years oil demand has behaved as if it were insensitive to price. Although consumption fell slightly in the early 1980s due to the OPEC price hikes, demand has risen steadily since. Between 1999 and 2005 demand rose 15%, despite a 5-fold increase in price. [24]

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[21] In 2004, the US imported 58% of the oil it consumed (BP Statistical Review 2005). Following loss of Gulf of Mexico production after Hurricanes Katrina and Rita in 2005, the US was obtaining 80% of its oil from imports or releases from the strategic petroleum reserve. (T. Whipple, *The Peak Oil Crisis: Waiting for Winter*, Falls Church News Press, October 31, 2005).

[22] Cold freshwater influx from melting of polar ice and Greenland glaciers is already cooling Northern Atlantic Ocean temperatures. Many scientists expect this will alter the Gulf Stream Current's path, such that it will no longer extend as far north. If that occurs, Norway, the UK and northern Europe will become colder. Meanwhile, mid- and equatorial latitudes are predicted to become warmer.

[23] The IEA notes in *Saving Oil in a Hurry: Measures for Rapid Demand Restraint in Transport*, ISBN 92-64-10941-2. April 2005, p 28: "The consensus range is that short-run fuel price elasticities are between –0.2 to –0.3, with long-run elasticities being between –0.6 to –0.8....The short-run effects occur almost immediately, while the long-run effects occur in time scales related to the turnover of the vehicle fleet and relocation of activities within an urban area." This presumes the price of oil will affect auto purchase decisions."

[24] Fibonacci (*Worth Its Weight in Oil)* points out that until mid-2005, oil's price increase mainly reflected devaluation of the U.S. dollar, as the price of a barrel stayed relatively constant in terms of euros, yen, and gold. Nonetheless, demand rose in the U.S., as well as abroad, during this period.

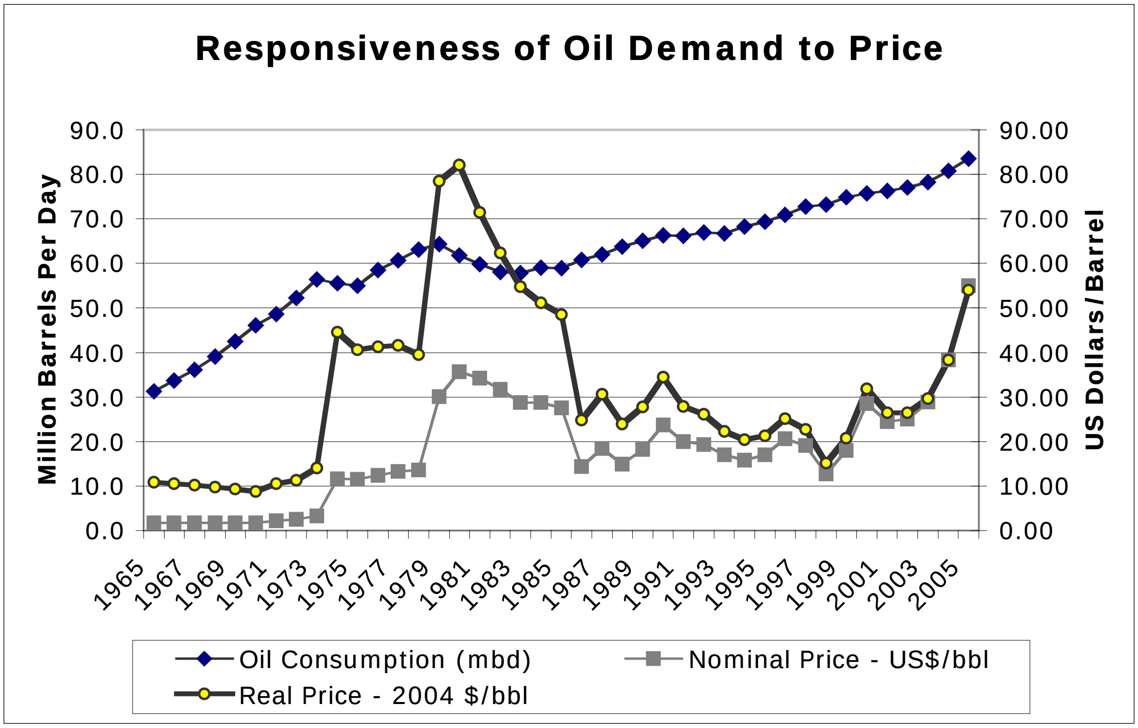

Figure 5. Responsiveness of oil demand to price. Data from BP Statistical Review 2005 and EIA Short Term Energy Outlook, October 2005.

This unexpected behavior could indicate that oil costs represent too small of a fraction of consumer income for them to care about price. Or, it could reflect the fact that almost 70% of oil consumption in the U.S. is for transportation. The just-in-time global industry and agriculture cannot readily shift out of oil use for transportation. Individuals can reduce discretionary travel, but cutting work-related driving means switching jobs or vehicles. It seems that people will more readily give up other consumption - like eating out - to continue driving while they wait for the price to come back down. In the short term, food producers absorb the added costs, reducing their already low margins.[25]

[25] Fearing to lose sales of their perishable products, farmers, fisherman, produce middleman and restaurant owners absorbed enormous energy cost increases when prices rose after the Gulf hurricanes of 2005. ("*The Industry: Gastronomics*", New York Times, October 30, 2005).

Energy and Economic Growth

> *Anyone who believes exponential growth can go on forever in a finite world is either a madman or an economist.*
>
> - Kenneth Boulding, economist

The growth of the Industrial Age has paralleled the growth of energy supply and in fact could not have occurred without it. The early Industrial Age, which began in England, was powered by coal, which yielded far greater energy density than wood and enabled an age of industrial machines and mechanized transport.[26] Because of cheaper, more abundant energy, society was revolutionized, restructured around factories and machines and the flow of goods and trade they engendered. Oil didn't gain its economic foothold until the late 1800's. Its original value was as lamp oil to replace the rapidly depleting whale oil supplies. Oil was scarce and pricey until Colonel Drake drilled his famous well in Titusville, Pennsylvania, in 1869, issuing in the age of cheap abundance. It was John D. Rockefeller who decided to find a use for all that surplus oil. Enter the combustion engine and Standard Oil of New Jersey, and the rest is history. Oil offered the greatest energy density of any substance yet known to man.[27] It rapidly replaced coal as the primary energy source, long before the coalfields were mined out. Oil ushered in the age of submarines and flying machines, the military industrial complex, the personal auto and the American Dream of a home in the suburbs. And every year since then, there has been more oil available than the year before.[28]

The Dependence of Productivity Growth on Expanding Energy Supplies

It's no wonder that economists initially didn't factor energy into their economic growth models. As long as energy supply growth kept up with or exceeded economic growth, it was invisible to the system, a given, outside factor that was not accounted for in their macroeconomic models.[29] But what happens if the exogenous, invisible hand of energy doesn't hold up its end of the growth deal? Will economic growth be possible? James Kunstler writes:

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[26] The switch from wood to coal for energy was driven by the depletion of England's forests. In fact, firewood in Europe became so scarce that large parts of Colonial New England's forests were chopped down and shipped to England to burn.

[27] Fissionable atoms have greater energy density than oil, however, nuclear power is unlikely to dethrone oil as the next energy, because it is neither as portable, versatile in use, or safe to handle. Most importantly, nuclear power is not a viable substitute for the mobile energy uses of oil.

[28] World Wars I and II interrupted the rate of oil production only briefly.

[29] The neoclassical economic models have been influential fiscal policy tools. They predict economic growth as a function of labor and capital productivity, enhanced by technological improvements, and moderated by investment/savings and depreciation, all determined by the interest rate. As the National Academies' report *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (Senate Committee on Energy and Natural Resources: 2006, 3) notes, "...work by Robert Solow and Moses Abramovitz published in the middle 1950s demonstrated that as much as 85% of measured growth in US income per capita

> The global energy predicament has powerful implications. For instance, if the supply of oil cannot grow, then industrial economies based on oil (and with no ready substitutes) will not continue to grow. If industrial economies do not grow, then financial instruments generated to represent the expectation of growth – stocks, bonds, derivatives, and currencies – will lose credibility and thus value. Economies now functioning on less-than-reality-based expectations, such as America's suburban housing bubble racket, modeled on supernatural credit creation and Ponzi-style multilayered debt...will find themselves in a bewildering new world of default, loss, and ruin. [30]

The debate about future economic growth can be distilled into two disparate world views: those of economists, for whom exponential growth is the logical result of a mathematical function, and supply is a function only of marginal cost, pricing and demand; and those of scientists, who believe growth will ultimately be constrained by the limiting factors of finite resources and carrying capacity of the ecosystem. Biological scientists have long studied how species stress their environments and the phenomena of population overshoot and collapse. Atmospheric, earth, and ocean scientists likewise view their worlds as systems of chemical, physical, and energy flows and transformations that operate in balance. [31] The renowned oil geophysicist, M. King Hubbert[32] summarized the intellectual conflict thus:

> The world's present industrial civilization is handicapped by the coexistence of two universal, overlapping, and incompatible intellectual systems: the accumulated knowledge of the last four centuries of the properties and

---

during the 1890-1950 period could not be explained by increases in the capital stock or other measurable inputs. The unexplained portion, referred to alternatively as the 'residual' or 'the measure of ignorance,' has been widely attributed to the effects of technological change." The original models were thus corrected to better match observed growth by adding a constant technological growth factor. A case can be made that the unrecognized factor behind economic growth has not been technology, per se, but the increasingly efficient control of increasing supplies of cheap energy that technology enabled. That is a topic for a different paper.

[30] James Howard Kunstler, "*End of the Binge: the exhaustion of our energy supply may end affluence as we know it*", in *The American Conservative*, September 12, 2005.

[31] The Club of Rome's infamous "Limits to Growth" report, was a systems modeling project performed by MIT scientists to examine constraints to population and economic growth (Donella H. Meadows, Dennis L. Meadows, Jorgen Randers, and William W. Behrens, III, *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind*, New York, Signet, 1972). The study fell into ridicule in the 1980s and 1990s when the global economy first slumped, then burst into seemingly unstoppable growth. However, the pendulum may be swinging back. See: Simmons "*Revisiting the Limits to Growth: Could the Club of Rome have been right after all?*" (2000). The original authors recently reran an updated version of their model and published *Limits to Growth: The 30-Year Update* (White River Junction, Vermont: Chelsea Green Publishing Company, 2004). It appears that many of their 1971 projections for population, resource depletion, food production, pollution, etc., reasonably predicted the observed behavior of these factors over the last 30 years.

[32] M. King Hubbert, known for his groundbreaking studies of oil field production "peaking" and decline, accurately predicted in 1956 the 1970 peak of U.S. domestic oil production. Consequently, the extrapolated maximum of world oil production is called "Hubbert's Peak".

interrelationships of matter and energy (Science); and the associated monetary culture which has evolved from folkways of prehistoric origin (Economics).

Economic Implications of a Reduced Oil Supply Rate

What would happen if oil production could not keep up with demand? The most obvious result is that oil would cost more and the price would become volatile. Because it is the lifeblood of so many aspects of business and standard-of-living in the developed world, oil scarcity and price increases will have far-reaching consequences.[33] Six of the most likely impacts are highlighted below:

Increased Competition for the Remaining Resource: Tight oil markets will increase geopolitical strife as countries maneuver to assure their long-term access to oil. "Energy security" will drive international policy. Oil scarcity will cause bidding wars between the agricultural, petrochemical, transportation, heating and electric power sectors. Previously sub-economic oil substitutes may become competitive.

Transportation Costs will Rise Significantly: American retailers depend on 12,000-mile-long merchandise supply lines from Asia that are fueled by cheap oil. Trucking, jet travel, trains and ship transport will all become more much more expensive. Commuting will consume a bigger portion of family income. Jet travel will become prohibitively expensive for leisure travel for the middle class.

Agricultural Costs will Rise: Reduced oil supplies will raise the prices of petrochemical feedstock for pesticides and herbicides.[34] Equipment fueling costs associated with planting, growing and harvesting will also rise. Finally transportation costs to market will rise. The impact to farmers will be higher costs and decreased profit margins. Consumers will face soaring food prices for US-grown and imported food.

The Cost of Living Will Rise: While transportation cost increases may not outweigh the cost savings of cheap foreign labor, they will cause the cost of goods sold to rise. Higher oil-related costs of manufacturing, food production and transportation will need to be passed on to customers. The poor and middle class will be hardest hit. As of May 2006, the consumer price index (CPI) had risen over 17.23%[35] since oil began its price rise in 1999.

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[33] Detailed and thoughtful discussions of the potential economic impacts of peak oil abound. See: Robert L. Hirsch, Roger Bezdek, and Robert Wendling, *Peaking of World Oil Production: Impacts, Mitigation, and Risk Management*, (U. S. Department of Energy, February 2005); Richard Heinberg *The Party's Over: Oil, War and the Fate of Industrial Societies* (Canada, New Society Publishers, 2003); James Howard Kunstler, *Long Emergency: Surviving the Converging Catastrophes of the Twenty-first Century (*New York: Atlantic Monthly Press, 2005). For intelligent essays, articles and discussions on the internet, start your search at: www.energybulletin.net and www.theoildrum.com.

[34] The Haber-Bosch process of fixing atmospheric nitrogen for use in fertilizer, which allowed the green revolution, is very natural gas intensive. Obtaining enough cheap gas in the future to continue this heavy use, especially in the US, will become a non-trivial problem.

[35] Based on the Bureau of Labor Statistics CPI inflation calculator. The CPI is often reported with the costs of energy and food removed. Economists justify this because those prices fluctuate so much. However, energy and food costs are a significant part of the cost of living and should be factored in to cost-of-living indices. For an analysis of how and why the CPI systematically underestimates inflation, see economist John Williams' website *Shadow Government Statistics: Analysis Behind and Beyond Government Reporting*, http://www.gillespieresearch.com/cgi-bin/bgn.

Contraction of the Global Economy: Consumers will lose discretionary purchasing power at the same time that factor costs rise and cheap goods from just-in-time global fabrication/assembly companies become uncompetitive. The clothing, grocery, auto, and electronics industries, among others, will be dramatically affected, as will tourism. Global recession is distinctly possible. In fact, U.S. recessions have historically followed rapid oil price increases (Figure 6).

The Re-Emergence of Regional and Local Economies: High oil prices will make local agriculture both necessary and cost-competitive again. The U.S. will suffer from the off-shoring of its industrial base until local manufacturing can be re-established.

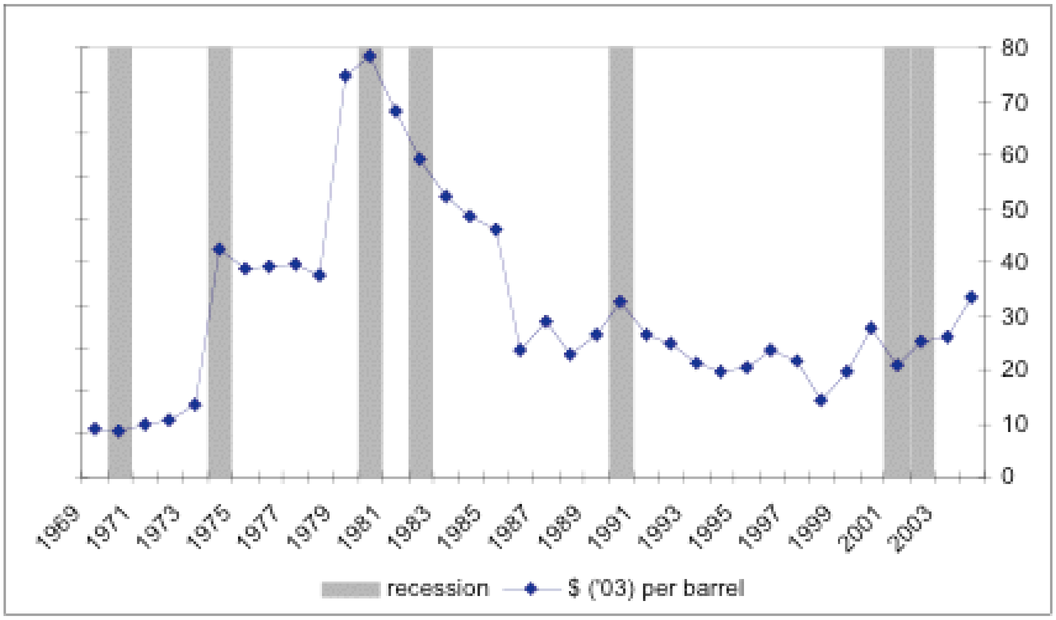

Figure 6. Historic relationship between oil price spikes and U.S. economic recessions Source: Hirsch, Bezdek and Wendling (DOE, 2005).

The U.S. government is understandably worried about the dependency of the economy on oil. In 2005, the Department of Energy published a commissioned report investigating the potential economic impacts of Peak Oil, *Peaking or World Oil Production: Impacts Mitigation, & Risk Management*. Authored by three well-respected energy industry and government insiders - Robert L. Hirsch, Roger Bezdek, and Robert Wendling - the “Hirsch Report” as it is commonly called, concluded that:

> The peaking of world oil production presents the U.S. and the world with an unprecedented risk management problem. As peaking is approached, liquid fuel prices and price volatility will increase dramatically, and, without timely mitigation, the economic, social, and political costs will be unprecedented. Viable mitigation options exist on both the supply and demand sides, but to have

> substantial impact, they must be initiated more than a decade in advance of peaking.[36]

The report also noted that "Oil peaking will create a severe liquid fuels problem for the transportation sector, not an 'energy crisis' in the usual sense that term has been used." The next two chapters evaluate current estimates of world oil supply and peaking dates and possible alternatives for filling an oil demand/supply gap when it develops.

[36] *The Hirsch Report*, 4.

CHAPTER 2
REALITY CHECK: TAKING INVENTORY OF PETROLEUM SUPPLY

The majors, they talk about plenty of oil and that they can produce more, but if you look at ExxonMobil, ChevronTexaco, BP[British Petroleum], all the production [is] going down every year. They don't replace and they don't add to production, but they say there's plenty of oil around.

Now why would they say that? One of the chief economists with one of the major oil companies... I was at a conference where he was... and I asked, why do they say that? And he said, can you imagine what would happen if one of these major oil company's CEO's got up and made a speech and he said, 'We're running out of oil'? I said there'd be panic and he said, 'That's right. They're not going to make the statement. They're going to say there's plenty of oil around'

- T. Boone Pickens[37]

When all else fails, look at the data.

- Old geologist saying

It's impossible to take an accurate inventory of in-the-ground petroleum supply because we can't see the data. First, the oil is underground, within and under layers of rock. Product coming out of an oil well can be measured, but geologists can only infer the volume of oil in the ground using remote sensing techniques[38], interpreted with a thorough knowledge of petroleum properties and occurrence. Estimating oil field size and recovery is a highly technical, but subjective art. In addition, oil reserve data are often held as state or company secrets. Publicly reported reserve figures may be significantly over- or understated for political or financial reasons, as the introductory quote to this chapter clearly shows. The public numbers are not verifiable. This absence of verifiable supply data is at the heart of the peak oil debate.

Not surprisingly, a wide spectrum of world oil inventory estimates exists, from dire to cornucopian. To plan intelligently, managers (or anyone!) must examine the various oil supply projections to decide the odds of them being correct and the risks if they are not. This chapter

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[37] EV World, *"Legendary oil magnate calls it, peak oil is here: Boone Pickens Warns of Petroleum Production Peak"*, Palm Springs, May 4, 2005.

[38] I use the term loosely here to include interpretation of data from geophysical logging tools, downhole sensors, multi-channel seismic and acoustics, satellite radar and imaging, etc.

discusses the underlying geologic reality of oil production, then considers the assumptions, biases, and uncertainties behind the most prevalent viewpoints on future oil supply.

The Geologic Production of Petroleum

Companies talk about "producing" oil, and the input costs of all the classic factors of production – capital, labor, etc. But oil companies are really in the exploration and extraction business, exploiting and depleting a finite resource that was "produced" by earth processes over millions of years under very specific geologic circumstances.[39] Through a century of testing their theories with a drill bit, exploration geologists have a very good understanding of the conditions needed to form an oil deposit. Simply put, the prerequisites are 1) an organic-rich source rock[40]; 2) a burial history long and deep enough to thermally alter (cook) the organic matter into oil[41]; and 3) a sealed trap in a nearby reservoir rock[42]. The maverick inventor Amory Lovins succinctly summarized the time and capital inputs invested in the geologic production of oil:

> The oil we're burning in two centuries took hundreds of millions of years to form. When the Russian chemist D.I. Mendelyeev figured out what it was, he exclaimed it was far too precious to burn. We've been burning it ever since - ten thousand gallons a second in America alone. Each gallon of gasoline took eons to form (very inefficiently) from a quarter-million pounds of primeval plants. Thus the average U.S. light vehicle each day burns 100 times its weight in ancient plants in the form of gasoline.[43]

[39] For an excellent discussions of oil formation in fairly non-technical terms, see Deffeyes, *Hubbert's Peak: The Impending World Oil Shortage*, (Princeton University Press, 2001).

[40] A theory of an inorganic, deep mantle origin for oil, known as abiotic oil formation, also exists (popularized by Cornell astrophysicist, Thomas Gold in *The Deep, Hot Biosphere: the Myth of Fossil Fuels*, Springer 1998; and Jerome Corsi *Black Gold Stranglehold: the Myth of Scarcity and the Politics of Oil*, WND Books, 2005). However, this "theory" does not meet the most basic requirements of a scientific theory – it is not testable. It has not been successful as a predictive model to locate oil, does not match empirical (observed) oil data, and is not used by the industry.

[41] Rocks that have not passed through the heat and pressure "oil window" are "immature" and do not generate oil. On the other hand, burying a source rock too long or deeply destroys its oil potential by breaking down its complex oil hydrocarbons into carbon and methane gas.

[42] Oil that does not encounter a trap continues migrating until it reaches the surface as a seep. There, oxygen and/or ground water degrade the oil into tarry bitumen.

[43] Lovins, *Winning the Oil Endgame*, 2.

Where the Oil Is and Where It Goes

Significant petroleum occurrence is restricted to a limited number of geologically predictable places on earth where the above conditions were met. The vast majority of oil is found in restricted sedimentary basins along the current or former edges of continents. River deltas, continental margins, deserts and arctic areas are the four present-day locations most likely to hold oil or gas deposits beneath them.[44] The most prolific oil-producing conditions are found in the Middle East in the "Oil Triangle" of Saudi Arabia, Kuwait, Iraq and Iran. In North America, oil is concentrated in the Gulf of Mexico and in basins along the edge of the Rocky Mountains. Other significant oil-prone areas include Russia, the Caspian Sea and the Atlantic continental margins of Africa and South America.[45]

A surprisingly high proportion of the world's oil - 47% - comes from a relatively few giant oil fields, which each produce at least 100,000 barrel/day.[46] Among these 116 fields, four aging "supergiants" together produce around 8 million bbl/d - about 10% of the world's daily production[47]. The remaining 53% of the 84 million barrels of oil[48] that the world consumes daily comes from over 4,000 smaller fields, each producing less than 100,000 bbl/d, and from old "stripper wells" past their prime that still produce a few barrels a day.

Since the earth's oil endowment is concentrated in so few places, a thriving trade has evolved exporting oil from producing to consuming countries. Figure 7 shows the most significant oil import/export relationships in 2004, based on volume. These trade dependencies are a major factor shaping the geopolitical landscape. For example, through the 1950's the US was the largest oil producer and exporter in the world. But by the 1970's it had become a net oil importer. This reversal in producible oil endowment relative to annual oil consumption forced major U.S. foreign policy shifts. Dependent on trading relationships, the U.S. could no longer afford to be isolationist. Currently, the U.S. produces about 8% of the world's daily supply from 2.5% of the world's reserves. This supplies roughly 40% of U.S. daily consumption. The remaining 60% is imported, principally from Mexico, Canada, Venezuela, West Africa, and Saudi Arabia.

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[44] See Roger N. Anderson, *"Why is oil usually found in deserts and arctic areas"*, part of the *Ask the Expert* series (published online by *Scientific American.com*, January 16, 2006).

[45] The largest remaining areas that have never been explored are the Arctic Sea, Antarctica, and parts of the South China Sea.

[46] Note that at 2005 rates, the world consumes 100,000 barrels of oil every 7 minutes.

[47] These are Ghawar (Saudi Arabia -1948), Burgan (Kuwait -1938), Cantarell (Mexico -1976), and Daquing (China - 1959). Almost 60 years old, Ghawar still contributes 4.5 mbd to world production, almost half of Saudi Arabia's total output. (Simmons, *Twilight in the Desert*). Simmons' summary report *The World's Giant Oil Fields: How Many Exist? How Much do they Produce? How Fast are they Declining?* is included as Appendix A of this thesis (M. King Hubbert Center for Petroleum Supply Studies, Colorado School of Mines, Hubbert Center Newsletter #2002/1).

[48] The production numbers quoted as "oil" here include associated natural gas liquids, because they are usually reported together in published production data.

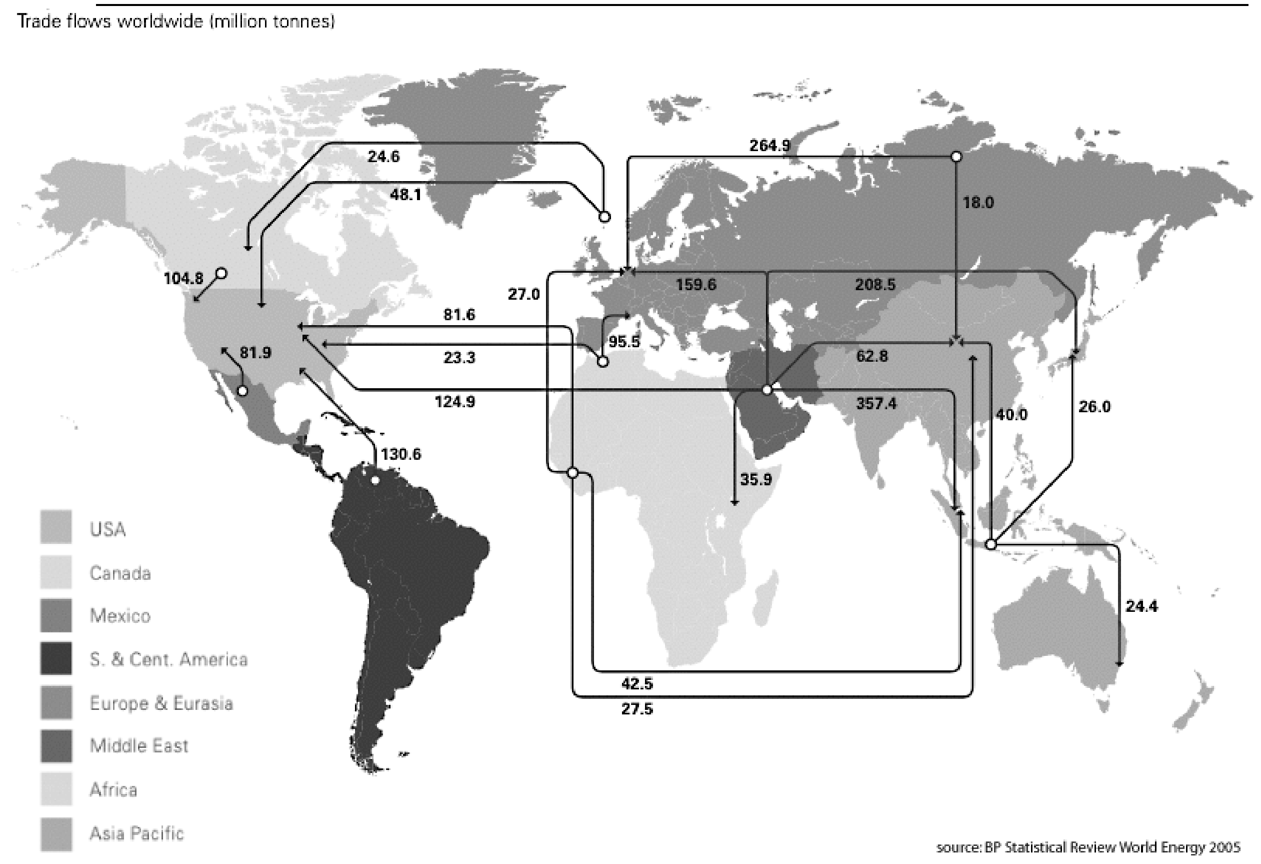

Figure 7. Major trade flows of oil from producing to consuming countries

Diminishing Returns of Production

The oil industry is not exempt from the law of diminishing marginal returns. Oil discovery and production rates increase early on as experience and innovation increase efficiency. Then marginal returns diminish to zero as production efficiencies decrease. After reaching a maximum output, marginal returns become negative and output declines.

Oil Field Discovery Rate

The world's readily accessible oil basins have already been explored for the easy oil. Geology didn't create many supergiant oil fields, and no new ones have been discovered in the past 30 years (see Appendix A). In each region, the largest fields are usually discovered early on, being "too big to miss". Subsequent exploration wells ("wild cats") discover less and less new oil, resulting in the classic "creaming curve" of cumulative production per number of wells drilled (Figure 8). Most reported oil well "hits" are the result of infill or step-out drilling in already discovered fields.

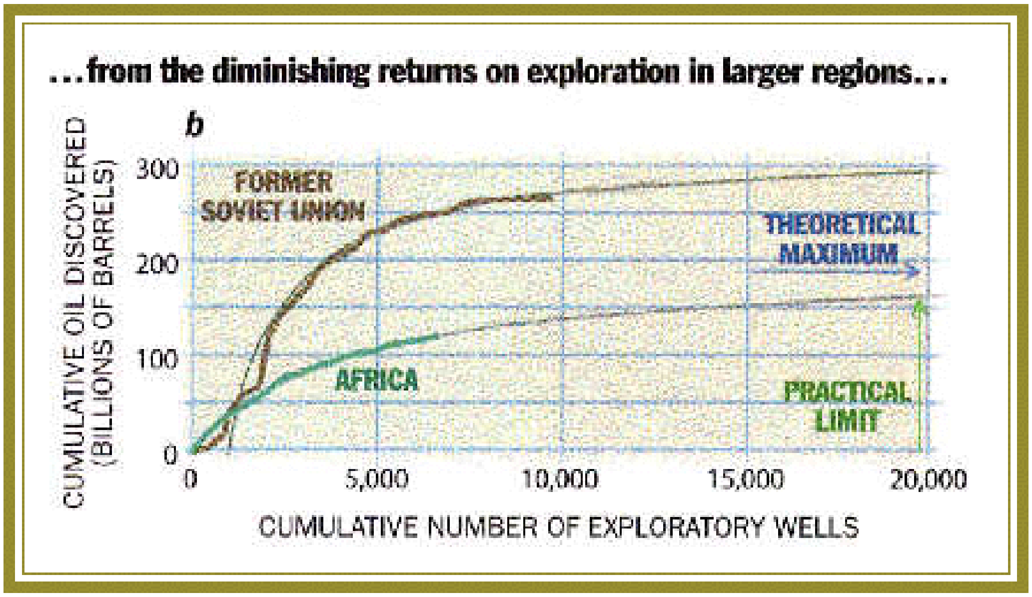

Figure 8. Example "Creaming Curve" for oil discovery. The big fields in a region are found early. Later exploratory wells discover less and less oil. Source: Colin J. Campbell, and Jean H. Laherrere, "The End of Cheap Oil" (*Scientific American*, March 1998: 77-83).

Although annual company reports don't highlight it, oilmen fully understand that the business of oil "production" depletes the finite resource base that is their product. If oil supplies are to grow, then the annual volume of oil discovered must exceed the amount consumed. As CEO of Halliburton, Dick Cheney described the dilemma:

> From the standpoint of the oil industry...for over a hundred years we as an industry have had to deal with the pesky problem that once you find oil and pump it out of the ground you've got to turn around and find more or go out of business. Producing oil is obviously a self-depleting activity. Every year you've got to find and develop reserves equal to your output just to stand still, just to stay even.[49]

At the 2005 rate of 84 mbd, 30 billion barrels of new oil must be discovered each year just to replace depletion of the existing stock. However, that hasn't happened since the 1980s, when net annual discovery (new oil minus depletion of existing fields by pumping) went negative (Figure 9). The world oil discovery rate peaked in the 1960s. These days, a banner discovery year for oil is 10 billion barrels. The obvious, but sometimes ignored reality is that the volume of oil ultimately produced cannot exceed the area under the discovery curve. Every year since 1982, the world has dipped deeper into its oil endowment.

[49] Dick Cheney in a 1999 speech to the London Institute of Petroleum. The reserves replacement problem is sometimes called "The Red Queen's dilemma" after Lewis Carrol's *Through the Looking Glass* character, because it takes "all the running you can do to stay in the same place."

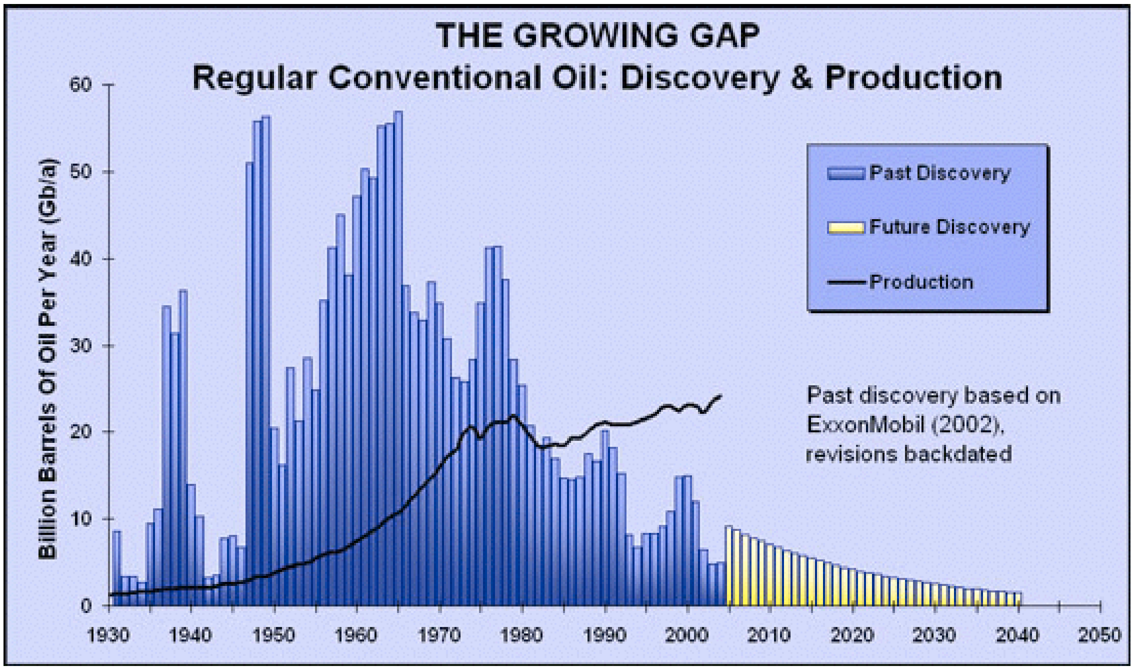

Figure 9. Source: Campbell, Association for the Study of Peak Oil (ASPO).

Oil Field Production, Decline and Depletion

Oil in a field is not evenly distributed in big "pools" that can be sucked out of a well like a straw. It occupies rock pores and fractures, some well-connected and some poorly. Typically, the oil-bearing horizons represent only a small fraction of the reservoir rock. These reservoir characteristics limit the rate at which the oil will flow to the well. In addition, oil removal is controlled by the pressure relationship between the oil, water, and gas in the field. Initial reservoir pressure is often sufficient to make oil flow into the wells, but as oil is extracted, the pressure drops and the rate of production declines. Pumps or enhanced oil recovery (EOR) techniques must be used to keep the oil flowing. Eventually, either the water table floods the producing interval or "lifting costs" make further extraction uneconomic. The now unproductive well is plugged and abandoned, usually leaving more than half the oil in the ground.[50] For this reason alone, the world will never run out of oil.

Oil production peaks and declines in every individual oil well over its lifespan. Figure 10 shows schematically how the production profiles of individual wells determine an oil field's overall production profile. Aggregate field peaking determines when regions, countries and ultimately the world's oil production will peak. After the world maximum is passed, the annual

[50] The rule of thumb is that only about 30-40% of the oil originally in place in a field can be extracted. The past 30 years saw major technological advances in oil field engineering. Today sophisticated, directionally drilled, maximum reservoir contact wells extract oil from thin horizons, allowing production to be maintained longer without water table encroachment. Enhanced recovery techniques like water or steam injection are routinely employed at the initial stages of field development to sweep oil towards extraction wells. However, even using the best technologies, oil recovery is only about 40%-50%.

oil production rate will begin to decline, no matter how much effort, technology, or money is thrown at the problem.

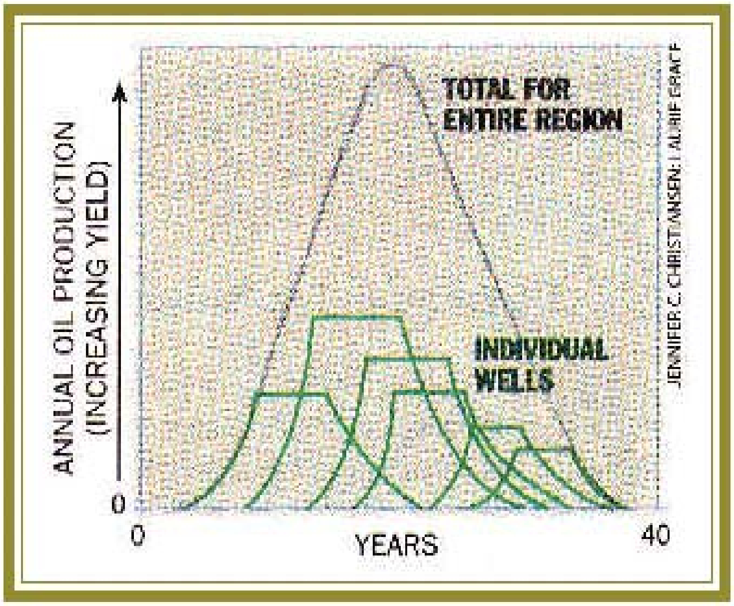

Figure 10. How aggregate production from individual oil wells determines field and regional production profiles. Source: Campbell and Laherrere, 1998.

To the Industry's initial surprise, stimulating a high oil production rate early in a field's life results in faster decline rates and shorter economic life after production peaks.[51] But the logistical costs of working in extreme environments, like the deepwater Gulf of Mexico, necessitate high production rates to recoup operating costs.[52]

Diminishing Oil Quality

The preferred crude oil is "sweet" and "light", because it can easily be refined into the most desired products, like gasoline and diesel. "Sour" (high sulfur) and heavy crude oils are less sought after, because they require special refining equipment to process the impurities. Large amounts of hydrogen must be added to heavy oil at the refinery to create the desired outputs of lighter hydrocarbon products. Naturally, sweet, light oil deposits were preferentially exploited first. Spare capacity and planned future production increasingly consists of sour and

[51] Offshore fields that have been aggressively developed and pumped, such as in the North Sea, show decline rates between 10% and 20% per year. Worldwide field production decline rates now approach 8% per year. Schlumberger Chairman and CEO, Andrew Gould, "*Technology and Production – A View for the Future*", keynote address at the 35th annual Offshore Technology Conference, Houston, Texas, May 4, 2004. Available at http://newsroom.slb.com/press/inside/article.cfm?ArticleID=172.

[52] In March 2006, Secretary of Energy Samuel Bodman informed Congress that much of the 255,000 bbl/d of Gulf of Mexico oil production that remained shut in 6 months after Hurricanes Katrina and Rita will not be restored to production. Most represents "mature" field production where rates are too low to justify rebuilding costs. Reuters, 14:8, March 9, 2006.

heavy oil.[53] Current Canadian oil production from tar sands is an example of production moving down the marginal quality curve.

Hubbert's Peak: World Oil Production Peaking and Decline

When will maximum world oil production - the infamous Hubbert's Peak - occur? Given the poor data reporting, the uncertainty about reserves and future discoveries, and the need for a rear-view mirror to identify the peak year, no one can say for sure. Geologist Colin Campbell, the founder of the Association for the Study of Peak Oil (ASPO), believes that conventional light to intermediate oil peaked in 2004 or 2005 (Figure 11). Based on current data, he estimates that heavy, deepwater, and polar oils will peak sometime around 2010-2012.[54]

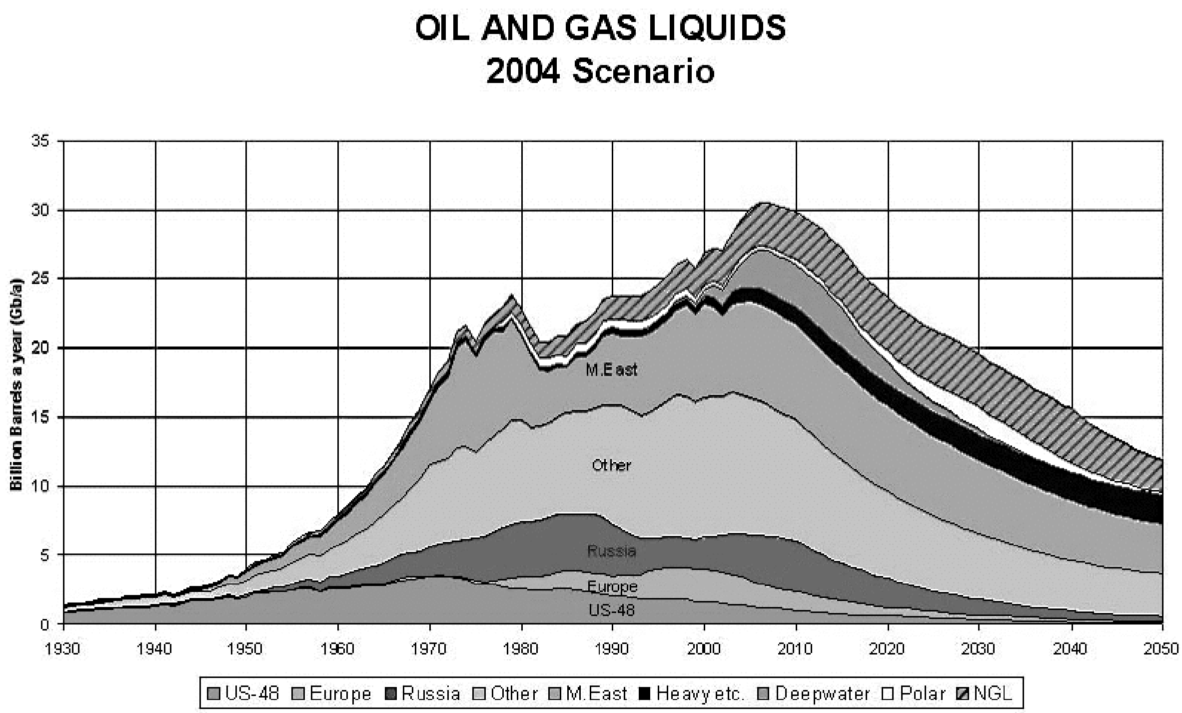

Figure 11. Campbell's predicted peaking of world liquid petroleum and natural gas
Source: Campbell 2005, Assoc. for the Study of Peak Oil (ASPO).

A search for a concrete date for Peak Oil – one a manager could plan around - uncovers a simmering debate. Many industry analysts estimate that the world will hit Peak Oil production

[53] Most current refineries are not equipped to handle sour, heavy oil. This is why the "extra" oil Saudi Arabia offered to provide after Hurricanes Rita and Katrina was spurned by the market.

[54] Now retired, but with continued access to proprietary industry databases, Campbell updates his estimates monthly. His charts and graphs are more widely distributed than any other peak oil interpretations in the public domain and can be found at any of the ASPO member websites.

between 2005 and 2020.[55] Many expect the "peak" to be a plateau.[56] The official agencies, USGS, EIA and IEA lean towards 2035 or later. The demand-based predictions of the EIA, for example, are that oil supplies will not peak until sometime between 2021 and 2067.[57]

There are many uncertainties involved in accurately predicting when world oil production will peak. On the supply side these include: unreliable reserve estimates; the rate of new oil discovery; weather or political disruptions of existing or planned production; and infrastructure constraints, such as the availability of seismic exploration vessels, drilling rigs, tankers, refineries, and skilled professionals. On the demand side, the main uncertainty is economic growth; demand and investment capital could both wither in an economic recession or depression. These factors collectively may end up determining the peak oil production rate and date more than geology does.

Since the peaking of individual countries will cumulatively determine the world oil production peak, it is critical to know which of the major producing countries have already peaked. Table 1 lists all countries that produced more than 1 million barrels/day of oil in 2004, their maximum historical production and the year it occurred. It is evident that, by 2004, 11 of these 19 countries had already peaked. A twelfth, Mexico, is widely expected to have peaked in 2005 based on reports that the supergiant Cantarell field has entered decline[58]. The linchpin country for Peak Oil is Saudi Arabia, due to it's large contribution to the world's daily supply (about 9.5 mbd in 2005). When the supergiant Ghawar field, which provides more than half of Saudi daily production, peaks, the world will have passed peak oil production.[59]

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[55] For example, Professor Deffeyes has calculated a December 16, 2005 date for Peak Oil, using a Hubbert linearization of annual/cumulative production P/Qt versus cumulative production Qt. Posted in February 2006 on his website at Princeton University: http://www.princeton.edu/hubbert/current-events-06-02.html

[56] Matthew Simmons defines "peak oil" as a sustained period of maximum production, probably on the order of a decade.

[57] John H. Wood, Gary R. Long and David F. Morehouse, *Long-Term World Oil Supply Scenarios: The Future is Neither as Bleak or Rosy as Some Assert,* DOE Energy Information Administration, 2004. Available at www.eia.doe.gov

[58] Adam Porter, interview with a senior engineer from Mexico's state oil company Pemex. Transcript published December 1, 2005 as OilCast #28, on www.oilcast.com.

[59] This may have already happened. Matthew Simmon's comprehensive literature study of Saudi Arabian oil fields (*Twilight in the Desert,* 2005) indicated significant production difficulties in Ghawar, including massive water injection projects to maintain reservoir pressure. Finally, the Saudis seemed unable to raise production above 9.5 mbd in 2005. Their reported excess capacity was heavy or sour oil from other fields. Hence the rear-view mirror may identify 2004 as the Saudi peak.

Table 1

Current and Maximum Historical Reported Production
in the Top Oil Producing Countries

Maximum Oil* Production of Top Producers
Thousand barrels daily

Country	2004 Production	Maximum Production	Year Maximum Production
Saudi Arabia	10,584	**10,584**	
Russian Federation	9,285	**11,484**	**1987**
USA	7,241	**11,297**	**1970**
Iran	4,081	**6,060**	**1974**
Mexico	3,824	**3,824**	**2005****
China	3,490	**3,490**	
Norway	3,188	**3,418**	**2001**
Canada	3,085	**3,085**	
Venezuela	2,980	**3,510**	**1998**
United Arab Emirates	2,667	**2,667**	
Nigeria	2,508	**2,508**	
Kuwait	2,424	**3,339**	**1972**
United Kingdom	2,029	**2,909**	**1999**
Iraq	2,027	**3,489**	**1979**
Algeria	1,933	**1,933**	
Libya	1,607	**2,139**	**1979**
Brazil	1,542	**1,555**	**2003**
Kazakhstan	1,295	**1,295**	
Indonesia	1,126	**1,685**	**1977**
TOTAL WORLD	80,260		
OPEC	32,927		

2004 Data from BP Statisical Review of Data 2005

* Includes crude oil, shale oil, oil sands and NGLs (natural gas liquids
- the liquid content of natural gas where this is recovered separately).
Excludes liquid fuels from other sources such as coal derivatives.

** Based on 2005 reports that the Super Giant Canterell field is in decline

Counting Oil Inventory: What's in the World Warehouse

The question is not the size of the tank; it's the size of the spigot.
- Jean Laherrere

There are many vested interests, as well as honest differences of opinion, in the public debate about Peak Oil. The various beliefs depend on whether people trust officially reported numbers and what they are willing to define as future oil reserves. The debate usually boils down to widely disparate estimates of how much oil (or oil-equivalent) resources are left to produce. That's actually the wrong question. The critical issue from a practical standpoint is: How much oil can be produced at a meaningful rate in the immediate and foreseeable future? To make any sense of the wide range of reported future estimates, we must first understand the general terminology of oil resource and reserve accounting.

Oil Resources versus Accessible Reserves

The words “oil supply” have no agreed meaning. Under the broadest definition, oil resources can be interpreted to include the earth’s entire petroleum endowment plus any other substance (natural gas, coal, biomass, etc.) that we can convert into oil. But not all resources are accessible, much less recoverable. As the next chapter will discuss, the alternatives are not truly oil equivalents from the perspective of either energy density or return on energy invested. To get a realistic inventory of liquid petroleum, we must restrict ourselves to counting oil reserves, not resources. That is, we must only count oil that is actually likely to be producible.

Reserve accounting is not standardized from company to company, nor even from country to country. Therefore, summing individual country reserves yields unrepresentative totals. [60] Most of the western world[61] reports their reserves as P2 (probability 50%) based on the following definitions:

> Proven (P1 or P-90) Reserves have a 90% certainty of existing and being producible at today’s prices using existing technologies.
> Probable (P2 or P-50) Reserves have a 50% probability of existing and being economic at today’s prices using existing technologies.
> Possible (P3 or P-10) Reserves are hypothetical to speculative with only a 10% chance of existing or being economic

Clearly, reserves are not static. In addition to growing through exploration, they can grow (or shrink) with market conditions. If prices rise, some reserves that were previously sub-economic will be reclassified as proven or probable[62]. But price spikes cannot call new oil into existence or overcome the geologic production constraints.

The most commonly used public reserve numbers are published by British Petroleum in their annual statistical review of world petroleum data. Table 2 reports official reserves for the major oil-producing countries. But, as their standard caveat explains, BP doesn’t necessarily use the numbers they publish.

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[60] For an excellent analytical discussion of world reserve accounting see Jean Laherrere, *When Will Oil Production Decline Significantly?* (European Geosciences Union, General Assembly 2006, Vienna, Austria, April 3, 2006.)

[61] The notable exceptions are the US and Russia, which report P1 and P3 numbers, respectively. In the United States, the Securities and Exchange Commission (SEC) allows companies to count as reserves only oil that is under current development, and for which extraction funds have been committed. This is extremely conservative, because in all probability, the companies will ultimately recover their P-50 estimates. By booking reserves only as they come into production, rather than when they are discovered, companies appear to “grow” proven reserves without actually discovering new oil. Therefore, US reserves have been historically understated. On the other hand, Russia traditionally reported proved + probable + possible reserves, so their estimates have likely been overstated. Reported reserves from OPEC countries do not follow the above classification scheme.

[62] The SEC defines oil price for reserves classification each year as price on December 31. Thus a high oil price the last day of December means a company will book more reserves in their annual report than they could a under a low price.

Table 2

Countries with the Largest Reported Oil Reserves[63]

	Thousand million barrels	Share of total	Reserves Productior ratio
Saudi Arabia	**262.7**	22.1%	67.8
Iran	**132.5**	11.1%	88.7
Iraq	**115.0**	9.7%	*
Kuwait	**99.0**	8.3%	*
United Arab Emirates	**97.8**	8.2%	*
Venezuela	**77.2**	6.5%	70.8
Russian Federation	**72.3**	6.1%	21.3
Kazakhstan	**39.6**	3.3%	83.6
Libya	**39.1**	3.3%	66.5
Nigeria	**35.3**	3.0%	38.4
USA	**29.4**	2.5%	11.1
China	**17.1**	1.4%	13.4
Canada	**16.8**	1.4%	14.9
Qatar	**15.2**	1.3%	42.0
Mexico	**14.8**	1.2%	10.6
Algeria	**11.8**	1.0%	16.7
Norway	**9.7**	0.8%	8.3
Angola	**8.8**	0.7%	24.3
United Kingdom	**4.5**	0.4%	6.0
Rest of World	**94.5**	**8.0%**	
TOTAL WORLD	**1188.6**	**100.0%**	**40.5**
of which: OECD	**82.9**	7.0%	10.9
OPEC	**890.3**	74.9%	73.9
Non-OPEC	**177.4**	14.9%	13.5
Former Soviet Union	**120.8**	10.2%	28.9

Modified from: BP Annual Statistical Review (2005)

Reserve accounting is further complicated because, over time, countries have changed what they report as oil. Historically, only production of “conventional” oil was reported, including the coveted “light, sweet crude”[64], the less favored “heavy, sour crude” and associated gas condensate liquids. Now, countries include “non-conventional” oil, which encompasses not only deep-water oil and polar oil, but also oil synthesized from “oil sands” and “oil shales”.[65]

[63] BP Annual Statistical Review 2005 caveat re: Source of data – The estimates in this table have been compiled using a combination of primary official sources, third-party data from the OPEC Secretariat, World Oil, Oil & Gas Journal and an independent estimate of Russian reserves based on information in the public domain. The reserves figures shown do not necessarily meet the definitions, guidelines and practices used for determining proved reserves at the company level, for instance those published by the US Securities and Exchange commission or recommended for the purposes of UK GAAP, nor do they necessarily represent BP’s view of proved reserves by country. The figure for Canadian oil reserves includes an official estimate of Canadian oil sands ‘under active development’. Oil includes gas condensate and natural gas liquids as well as crude oil.

[64] Light oil contains mainly long-chain hydrocarbon molecules, with low sulfur (hence “sweet”) or other impurities, which is easy to refine into fuels like gasoline or chemical feedstocks.

[65] These are not actually crude oil, but solid ores. Extracting the hydrocarbon in tar sands and oil shales and converting it to oil requires large scale, energy intensive mining operations.

Combining these two fundamentally different types of oil in the reports gives the false impression that 1) reserves of conventional supplies are growing, 2) that these additional reserves will give the same energy returns per investment as conventional oil, and 3) that they can be produced at the same rate as conventional oil. This masks the decline of conventional oil fields.

Three Camps: Peak Oilers, Official Agencies, Optimists

Although we don't know the exact shape that the Peak Oil curve will take, it is safe to estimate that after the first half the ultimately recoverable reserves (URR) of oil have been consumed, the world will be at or near peak oil production.[66] Expressed as a ratio, Peak Oil will occur approximately when

$$\frac{\text{cumulative production}}{\text{ultimately recoverable reserves}} = \frac{1}{2}$$

At the end of 2005, cumulative reported world oil production was just over 1 trillion barrels. Three camps have emerged, based on their beliefs concerning the value of the denominator:

1) The Peak Oil Crowd: URR = approximately 2 Trillion bbl[67]
   Peak is now or within 10-15 years. It is urgent to start preparing.
2) Official Agencies: URR = approximately 3 Trillion bbl[68]
   Peak is several decades off. There is plenty of time to prepare.
3) Technology Optimists: URR = at least 7-8 Trillion bbl oil equivalent[69]
   Peak is so far away as to not be a concern.

Each group includes different assumptions in their estimates of the ultimately recoverable oil, which are generalized and briefly discussed below.

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[66] In individual fields, the documented peak has sometimes occurred sooner than the volumetric midpoint, in which case the decline may be gentle. Other fields have reported peak production well past the midpoint, followed by much steeper decline. Aggregate production curves (regional or country level) tend to approximate bell curves.

[67] The Oil Depletion Analysis Center (ODAC at www.odac-info.org) notes: "Assessments of the world's ultimately recoverable oil reserves vary, but 65 published studies by oil companies, geologists, government analysts and consultants over the past 50 years have produced remarkably consistent estimates. The overwhelming majority of these put the world's original endowment of recoverable oil at no more than about 2,400 billion barrels; the average estimate is 2,000 billion barrels." Note that this estimate fits with the cumulative production + the reserves reported in BP's annual statistical review.

[68] This estimate, which is the basis of the International Energy Agency projections, originates with the U.S. Geological Survey's World Petroleum Assessment 2000 (Digital Data Series - DDS-60. Available at http://pubs.usgs.gov/dds/dds-060/). Previous USGS reserve estimates had been consistent with the 2 trillion bbl estimates of ultimately recoverable reserves. At least one of the report's authors, Les Magoon, who directed the team's assessment of North American Reserves, has published dissenting reports, agreeing with the Peak Oil Crowd.

[69] In addition to conventional oil reserves, Technology Optimists count alternative supplies on an oil-equivalent basis. These include 4 trillion barrel of oil equivalent (BOE) of oil sands and 3 trillion BOE) of oil shale. Some people also include 3-4 trillion (BOE) of methane hydrate.

The Peak Oil Crowd

The Peak Oil Crowd tend to work in the earth sciences, the oil industry, agriculture, or logistics – all physical, observational practices. They think that official reserves are overstated for political and financial reasons, especially those of OPEC and Russia. They believe that up to 90% of the world's accessible oil has already been discovered and that additional reserves will become much harder to find and produce and much more expensive. They don't agree on the exact date that Peak Oil will occur or the shape of the peak, but most place the date between 2005 and 2020. Many believe that production could increase, then plateau for a period of 5 to 10 years due to increased deepwater production before starting to taper off. Others believe the peak is imminent and the decline will be precipitous. Although they agree that alternative fuels could slow the decline, Peak Oilers often do not count alternative oil sources in reserves. They don't believe the alternatives can provide the same amount of energy as oil, nor be produced at a meaningful rate. Critics call them "doomers" and practitioners of "junk economics"[70] who fail to account for reserve growth, the impacts of technological innovation, or the effects of pricing on curbing demand and introducing new supply.

Official Agencies

The oil supply numbers published by the highly respected International Energy Agency are quoted as gospel by government and policy people throughout the world. According to IEA projections issued between 2000 and 2005, world oil supply will grow until at least 2035, or even 2050.[71] The IEA quotes their source of data as the U.S. Geologic Survey, World Petroleum Assessment 2000 (based on 1995 data).[72] However, the 3.3 trillion barrel URR estimate from the USGS study is regarded as unrealistically high by many geologists and analysts.[73] The 2000 Assessment is 44% higher than the 2.3 trillion bbl URR estimate that the USGS had reported in 1998. In addition to assuming improbably high reserve growth, the 2000 survey assumed a five-

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[70] However, since many science-types regard economics as junk science, they take the insult as a compliment.

[71] IEA estimates traditionally show supply growing to meet demand, which is based on projected annual world GDP growth of 2-3%. They have explicitly assumed that any shortfall in supply could be met by increasing OPEC production, especially in Saudi Arabia. Since the Fall of 2005, however, the IEA has been revising its monthly demand growth projects downwards to align better with a smaller supply.

[72] This study presented a probabilistic analysis of the oil potential in all the oil-favorable basins in the world. Teams estimated proved reserve (P-95) numbers (meaning it is 95% probable that the amount of oil is present) and very high possible reserve (P-5) numbers to allow for speculative oil discovery. They then performed Monte Carlo analysis to come up with the P-50 numbers used by the IEA. The study also allowed for significant reserve growth, modeled on US historical reserve growth rates.

Critics protest the USGS' application of a US reserve growth factor to the rest of the world. They argue that initial reserves in the U.S. were under-reported, resulting in a large growth factor. They believe that in OPEC and Russia, however, reported reserves have been significantly overstated. Application of the optimistic US growth factor to already inflated reserve numbers in other countries would result in unrealistically high estimates.

[73] See, for example, Jean Laherrere, *Is the USGS 2000 Assessment Reliable*, May 2, 2000. Published on the cyberconference of the WEC on May 19, 2000. http://energyresource2000.com

fold increase in the oil discovery rate, which has not occurred. Hence, many critics regard the USGS and IEA reserve estimates as political numbers.

Technology Optimists

This group tends to consist of economists, industry spokesmen, technophiles, and other optimists who believe strongly in the power of the market and human ingenuity. They profess faith that things will work themselves out once price sends its signal. The optimist camp does not limit itself to accessible reserves. It considers all the lower-grade hydrocarbon resources to be potential candidates for replacing oil as soon as price is high enough to make their extraction and conversion profitable. Critics say that they confuse resources with viable oil reserves that can be produced economically at a useful rate and that they are relying on faith in hypothetical technological innovations that are not yet even in the R&D stage.

Liars' Poker: Got Oil?

While U.S. reserves are under-reported due to SEC requirements, nationally held reserves in other countries may be overstated for political reasons. A country with declining reserves may fear losing their international clout if they report reduced reserves. The biggest system shocks will arise if the largest reported reserves, those of the OPEC countries bordering the Arabian Gulf, have been overstated. Many believe that indeed has happened. This in fact, is the essence of Matthew Simmon's analysis of Saudi oil field studies and reserve estimates in *Twilight in the Desert*.

OPEC's 1980s Reserves Leap

Many industry analysts believe that OPEC's reserves are probably significantly lower than reported. No verifiable data has been released since the countries nationalized their reserves. In the mid-1980s, reported reserves in many OPEC countries jumped inexplicably[74] (Figure 12), yet there were no reported new discoveries or advances in technology. More than 300 billion barrels of oil were added to the official supply.

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[74] In the face of an oil glut, brought on by the opening of the North Sea and Alaska's North Slope oil fields coincident with reduced demand after the 1970s oil price spikes, OPEC initiated a production quota system to maintain pricing control. Each member's allowable production was based on their share of total OPEC reserves. In 1985, tiny Kuwait suddenly reported 30 billion barrels of additional reserves. Within a few years the reported reserves of Iraq, Iran, Venezuela and United Arab Emirates jumped. In 1989, the Saudis booked an additional 90 billion barrels.

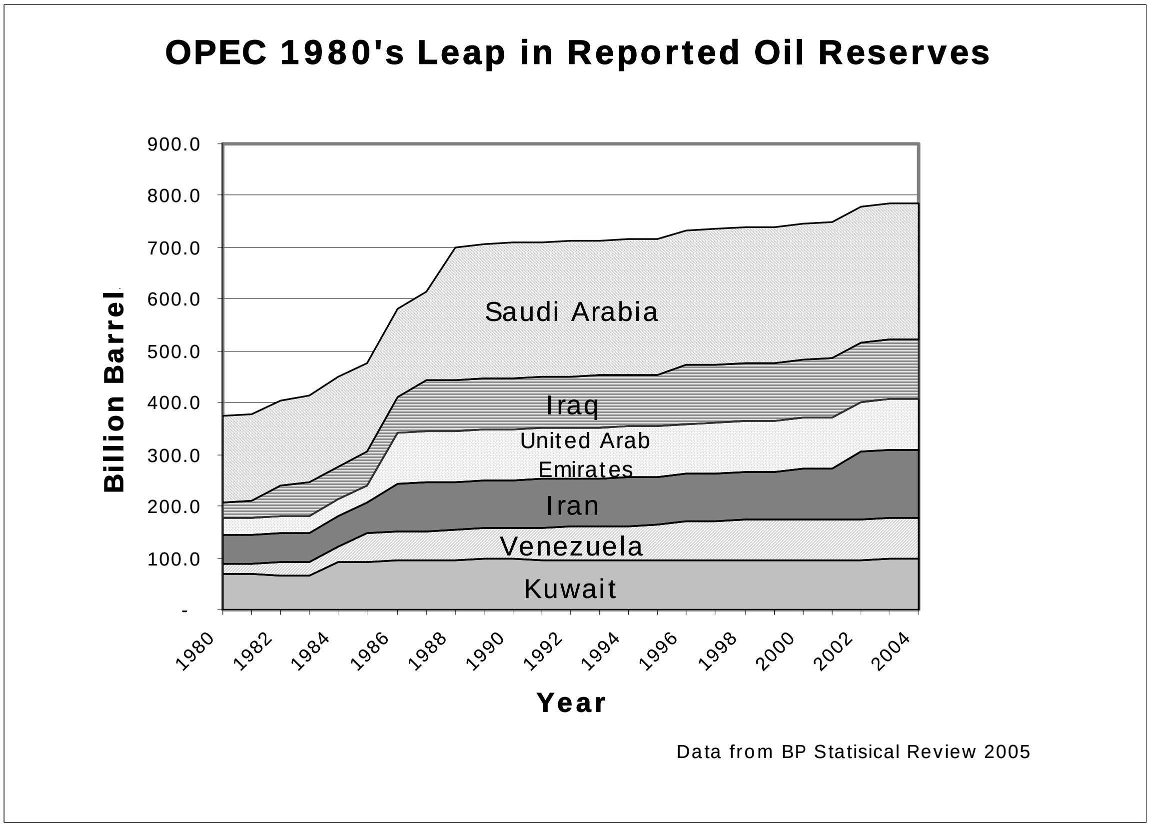

Figure 12. Over the course of the 1980s, reported OPEC reserves nearly doubled.

Many believe that the newly reported oil was only "paper reserves", but they were incorporated in official "proved" reserves from that point onwards. Matthew Simmons and Colin Campbell now believe that OPEC countries may have switched to reporting their ultimately recoverable reserves instead of remaining reserves. This interpretation could explain why most OPEC countries' reported reserves remained virtually flat for the following 15 years despite heavy annual production. [75]

Bracketing the Range of Possible OPEC Reserves

A simple spreadsheet analysis (Figure 13) using published reserve data for Saudi Arabia illustrates the 160 billion barrel supply shock that is possible between the best and worst case scenarios.

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[75] In January 2006, Petroleum Intelligence Review reported a Kuwaiti oil official stating that Kuwait's actual reserves were only about 48 billion barrels instead of the reported 90. (Byron King, *"Things Just Got Worse"*, January 25, 2006**,** reported on line at www.EnergyBulletin.net).

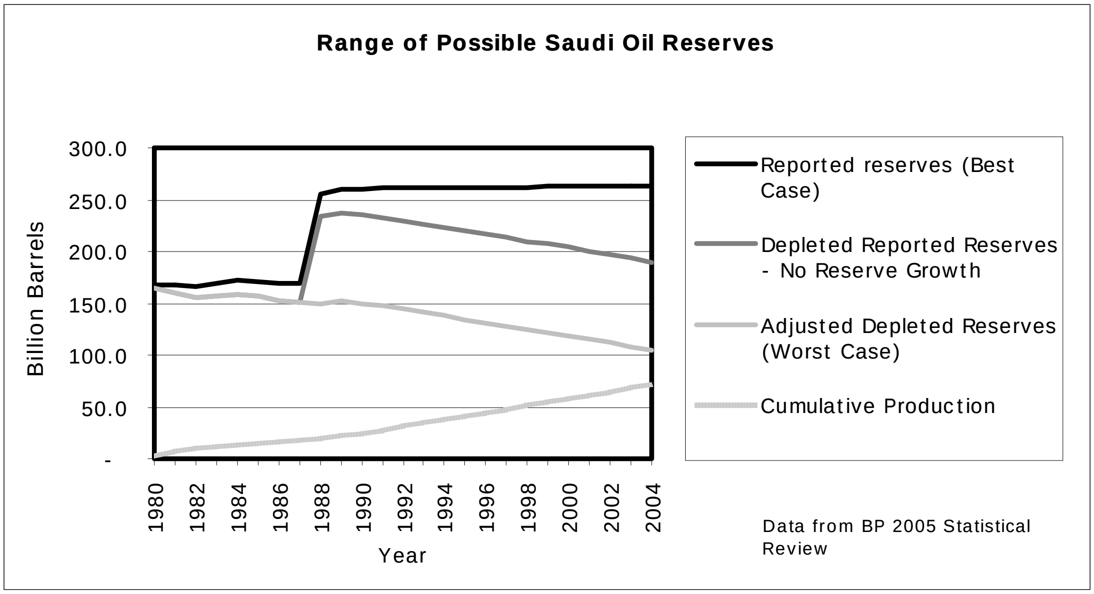

Figure 13. Best case: Approximately 260 billion barrels of officially reported reserves remain to be pumped. Annual additions to reserves = annual consumption. Worst case: reserves added in 1988 and cumulative production since 1980 are both subtracted from reported reserves. In that case, only 100 billion barrels or so remain to be pumped.

The best case assumes the 1980s reported reserve increases are real, and that every year the oil that is pumped is replaced by new reserves. If so, then Saudi Arabia still has about 260 billion barrels of oil remaining. The worst case assumes the 1980s additions were only “paper reserves”, or an accounting switch to reporting estimated total recoverable oil. It further discounts reported reserves by subtracting annual production, assuming no reserve replacement. Under the worst case, remaining Saudi Arabian supplies could be as low as 100 billion barrels.[76] If the same exercise is conducted for all of the OPEC countries, about 350 billion barrels of oil supply disappear under a worst case scenario. Suddenly, the world’s oil future looks potentially a lot bleaker. Without transparent reserve data reporting, there is no way to know how much oil can realistically be expected to come from OPEC in the future. While the truth probably lies somewhere between the best and worst case scenarios, it is not safe to assume that OPEC will be able to increase both reserves and production rate in the future to meet growing demand. Yet that is exactly what the USGS, the IEA and the entire western world are gambling on.

Geopolitical Realities of the Distribution of Remaining World Oil

Almost 75% of the officially reported reserves in the world are located in OPEC countries (Table 2). More than half of that – some 42% of the remaining reported oil in the world - is located in Saudi Arabia, Iraq and Iran. After the Middle East, Russia reports the largest percentage (6%) of the total reserves. The U.S. and its two largest suppliers – Canada and

[76] Matthew Simmons’ 2005 book *Twilight in the Desert* cast considerable doubt on officially reported Saudi oil reserve numbers and pumping capacity based on his evaluation of numerous oil field engineering reports.

Mexico – have only 5% of the world's reserves between them. These are principally in the Gulf of Mexico and the Canadian oil sand deposits in Alberta.

Americans tend to think that oil production is controlled by the international oil companies (IOCs), [77] but approximately 75% of the world's oil supply is nationally owned.[78] The IOCs have drilling access to only about 25%. Much of this is through contracts to develop nationally owned oilfields, where the national oil companies (NOCs) lack the technical or financial resources to develop their fields. The IOCs are aggressively seeking greater access to this oil through partnerships and privatization.[79] The remaining unexplored areas with geologic potential for large oil fields are in deep water off the margins of Africa and Brazil, in the South China Sea and in polar regions. Countries adjacent to these areas are currently jockeying over offshore drilling boundaries.

Is There a Rate Limit to Production?

Clearly, it is critical to offset depletion of existing oil fields with new discoveries if the oil supply is to be replaced, much less grow. However, in the short term, the corollary issue of maintaining the current rate of production is more important to the functioning of the world economy. Each year, the additional oil brought into production must exceed the annual decline rate of existing production, or net production will fall. The two issues are analogous to replacing assets versus keeping a positive cashflow.

The Growing Gap: So Much Depletion, So Few New Megafields

New fields don't come online overnight. It takes 4-10 years to bring a new discovery into production. Managers know what is "in the pipeline" and petroleum analysts track it closely.[80] There were 16 new megafields (at least 500 million barrels) reported in 2000, 11 in 2001, and 5 in 2002. No new megafield discoveries were reported in 2003 or 2004. According to Skrebowski, the next five years should see about 3.5 million barrels/day of new production come onstream each year, principally from deepwater fields. Cumulatively adding up to 16.6 mbd new production by 2011, this could offset production declines from existing fields for a few

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[77] Through a series of mergers beginning in the 1980's and continuing through the present, the multi-national IOCs now consist of a few ultra-giant companies with revenues larger than those of many small countries: ExxonMobil, ChevronTexaco, British Petroleum (BP), ConocoPhillips, Total-Fina-Elf, and Shell. Mid-size independents like Andadarko, Marathon, etc. risk takeovers in the future.

[78] This oil is produced by national oil companies (NOCs) like Statoil (Norway), Aramco (Saudi Arabia), Pemex (Mexico), Sinopec (China) etc.

[79] According to Kjell Aleklett, President of Sweden's Association for the Study of Peak Oil, ("*Report from the 7th International Oil Summit in Paris*", ASPO, April 10, 2006) "a major topic for the oil summit was much discussion about needed collaboration between NOCs and IOCs."

[80] Chris Skrebowsi of Petroleum Review tracks oil megaprojects (>500 million barrels) scheduled to come on line by 2010. See *"Prices Set Firm, Despite Massive New Capacity" (Megaprojects Update)* (Petroleum Review, October 2005, pp. 36-40), included as Appendix B. An avid peak oil community of academics is also modeling this data at The Oil Drum website. Cambridge Energy Research Associates (CERA – now owned by IHS) also tracks planned production for government and industry, but their data is proprietary.

years. However, being principally deepwater fields, the new production will likely ramp up quickly, then decline rapidly. Based on North Sea experience, it is reasonable to expect production to start declining within 10-12 years.

Another simple spreadsheet analysis illustrates the potential supply/demand gap that could develop over the next 10 years. In Figure 14, I've extrapolated demand at growth rates of 1.5% and 3%. Then I've plotted Skrebowski's projected new deepwater production and used it to offset current world production decline rates of 2% to 5%.[81] In reality, the world decline rate will start out small, then increase as more individual fields and regions tip into decline.

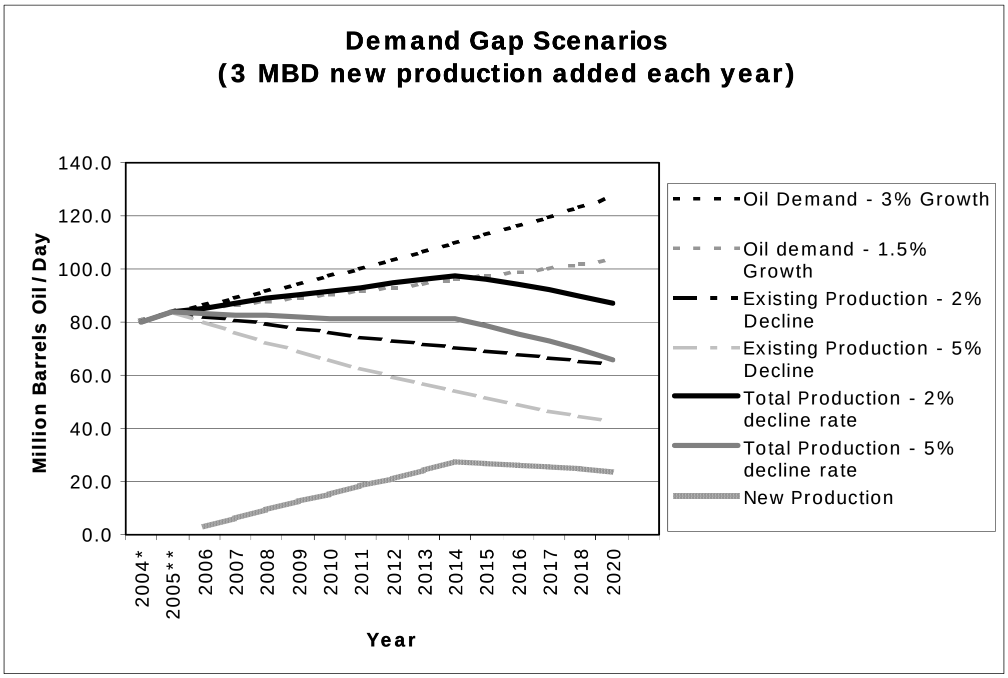

Figure 14. Projected gap between oil demand and supply at 1.5% and 3% demand growth, assuming 2% to 5% annual decline in existing production. Annual additions to production of 3mbd are projected, with new fields beginning to decline after 10 years.

The potential shortfall is obvious. If the new field numbers prove accurate, the current rate of production might be sustained, or even grow, until 2015. But it could prove very difficult to meet any signficant growth in demand. Figure 15 illustrates the supply/demand deficit. As Figures 14 and 15 make clear, a demand/supply gap could arise before peak oil production is reached. Once demand exceeds the supply rate, the world will tip from a buyers' to a sellers' market for petroleum. The incipient demand gap will be recognized by price increases, price volatility, and market uncertainty. Production could still increase from year to year, but it won't

[81] This plot is a variation of the "oil-a-gator" graphs that Chris Skrebowski showed at the November 2005 ASPO conference in Denver, Colorado. While he believes average decline rates in individual fields (Type I depletion) are in the 5% - 8% range noted by Schlumberger, Skrebowski uses a world decline rate (Type III depletion) of about 1.6% for his models.

fill the gap. The economic impacts will have begun. System weaknesses will become manifest. Physical shortages could occur in places. The "Big Rollover" as USGS Geologist Les Magoon calls it, will be very disruptive to business as usual.

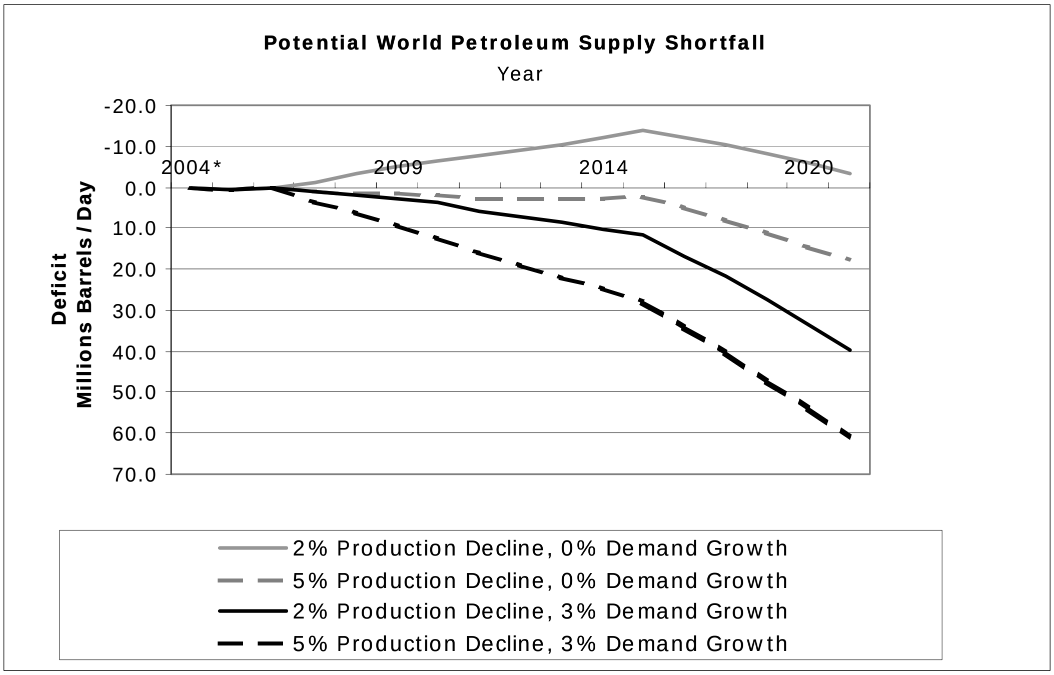

Figure 15. Projected oil supply deficit at demand growth rates of 0% and 3%, given current production decline rates of 2% to 5%. New production estimated at 3 mbd per year, with new fields entering decline after 10 years.

This inventory delivery data should set off alarm bells for any competent business manager. The inescapable conclusion: just-in-time delivery of future oil supplies is not a prudent operating assumption. Even if a new supergiant field were discovered this year (and the odds of finding another Ghawar are exceedingly small), there would still be a major world production gap for several years while the new discovery came on line.[82]

Production and Delivery Constraints

Other production constraints besides Peak Oil can create a demand gap. There are numerous physical, technological, and logistical challenges involved in bringing oil from the ground to market. These include:

[82] Note also that although the giant Alaskan North Slope fields did significantly slow the decline of US oil production, they did not return the US to peak production rates.

- geological limits to withdrawing the oil from the reservoir
- technological limits to withdrawing oil from the reservoir
- infrastructure limits, including the availability of drilling rigs, production platforms, tankers, and pipelines
- refinery capacity to process high volume or heavy/sour oils
- skilled worker shortage due to aging work force, two decades of consolidations and layoffs, and lack of training/recruiting new hires

Any of these constraints can limit the rate of petroleum production. The EIA Short-Term Energy Outlook (September 2005) offered this sobering projection:

> Moreover, only weak production growth in countries outside of the Organization of Petroleum Exporting Countries (OPEC) is expected. With the loss of production in the Gulf of Mexico from the hurricanes, production declines in the North Sea, and the slowdown in growth in Russian oil production, non-OPEC supply is projected to increase by an annual average of only 0.1 million barrels per day during 2005 before increasing by 0.9 million barrels per day in 2006. In addition, worldwide spare production capacity is at its lowest level in 3 decades; and in reality, only Saudi Arabia has any spare crude oil production capacity available. Lastly, the continued geo-political risks, such as the insurgency in Iraq and potential troubles in Nigeria and Venezuela, have boosted the level of uncertainty in world oil markets.

Steve Andrews, of the Association for the Study of Peak Oil – USA noted in 2005:

> Oil capacity today is not production limited but rather processing limited. That is to say, the DOE reports the world's refining capacity has leveled at around 83 mmbd for some time and refinery expansions are slow and costly. We have seen new downstream capacity investments average 300 mbd/year over the last several years. Doubling that rate would still put major changes in refinery expansions well into 2010 and beyond. Therefore the refinery capacities are now the effective ceiling for oil production.

We can’t produce our way out of the demand gap. Once demand exceeds the limiting production rate (refining capacity today, peak oil tomorrow), the supply/demand equation can only be solved by oil demand reduction through demand destruction, by substitution, energy efficiencies, and conservation.

Descending Hubbert's Peak

After oil production has passed Hubbert's Peak, some of the current capacity constraints (like refineries) will no longer be limiting factors of production. However, the diminishing marginal production of conventional oil will be an ever-increasing constraint for business and life as usual. Closing the supply/demand gap will create significant new operational realities in a world where every year there is less easy oil available than the year before.[83]

Near the top of the production curve, the decline rate will be low. If we are lucky, production will remain flat for a while, creating a plateau. But on the far side of the curve, the production decline rate will increase, possibly quite rapidly. During this period, demand will have to be reduced dramatically, year after year, if it is to stay in line with the decreasing supply.

The strategic management question of the century is: How will this demand gap be resolved and how long will it take? The answer will depend on whether supply can be increased to meet the anticipated demand, and/or oil substitutes can make up the difference. If not, then demand must be destroyed to match the available supply.

[83] Note the significant omission of the word "cheap". The world may have already reached maximum production for the sweet, free-flowing, easy stuff. Deepwater, polar, sour, and heavy oil come next, at much greater expense and lower net return on energy. After that, it's on to the surrogates – tar sands, gas-to-oil, coal-to-oil, biomass-to-oil, and oil shale - which must be synthesized, at even greater effort and expense, into liquid petroleum.

CHAPTER 3
WE'LL JUST DO SOMETHING ELSE!
CAN SUBSTITUTES OR TECHNOLOGY FILL THE LIQUID PETROLEUM GAP?

> *This is the miracle of oil. It has a very high energy density, you get it by sticking a pipe in the ground, you carry it in a bucket, you use it by lighting a match to it. Any other energy source we know of suffers by comparison in at least one of those characteristics.*
>
> \- neutrino23[84]

In 2006, with oil prices soaring, alternative fuels and energy conversion technologies are suddenly in the media and on investors' radar.[85] As investment money moves to the new endeavors, the free market theory goes, technological innovation will lower the marginal cost, thereby bringing the price down and keeping energy affordable. After all, ingenuity is the hallmark of our species. Is there any reason to suspect it might not work in the case of oil?

This chapter provides a cursory review of the alternative fuels that are most often cited as energy sources to replace oil.[86] Popular and scientific literature, as well as the internet, are filled with discussions of the possibilities and limits of various substitutes. As always, it is important to determine the affiliations and vested interests of the authors, because there is a lot of contradictory information, and downright hype, floating around. Paul B. Weisz summarizes the situation for oil substitutes thus:

> Our basic choices are limited. Nature's energy resources are confined to two categories: Earth-stored fossil residues and nuclear isotopes, whose economic utility is limited by the finite amounts that exist on Earth, and the radiation flux of solar energy, whose economic utility is limited by the finite rate at which we can

[84] In blogger discussion at The Oil Drum (www.theoildrum.com).

[85] Spencer Reiss,*"Why 5$ Gas is Good for America"*, Wired Magazine, Dec 2005. This cheerleading article on energy investment opportunity notes that oil sands become economic at $35/bbl oil, oil shale at $70/bbl oil, etc.

[86] The topic is enormous and complex, and undoubtedly will provide a number of well-paid engineering careers in the near future. For excellent discussions of alternative fuels, see: Kenneth Deffeyes, *Beyond Oil:The View from Hubbert's Peak* (New York: Hill and Wang, 200); Richard Heinberg *The Party's Over* (2003) and *Power Down* (BC Canada: New Society Publishers, 2004); Vaclav Smil, *Energy at the Crossroads: Global Perspectives and Uncertainties*, (Cambridge, Massachusetts, The MIT Press, 2003); Ronald Cooke, "*Alternative Energy: Evaluating our Options"*, (The Cultural Economist, March 22, 2006), Paul B. Weisz, "*Basic Choices and Constraints on Long-Term Energy Supplies"* (Physics Today, Vol. 57, Issue 7, p. 47-53, July 2004); and Eileen Westervelt and Donald Fournier, *Energy Trends and Implications for U.S. Army Installations*, (Technical Note, U.S. Army Corps of Engineers, Engineer Research and Development Center, ERDC/CERL TN-05-01, September 2005).

> capture the Sun's energy and by the land areas that societies can dedicate to harness it. [87]

As the Hirsch report concluded, Peak Oil will represent a "liquid fuels" crisis, not a conventional energy crisis. The vast majority of the world's oil is consumed as transportation fuel, so the need for mobile fuels will drive demand. Very little of the oil consumed in the U.S. is for electricity (2%) or residential and commercial use (6%), and there are ready substitutes for that (natural gas, coal, nuclear, etc.)[88]. Therefore, the discussion here will be restricted to analyzing substitutes for mobile fuel. These are limited to carbon sources that can be converted to liquid fuel: other fossil fuels - oil sands, oil shale, natural gas, and coal – and the so-called renewables[89] - ethanol, biodiesel and hydrogen[90].

Many in the technology optimist camp consider the various energy resources to be fungible, meaning they regard them as completely interchangeable in their ability to provide units of energy.[91] Most in the Peak Oil crowd say you must account for energy erosion each time one source of energy is converted to another. They stress rate of delivery issues and the need to evaluate energy return on energy invested (EROEI), a telling metric that I will expand on later in the chapter. Since the energy delivery rate is more important than the absolute volume of a resource, I will consider the potential liquid fuel substitutes from that perspective.

The Fossil Fuel Options

Oil Sands

An estimated resource of 4 trillion barrels of oil is contained in heavy oils and oil sands, including the extensive tar sand deposits[92] in Alberta, Canada. Of this, 800 billion barrels is estimated to be recoverable.[93] Canadian oil sands production became marginally profitable when

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[87] Ibid. Weisz is emeritus professor of chemical and bioengineering at the University of Pennsylvania and former senior scientist and manager at the Central Research Laboratory of Mobil Corporation.

[88] As noted previously, the Northeastern U.S. is an exception, because 33% of its homes are heated by oil and swtiching fuels requires big ticket refitting by homeowners.

[89] Weisz notes that "energy, once used, is not regenerable. So the public term 'renewable energy' is misleading." There are renewable energy sources (solar, wind, tides and hydroelectric), but these provide substitute energy for stationary fuel purposes like generating electricity or heat. Except for wind powering sails, they cannot directly provide mobile energy.

[90] Hydrogen is often cited as a renewable energy source for alternative transportation fuel. But in fact, the source of the energy it carries is usually extracted from natural gas. When that is the case, then hydrogen is actually a non-renewable, fossil-fuel derivative.

[91] For example, see Klaus Lackner and Jeffrey Sachs, *A Robust Strategy for Sustainable Energy*, Brookings Institute, Brookings Papers on Economic Activity, 2: 2005.

[92] Canadians and investors prefer the term "oil sands", but "tar" is a more accurate description.

[93] ExxonMobil, *Outlook for Energy: A 2030 View*. Cited in Alfred J. Cavallo *"Oil: Caveat Empty"*, Bulletin of the Atomic Scientists: May/June, 2005, 16-18.

oil hit $35/bbl; they are currently a very hot energy investment.[94] The sands are strip-mined or heated in-situ to release the bitumen. Enormous quantities of water and natural gas are required to generate the steam heat. The natural gas also provides the source of hydrogen needed to create synthetic crude from the bitumen. Competing demands for both gas and water and scarce supply make them limiting factors that will drive up the production price. A new natural gas pipeline is planned from the MacKenzie Delta to Alberta to provide energy for tar sand extraction. French oil company Total has even proposed building a dedicated nuclear power plant in Alberta, exclusively to provide steam and hydrogen for the oil sand production.

The potential oil volume of oil sand resources is often touted as greater than worldwide reserves of conventional oil. However, achievable daily production of oil from the sands is rate-limited. Canada produced about 1 mbd from oil sands in 2005, and expects to ramp up to a mere 4 mbd by 2030 [95]. Oil sand production could thus help offset declining oil production, currently estimated at 1.5 to 4.5 mbd/year, but is unlikely to provide a significant percentage of the world's liquid petroleum needs. In addition, the environmental impacts associated with oil sand production are severe.

Oil Shale[96]

The saying out West is "Oil shale is the energy of the future and always will be."[97] There are vast deposits of "uncooked" oil source rock in Utah, W. Colorado, and Wyoming.[98] The total estimated oil shale resource is about 3 trillion bbl oil[99]. Many attempts at commercial extraction have been tried and abandoned over the past 95 years. The target oil rock is 1000 feet below the surface. Underground mining has been proposed, as have open pit mines 2000 feet deep. The rock must be retorted to 1000 degrees Fahrenheit to convert the kerogen in the shale to liquid oil. Voluminous quantities of water and energy are required. The residual rock is contaminated with arsenic and occupies a greater volume than before the oil extraction, creating massive environmental disposal problems.

Oil shale re-emerged as a hot alternative energy investment in 2005 when oil hit $60/bbl. The RAND Corporation estimates that U.S. oil shale could provide 25% (5 mbd) of the U.S. current consumption of 20 mbd for 400 years.[100] Shell is currently planning a 10-acre pilot

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[94] Shares of Suncor, Syncrude, and the Canadian Oil Sands Royalty Trust tripled in value from 2004 -2005. China has invested heavily in Canadian tar sand development, including building a pipeline from Alberta to the Pacific.

[95] ExxonMobil, *Outlook for Energy*.

[96] Technically, it's organic marlstone, but bankers won't invest in that.

[97] Attributed to geologist Walter Youngquist.

[98] The entire oil shale area was declared part of the National Strategic Petroleum Reserve in 1912.

[99] ExxonMobil, *Outlook for Energy*. However, Exxon's forecasts in the same document show no contribution to world supply from oil shale even by 2030. Cited in Cavallo, *Oil: Caveat Empty.*

[100] Bartis, James T., Tom LaTourrette, Lloyd Dixon, D.J. Peterson, Gary Cecchine, *Oil Shale Development in the United States: Prospects and Policy Issues*, a RAND Corporation Monograph, prepared for the National Energy Technology Laboratory of the U.S. Department of Energy. Santa Monica, the RAND Corporation, 2005. However,

project on Mahogany Ridge, Colorado for in-situ recovery.[101] Like the oil sands, daily production of the oil shale will be rate-limited. Assuming the pilot works, Shell hopes to produce 100,000 bbl/day by 2020. That's a 7-minute supply at current world consumption rates. On the downside, the energy required to produce 100,000 bbl/d shale oil will require building a $3 billion dedicated power plant, Colorado's largest, which would consume 5 million tons of coal/year. Currently, the world's greatest commercial production is from Estonia, which has no oil, coal or natural gas, but produces 16,000 bbl/d of shale oil. Randy Udall notes:

> If crude oil is king, oil shale is a pauper. Pound per pound, oil shale contains just one-tenth the energy of crude oil, one-sixth that of coal, and one-fourth that of recycled phone books.... The "vast," "immense," and "unrivaled" deposits of shale buried in Utah and Colorado have the energy density of a baked potato. [102]

Natural Gas

Natural gas is the most obvious substitute for oil. It has a similarly high energy density, burns cleanly, and can be converted to liquid fuel that could be used in many existing vehicles with minor adaptation. A national pipeline delivery infrastructure is already in place. The major problem with using gas-to-liquid (GTL) as a substitute fuel is the competing demands for its use and North America's tight supply. Because it burns more cleanly than other fossil fuels, natural gas is the fuel of choice for power plants, which must meet strict emission standards. It is the essential source of hydrogen for the Haber-Bosch process that fixes atmospheric nitrogen into ammonia for the fertilizer modern agriculture depends upon. It is a crucial energy and hydrogen input for oil sand production. It is the principal source of hydrogen for petroleum refining and fuel cells. And it is a coveted heating fuel. While as recently as 2002 natural gas was thought to be "clean, cheap, and abundant", it is now apparent that U.S. gas production actually peaked in 1973 and is now in steep decline[103].

Canada supplies most of the natural gas imports to the US, but its fields are likewise experiencing steep decline, and Canadian domestic demand is growing, for residential and commercial use, as well as for the huge oil sands projects. Importing natural gas across oceans is neither easy nor cheap. It must be frozen and compressed into liquified natural gas (LNG) to be transported by tankers. There is now a worldwide shortage of LNG tankers and a long wait list to build them, but the U.S. has been slow to take an interest in LNG. There are only 4 LNG unloading terminals in the U.S. and extensive NIMBY opposition to building more. Within the

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the report also notes that there are as yet no proven technologies to extract the oil commercially and concedes that under a "high growth" scenario, production of even 3 mbd from U.S. oil shale is more than 30 years in the future.

[101] Shell intends to heat the oil shale at 1000 ft depth to 700 degrees for 3 years by drilling 200 injection wells on 30-foot centers. After the kerogen is "baked" to oil, it will be pumped to the surface. To keep out groundwater during the process, a cryogenic freeze wall must be installed to 2000 feet. If all goes as planned, Shell hopes to ultimately extract 1 million bbls/acre. The go/no-go decision on larger-scale production won't be made until 2010. (Udall and Andrews, 2005).

[102] Udall and Andrews, *The Illusive Bonanza: Oil Shale in Colorado – "Pulling the Sword from the Stone"*, 2005.

[103] Deffeyes (2005); Simmons, *Today's Energy Reality* (2005).

U.S., natural gas will soon command a premium price that will likely rule it out as a liquid fuel substitute for everyday transportation.

Methane Hydrates

Methane hydrates are frozen natural gas deposits beneath tundra permafrost and within ocean sediments along the continental shelf. Unstable at atmospheric temperature and pressure, the solid hydrate quickly reverts to a gaseous state when brought to the surface. The quantity of frozen methane entrapped in these sediments is unknown, but some believe they may contain more energy than the world's oil, natural gas and coal combined.[104] The existence of gas hydrates has been known since the 1970s, but so far, no one has engineered a way to extract them safely or commercially. Japan, Russia, India, and the U.S. all have programs to study the extent of their methane hydrate resources. The hydrates tend to be relatively sparsely disseminated in the sediments and will not flow unless heated or depressurized, which will make economic recovery difficult.[105] Further, disruptions of the marine hydrates could cause violent releases of methane, possibly triggering submarine landslides. Methane hydrates represent an engineering challenge that could pay off in certain cases. But with no success yet in sight, it is highly doubtful they could be made commercially available within the next 10-20 years.

Coal-to-Liquid (CTL)

Synthetic gasoline can be created from coal (carbon) by adding hydrogen using the Fischer-Tropsch method. The Germans employed the technique to produce aviation fuel and diesel for their army during World War II when they were cut off from crude oil supplies, and South Africa under apartheid used an updated variation of the method.[106] Since the U.S. has the most abundant coal resources in the world, gasoline from coal is often suggested as one of our easiest substitutes.[107] While the U.S. deposits are large, they are being looked to for many competing future uses. As natural gas becomes scarce, coal-gasification is already being substituted to produce hydrogen needed for refineries.[108] Coal-fired power plants are also being commissioned at a high rate now that natural gas appears less abundant.[109] The estimated U.S.

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[104] Deffeyes, *Beyond Oil*.

[105] Even in economic concentrations, methane hydrates would suffer from the same problem that plagues natural gas. Without a pipeline to transport it to a market, it is just "stranded" gas with no market value. Vast quantities of co-produced natural gas at oil fields have thus been flared.

[106] Deffeyes, *Beyond Oil*.

[107] Macroeconomist Jeffrey Sachs predicts that the price of oil will rise only to the point where production of coal-to-liquid (CTL) becomes economic. (Lackner and Sachs, *Robust Strategy for Sustainable Energy*).

[108] Deffeyes, *Beyond Oil*.

[109] There are 135 new coal-powered plants are on the drawing boards in the U.S. alone. (*"10 States Sue EPA on Emissions"*, New York Times (April 27, 2006).

coal reserve life of 250 years (at 2004 consumption rate) rapidly drops to 30 – 50 years if it is used to meet U.S. gasoline demand, too.[110]

Another problem is that coal requires more energy to mine than in the past. Like oil, much of the easy-to-access high-grade anthracite has been mined; the remaining resource is lower grade lignite. Today, coal is being strip-mined in Appalachia by removing mountain tops. CTL suffers from the usual environmental complaints about coal: mine wastes, sulfur emissions, acid rain, health effects, global warming, etc.

The So-Called Renewable Fuel Options

Biofuels and hydrogen are widely touted as renewable alternatives for liquid petroleum. Both have gained near-mythic status in the popular vernacular as environmentally benign fuels that will power the vehicles and economies of the future. But neither is truly "renewable" nor "green"; both depend on large fossil fuel inputs. And once again, rate, scale, and net energy are critical considerations.

Biofuels (Corn Ethanol, Cellulosic Ethanol, Biodiesel)

Ethanol created from biomass can be used directly in existing cars. In the U.S., the usual ethanol feedstock is corn. Cornell University agricultural scientist David Pimentel, who has done extensive studies on corn-to-gasoline, points out a fundamental input-yield problem: It takes about 70% more energy to grow and process corn ethanol than the combustion of that ethanol yields. He calculates a net energy loss of 54,000 Btu per gallon of corn ethanol, and notes that it can only be profitable when subsidized.[111] "Abusing our precious croplands to grow corn for an energy-inefficient process that yields low-grade automobile fuel amounts to unsustainable, subsidized food burning" he says.[112] It should be noted that many others, including the U.S. Department of Agriculture, calculate low, but positive, net energy for corn ethanol. Much depends on which input costs are included, whether irrigation is used, whether external costs are considered, and how many miles the corn and finished ethanol have to travel.

More hopeful is recent research into the use of "cellulosic" ethanol from switch grass or sugar cane waste, because it can grow in less fertile soil and requires fewer energy inputs.[113] However, land requirements are still large, and significant energy is required to convert the

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[110] Deffeyes, *Beyond Oil*.

[111] Pimentel, David, and Tad W. Patzek, *Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower*, National Resources Research, Vol. 14, No. 1, March 2005. pp. 65-76. Speaking at an NYC local energy solutions conference on April 28, 2006, Pimental noted that converting 100% of the U.S. corn crop to ethanol (at a net energy loss) would only yield 7% of the vehicle fuel needed by the U.S.

[112] Roger Segelkin, *CU scientist terms corn-based ethanol 'subsidized food burning"*, New York, Cornell Chronicle, August 23, 2001.

[113] Brazil has developed a viable ethanol industry using sugar cane waste product. However, extensive demand of cane for fuel created a sugar shortage and soaring commodity prices in 2006.

biomass to ethanol.[114] Weisz notes that the net energy production of solar to biomass (via photosynthesis) to fuel is about two orders of magnitude less than direct conversion of solar to energy through photovoltaics.[115]

In summary, small-scale use of biodiesel from recycled waste product can be an economic gasoline substitute. But large-scale crop growing dedicated to producing biofuels is probably not a best use of resources. So far, the return on energy for biofuels production is marginal to negative. In addition, the external costs of soil erosion and groundwater mining must be considered, as should the opportunity cost of using farmland to grow oil instead of food.

Hydrogen

The future "hydrogen economy" has been highly touted as the replacement to the oil economy in the popular press. But its debut keeps receding into the future. No one is realistically expecting affordable hydrogen cars before 2020 or 2030. In addition to the safety and storage issues, switching transportation to hydrogen would require a complete rebuilding of our auto, pipeline and fuel station infrastructure.[116] Beyond that, it's not clear where the hydrogen would come from.

There are no naturally occurring deposits of elemental hydrogen. It must be separated from compounds where it has bonded with other elements. The preferred source of hydrogen is a fossil fuel - natural gas (methane, CH_4) - which yields four hydrogen atoms for every carbon atom. Recently, however, natural gas has become so scarce and expensive in the U.S. that refineries have turned to coal gasification to produce hydrogen.[117] Hydrogen can also be obtained by electrolyzing water, but the energy required to split the H_2O molecule is greater than the energy delivered by the hydrogen, so the process is a net energy loss.[118] Therefore, hydrogen should not be thought of as a fuel source itself, but as a carrier or storage medium for energy from other sources.[119]

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[114] Transportation of ethanol to its point of use is another problem. Ethanol is too corrosive to be transported in pipelines, so it must be trucked. This is one of the problems facing the U.S. for the summer of 2006, since ethanol has been mandated to replace the suspected carcinogen MTBE as a summer gasoline additive.

[115] Weisz, *Long-Term Energy Supplies.*

[116] Pierre-Renee Bauquis, Vice President of the French Energy Institute says: "Hydrogen is not the fuel of tomorrow.... Commercial production of hydrogen is two to five times the cost of the fossil fuels used to make it. Transportation is impossible. It is two times as costly to transport hydrogen as it is to transport electricity. The storage costs for hydrogen are one hundred times the cost of liquid petroleum products." Reported by Michael Ruppert, *Paris Peak Oil Conference Reveals Deepening Crisis*, June 9, 2003. www.fromthewilderness.com.

[117] Deffeyes, *Beyond Oil.*

[118] As CalTech physics professor David Goodstein notes in *Out of Gas: The End of the Age of Oil* (New York: W.W. Norton & Company, 2004), "The economics of [using electricity to hydrolyze water] are such that you end up using the equivalent of six gallons of gasoline to make enough hydrogen to replace one gallon of gasoline. So this solution is not a winner in the short run."

[119] Many environmentalists propose using renewable energy, like wind power, to break the water bonds to provide clean hydrogen. This might be able to provide small-scale power locally, but would not be practical for large-scale replacement of oil use. And it again begs the energy erosion question: why not use the wind power directly? A very local solution might be wind-generated electricity used to generate hydrogen, which can be stored in small fuel cells.

There is already a billion dollar/year market for hydrogen to make fertilizer and upgrade heavy oil in petroleum refineries.[120] As conventional oil peaks, demand for hydrogen to synthesize light oil from heavy oil and oil sands will soar. This in turn will increase demand for natural gas as a source for the hydrogen. Technology, infrastructure and net energy aside, it is unrealistic to expect cheap, abundant hydrogen to fuel the U.S. auto fleet after peak oil.[121]

Energy Return on Energy Invested (EROEI)

There are many factors that should be considered when evaluating substitute fuels.[122] The governing economic reality is that producer costs must be less than consumer costs.[123] Another critical question is: How much energy is delivered to society versus consumed in the activity of producing each unit. This difference is net energy,[124] also expressed as energy return on energy invested or EROEI.[125]

Predictably, the EROEI for oil has diminished over time. Hall and Cleveland note that in 1930, oil's EROEI was around 100:1, meaning that 100 units were delivered for every unit expended in finding and producing it – a net gain of 99 units of energy. By 1970, the EROEI had fallen to 25:1; Today it can be as low as 3:1 for deepwater production. By comparison, EROEI for the Canadian oil sands is about 1.5:1, giving a net gain of only 0.5 units. When EROEI reaches 1:1, production of a resource is no longer useful from a net energy perspective. Each unit of energy produced must be reinvested in producing the next unit. When the ratio is less than 1, obtaining the resource is a net energy loss. For example, the EROEI of corn ethanol is about 1:1.3.[126]

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[120] Deffeyes, *Hubbert's Peak.*

[121] Both inventor Amory Lovins and former CIA Director James Woolsey have publicly ruled out hydrogen as an alternative fuel to replace oil. They believe we must "work with what we've got" for the transition. Panel discussion at New York University, November 2005, "Winning the Oil Endgame: Business Opportunities in a Reduced Petroleum Economy."

[122] See the excellent synopsis by Ronald R. Cooke, *"Alternative energy: evaluating our options"*, published online by The Cultural Economist (March 22, 2006). Available at www.energybulletin.net.

[123] This presumes producer costs are not subsidized.

[124] Net energy is often expressed in Quads (Q). 1 Quad = 1 quadrillion (10^{15} BTU) or approximately 2.5 x 10^{14} kcal. The U.S. consumes about 100 Q/year, roughly 1/4 of the total world demand. Energy Information Administration, *Annual Energy outlook 2004*, rep. no. DOE/EIA-0383 (2004). www.eia.doe.gov/oiaf/aeo. Net Energy $Q_{NE} = Q_{PR} - (Q_{OP} + E/T)$, where Q_{PR} is the rate of energy production, Q_{OP} is the energy consumed for its operation, and E/T is the energy invested in its creation over its lifetime.

[125] EROEI (or EROI) is the ratio of the amount of energy produced to the amount of energy invested. The term was pioneered by ecologist Charles A. S. Hall who noted that predators must obtain more energy from their prey than they expend in catching it. Hall carried the yield per effort concept over to the petroleum industry in the 1980s. (Charles Hall and Cutler Cleveland, *EROI: Definition, History, and Future Implications*, presentation at ASPO-USA conference, Denver, November 2005.)

[126] Pimentel and Patzek (*Ethanol Production using Corn)* note that studies that come up with positive EROEI for corn ethanol omit some of the fossil fuel inputs that he counts from their calculations.

Even if net energy is positive and the alternative fuel can be produced without a financial loss, it won't have the same energy content as a barrel of oil. Energy density determines how much work a fuel can do. As Ronald Cooke notes:

> ...Not all energy thus produced is equal. The energy content of a gallon of diesel fuel is (roughly) 139,000 Btu, the energy derived from a gallon of gasoline is (roughly) 124,000 Btu, and the energy in a gallon of ethanol is (roughly) 80,000 Btu. Can you guess which fuel will give us the best vehicle mileage?

Thus, it will take 1.55 times more ethanol than gasoline to drive 100 miles.[127] Steve Andrews and Randy Udall compiled the following energy density reference chart:

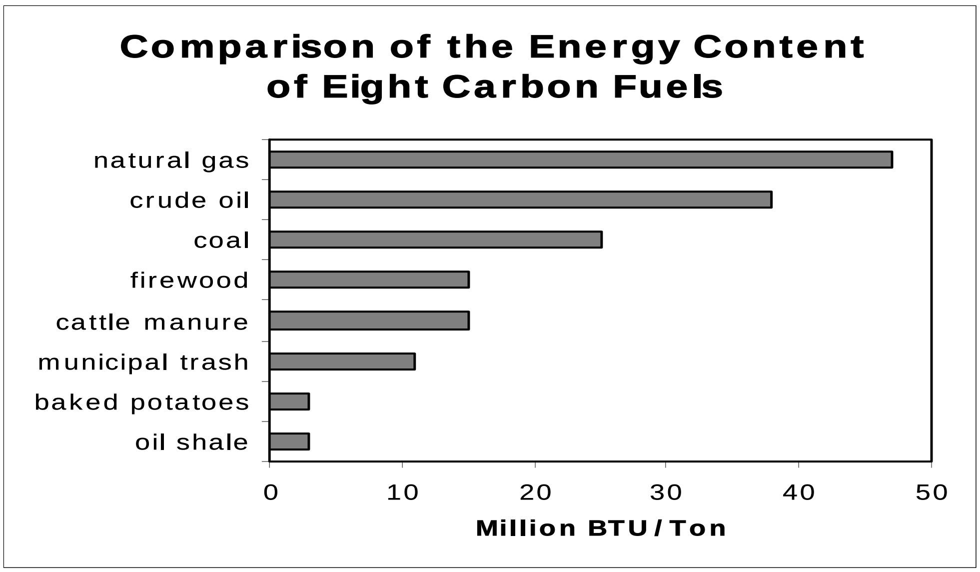

Figure 15. Modified from Andrews and Udall (2005).

Although nothing can truly substitute for oil's current role in our economy, alternative fuels will increasingly be used to synthesize or replace oil in the future. This will help compensate for oil depletion, but it won't allow overall oil consumption to increase. The alternatives can't scale to replace current rates of production, much less the expanded rates needed for growth. All involve paying a higher cost and greater inconvenience to obtain a lower net energy. All are limited in their delivery rates, require large and limiting inputs of other natural resources (land, water, natural gas, etc.) to produce, and create significant environmental impacts from mining, waste disposal or carbon release.

There are no cheaper surrogates to substitute into. Aside from EREOI, the economic impacts of higher energy prices to consumer and producer prices must be taken into account. At a higher price for lower-energy substitutes, people will be much less satisfied than they were with cheap oil.

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[127] If the ethanol is produced at a net energy loss, maybe they can "make it up in volume."

A final consideration is energy erosion. Every time one form of fuel is converted to another, net energy in the system is reduced. If large, expensive power plants burning natural gas, coal or uranium, must be built to provide the energy needed to create oil from tar sands and oil shales, it begs the question: Why not use the higher quality source fuels or the electricity from the power plants directly? As Randy Udall says, "Why would you feed the dog steak and eat his Alpo?"[128] This doesn't mean that you can't make money developing a low EROEI resource or net energy loser. Government subsidy or investor speculation can externalize the costs. In fact, expensive oil will prove quite profitable. But the energy spent to generate less energy won't be available for other uses. Manhattan Institute economist, Peter Huber, opines that EROEI is irrelevant:

> Eroei calculations now litter the energy policy debate. Time and again they're wheeled out to explain why one form of energy just can't win--tar sands, shale, corn, wood, wind, you name it. Even quite serious journals--Science, for example--have published pieces along these lines. Energy-based books of account have just got to show a profit. In the real world, however, investors don't care a fig whether they earn positive Eroei. What they care about is dollar return on dollar invested. And the two aren't the same--nowhere close--because different forms of energy command wildly different prices. Invest ten units of 10-cent energy to capture one unit of $10 energy and you lose energy but gain dollars, and Wall Street will fund you from here to Alberta.[129]

I rest my case.

Technology to the Rescue?

Optimists argue that Peak Oil will not be a great problem, because technological innovation will help find and develop new energy sources and make the old ones more efficient. They point to the exponential growth in technological advances over the past century, from horseless carriages and polio vaccines to space travel, genetic engineering and nanotechnology. Undoubtedly there will be significant technological breakthroughs in the years to come. But technology requires time, substantial capital and energy to develop. Consider any of the lifestyle-altering technology of the last century, such as cars, planes, computers, or the internet. Realistically, each took 20 to 30 years, or more, to move from idea through research and development to application to widespread adoption. So, a prudent manager will not rely on technologies that have not yet been conceived or proven to rescue them from a liquid petroleum gap over the next 20 years.

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[128] Udall and Andrews, *Illusive Bonanza*.

[129] Peter Huber, "*Thermodynamics and Money",* Forbes, 10/31/05. Huber is the co-author, with Mark Mills, of *The Bottomless Well: the Twilight of Fuel, the Virtue of Waste, and Why We will Never Run out of Energy,* Basic Books, 2005.

Enhanced Exploration and Oil Recovery

Hirsch and Simmons both point out that although there were enormous technological advances in petroleum industry in 1980s and '90s, especially in 3-D seismic exploration and reservoir engineering, the rate of new field discoveries and production continued to plummet (Figure 17).[130] The new technologies did, however, increase the speed of oil extraction, thus accelerating the depletion of world supplies.

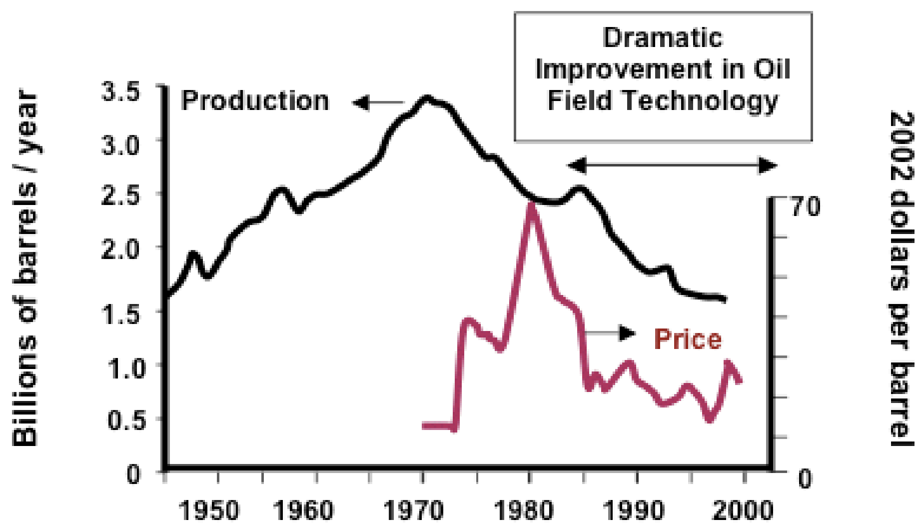

Figure 17. Oil production in the US (Lower 48) has declined steadily since the 1980's despite impressive technological advances in exploration and oilfield development Source: Hirsch, et al (DOE, 2005).

Diminishing Returns to Technological Innovation

Not surprisingly, technological advances in any field are subject to diminishing returns in productivity. OECD economist Angus Maddison writes:

> ...It is clear that technical progress has slowed down. It was a good deal faster from 1913 to 1973 than it has been since. The slowdown in the past quarter century is one of the reasons for the deceleration of world economic growth. "New economy" pundits find the notion of decelerating technical progress unacceptable and cite anecdotal or microeconomic evidence to argue otherwise. However, the impact of their technological revolution has not been apparent in the

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[130] Robert L. Hirsch, *The Inevitable Peaking of World Oil*, The Atlantic Council Bulletin, Vol 16, No. 3, October 2005; and Simmons (*Twilight in the Desert* and numerous talks).

> macroeconomic statistics until very recently, and I do not share their euphoric expectations.[131]

In summary, technology is the tool that enables us to employ energy in efficient ways. But it is not energy. As James Howard Kuntsler puts it:

> [The idea] that technology will rescue us from energy scarcity...is based on the idea that technology can be substituted for energy, that they are virtually interchangeable. This is just a plain misunderstanding of reality.[132]

Conservation and Efficiencies

> *Most of the oil now used in the United States (and the world) is being wasted, and can be saved more cheaply than buying it.*
>
> *- Amory Lovins*

After decades of low oil prices, current oil use in the U.S. is extremely inefficient. Recent studies financed by the U.S. Department of Energy, the Pentagon, and the Army, all conclude that conservation and increased efficiency are the most critical and cost-effective actions that can be taken to reduce oil dependency. [133] The Westervelt and Fournier study for the Army concluded:

> Energy efficiency is the least expensive, most readily available, and environmentally friendly way to stretch our current energy supplies. This ensures that we get the most benefit from every Btu used. It involves optimizing operations and controls to minimize waste and infusing state of the art technology and techniques where appropriate. The potential savings for the Army is about 30 percent of current and future consumption. Energy efficiency measures usually pay for themselves over the life cycle of the application, even when only face value costs are considered.

The report advocated immediate action by the Army and promoted a national agenda of energy efficiency and investment in renewable energy technologies.

Amory Lovins, who pioneered the terms “nega-barrels” and “nega-production” to describe saved oil expenditures, believes that the savings from displacing current oil use could total $130 billion/year by 2025. [134] In the short term, conservation could play an immediate role

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[131] Angus Maddison, *The World Economy: A Millennial Perspective*, Development Centre of the Organisation for Economic Co-operation and Development, OECD, 2001, p. 25.

[132] Kuntsler, *The End of the Binge.*

[133] See, for example: IEA (*Saving Oil in a Hurry*); Lovins (*Winning the Oil Endgame*); Hirsch, Bezdek, and Wendling (*Hirsch Report*); Westervelt and Fournier (*Energy Trends – U.S. Army).*

[134] Lovins recommends replacing the entire U.S. vehicle fleet (cars, trucks, and airplanes) with light-weight, carbon-polymer vehicles. This would involve significant new-vehicle fabrication costs and scrapping of old vehicles. It

in reducing oil consumption through measures like lowering highway driving speeds, cutting number of trips, keeping vehicle tires properly inflated, optimizing logistics, etc. Improvements in vehicle efficiency, etc., will take longer to achieve, because these rely on development of new technologies and the turnover rates for new consumer purchases of big-ticket items. As always, there will ultimately be diminishing marginal returns to oil savings through both conservation and efficiencies.

A Question of Risk Management

None of the alternatives discussed in this chapter is a silver bullet that can kill the oil supply/demand gap. But many of them could reduce the gap and collectively, with sufficient time, they might be able to fill it. The 2005 DOE study by Hirsch, et al, used a "wedge analysis" approach to examine how quickly various mitigation measures – enhanced oil recovery (EOR), coal, heavy oil, gas-to-liquids (GTL), and efficient vehicles – might be able to realistically replace oil demand (Figure 18). The report postulates that mitigation efforts initiated at least 20 years ahead of Peak Oil could potentially align future supply with demand. But a significant supply shortfall would arise if mitigation efforts were started with shorter lead time.

The Hirsch report concluded that:

> Prudent risk management requires the planning and implementation of mitigation well before peaking. Early mitigation will almost certainly be less expensive than delayed mitigation. A unique aspect of the world oil peaking problem is that its timing is uncertain, because of inadequate and potentially biased reserves data from elsewhere around the world. In addition, the onset of peaking may be obscured by the volatile nature of oil prices. Since the potential economic impact of peaking is immense and the uncertainties relating to all facets of the problem are large, detailed quantitative studies to address the uncertainties and to explore mitigation strategies are a critical need.

The rest of this paper uses a strategic management approach to evaluate several paths that could be taken in response to Peak Oil. My intent is to establish a qualitative framework to guide management decisions we need to make now about our future.

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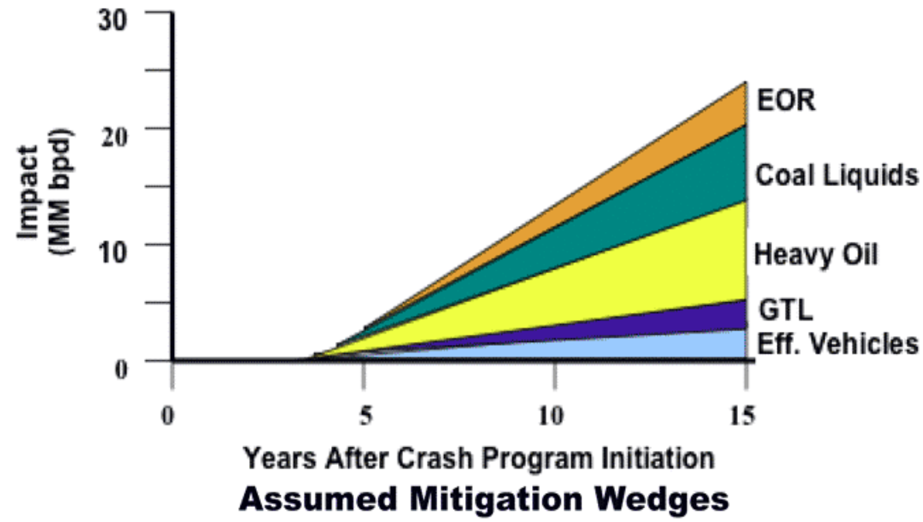
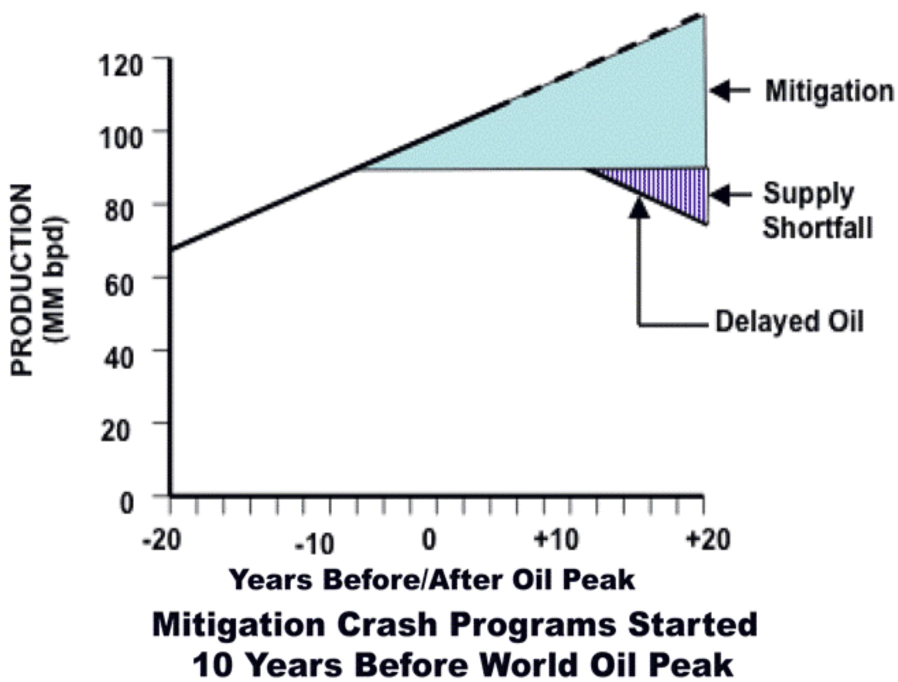
also presumes the future economy will be as highway dependent as the current one. Matt Simmons, on the other hand, advocates a major reduction in highway travel by trucks and cars, with a shift to rail and boat for energy-efficient freight transport.

A



B



EOR: enhanced oil recovery
GTL: gas-to-liquid oil

Figure 18. Mitigation “wedge analysis” showing A) the potential contribution of various oil replacement options for the first 20 years after initiation, and B) the supply shortfall that will result if mitigation not initiated until 10 years before world oil peak. Modified from Hirsch, Bezdek and Wendling, Peaking of World Oil Production: Impacts, Mitigation, and Risk Management, DOE, 2005.

PART II

OIL TRANSITION ENDGAME:
GAMBLING FOR OUR ENERGY FUTURE

The problems associated with world oil production peaking will not be temporary, and past "energy crisis" experience will provide relatively little guidance. The challenge of oil peaking deserves immediate, serious attention, if risks are to be fully understood and mitigation begun on a timely basis.

- Hirsch Report to DOE, 2005

If kindness and comfort are, as I suspect, the results of an energy surplus, then, as the supply contracts, we could be expected to start fighting once again like cats in a sack.

- George Monbiot

Never take life quite seriously.
After all, we'll never get out of it alive anyhow.

- Ahentop, 5000 BC

If the courses are departed from, the ends will change.

- Charles Dickens, A Christmas Carol

CHAPTER 4

TRANSITION TO A REDUCED PETROLEUM ECONOMY: DEFINING THE GAME

In the simulated world, the primary goal is growth. The... population will stop growing only when it is very rich. Its economy will stop growing only when it runs into limits. Its resources decline and deteriorate with overuse. The feedback loops that connect and inform its decisions contain substantial delays, and its physical processes have considerable momentum. It should therefore come as no surprise that the most likely mode of behavior of the model world is overshoot and collapse.[135]

Description of MIT's World3 Model

Why a gaming exercise to examine possible peak oil responses? It's a time-honored way to play out what-if scenarios without suffering any real consequences. Many government agencies[136], companies and even cities routinely play out emergency response scenarios. [137] For this strategic management exercise, I've taken a simple game theory/qualitative risk assessment approach. First, I designate a set of possible underlying "states of nature" with their probability of occurrence. I identify the players, the stakes (plausible outcomes or "pay-offs"), the rules, and the preferred outcomes. Next, I examine a variety of tactics that players could select to achieve their objectives. Then, I consider four obvious strategic approaches that could be chosen to transition from an oil-based economy, comparing their probable outcomes, desirability and risks, and selecting the approaches most likely to succeed. Lastly, I analyze some of the factors that could cause even the best approaches to fail.

Identifying the "States of Nature"

Figure 19, reproduced on the next two pages, shows five schematic cartoons from the "Oil Scenarios" website that summarize the range of opinions on the availability of remaining

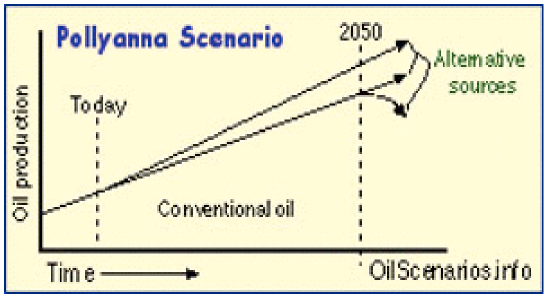
[135] From Meadows, et al., *Limits to Growth: the 30 Year Update*, 2004. p. 167.

[136] The CIA has been gaming peak oil since at least the 1970s. One such scenario provided the storyline for the 1975 Sydney Pollack film, Three Days for the Condor.

[137] For example, in June 2005, the National Commission on Energy Policy and Securing America's Future Energy (SAFE) simulated an "Oil Shockwave" caused by Nigerian unrest followed by Al Qaeda attacks on oil facilities in multiple countries. Participants played roles of White House cabinet members reacting to the crisis and included former CIA Directors Robert Gates and James Woolsey, former EPA administrator Carol Browner, and former Marine Corps commandant Gen. P.X. Kelley. John Mintz, "*Outcome Grim at Oil War Game: Former Officials Fail to Prevent Recession in Mock Energy Crisis*", Washington Post, June 24, 2005.

world oil supply.[138] Let's consider these five scenarios the possible "States of Nature" – the underlying, but unknowable geological endowment of recoverable oil that will govern the timing of world oil production peak. Only one scenario represents the actual situation, but we can't be certain which it is.

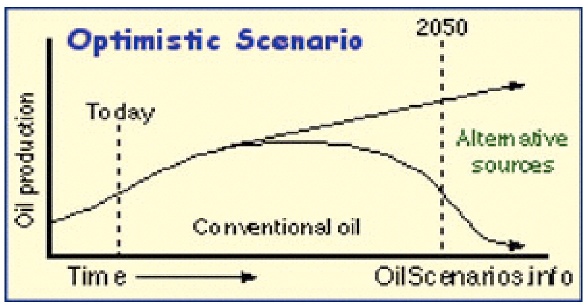
A.



Pollyanna Scenario

Oil production can be increased to meet all future demands for at least 40 years

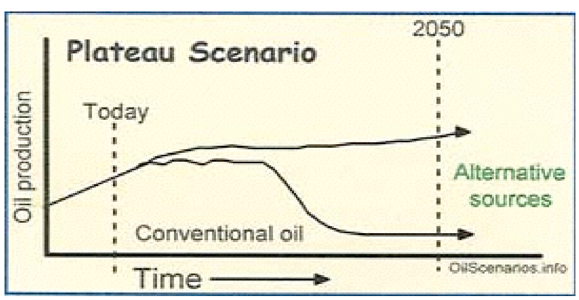
B.



Optimistic Scenario

Oil production in combination with conservation and alternative resources can meet the growing demands of society for the foreseeable future

C.



Plateau Scenario

Fossil fuel production will plateau in the next decade resulting in a volatile energy market and restricted world economy however people will be able to adapt lifestyles to the changing energy environment

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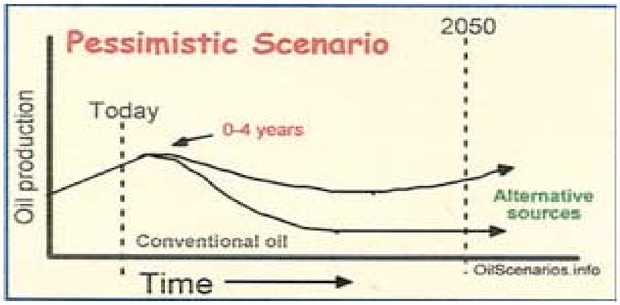
[138] www.oilscenarios.info does a good job of summarizing the various viewpoints concerning peak oil predictions and lists their principal advocates.

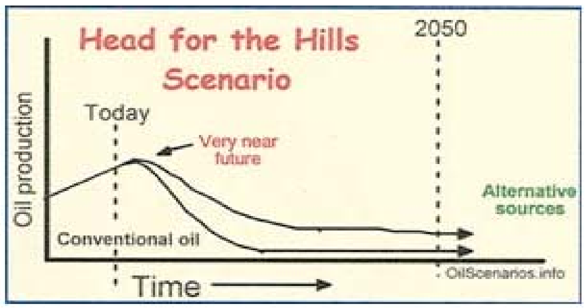
D.



Pessimistic Scenario

Oil production will not meet demand, forcing conservation and alternative energy use over the next decade however total energy resources will still decline slowly resulting in a gradually retracting world economy

E.



Head for the Hills Scenario

Oil production will peak and decline rapidly in the near future resulting in widespread energy shortages resulting in catastrophic collapse of many elements of modern society due to our lack of preparation

Figure 19. "States of Nature": Five peak oil scenarios (A-E) represent the range of opinion on the peaking date for conventional oil production, the steepness of the decline, and the extent to which other sources will provide alternative oil. Source: Oilscenarios.info website.

Probability of Occurrence

In my opinion, most evidence in the public domain supports the Plateau, Pessimistic, or Head-for-the-Hills scenarios. Therefore, I have ranked the probabilities of occurrence for the various states of nature as follows: A) Pollyanna – 1%; B) Optimistic – 10%; C) Plateau – 35%; D) Pessimistic – 40%; and E) Head-for-the-Hills – 14%. The reader may adjust the probabilities to reflect their own assessment. Such changes of a priori assumptions could provide input to further research and another academic paper. But for this paper, I assume the probabilities above.

The Players: Oil Haves, Heavy Users and Have-Nots

The geopolitical distribution of the remaining oil differs markedly from the distribution of its heaviest users (Table 3). Therein lies the motivation for much of the foreign policy and real war that has characterized the last century. More than half of the countries that are heavy oil users are also net importers. The U.S., an Oil-Have that is the heaviest user of all, imports more than 60% of its daily needs. Therefore, it will increasingly play the game from the perspective of a Have-Not. Clearly, China will be playing the transition endgame as a Have-Not, too.

Table 3

OIL ENDGAME - THE MAJOR PLAYERS						
THE HAVES Top 15 Oil Reserve Countries			**THE HEAVY USERS** Top 15 Oil Consumers*			
2004 Data	**Reserves Billion bbl**	**% Total**		**Daily MBD**	**Annual Billion bb**	**% Total**
Saudi Arabia	262.7	22.1%	USA	20.5	7.5	25.4%
Iran	132.5	11.1%	China	6.7	2.4	8.3%
Iraq	115.0	9.7%	Germany	2.6	1.0	3.3%
Kuwait	99.0	8.3%	Russian Federation	2.6	0.9	3.2%
United Arab Emirates	97.8	8.2%	India	2.6	0.9	3.2%
Venezuela	77.2	6.5%	South Korea	2.3	0.8	2.8%
Russian Federation	72.3	6.1%	Canada	2.2	0.8	2.7%
Kazakhstan	39.6	3.3%	France	2.0	0.7	2.4%
USA	29.4	2.5%	Mexico	1.9	0.7	2.3%
Canada	16.8	1.4%	Italy	1.9	0.7	2.3%
Qatar	15.2	1.3%	Brazil	1.8	0.7	2.3%
Mexico	14.8	1.2%	United Kingdom	1.8	0.6	2.2%
Brazil	11.2	0.9%	Saudi Arabia	1.7	0.6	2.1%
Norway	9.7	0.8%	Spain	1.6	0.6	2.0%
United Kingdom	4.5	0.4%	Iran	1.6	0.6	1.9%
Total Rest of World	190.9	16.1%	Total Rest of World	27.1	9.9	33.6%
TOTAL WORLD	**1188.6**	100.0%	**TOTAL WORLD**	80.8	29.5	100.0%

*Heavy Users may be Oil-Haves (Shaded) or Have-Nots

All Data from BP Statistical Review 2005
OPEC reserves not discounted

The Oil Endgame pits Oil-Haves against Heavy Users. Shaded countries have significant reserves, but also heavy consumption. They must balance the revenue benefit of exports with the need to provide oil for their own populations. Heavy Users that are net importers, like the U.S., will play the game as oil Have-Nots. Note that OPEC countries contain 75% of the reported reserves.

The Stakes: A Matrix of Plausible Outcomes

Figure 20 presents an array of speculative outcomes to the Peak Oil endgame. The envisioned outcomes are intentionally extreme to make the contrasts between them starker. But all have analogs in history or have been played out in speculative fiction.[139]

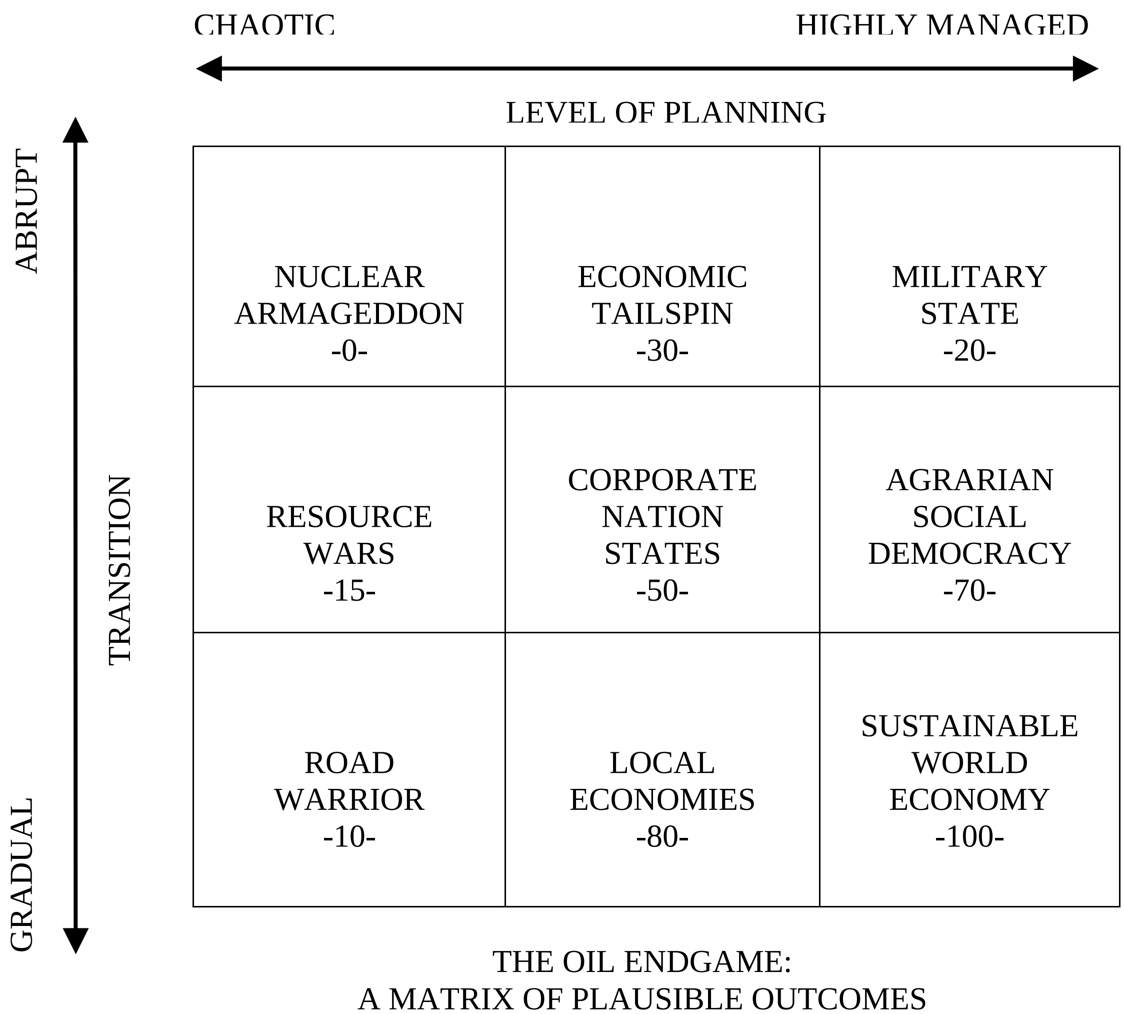


Figure 20. The outcomes are scored on a subjective scale of relative desirability from 0 (low) to 100 (high).

Outcomes are sorted on the x-axis based on the degree of transition planning, which could range from zero (chaos/collapse) to a highly managed transition into a reduced petroleum

[139] The archetypical post-peak oil movies are “Mad Max” and its sequel “Road Warrior”. Societal breakdown scenarios envisioned in literature include: “Memoirs of a Survivor” (Doris Lessing), “Oryx and Crake” (Margaret Atwood), and “The Parable of the Sower” (Octavia Butler).

economy. The Y-axis portrays the transition time allotted to prepare for life on the downward side of Peak Oil, which ranges from abrupt (little to no warning) to gradual (20-30 years preparation time, whether wisely used or not).

The stakes are high. Extreme negative outcomes are possible, including nuclear obliteration, or collapse of civilization and a return to a pre-industrialized standard of living. Less severe, even positive, outcomes are also possible. At the positive extreme, the transition from fossil fuels is consciously managed to achieve a sustainably high standard of living for a majority of the world's people.[140]

Chaotic/Collapse Outcomes

- **Nuclear Armageddon**: Also known as "Last Man Standing" or "If I can't have it, you can't either", one of the have-not superpowers (e.g. U.S. or China) or a "rogue state" (e.g. Pakistan or Korea) exercises the nuclear option to prevent others from access to oil resources. This brings the game to an abrupt end.

- **Resource Wars:** Code-named "War that will not end in our lifetime"[141], increased competition for remaining petroleum supplies leads to a perpetual state of proxy wars, direct military intervention/occupation, and escalating terrorism until recoverable supplies are exhausted, or simply no longer worth fighting for.

- **Road Warrior[142]:** As petroleum supplies become increasingly scarce, civil society breaks down into tribal units scrambling to stay alive and defend their hoarded resources from marauders.

Semi-Chaotic to Quasi-Managed Outcomes

- **Economic Tailspin/Global Recession:** The sudden and unforeseen onset of oil supply shortages undermines the economy, leading to price spikes, fuel delivery disruptions, reduced GDP, spiraling petroleum import deficits and a dollar crisis. Periods of inflation/hyperinflation alternate with recession/depression. A global recession ensues.

- **Corporate Nation-States:** Under this variation of Return to Feudalism, arable land and resource ownership ends up concentrated in a small group of elites or companies. Everyone else works for them as tenant farmers, indentured laborers, or soldiers, in return for income or basic necessities and protection.

- **Local Economies/Community Solutions:** Intentional communities develop around local agriculture, supporting local businesses and reaching decentralized agreements on resource usage and group governance. They concentrate on energy efficiencies and micropower to maintain a decent standard of living in a supportive social network. Interaction with the outside world is via telecommuting and mass transit.

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[140] Determining a hypothetical set of conditions under which this would be possible has been the goal of the World3 computer modeling scenarios run by the MIT scientists and modelers (Meadows et al, *Limits to Growth: 30-year update*).

[141] This phrase was introduced into public lexicon as a nominal "war on terror" by Vice President Dick Cheney in 2001, and has been reinforced by wide repetition since.

[142] In honor of the Mad Max and Road Warrior movies, starring Mel Gibson.

Highly Managed Transition Outcomes

- Military State: Due to oil shocks and supply disruptions, the government declares a state of emergency, imposes rationing and curfews and severely restricts movement of the population. Military police (or contract security) quell periodic civil uprisings. Picture New Orleans in the aftermath of Hurricane Katrina, but without the flooding.

- Agrarian Social Democracy: A centralized planning decision directs a society-wide effort and national resources towards feeding the population. A significant portion of the population becomes farmers. Land ownership and farm operations are scaled to a low-energy, community level with significant participation of individuals in local decisions and governance (e.g., post-Soviet Cuba[143] rather than the failed Soviet socialist model of huge collective, high-energy-input farms).

- Sustainable World Economy: A full-scale, international cooperative effort is implemented to dramatically reduce energy consumption, enhance technological efficiencies and develop renewable energy sources and alternatives. The mitigation actions are initiated early enough to prevent severe energy disruptions and hardship. The world population stabilizes at a high level of sustainable human welfare.[144]

Preferred Outcomes

These are not the only possible outcomes and the reader is invited to substitute different visions.[145] The point is that some of the outcomes (e.g., Nuclear Armageddon, Military State, Resource Wars and Road Warrior) are highly undesirable and, in my opinion, should be avoided at all costs. However, these destructive outcomes are quite possible under either abrupt or unplanned (chaotic) transitions. The abrupt outcomes (Armageddon, Economic Tailspin, and Military State) are inherently unstable and would eventually devolve to other outcomes. Quasi-managed options (Economic Tailspin and Corporate Nation State) involve significant hardship and financial insecurity and portend the end of the Middle Class. The most satisfactory outcomes (Sustainable World Economy, Local Economies, and Agrarian Social Democracy) are achievable options only with sufficient transition time and focused preparation.

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[143] When the Soviet Union collapsed, Cuba abruptly lost its major supplier of imported petroleum. Fortunately, emergency plans to mitigate a potential U.S.-led oil blockade had already been prepared. Using these, the Cubans implemented a crash program to switch to decentralized, low-energy intensity agriculture. A painful transition - the “Special Period” – followed, where the average Cuban lost 30 pounds, but thousands of small bio-intensive farms now successfully feed the population. The status of farmers was elevated to that of doctors. (Faith Morgan and Megan Quinn, *The Power of Community: How Cuba Survived Peak Oil*, 53-minute DVD produced by Community Service, Inc., copyright 2006).

[144] This is the ideal outcome that is achieved by mid-century under MIT’s World3 modeling scenario 9, when inputs are set at: families limited to 2 children; industrial output per capita is fixed; and improved technologies abate pollution, conserve resources, increase land yield, and protect agricultural land. (Meadows, et al, *Limits to Growth:30-Year Update*, 244).

[145] It is easy to envision other negative outcomes, such as Four Horseman of the Apocalypse (war, famine, pestilence, and death ride out to reduce the population to a sustainable level), or Asian Revenge, in which Americans end up as day laborers for wealthy Chinese who now own their houses and all their assets. Additional positive outcomes are harder to imagine.

Asymmetric Risks

Due to the high stakes, and the limited number of acceptable outcomes, the risks of the game are highly asymmetric. On the one hand, taking radical action now might leave some accessible oil in the ground (money on the table). On the other hand, the risk of not acting is to significantly increase the probability of catastrophic outcomes. Transition time is of the essence. The number of potentially satisfactory outcomes is reduced if action is not initiated significantly before the peak. As Robert Hirsch notes in his white paper to DOE on Peak Oil mitigation:

> The world has never faced a problem like this. Without massive mitigation more than a decade before the fact, the problem will be pervasive and will not be temporary. Previous energy transitions (wood to coal and coal to oil) were gradual and evolutionary; oil peaking will be abrupt and revolutionary. [146]

The Goal

Given an unknowable state of nature, i.e. the true amount of remaining oil, its peak production date, and the quantity of production that can realistically be replaced by alternative sources, the player(s) must select a course of action(s) to avert a potentially catastrophic outcome. Advanced players may try to optimize their outcome from among the several satisfactory ones. Expert players will try to manage the transition with as little social pain, economic hardship and dislocation as possible.

The Rules

There are no rules of etiquette. Alliances of any sort are allowed. Treaties may be broken. Military intervention, trade agreements, tariffs, and terrorism are all allowed.

Players may only employ resources and technologies that exist today, or that may reasonably be expected to become available within the next 10 to 20 years. Divine or alien interventions are ruled out as strategies, as are any proposed technologies that defy the second law of thermodynamics.[147]

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[146] *The Hirsch Report,* 64.
[147] e.g., no perpetual motion machines.

CHAPTER 5
A PALETTE OF STRATEGIC ACTIONS

The art of war teaches us not to rely on the likelihood of the enemy's not coming, but on our own readiness to receive him.

-Sun Tsu (The Art of War)

Tactics are specific actions, or tools, which players have at their disposal to implement their strategic approaches to a problem. This chapter considers the most obvious types of tactics that might be employed within different sectors to advance diverse objectives in the oil endgame and to reduce sector exposure to peak oil impacts during the transition to a reduced petroleum economy. The range of tactics available are encompassed by:

1) **the free market** - passive action;
2) **government action -** centralized decisions to intervene through military action, policy, or spending;
3) **private sector action** - decentralized investment decisions and voluntary behavior changes by businesses and individuals taken to benefit the entity; and
4) **collective action –** community or societal actions taken to benefit the members of the group and ensure its survival.

Table 4 shows the palette of strategic actions that will be considered for this paper.

Table 4 Potential Strategic Actions (Endgame Tactics) Available to the Different Sectors		
MAR- KET	M-1	Let Market Pricing Equilibrate Supply and Demand
GOVERNMENT	G-1	Governments Secure the Oil - Nationalization - Trade and Development Agreements - Military Threat or Intervention
	G-2	Market Interventions - Price Caps - Rationing - Fuel Consumption Taxes - Subsidies and Incentives - Fiscal Policy
	G-3	Spending on Research & Development and Infrastructure
	G-4	Policy and Law - National Energy Policy - International Cooperation Policies
PRIVATE SECTOR	P-1	Protect Self Against Short-Term Price and Supply Shock
	P-2	Shift Values Towards Sufficiency & Long-Term Sustainability - Conservation/Reuse - Best Use of Finite Resources - Shift Investment Dollars - Renewable Energy, Education
SOCIAL GROUP	S-1	Reinforce Community Values by Exerting "Norming" Pressure
	S-2	Leverage Resources

The Free Market Tactic
(Business as Usual – No Action Alternative)

Tactic M-1: Let Market Pricing Equilibrate Demand with Supply

The classical economic tactic is to rely on market pricing to bring demand into equilibrium with supply in the long term through the adaptive behavior of both buyers and sellers. Another name for this tactic is "demand destruction through pricing". If the market works, then rising price signals consumers to shift their demand downwards and drives a switch to substitutes. When demand for substitutes is sufficient, investment dollars will follow, which will lead to technological improvements, which will eventually lower the price. Meanwhile, the high price of oil should lead to investment in exploration and production.[148] Marginal oil deposits previously judged sub-economic will be brought into production. And at higher prices, substitute energy sources that were formerly sub-economic may become marginally profitable. Investment dollars will switch to oil sands, oil shale, coal, natural gas liquids and LNG. Demand will grow for greater energy efficiency, and therefore investment dollars will be directed towards that, too. All of these market factors should lead to increased supply. However, given the expected increase in overall energy demand, the rising marginal costs of inputs (machinery and energy to extract or synthesize oil), and the lower expected energy return on energy invested for deepwater, heavy, and substitute oils, it is unlikely that market forces will return us to cheap oil or alternative energy.[149]

Downside Risks of Market (Non-)Action

As we have seen, in the short term, demand for oil, especially in the transportation sector, is very inelastic to completely insensitive to price. Thus, as oil scarcity hikes prices, the people and businesses on the margins will be hit hard by an income effect. Some will be forced out of work/business when they can't afford their transportation fuel requirements. Without any substitutes of comparable energy density to be had for their energy dollar, people will have to drop to a lower level of satisfaction. The regressive distributive effect of high oil prices leads to social inequity issues, including class resentment and social unrest.

Market Failures

Perhaps the biggest problem with relying on the market to address peak oil is this: the oil market doesn't meet the operational requirements for a functional free market. For starters, over 85% of world oil is produced, not by independent firms, but by nationally owned companies. Second, there are so many transactions involved in each sale, from primary producers, transporters, and refiners, to governments and commodity futures speculators, that the price of a

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[148] The higher oil prices in 2004 and 2005 did create some of the expected effect on the supply side. Exploration drilling has picked up. The major international oil companies are recruiting geologists for the first time in two decades. Additional drilling rigs are backordered.

[149] An indicator of this is the oil futures market, which between 2003 and 2005 switched from decades of pricing 5-year oil futures at $20/bbl to $65 or $70/bbl.

gallon of gasoline bears little relation to the underlying marginal cost of producing a barrel of oil. Specific conditions that interfere with free-market oil pricing include:

Cartel Pricing: Historically, supply levels have been regulated to support desired oil price ranges, first by the Texas Railroad Commission, later by OPEC.[150]

Asymmetric Information: Producing companies and countries hold confidential information about the quantity and quality of their supplies that is not available to consumers.

Barriers to Entry/Exit: You can't just join this game on a whim. To enter, a country must have a geologic endowment of oil. A firm must have access to an endowed country's oil. Costs of entry favor large multinational corporations. Countries with endowments can't voluntarily choose to exit the game.

Uncosted Externalities: - There are significant external costs to society that are not captured in the price of oil, including pollution, global warming, and the maintaining of military forces to protect supply.[151]

Market Intervention: Many governments subsidize exploration and production costs and add taxes to the output, such that prices do not reflect the marginal cost of production.

For all of the above reasons, oil price signals are not reliable indicators of supply scarcity in the short run. Nor can we expect them to be good regulators of supply and demand in the short term. In fact many analysts argue that oil is significantly underpriced,[152] sending a false signal to the market. The market tool may therefore be of limited effectiveness in the oil transition endgame.

Government Strategic Actions (Public and International Policy Tactics)

Governments have a large role to play in the transition endgame as many of the aspects of oil supply and delivery involve national interest, international relationships, and enormous

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[150] The OPEC cartel was formed in 1960 to defend the price of oil from a unilateral price cut by Standard Oil of New Jersey. Modeled after the Texas Railroad Commission, OPEC was not able to fully assume the role of world price regulator until the 1980's, when members nationalized their oil supplies. (Daniel Yergin, *The Prize*, Chap. 26). Ken Deffeyes (*Hubbert's Peak*) says he realized U.S. production had peaked when he read a 1970 announcement by the Texas Railroad Commission lifting production ceilings to allow all-out pumping. When OPEC repeatedly allowed members to pump above quota in 2005, it signaled essentially the same thing, i.e., that it had lost pricing power.

[151] Amory Lovins (*Winning the Oil Endgame*) estimates that internalizing these external costs would add $25 to $77 to each barrel of oil.

[152] Including energy investment banker Matthew Simmons, and Rocky Mountain Institute founder Amory Lovins. Coal economist, E.F. Schumacher (*Small is Beautiful: A Study of Economics as if People Mattered*. Abacus edition, London: Sphere Books, Ltd., 1974), and agricultural economist John Ikerd (*Sustainable Capitalism: A Matter of Common Sense*. Bloomfield, Connecticut, Kumarian Press, 2005), argue that finite resources are often not priced realistically until they become obviously scarce. Others (e.g., Leonardo Magueri, (*"Two Cheers for Expensive Oil"*, in *Foreign Affairs*, March/April 2006, pp. 149-161) and Spencer Reiss *(Why $5 Gas is Good for America*) argue that high prices are needed to spur investment in additional refining capacity, exploration, and alternative energy sources.

investments. Realistically, these issues cannot be effectively addressed with market or private sector tools. A wide range of strategic tactics is available to governments, ranging from policy to military action. Oil-Haves and Have-Nots will favor different tools.

Tactic G-1: Governments Secure the Oil

Nationalization

Nationalization of natural resources is an effective way to obtain government revenues and to control production and allocation decisions. Clearly, this time-honored tactic is only available to Oil-Haves. OPEC, Norway, and the United Kingdom have all nationalized their oil and gas fields.[153] Norway and Venezuela have chosen to use their oil revenues to support large national social welfare programs, while a significant portion of oil revenue in Arab countries is spent on maintaining the extended families of the rulers. Many countries employing the nationalization tactic end up with "boundary issues" with neighboring countries. Currently, most of these relate to drilling rights in coastal waters with high potential for oil discoveries.[154] Note that when an oil field straddles international boundaries, one country can steal the other's oil by directional drilling or "sucking harder on the straw".[155]

Trade and Development Agreements

This tactic, negotiated between Oil-Haves and Have-Nots, reduces uncertainty about long-term access to supplies. For example, the International Monetary Fund (IMF) and World Bank can agree to provide aid and development packages to a country in exchange for access to the countries national resources by international corporations. Or an Oil-Have can create a political support block to guarantee a nearby market by offering aid, as did Venezuelan president Hugo Chavez with the formation of the Petrocaribe Alliance.[156] Have-Not China has been especially active in forging oil/development alliances over the past few years. These include BRIC (Brazil, Russia, India and China); an alliance between Russia, China, and Iran to assure access to oil in exchange for arms, protection, and development aid; commitments for tar sand oil from Canada in exchange for building pipelines, and recent "bilateral hydrocarbon

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[153] For example, starting in 1970 Saudi Arabia gradually bought ownership of the Arabian American Company (ARAMCO), which until then had been wholly owned by the "seven sisters" Exxon, Shell, BP, Mobil, Chevron, Texaco, and Gulf. When they realized the company would soon be nationalized, the IOCs encouraged all-out pumping of the fields, convincing the Saudis that production was not rate-sensitive. Matt Simmons, researching his 2005 book, *Twilight in the Desert,* concluded that the high extraction rates of the late 1970s caused irreparable damage to the Saudi fields, lowering the amount of ultimately recoverable oil.

[154] China and Japan have been squaring off over boundaries in the China Sea and polar ice melt has caused a scramble for the U.S., Russia and Canada to determine Arctic Sea offshore drilling boundaries. (*"As Polar Ice Turns to Water, Dreams of Treasure Abound"*, New York Times, October 10, 2005.)

[155] Saddam Hussein claimed he attacked Kuwait in 1990 after he discovered the Kuwaiti's had been stealing Iraq oil by drilling horizontally under their border (Ruppert, *Crossing the Rubicon*, New Society Publishers, 2004).

[156] Umberto Marquez reports that under the alliance, Venezuela will provide 198,000 barrels a day of oil to 13 Caribbean nations, with financing for up to 40 percent of the bill. In addition, Caracas will accept payment in the form of products or services. http://www.ipsnews.net/news.asp?idnews=31614.

cooperation agreement with India to make joint oil ventures rather than compete in bidding wars".[157]

Finally, Oil-Haves can form their own trade agreements to maintain desired price levels, a prime example being quota setting by the Organization of Petroleum Exporting Countries cartel. Note that as OPEC member Indonesia has recently become a net oil *importer*, it may soon be forced to forge new alliances.

Military Threats/Occupation

Military intervention, or the threat of it, is perhaps the most high-cost and risky way for governments to secure oil, but is historically a much used tactic. Many of the strategic moves in WWI and II involved military incursions by Germany to gain access to oil or by the Allies to cut it off from oil supply. The U.S. invasion and occupation of Iraq could be considered a high-cost military effort to obtain energy security through direct intervention. Threats of military action are far cheaper than moving armies, but are only effective so long as the threatened entity believes they will be backed by action.[158]

Less direct, but still costly, tactics involve military control of oil trade routes. This can be effectively restricted to "choke points" through which many of the world's oil tankers must pass like the Straits of Malacca, Gibralter, Hormuz, and the Bosporus; and the Suez and Panama Canals.[159]

<u>Tactic G-2: Market Interventions</u>

Governments have many options available to intervene directly in the markets to achieve their economic, political, and policy objectives. These include price caps, rationing, taxation of either suppliers or users, subsidies and incentives, and fiscal policy to control the interest rate and money supply.

Price Caps

When oil prices surge, people often demand that the government impose price caps.[160] While this tactic is politically expedient, it is a bad idea from an economic perspective. Producers are forced to take below-market prices, while the low prices create excess consumer demand (shortage). Thus, employing this tactic exacerbates the supply/demand imbalance.

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[157] Indrajit Basu**,** *India, China pin down $573m Syria deal*, Asia Times, Dec 22, 2005 http://atimes.com/atimes/China_Business/GL22Cb06.html

[158] Bellicose rhetoric between Iran and the U.S. throughout 2005 and early 2006 is an example of a high stakes tactic to reach a stable supply agreement, while both sides gamble that their bluff of military intervention will not be called.

[159] China's proposed oil pipeline across Myanmar (formerly Burma) will bypass the infamous straits of Malacca, where 40% of the world's piracy occurs (Asia Times, March 2, 2005). China has also increased its military budget and started building a blue-water Navy, which will allow it to challenge U.S. supremacy of the seas**.**

[160] For example, Hawaii called for gasoline price caps after Hurricanes Katrina and Rita (Reuters, August 25, 2005).

Rationing

Whereas the market rations by price, governments can impose mandatory rationing, either with or without price controls. In fact, the 26 IEA Treaty members, which include most of the OECD, are required to keep emergency stockpiles and to have oil rationing plans on file.[161] The usual non-price rationing approach is for the government to set a price ceiling to limit producer supply to the desired level, then allocate coupons to eligible drivers authorizing them to purchase the available supply. This tactic allows equal access to fuel, regardless of income, but it creates the classic market inefficiencies of price ceilings discussed above. Inevitably, a black market arises, allowing some excess demand to be met at the true market-demand price. The other likely collateral consequence is a counterfeit coupon market. As with freshly printed or counterfeit money, the benefits will accrue to the people receiving the fraudulent coupons first, while latecomers with legitimate coupons find themselves unable to purchase gas. If coupons are not issued, then the rationing is accomplished by queuing (also known as "rationing by inconvenience").

The second rationing approach involves mandated output restrictions on the supply side, but allows producers to receive the market demand price. The idea is similar to the use of OPEC quotas to maintain a certain price range, only in this case the quotas are set to maintain a certain demand range.[162] The tactic is regressive policy in that the working poor and middle class would have to pay a much higher percentage of their income to compete with the wealthy to buy gas. However, it does reduce demand through pricing, and encourages a switch to mass transit, carpooling and telecommuting. The high prices would also encourage exploration for new supplies for future use and be an incentive to invest in efficiencies and alternative fuels.

Fuel Consumption Taxes

Another tactic to reduce oil demand is to impose a fuel consumption tax at the pump.[163] Both the producer and consumer bear the burden of a fuel tax, though inelastic demand for gasoline makes the consumer pay the lion's share. Since the producer receives less than market price, the policy creates a disincentive to finding and developing additional supply. Like supply rationing, a fuel tax reduces overall demand, but penalizes the working poor. It has the advantage of increasing government revenues, which could help offset a budget deficit. "Cutting income taxes while increasing gasoline taxes would lead to more rapid economic growth, less traffic congestion, safer roads, and reduced risk of global warming," recommends Harvard

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[161] Per the Agreement on an International Energy Program (I.E.P. Agreement), 18 November 1974, as amended. Available at http://www.iea.org/Textbase/about/IEP.PDF. This requirement is met in the U.S. by its strategic petroleum reserve and a *Standby Gasoline Rationing Plan*, U.S. Department of Energy, Washington, D.C., June 1980.

[162] Another example of supply restricted price rationing is the auctioning of pollution permits authorizing emissions up to a given policy target level.

[163] Fuel consumption taxes are heavily used in Europe, where consumers pay more than double the US price for gasoline, but the idea has been unpopular with consumers, automakers, the oil industry, and politicians in the U.S. When I asked energy investment banker, Matt Simmons (after a presentation at Columbia University) what he thought about using fuel taxes to curb consumption, he said, "That's a horrible idea!"

macroeconomist and White House economic advisor, Gregory Mankiw.[164] A government could invest the revenue from this tax in development of mass transit and alternative energies to make them affordable substitutes in the future. If wisely reinvested, fuel tax revenues could be an effective component of a strategic solution to the oil supply/demand gap.

Incentives for Conservation and Alternatives

Governments can provide incentives for desired behavior in the form of subsidies, tax deductions and tax credits. Examples of this tactic are fuel efficiency tax credits for buying hybrid cars, and tax deductions for installing energy efficient appliances.[165] Incentives can be enacted at the federal or state level, or both. This tactic should not be used to subsidize net energy losers. For example, U.S. subsidies to farmers to grow corn to be converted to ethanol for a net-energy loss, should be recognized as politically motivated, and not confused with legitimate efforts to reduce oil consumption or develop viable alternative energy sources. Similarly, large tax credits for purchasing SUVs undermine incentives to save fuel elsewhere.

Fiscal Policy

Governments with central banks have two tactics available to influence consumer demand and producer investment through fiscal policy: they can increase the prime lending interest rates and/or adjust the money supply directly. Paul Volcker, Alan Greenspan's predecessor as chairman of the Federal Reserve, used interest rate hikes to control U.S. inflation following the oil price spikes of 1970s. The policy was perhaps too effective. Demand fell dramatically in the ensuing economic recession. Robert Hirsch, et al, note in their 2005 DOE white paper:

> Monetary policy is more effective in controlling the inflationary effects of a supply disruption than in averting related recessionary effects. Thus, while appropriate monetary policy may be successful in lessening the inflationary impacts of oil price increases, it may do so at the cost of recession and increased unemployment. Monetary policies tend to be used to increase interest rates to control inflation, and it is the high interest rates that cause most of the economic damage. As peaking is approached, devising appropriate offsetting fiscal, monetary, and energy policies will become more difficult. Economically, the decade following peaking may resemble the 1970s, only worse, with dramatic increases in inflation, long-term recession, high unemployment, and declining living standards.[166]

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[164] Quoted by Gregg Easterbrook, *The 50-cents-a-gallon Solution*, New York Times Op Ed, May 25, 2004. The influential Thomas Friedman, recently suggested that Americans would readily accept a gasoline tax if presented in terms of increasing energy security and reducing global warming (*"Who's afraid of a gas tax?"* New York Times Op Ed, March 1, 2006).

[165] Amory Lovins (*Winning the Oil Endgame*) suggests issuing "feebates" to car buyers, instead of rebates. These are price incentives, awarded at the time of purchase, to influence people to buy more fuel-efficient cars. Cars with low gas mileage ratings have a penalty assessed to the sticker price, whereas cars with high gas mileage receive a "feebate".

[166] *The Hirsch Report*, 32.

UK energy economist Andrew McKillop believes use of the “interest rate weapon” to reduce demand would be a much riskier tactic now than in 1980s:

> Economic 'adjustment' through destroying demand by self-imposed recession [using the “interest rate weapon”] is a tried-and-tested strategy. The last time it was used widely in the OECD countries, in 1980-83, the impact was surely to reduce oil prices (in 2005 dollars from a peak around $110/bbl in late 1979 and early 1980, to around $60/bbl in 1984), but the collateral economic and social damage was awesome. In addition, the actual oil savings generated by this self-imposed recession was no more than about 9.6%, concentrated in the 3 years of most intense recession (1980-82), with oil demand continuing to grow again the moment world economic growth was restored. Unlike today, the OECD economy entered this 'adjustment-by-recession' with balanced budgets in most countries, including the USA, in 1979-80. The financial, economic and geopolitical risks, today, from recourse to 'the interest rate weapon' are almost open-ended. [167]

In addition to oil, employment of fiscal policy will affect all demand. Thus, use of this tactic is cautioned.

<u>Tactic G-3: Government Spending on R&D and Infrastructure</u>

Governments can participate directly in the energy transition market by spending public monies on R&D and infrastructure. For example, they can choose to invest in public transportation and energy monopolies like railroads, LNG terminals, and power utilities. They can also invest in high-cost, high-risk research with uncertain outcome that the private sector cannot take on, such as research into creating and harnessing energy fusion. Governments can choose to invest in infrastructure for non-hydrocarbon energy, as Denmark and Germany are doing with wind power and China is doing with nuclear power plants. Because the military spends so much on oil delivery logistics support and readiness, government R&D investments in military fuel logistics efficiencies could also pay off handsomely in increased energy security, reduced military expenditures, and prolonging the life of world oil reserves. [168] As with all government spending, distinctions must be recognized between spending for private gain or political patronage and true investments in public goods.

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[167] Andrew McKillop: *Open shift to the Euro would further lock-in higher oil prices*, Oil & Gas, May 17, 2005.

[168] Amory Lovins, (*Winning the Oil Endgame*, 20) notes that "...the U.S. pays two to three times as much to maintain military forces poised to intervene in the Gulf as it pays to buy oil from the Gulf." The U.S. Army Engineer Research and Development Center advocates an immediate campaign to reduce oil dependency in their own operations, noting the investment in energy efficiency and renewable resources could result in “potential savings for the Army of about 30 percent of current and future consumption”. (Westervelt and Fournier, 2005)

<u>Tactic G-4: Energy Policy</u>

National Energy Policy

Governments have a powerful tool in their ability to promulgate energy policy at the national level. Such policy can direct government expenditures to mandated programs, and perhaps more importantly, signal a country's energy philosophy and values to its own populace and the outside world.[169] Unfunded mandates, or defunding previous initiatives signals that a policy is low priority.

United States: Since the 1973 oil crisis, the de facto U.S. energy policy has been the Carter Doctrine, which states: "any attempt by an outside force to gain control of the Persian Gulf will be regarded as an assault on the vital interests of the United States of America, and...will be repelled by any means necessary, including military force."[170] Vice-President Cheney's 2001 energy task force recommendations on energy policy focused primarily on energy security, but also recommended development of alternative energy sources, especially "clean" coal and nuclear power.[171] The Bush Administration 2005 Energy Policy largely follows the task force recommendations. Critics point to the small focus on developing renewable energy sources and the lack of emphasis on reducing per capita oil use through conservation.[172]

Europe: European countries (Oil Have-Nots) have been more aggressive than the U.S. in promulgating energy policy. Sweden, for example, has recently declared the goal of energy self-sufficiency by 2020, eschewing use of both fossil fuels and nuclear fuels for renewable wood-, water- and wind-generated energy coupled with conservation and energy efficiency. With the peaking of North Sea oil in the United Kingdom (1999) and Norway (2001), these two Oil-Haves have initiated policies of conservation, efficiencies, and the development of alternatives. Because their populations are already accustomed to high fuel consumption taxes, European energy policy initiatives are easier to fund than they would be in the U.S.

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[169] For example, throughout the Carter administration, the Government funds targeted for research on alternative energy sources increased dramatically. However, during his first term the following president, Reagan, decreased funding for alternatives research back to pre-Carter levels, and it has not increased significantly since.

[170] President Carter's State of the Union Address, 1980.

[171] National Energy Policy Development Group, *National Energy Policy: Reliable, Affordable, and Environmentally Sound Energy for America's Future*, May 2001. Washington, D.C., U.S. Government Printing Office. ISBN 0-16-0508-14-2

[172] President Bush, meanwhile, has changed his signaling in public statements from *"We need an energy bill that encourages consumption"* (speech in Trenton, NJ, September 23, 2002) to *"America is addicted to oil"* (State of the Union Address, January 31, 2006).

<u>China:</u> Being a net importer of oil, gas, and many metals, China's de facto energy policy is to secure future access to all the oil and raw materials it can. It is aggressively pursuing this through a combination of investments, aid, trade agreements, and military threat. Suffering the energy inefficiencies and environmental consequences of rapid growth, China realizes it must develop national policies on conservation and pollution control and invest in alternative energy research and development.

International Cooperative Agreements

Because the peaking of world oil is a global economic problem with distribution issues that cross national boundaries, international agreements on oil allocation and conservation are important strategic tactics to consider. International trade and development agreements such as BRIC and the Caribe Alliance have already been discussed. Below I consider two examples of international agreements to reduce oil consumption and assure some global equity of supply allocation.

<u>IEA Treaty:</u> The International Energy Agency was formed by a group of developed countries during the 1973-1974 oil supply crisis to coordinate emergency response measures. Its 26 member countries, including the U.S., are bound by the International Energy Program Agreement (I.E.P).

> Demand Restraint as an Emergency Response Measure Emergency response is a main element of the IEA's treaty, the...I.E.P. Agreement. It includes the important commitment by IEA Participating Countries to hold oil stocks equivalent to at least 90 days of net oil imports. The I.E.P. Agreement also defines an integrated set of emergency response measures, including "stockdraw" (use of emergency oil reserves), demand restraint, fuel switching, surge oil production, and sharing of available supplies, for major international oil disruptions which reach the 7% threshold (the "trigger") defined in the I.E.P. Agreement. [173]

The IEA's recommended oil-saving policies are summarized in Table 5. All participating countries are expected to have emergency plans on file to "immediately implement demand restraint measures sufficient to reduce oil consumption by 7% of normal demand levels. In a more severe disruption, this could be raised to 10%.... Measures to achieve demand restraint fall into three main classes - persuasion and public information, administrative and compulsory measures, and finally, allocation and rationing schemes."[174] Note that because the US is the largest oil consumer in the world, a mandatory 7% reduction in the US (about 1.5 million barrels/day) would save more oil than a 7% reduction anywhere else.

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[173] IEA, *Saving Oil in a Hurry*.

[174] Ibid. It was under the I.E.P. Agreement that the IEA member countries released 120 barrels of crude oil and refined product (gasoline) from their strategic petroleum reserves to aid the U.S. after Hurricanes Katrina and Rita in the Fall of 2005. Fifty percent came from the U.S.'s own reserves, the remainder mainly from Germany, Japan, France and Spain.

Table 5

Relative Fuel Savings from Different Oil Conservation Measures that IEA Member Countries Might Impose	
Potential Oil Savings by Category	**Measure**
VERY LARGE More than one million barrels per day	**Carpooling**: large program to designate emergency carpool lanes along all motorways, designate park-and-ride lots, inform public and match riders.
	Driving ban: odd/even license plate scheme. Provide police enforcement, appropriate information and signage.
	Speed limits: reduce highway speed limits to 90km/hr. Provide police enforcement or speed cameras, appropriate information and signage.
LARGE More than 500 thousand barrels per day	**Transit**: free public transit (set fares to zero).
	Telecommuting: large program, including active participation of businesses, public information on benefits of telecommuting, minor investments in needed infrastructure to facilitate.
	Compressed work week: program with employer participation and public information campaign.
	Driving ban: 1 in 10 days based on license plate, with police enforcement and signage.
MODERATE More than 100 thousand barrels per day	**Transit**: 50% reduction in current public transit fares.
	Transit: increase weekend and off-peak transit service and increase peak service frequency by 10%.
	Carpooling: small program to inform public, match riders.
	Tire pressure: large public information program.
SMALL Less than 100 thousand barrels per day	**Bus priority**: convert all existing carpool and bus lanes to 24-hour bus priority usage and convert some other lanes to bus-only lanes.

Note: Oil-saving effects of policy summed across all IEA countries.
Modified from: International Energy Agency, *Saving Oil in a Hurry*, 2005.

Oil Depletion Protocol: [175] The Association for the Study of Peak Oil (ASPO) is promoting a protocol to governments worldwide as the basis of an international agreement to slow the rate of oil depletion in the face of Peak Oil. The crux of the agreement is that:

1) Producing countries must cut back production to match their individual depletion rate, and
2) Importing countries must cut back their consumption to match the global depletion rate.

The protocol is potentially a very powerful tool for achieving an international agreement on a plan to manage the peak oil transition.

[175] Also known as the "Uppsala" or "Rimini" Protocol, after the two international peak oil conferences at which it was first presented, by Colin Campbell, the founder of ASPO, The current draft of the protocol can be viewed at **http://www.postcarbon.org/initiatives/oildepletion**.

Downside Risks of Government Actions

Because government decisions are usually centralized, there is an inherent danger that ruling elites or corrupt heads of state will choose tactics to maximize their personal gain from the oil crisis, instead of acting in the best interest of their countries. Enormous sums of money will change hands. Equitable allocation of oil and gasoline will be volatile issues. Governments with large militaries will tend towards militaristic solutions.

Private Sector Strategic Actions (Individual and Business Tactics)

Many tactics are available to individuals and businesses, to the extent that they are free to direct their energies, resources, and investments towards outcomes that they perceive will promote their chances of survival.

Tactic P-1: Protect Against Short-Term Price and Supply Shock

A first response in the private sector will be to try to protect against price and supply shocks in the immediate and short term. The predominant mechanisms will be financial hedging, stockpiling, and cutting non-essential spending. Companies will try to avoid the uncertainty and volatility of the spot market by locking in long-term supply and delivery contracts. They may choose to invest in warehousing increased inventories, instead of relying on just-in-time supply. If conditions worsen, companies will shed staff and benefits, substituting contract labor as needed. Companies with spare cash may try to reap speculative profits by investing in energy sectors and commodities.

After cutting back discretionary spending on oil and basic living expenses, individuals may resort to hoarding gasoline supplies, and if conditions deteriorate, food, and possibly, cash and guns. Wealthy individuals can invest in ownership of scarce resources or power and transportation infrastructure.

Tactic P-2: Shift Priorities Towards Long-Term Sustainability

Effective actions to mitigate impacts from peak oil will require a shift in the perception of an action's "value" from the short-term gain or monetary profit derived to the long term benefit received. If taking a short-term gain means sacrificing the long-term survival of the organism, then thinking individuals (rather than "economically rational" ones) can choose to recalibrate the time-value of their actions and investments to favor long-term sustainability. Individuals and companies can "vote with their dollars" for:

Conservation/Efficiencies/Reuse: Energy saved creates "nega-barrels, "nega-watts" and "nega-dollars" not spent. Lovins argues that the cost of saving each barrel of oil or watt can be significantly less than buying the energy would have been.[176] This is one of the most powerful tactics available.

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[176] This is a constant refrain in Lovins' work. Many examples of "nega-" savings can be found in *Winning the Oil Endgame*.

Education: Time and money spent teaching (or learning) science, technology, history, and how to make and fix things - rather than toss them and buy new ones - will be repaid handsomely. Engineers (chemical, mechanical, electrical and nuclear) will be especially needed, as will people trained in high productivity, low-energy-input agriculture. Business schools will need to develop new models of sustainable economics.

Reduced Transportation: Individuals can switch to mass transit, fuel-efficient cars, and ideally shorter commutes. Companies can support this by allowing flexible workweeks and telecommuting. High fuel costs will shrink the global economy for manufacturing. Companies can restructure their processes to reduce the miles traveled by each product in its manufacture and distribution.

Local and Organic Agriculture: People can buy locally grown food in season, reducing food transportation miles. They can switch to organic foods, which require less fossil fuel inputs per unit of production because they don't use oil-based fertilizer and pesticides.

Research & Development: Renewable energy sources and technologies that make fuel use more efficient offer the best potential to fill the demand gap and slow the oil production decline. By definition, renewable energy sources will be the only ones available after the accessible fossil fuels are depleted. So the share of renewable sources in the energy mix can only increase between now and then.

Downside Risks of Private Sector Actions

Individuals and companies can make many decisions about how they use the remaining oil. In fact, private sector decisions to conserve oil could play a crucial role in prolonging the peak oil transition time. But ultimately, individuals, and most companies, don't have direct access to oil-in-the-ground or the infrastructure that delivers it, nor control over the armies that increasingly will determine where the oil ends up. To the extent that individuals and companies can achieve energy self-sufficiency through local, decentralized energy systems, they will have some control over their energy destinies. But they could find themselves at odds with governments that have different agendas for energy distribution. Furthermore, lone individuals, family units, or companies with resources will need to be prepared to defend themselves against the less fortunate.

Collective Strategic Actions
Tactics for Societal Groups

Individuals can choose to act within societal groups – defined by kinship, geography or other affiliation - which provide strength in numbers. Groups can form cooperative alliances, similar to governments, but groups are more likely to incorporate decentralized decision making and input at the local (community and regional) level. Within the context of the game, the primary aim of collective action tactics is to ensure a group's access to petroleum or other energy. In the real world, there is a growing movement towards "re-localization", where groups of people are consciously attempting to make their communities and economies more self-sufficient in anticipation of Peak Oil.[177]

Tactic S-1: Change Values and Reinforce Behaviors through Group Norms

One of the primary characteristics of groups is social norming, which imposes the group's behavioral values on the individual through his desire to be accepted and approved by the other group members. Ideas introduced by influential and respected members of a group are likely to be adopted with minimal resistance by the group. Individual members will also accept restrictions on their actions if they believe a) it is necessary for the good of the whole, and/or b) they will be ostracized if they do not conform. Use of established groups to educate members about peak oil and to encourage individual behavioral shifts towards conservation and efficient energy use could be a powerful and effective strategy to help accomplish a successful transition.

As liquid petroleum becomes scarcer, societal groups may well override individual choice to determine the best uses for the remaining oil. For example, a village could decide the best use of their allocated oil was to pump groundwater from a municipal well rather than to fuel SUVs of long-distance commuters. Or a town might prohibit gasoline powered leaf blowers, instead requiring in-situ mulching of autumn leaves.

Tactic S-2: Leverage Pooled Resources

The selectively pooled resources of individuals can give groups the ability to address collective needs cheaply and efficiently. Intentional communities, for example, often combine private home ownership with areas of common living, shared responsibility and group ownership of big-ticket tools and appliances like lawn mowers and rototillers.[178] Group leverage can also provide:

Food, Water and Energy: Groups can provide and/or store supplies of these basic requirements and oversee their equitable allocation according to the group norms.

Security and Protection: Groups can protect and assist their members during difficult times, such as loss of job or spouse, and can provide a greater level of security from physical danger than is available to unaffiliated individuals.

Votes: Large groups or alliances of groups can influence policy at the regional, state, and national level through their voting power.

Purchasing Power: Pooled financial resources and collective purchasing decisions can encourage local and regional businesses to provide the group's needs.

Mobs: Never underestimate the persuasive power of an angry group.

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[177] Julian Darley's Post Carbon Institute (www.postcarbon.org) was formed as an internet resource to pool the experience of groups that are attempting re-localization efforts. Within the New York region there are several re-localization initiatives, including "Sustainable Hudson Valley" and a county-wide effort in Franklin County.

[178] There are many intentional communities in the U.S., from a few surviving hippie communes, to semi-suburban enclaves of working professionals, such as Ecovillage in Ithaca, New York. A good starting resource for this topic is Community Solution in Yellow Spring, Ohio. See www.communitysolution.org.

Downside Risks of Collective Actions

Collective action is a powerful tool for addressing peak oil. But, groups do have their downside, especially in a culture like the U.S. that idolizes cowboys, rugged individualism, and personal mobility. Groups can stress conformity to the point of repression. Groups often become insular, suffer from provincialism, and sometimes foster hate crimes. Nonetheless, as petroleum, food and water become scarcer, group affiliation may be critical to getting supplies.

CHAPTER 6
STRATEGIC CHOICES – SOCIETAL PRIORITIES

Perhaps a crux of success or failure as a society is to know which core values to hold on to, and which to discard and replace with new values, when times change.

- Jared Diamond (Collapse, 2005)

Multiple tactics to meet the upcoming decline in petroleum production can be selected from the palette of strategic actions and combined into strategic approaches. The course of action Americans choose will depend largely on prevailing societal attitudes and values, as well as how long it takes for the peak to manifest itself. Several possible strategic approaches are considered below.

Four Possible Approaches to Transition to The Reduced Petroleum Economy

1) The American Way of Life is Non-Negotiable[179]: Hanging onto Lifestyle

This is Plan A, the publicly stated US policy position. It involves securing access to the world's oil at all costs, militarily if necessary. This course of action, which has defined America's foreign policy since before the fall of the Soviet Union, is based on the premise that America's security and economic well-being depend on its global hegemony as the sole superpower. [180] The attitude also reflects a political reluctance at the highest levels to ask Americans to reduce their oil consumption in the face of emerging supply tightness. Using this strategy, there is no preparation for a peak oil crisis, other than market signaling and the continuing efforts of the US government to secure access to oil through military threats and interventions.

2) To the Victors Go the Spoils: Privatization of the World's Energy

This approach is closely related to Approach #1, but transcends national boundaries and involves active investment by certain private sector groups to protect themselves and profit from

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[179] President George Bush, Sr., speech at Earth Summit on the Environment, Rio de Janeiro, 1992. However, the quote is usually attributed to Vice-President Dick Cheney.

[180] Most influentially articulated by Zbigniew Brzezinski, *The Grand Chessboard: American Primacy and its Geostrategic Imperatives* (New York: Basic Books, Perseus Books Group, 1997) and Donald Kagan, Gary Schmidt, and Thomas Donnelly, *Rebuilding America's Defenses: Strategy, Forces and Resources for a New Century,* A report of The Project for the New American Century (2000).

the upcoming crisis. In this case, the global elite (transnational corporations and wealthy families) attempt to gain control of the remaining oil supplies, principally through privatization of nationally held resources. Their investments are protected by private security forces or government-provided armies. Public utilities are also privatized, thus transferring control of energy distribution and mass transportation to the private sector. The government may act at behest of the elites to ration some oil to the populace, while keeping less restricted supplies for themselves.

3) What Color is Your Parachute? Full-scale Preparation Effort

This approach assumes that people become aware of the pending crisis and its magnitude early enough to try to prepare. The government institutes a full-scale, multi-faceted effort to meet the challenge, using every viable tactic in its arsenal. It puts the country on a "war footing" through a massive education campaign and begins extensive conservation and R&D efforts, as well as investment in energy and transportation infrastructure. It intervenes to achieve immediate oil demand reduction via fuel taxes, gasoline rationing, and incentives for more efficient travel. Finally, the government enacts a sustainable national energy policy and pursues international cooperative agreements on production and allocation of a depleting world oil supply. The private sector, after employing short-term tactics to protect themselves from oil supply shock, starts shifting values, intellectual effort and investment dollars towards long-term energy sustainability. They cut oil consumption while making aggressive investment in renewable energy sources, efficiencies, mass transportation and local agriculture. Societal groups reinforce the value shift towards conservation, efficiencies and sustainable technologies and pool resources to leverage their impacts.

4) Small is Beautiful[181]: Power Down to Sustainable Communities

Under this approach, people begin a conscious move away from centralized government and towards self-sufficient, intentional communities and regional alliances, in the belief that they can scale back consumption significantly while still maintaining a comfortable standard of living and actually enhancing quality of life. Personal, business, and social tactics focus on efficient technologies, conservation, local renewable energy sources, reduced transportation use of oil, regional food sources and local livelihood.[182] This approach is independent of, and may end up at odds with, Government tactics that are simultaneously employed.

Speculated Playouts under the Four Approaches

Possible endgame outcomes for each of the four strategic approaches under each of the five states of nature are shown in Table 6. The consequences of selecting each approach are summarized and compared in Table 7 and discussed below.

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[181] After E.F. Schumacher's seminal book, *Small is Beautiful: A study of economics as if people mattered*.

[182] These tactics epitomize the values of participants at the Community Solutions to Peak Oil Conference, held in Yellow Springs, Ohio in 2005.

Table 6

Possible Endgame Outcomes Under Different States of Nature

	States of Nature - Timing of Peak Oil				
	A **Pollyana**	**B** **Optimist**	**C** **Plateau**	**D** **Pessimist**	**E** **Head-for-Hills**
Years til Peak	40+	15-30	5-15	0-7	0-2
Probability of Occurrence	1%	10%	35%	40%	14%
Strategic Approach					
1) Non-negotiable American Lifestyle	Nuclear Armageddon Resource Wars	Nuclear Armageddon Resource Wars	Nuclear Armageddon Resource Wars Economic Tailspin	Nuclear Armageddon Road Warrior Resource Wars Economic Tailspin	Nuclear Armageddon Road Warrior Resource Wars Economic Tailspin
2) To the Victor go the Spoils - Privatize Resources	Resource Wars Corporate State	Resource Wars Corporate State	Resource Wars Military State Economic Tailspin Corporate State	Resource Wars Military State Economic Tailspin Corporate State	Military State Economic Tailspin
3) Parachute - Full-scale Preparation	Agrarian Democracy Local Economies Sustainable World	Agrarian Democracy Local Economies Sustainable World	Corporate State Agrarian Democracy Local Economies	Military State Economic Tailspin Corporate State	Military State Economic Tailspin
4) Small is Beautiful - Power Down/Re-localize	Nuclear Armageddon Economic Tailspin Military State Agrarian Democracy Local Economies	Nuclear Armageddon Military State Economic Tailspin Agrarian Democracy Local Economies	Nuclear Armageddon Military State Economic Tailspin Agrarian Democracy Local Economies	Nuclear Armageddon Military State Economic Tailspin	Nuclear Armageddon Military State Economic Tailspin

Available Outcomes	Years to Implement	Desirability Rating
Nuclear Armageddon	0-2	0
Road Warrior	5-30	10
Resource Wars	2-15	15
Military State	1-5	20
Economic Tailspin	0-5	30
Corporate Nation State	2-15	50
Agrarian Democracy	5-15	70
Local Economies	10-25	80
Sustainable World Economy	20-30	100

Table 7

Comparison of Four Strategic Approaches to Managing the Transition From Peak Oil Production to a Reduced Petroleum Economy							
STRATEGIC APPROACH	**TACTICS EMPLOYED**	**LEVEL OF PREPARATION**	**TRANSITION TIME**	**POST PEAK DESCENT**	**AVAILABLE ENDGAME OUTCOMES**	**DESIRABIL-ITY SCORES**	**EXPECTED VALUE OF PAYOFF**
The American Way of Life is Non-Negotiable	M-1 G-1 (Military)	Govt. – Low Public - None	Abrupt 0-2 years	Very Steep, Bumpy, Hard Landing	Nuclear Armageddon Road Warrior Resource Wars Economic Tailspin	0 10 15 30	**14**
To the Victor go the Spoils (Privatization of the World's Energy)	M-1 G-1 (Military) G-2 (rationing) P-1	Govt. – Low to Moderate Corp./Elites – High Public - Low	Short to Moderate 2-15 years	Steep, but Controlled	Resource Wars Military State Economic Tailspin Corporate State	15 20 30 50	**29**
Parachute **(Full-Scale Preparation)**	M-1 G-1 (Trade&Aid) G-2 (rationing, fuel or carbon taxes, incentives) G-3, G-4 P-1, P-2 S-1, S-2	Govt. – High Public - High	Moderate to Long 15-30 years	Plateau to Gradual Less Bumpy Softer Landing	Military State Economic Tailspin Corporate State **Agrarian Democracy** **Local Economies** **Sustainable World**	20 30 50 **70** **80** **100**	**49**
Small Is Beautiful: **(Power Down/Re-localize**	M-1 P-1, P-2 S-1, S-2	Govt. - None Public - Mod. to High	Short to Moderate 2-15 years	Steep. locally moderate. Softer Landing	Nuclear Armageddon Military State Economic Tailspin **Agrarian Democracy** **Local Economies**	0 20 30 **70** **80**	**27**

Key: M-1: Market pricing; G-1: Government secures the oil; G-2: Market interventions; G-3: Government Research&Development; G-4: national and international policy; P-1: private actions to avert price/supply shock; P-2: investment shift to long-term sustainability; S-1: social norming: S-2: leveraged resources. **Preferred outcomes shown in bold.** The expected payoff values are calculated from the average desirability scores for the outcomes for each given strategy/state of nature, weighted by the probability of occurrence for the given state of nature.

1) Non-Negotiable American Way of Life

This approach has the effect of driving full speed ahead with the breaks removed. Following it, Americans become even more insular in attitude and militaristic abroad. Resource wars are conducted full-time, through direct intervention and surrogates. The trade deficit for oil and the national debt spiral out of control, and the country has trouble financing its 20+ million barrel/day petroleum habit, but does not cut back consumption. Within the Muslim world, hatred of Americans kindles increased terrorism and sabotage of oil infrastructure. China and the U.S. risk war over access to the remaining oil supplies.

Without any warning or preparation, the transition to post-peak oil production - no matter if now or in 20 years - hits the public abruptly. The resulting decline in oil availability can only be solved through brutal demand destruction through pricing and supply disruptions. Economic hardship and dislocation is extreme. Probable outcomes are increasingly violent and militaristic in the short term, and chaotic in the long term, resulting in the breakdown of government and society. In the short term, Continuity of Government (COG) plans are enacted, resulting in a U.S. military state until the populace rebels. Final outcomes potentially include Nuclear Armageddon under an abrupt transition scenario or Road Warrior under a gradual transition scenario.

2) To the Victors Go the Spoils

This scenario plays out similarly to the first with respect to ongoing resource wars and the exploding government trade and budget deficits. The wholesale transfer of public assets to the private sector creates dangerously imbalanced social equity and wealth. National boundaries and governments cease to have more than symbolic meaning. Those holding real assets, especially oil, wield great power (pun intended). But now, rightly mindful of barbarians at the gate, the elites must reside in walled compounds protected by armies. The middle class finds itself increasingly powerless, and unable to afford an independent and mobile lifestyle. In debt beyond their wildest imagination, they are forced to sign long-term, low-wage contracts to work for the elite businesses that can offer them debt relief, physical protection, and a chance to earn enough to buy the basic necessities. Although Economic Tailspin and Military State outcomes are both possible under an abrupt transition, the most stable outcome achievable under this approach is Corporate Nation States.[183]

Under this strategy, the American way of life is highly negotiable; the middle class' current access to cheap energy is transferred to the highest bidder. With corporations and wealthy elites holding all the assets and managing the post-peak transition, the decline is neither as steep nor as bumpy as under the non-negotiable American lifestyle approach. However, this approach creates significant resource allocation, security, and liberty issues for most of the US population.

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[183] Apologies to Neal Stephenson, to whom I owe credit for the Corporate Nation State vision, which I have lifted, altered and diluted from his futuristic novels *Snow Crash* and *The Diamond Age*.

3) Parachute: Full-scale Preparation Effort

Under this scenario, the unplanned outcomes on the matrix are avoided. However, the abrupt undesirable outcomes of Economic Tailspin and Military State are still possible if the onset of peak oil occurs before the preparation efforts are put into effect or have time to achieve results. With a short time horizon, the "hard landing" will not be averted. Demand destruction will occur through harsh price shocks and economic depression and/or militarily enforced reduction of oil consumption. But with sufficient preparation time for conservation to curb demand and investment to develop alternative and efficient technologies and mass transit, the slope of the oil decline curve would be less steep and bumpy than under any of the other scenarios. With full-scale preparation for a long enough period it might be possible to achieve the three most acceptable outcomes – Agrarian Social Democracy, Local Economies, and Sustainable World Economy.

4) Small is Beautiful: Power Down/Re-localize

Under this approach, individuals and local groups that manage to scale down their energy requirements and switch to local jobs and food sources are able to insulate themselves to some degree from the price shocks and hardships that face the unprepared. Given sufficient time, these groups could establish viable Local Economies. With sufficient numbers, they could attain enough political clout to affect energy policies and resource allocation within their regions. Different regions would develop different survival strategies, depending on their unique geography and demographics as well as their natural resource endowment. Agrarian Social Democracy models might be selected in some areas. Many communities would undoubtedly fail. Hardship could be the norm. Successful communities would need to build defenses and alliances to protect themselves from hungry, migrating hoards.

As with the other three scenarios, an abrupt transition to post-peak oil would still result in undesirable outcomes. Because the Small-is-Beautiful approach cannot exert restraining influence at the national level, the Nuclear Armageddon outcome remains possible under this scenario.

Selecting the Preferred Strategy

Before choosing one strategy over another, it is useful to bracket the range of possible payoffs and opportunity loss risk. The expected payoff values shown in Table 7 assumed that every outcome assigned to a strategy under a given state of nature had an equal chance of occurring. A realist would use this method to calculate the odds. An optimist, however, would consider the best possible outcomes and the maximum they might win through their gamble, while a pessimist would look at how much potential payoff they would leave on the table by making the wrong decision. Table 8 shows the best outcome available under each strategy for a given state-of-nature and the probability-weighted best payoff score. In contrast, Table 9 is an opportunity loss table. It compares the maximum scores attainable for each strategy under each state of nature, and calculates how much gain would potentially be foregone by not selecting the winning strategy for that state.

Table 8

Oil Endgame Payoffs
Best Possible Outcomes

	States of Nature - Timing of Peak Oil					
	A Pollyana	**B Optimist**	**C Plateau**	**D Pessimist**	**E Head-for-Hills**	**Probability-Weighted Best Outcome**
Years til Peak	40+	15-30	5-15	0-7	0-2	
Probability of Occurrence	1%	10%	35%	40%	14%	
Strategic Approach						
1) Non-negotiable American Lifestyle						
Best possible outcome(s)	Resource Wars	Resource Wars	Economic Tailspin	Economic Tailspin	Economic Tailspin	
Best possible score	**15**	**15**	**30**	**30**	**30**	**28**
2) To the Victor go the Spoils						
Best possible outcome(s)	Corporate State	Corporate State	Corporate State	Corporate State	Economic Tailspin	
Best possible score	**50**	**50**	**50**	**50**	**30**	**47**
3) Parachute - Full-scale Preparation						
Best possible outcome(s)	Sustainable World	Sustainable World	Local Economies	Corporate State	Economic Tailspin	
Best possible score	**100**	**100**	**80**	**50**	**30**	**63**
4) Small is Beautiful - Power Down/Re-localize						
Best possible outcome(s)	Local Economies	Local Economies	Local Economies	Economic Tailspin	Economic Tailspin	
Best possible score	**80**	**80**	**80**	**30**	**30**	**53**

Table 9

Opportunity Loss Risks to the Oil Endgame
if Non-Optimal Strategy is Chosen

	States of Nature - Timing of Peak Oil					
	A Pollyana	**B Optimist**	**C Plateau**	**D Pessimist**	**E Head-for-Hills**	**Probability-Weighted Opportunity Loss**
Years til Peak	40+	15-30	5-15	0-5	0-2	
Probability of Occurrence	1%	10%	35%	40%	14%	
Strategic Approach						
1) Non-negotiable American Lifestyle						
Best Possible Outcome, Chosen Strategy, Given State	15	15	30	30	30	
Best Possible Outcome, Any Strategy, Given State	100	100	80	50	30	
Potential Opportunity Loss	**-85**	**-85**	**-50**	**-20**	**0**	**-35**
2) To the Victor go the Spoils - Privatize Resources						
Best Possible Outcome, Chosen Strategy, Given State	50	50	50	50	30	
Best Possible Outcome, Any Strategy, Given State	100	100	80	50	30	
Potential Opportunity Loss	**-50**	**-50**	**-30**	**0**	**0**	**-16**
3) Parachute - Full Scale Preparation						
Best Possible Outcome, Chosen Strategy, Given State	100	100	80	50	30	
Best Possible Outcome, Any Strategy, Given State	100	100	80	50	30	
Potential Opportunity Loss	**0**	**0**	**0**	**0**	**0**	**0**
4) Small is Beautiful - Power Down/Re-Localize						
Best Possible Outcome, Chosen Strategy, Given State	80	80	80	30	30	
Best Possible Outcome, Any Strategy, Given State	100	100	80	50	30	
Potential Opportunity Loss	**-20**	**-20**	**0**	**-20**	**0**	**-10**

Not surprisingly, the highest payoffs obtainable under *any* state of nature occur when the Parachute – full-scale preparation approach is selected. As a direct consequence, the potential opportunity loss for the Parachute scenario is zero.

The non-negotiable American way of life is not a viable solution. The US no longer has the domestic oil to pull it off; it is too import-dependent. This strategy does not adequately acknowledge the new geopolitical realities of China's rise to Super Power status or Russia's re-emergence as an Oil-Have and the king of natural gas. Entailing both abrupt transition and zero advance planning, the odds for this strategy favor the Nuclear Armageddon outcome. The downside risks for the non-negotiable approach are greater than for any other scenario. It should thus be ruled out.

With the additional time and planning under the To-The-Victor-Go-the-Spoils approach, the Nuclear Armageddon outcome might be averted. After all, annihilation of the world as we know it would spoil any victory. However, the outcomes that are available to the Victor involve significant military control and hardship for the vast majority of people, and none is considered desirable.

The Small-Is-Beautiful approach has substantial merit. Two acceptable outcomes are possible and individuals and societal groups can start preparations immediately, without waiting for the government to take action. The downside risks of not selecting this approach are very low. But without government investment in infrastructure and international cooperation to allocate the oil between nations, this strategy cannot control the larger forces that could lead to Resource Wars, Nuclear Armageddon, or a Military State.

Therefore, assuming we don't belong to a group that actually desires Nuclear Armageddon or collapse, that we'd like some sort of free future for our children, and that the Cornucopians are probably (99%) wrong, the rational thing is to choose the Parachute approach. That is, to start full-scale preparations immediately. Frankly, given the stakes, we should simultaneously employ the Small-is-Beautiful approach and any other strategies that have a chance of improving the outcome.

Uncertainty Risk

Time is the critical success factor. We do not know which state-of-nature concerning oil reserves is true, although increasingly, the evidence supports the more pessimistic calculations of oil production peaking between 2005 and 2015. Looking at timing from a triage standpoint, the prevalent attitudes are:

1) <u>Pollyanna or Optimist Scenario:</u> Peak Oil is too far in the future to worry about. No action is needed.
2) <u>Plateau or Pessimist Scenario:</u> Peak Oil could occur any time over the next 10 to 20 years. Start full-scale mitigation now (need minimum 20 years). The sooner mitigation starts, the more of the "gap" it will be able to fill.
3) <u>Head-for-the-Hills Scenario</u>: Peak Oil is now. Things have progressed beyond the tipping point. Actions initiated now will not be able to reverse the course of events. Save yourself if you can, but give up on the rest.

Attitude #1 is unduly risky; the consequences of being wrong by starting mitigation too late are severe. Attitude #3 is fatalistic and a self-fulfilling prophesy; the consequence of being wrong is that patient will still die. As Tables 6,8 and 9 show, there is no acceptable outcome available under the Head-for-the-Hills scenario. The best that can be hoped is to avoid Nuclear Armageddon. My personal triage decision is therefore to choose attitude #2 – to act where there is some hope of improving the outcome.

The consequence of starting actions prematurely is relatively minor, and furthermore unlikely. With significant lead times of 15-30 years needed before peak to effect a planned transition, we already have a late start. Matthew Simmons notes that the US has no viable Plan B for a post-petroleum economy. His recommended Plan B is therefore to use every resource at our disposal to buy time to develop a Plan C.[184] As the payoff tables demonstrate, the longer Peak Oil can be postponed and/or a production plateau maintained through immediate actions to reduce the consumption rate, the better the set of possible outcomes and the higher chance of achieving a desirable one. Though we can't control the state-of-nature with respect to the world's recoverable oil endowment, we may be able to affect the shape of the downward slope.

A Question of Societal Values

Ultimately, our choices will come down to individual and societal values. What will Americans be willing to give up in exchange for high-priced oil when their credit runs out? Their big houses? Their leisure time? Their retirements? Their children's future? Their freedom? What will they be willing to give up to transition to a lower fuel economy, where every year there is less available than the year before? Their personal mobility? Their dreams of upward mobility? Their expectations of exponential growth? Their place in the world?

What is the potential upside to reducing petroleum consumption? Shorter commutes, a less frenetic pace, a healthier life style, greater interdependence with family and community, greater self-sufficiency, more time to read and play music, less debt, survival. Though "standard of living" will have to fall, it may be possible to achieve a higher quality of life. Studies have repeatedly shown that, once a certain basic level of needs is met, happiness and wellbeing do not correlate well to either wealth or per capita energy use.[185]

A key societal question is whether the decisions about our energy future will be made at a centralized or local level, and how much influence or independence the average person will have

[184] Given enough transition time and an all-out investment of resources, Hirsch, Simmons, Lovins, Bartlett, Woolsey, and even the pessimist Deffeyes, believe we could end up in 20–30 years with a sustainable non-petroleum economy. But they are all petrified about the short-term prospects if we don't start a war-scale effort immediately. All of these men have put their considerable reputations at stake to lobby the White House and to go out on the lecture circuit to plead for immediate action. The MIT World3 Limits-to-Growth modelers also concluded that a sustainable future was possible, but only if preparation was started immediately.

[185] The World Bank has published world values surveys comparing happiness to GNP/capita (*World Development Report* 1997). See also, Vaclav Smil (*Energy at the Crossroads*, 95-107), which summarizes research comparing per capita energy use to quality of life indicators such as infant morality, female life expectancy, human development, political freedom, etc. See also Jason Ventoulis and Cliff Cobb, *The Genuine Progress Indicator: 1950-2002 (2004 Update)*, Sustainability Indicators program, Redefining Progress, March 2004 (www.rprogress.org). The genuine progress indicator (GPI) includes social and environmental costs.

to participate in those decisions. Another key question will be whether we can change our definitions of present and future net economic value to cross generations.[186]

Environmental Welfare: Green Concerns versus the Economy

As fuel becomes scarcer and people become desperate to maintain the same level of comfort and mobility, environmental regulations are likely to be relaxed or repealed. Even pre-Peak the US government has proposed revisions to rules for offshore drilling, permitting of coal-fired power plants, and eminent domain to site critical energy infrastructure such as LNG terminals. Some of the mitigating actions for Peak Oil will therefore put environmentalists on a collision course with government and businesses. But, as Richard Heinberg notes:

> The lifestyle of the typical U.S. environmentalist is only slightly less destructive than that of the average economist. Their incomes will disappear as rapidly as those of the economist when fossil fuels deplete. Economists ignore the environmental problems while environmentalists ignore the deeper causes....But until environmentalists grasp the implications of Peak Oil, they will be satisfied to replace a Ford with a Toyota Prius, assuming that the relatively small improvement in mileage will allow our wasteful lifestyle to continue. [187]

To be productive, the dialog will need to shift from environmental purity at all costs to long-term sustainability of both resource use and the carrying capacity of the environment.

[186] Agricultural economist John Ikerd (*Sustainable Capitalism*) believes one of the fundamental flaws in our current time-value of money equations is that the present value of an investment is considered only with respect to the generation making the investment, whereas the future value may accrue to the next generation, who may place quite a different value (negative or positive) upon the investment. This helps explain why people choose consuming resources now versus saving them for later, possibly different, generations.

[187] "*Peak Oil – Peak Economy*" in *New Solutions*, Number 5, April 2005. Available online at www.communitysolution.org

CHAPTER 7
FAILURE ANALYSIS:
WHAT COULD POSSIBLY GO WRONG?

Sometimes I wonder whether the world is being run by smart people who are putting us on or by imbeciles who really mean it.

- Mark Twain

We have met the enemy, and he is us!

- *Pogo*[188]

A key component of successful strategic planning is failure analysis. Internal system weaknesses and points of vulnerability can interfere with successful implementation of even the best plan. Unforeseen external events can make a former plan of action worthless. Prudent managers therefore identify the factors and events that are most likely to keep them from achieving their objectives. Failure contingency plans can then be designed ahead of time. The biggest impediments to managing the transition to a post-petroleum world are likely to be barriers to investment in the solutions, and human resistance to admitting the problem and changing behavior.

Barriers to Investment in Increased Oil Production and Alternative Energy

Major international oil companies are not pumping a very high percent of their record profits into increased exploration, production or refining capacity. Instead, they have been shedding marginal properties to smaller oil companies, using their cash balances to buy natural gas and coal companies, paying shareholder dividends or buying back shares. Why? The biggest reason is that risks are high, but the expected return on investment is not.

Return on Investment

Historically Poor Margins

The petroleum business has historically operated on boom/bust cycles. Oil exploration produced poor marginal returns over the past 20 years because it cost more to look for new oil

[188] Walt Kelly's comic strip hero.

than the new, generally lower quality fields would be worth at current market price.[189] The oil glut of the mid-1980's though 1990's also made oil refining a very low-profit business, and investors are still gun-shy. Even with tripling oil prices over the past 3 years, investors fear spending billions in new refinery capacity only to end up with overcapacity. There's also not much incentive to build new refineries if oil production has, or is about to peak. A decrease in the current rate of crude oil inputs would guarantee refinery overcapacity.[190]

Rising Exploration and Production Costs

Exploration, development, and production have all become more expensive in the past five years. Rising cost factors include:

Work in Extreme Environments: Increasingly the oil industry works in polar regions, deepwater, ultra-deep water, and politically volatile regions that require significant logistical support.

Short Supply of Rigs, Ships, People: Years of industry consolidation have resulted in a tight supply of drilling rigs, seismic exploration vessels, trained geologists and engineers, etc.[191] Currently, these factor costs are being determined in bidding wars.

Production in Environmentally High Risk Areas: The Gulf of Mexico suffered category 5 hurricanes in the past two years. Each time, production was shut-in, platforms were destroyed, rigs lost, and new projects delayed. Insurance companies are seriously re-assessing their risks and re-evaluating the premiums to insure energy companies in hurricane-prone areas.[192]

Production in Politically High Risk Areas: Many oil regions – e.g., Nigeria, Iraq, etc. - are politically volatile. Both industry personnel and infrastructure can be targeted for terrorism and sabotage.

Decreasing EROEI: It takes more energy to find and get oil out of mature fields and marginal environments. Combined with rising energy prices, this means significantly higher input costs for each barrel of oil extracted.

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[189] Wood Mackenzie reported in 2004 that the top-10 oil companies collectively spent about $8billion on exploration in 2003, discovering field with a net present value of only $4billion. While noting record oil prices would likely lead to rising exploration spending, they cautioned "a number of constraints will continue to act on exploration performance, the most important of which being access to material opportunities". (*"Top oil groups fail to recoup exploration costs"*, reported in Financial Times, carried in New York Times, Oct. 10, 2004.)

[190] Simmons notes that energy investors won't put money into refineries because they expect them to have only a 1% return on investment.

[191] One indicator of the skilled manpower shortage: the average age of petroleum engineers is 51. (*"Oil Industry Struggles to Patch Holes in the Pipeline"*, New York Times, Oct. 28, 2005.

[192] Towers Perrin Tillinghast, *Hurricane Katrina: Analysis of the Impact on the Insurance Industry,* October 2005. The report refers to scientific studies indicating that the underlying cause of increased hurricane intensity may be due to global warming. If so, then hurricane damage can be expected to increase in the future. Instead of a 100- or 500-year storm, magnitude-5 hurricanes in GOM may become 10- or 50-year storms.

Cost of Entry

The size of investment required is enormous for offshore exploration/production, pipelines, LNG tankers, loading/offloading terminals, etc. Entry cost to the large-scale, centrally controlled alternative energy/efficiencies game - railroads or mass transit, wind farms, solar arrays, hydrogen, nuclear power, etc. – is also prohibitive to all but governments or large multinational corporations. Development of wind farms and solar arrays, however, may be scalable. Most large entities will not be interested in developing small-scale alternative energies that are used off-the-grid, because they will not be able to sell metered energy through them. There are therefore market niches for small- to medium-sized companies and entrepreneurs in scalable renewable energy fields like local wind farms and solar arrays linked to hydrogen fuel cells.

Uncertainties and Financial Risk

Companies considering investment in energy production must weigh the financial risks inherent in a volatile market. These include:

Uncertainty of Future Oil Price: Two years ago, oil companies based investment decisions on an assumed future cost of $25/bbl oil. Today they use $45 to $50. But what is a realistic price to use for a project that won't pay off for two to ten years?

Uncertainty of Future Cash Flows: Future price, demand, and availability of product are all more unpredictable than they have ever been.

Insurance Risk: The actuaries keep recalculating the payout risks and premiums for extreme weather, terrorism, and nationalization of oil fields.

Short Investment Horizon

Perhaps the major problem with the current economic/business model is that it is driven by shareholder expectations of immediate gain. The need to report quarterly profits to shareholders may interfere with a company's ability to invest in long-term projects. It is very hard to "sell" an investment that will not payback for many years in this culture.[193] In the 1980's, businesses had retreats to talk about their 5-year plans. Those disappeared in the 1990's, replaced by annual and quarterly projections. Today, it is a rare company that has a 10-year vision.

Value is a collectively held, subjective belief. The determination of the net present and future value of investments will shift with time as more people realize that some things (oil, some metals, clean drinking water) will be enormously more valuable in the future than they are now. Even in the current bull market for commodities, energy resources are still undervalued with respect to their future worth.

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[193] However, Toyota Motor Company did just that with development of its Prius hybrid car technology. Japan has no oil of its own, and Toyota determined in the early 1990's that high-efficiency cars would command a premium within a decade or two. It therefore invested heavily on a visionary gamble to be the industry leader in hybrid gasoline-electric technology. Toyota created a "skunk works" type division, gave it a mandate, a deadline and free rein, then ran the division at a loss while they sewed up over 300 patents. Today Toyota is the undisputed leader in hybrid autos, licensing its patented technologies all over the world.

Behavioral Hurdles

Acknowledging the Elephant: Aligning Perception with Reality

The cognitive disconnect between the officially stated position and what is actually known about the energy situation must be resolved before any constructive mitigating actions can be taken. Acknowledgment of a problem is a prerequisite to voluntary behavior change.[194]

One of the main Peak Oil transition problems is communicating the information so that it is received and assimilated, not blocked. Research in the field of cultural cognition has shown that people will reject information that is not consistent with their existing beliefs, unless it is delivered by someone they consider credible, i.e., someone whom they believe shares their cultural values[195]. This is why it will be important for peak oil education to be disseminated within groups by trusted members.

Recalibrating Expectations in the Persistence of Belief

Humans and human systems resist change. The reality of peak oil contradicts the lifetime experience of everyone alive today. The implications of a constantly diminishing, rather than increasing, oil supply are literally unthinkable to most people. Denial will understandably be the most pervasive first response.[196] People will not accept information indicating that their present lifestyles and expectations are not sustainable. They will attribute the early manifestations of long-term supply constraints to other, temporary causes – hurricanes, disruptions due to war or terrorist acts, lack of investment in refining capacity or new exploration prospects, greed of the oil companies, etc.

As uncertainty grows about the long-term viability of supply, there will be attempts to "shoot the messenger". Those most invested in protecting the status quo will attempt to discredit the sources of information and people will grasp at implausible reassurances from public figures and officials that there's no cause for alarm.[197]

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[194] President Bush's statement that "America is addicted to oil" in his 2006 State of the Union Address, acknowledged the consumption part of the equation, but did not admit the long-term structural supply problem or the impossibility of kicking the imported oil habit when domestic supplies are sufficient to meet America's full oil needs for less than 4 years. His words in that venue constitute high-profile signaling, perhaps a prelude to mandated conservation or rationing.

[195] Dan M. Kahan and Donald Braman, "Cultural Cognition and Public Policy". June 2005. Yale Law School, Public Law Working Paper No. 87.

[196] This observation is common in Organizational Behavior and Change Management literature. People must move through the stages of denial, anger, loss, and acceptance before they are willing to consider any actions that will change the status quo.

[197] Witness the loud pronouncements in Spring 2005 from Saudi Arabian officials about their ability to increase production to 18 mbd for the next 50 years, immediately preceding publication of Matt Simmon's book *"Twilight in the Desert"*. Yet throughout 2005, Saudi Arabian oil production held fairly close to 9.5 mbd, even after the hurricane supply disruptions in the Gulf of Mexico increased demand.

Gaming the System

Another major impediment that we collectively face is the universal impulse for individuals to try to beat the system – to win if possible, or at minimum not to be chumps. Games that will influence our choices of behavior include:

Jevons' Paradox[198]: When one player conserves a resource, the other players can consume his savings. Thus, if conservation is not universally employed (or imposed) it can rapidly become a Sucker's game.

Zero Sum Game: In a finite resources game, one side's increase in consumption is another side's loss. When the available resource diminishes every year, it's actually a Less-than-Zero-Sum game. Players are knocked out, like in musical chairs.

Market Speculation: People will not be able to resist the chance to profit from speculating in the energy crisis. The compulsion to gamble for the last dollar on the table will divert time and resources away from preparation and long-term investments to achieve a successful transition.

Nash Optimal Solution: If the optimal collective outcome involves all sides foregoing the maximum-gain play, then each player has to trust that all the other players will act in the best interest of the group, rather than take the prize. No one will be willing to make the first move.

Culture of Immediate Gratification

Like investors with a short investment horizon, many people in the developed world have become accustomed to satisfying their wants on demand, in exchange for cash or credit. They buy prepared meals. They landscape with 80-year old trophy trees. They seldom invest their time and energy in projects that will not pay off within their own rather short attention span. Exhibiting similar behavior, politicians wont back or fund projects that will not pay off within the current election cycle. In fact, the two- to four-year election-cycle may be the biggest institutional constraint to successfully initiating long-term government policies to address peak oil.[199]

The Value of System Shock in Change Management

Organizational change managers and risk assessors recognize that most people will not voluntarily alter their behavior unless they have been subjected to a system shock of some sort. Following the shock, a window of opportunity opens, within which people are receptive to

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[198] William Stanley Jevons, a coal economist during the early Industrial Revolution and one of the fathers of utility theory, noted that efficiencies that save energy lower the price of using the energy, thereby increasing demand, which results in more energy being used than before the savings.

[199] Intelligence analyst, Jeff Vial, talking with senior executives in the Department of the Interior about Peak Oil concluded that "there is a structural block to the solution to this problem....It just isn't politically realistic to back a project that won't pay off in time for the next relevant election cycle—even if you could find politicians that would be willing to sacrifice their own re-election for the greater good, they would still be hamstrung by the unavailability of the campaign funding which they require, and would likely lose in the next election to a candidate who is promising a short-term benefit." (*Smoke & Monetary Policy*, published by Theory of Power, March 27, 2006. Available at www.energybulletin.net)

different modes of thinking, acting and organizing.[200] Both price shock and supply shock should become increasingly common as we near and pass peak oil.

Oil Supply shock: Following the OPEC oil shocks of 1973 and 1979, people did change their values for a few years towards energy conservation and cars with better mileage. The Cubans changed their entire economy, including transportation and agriculture, when their oil supply was cut off after the collapse of Russia.[201] Surprisingly, however, Hurricanes Katrina and Rita in 2005, which wiped out 25% of Gulf of Mexico production for several months, did very little to alter American behavior.

Oil Price Shock: Not only oil price, but its volatility have increased greatly in the past few years. Some analysts (e.g., Stephen Roach, Matt Simmons) have predicted price spikes to over $100/barrel, but Simmons has also predicted that people won't change their driving behavior until gasoline is $7-$8 at the pump. It is the uncertainty of prices that will cause businesses to reduce their demand. As Chapter 1 showed, oil price shock historically leads to recession, a time-honored way of reducing demand.

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[200] For example, the terror attacks of 9/11 changed American's willingness to preemptively attack the Middle East. Zbigniew Brzezinski in his 1997 book, *The Grand Chessboard* had predicted that American public would not tolerate military invasions of Central Asia unless preceded by a shock of Pearl Harbor magnitude.

[201] Megan Quinn and Patrick Murphy (2005 talk at Community Solutions Conference).

CHAPTER 8
CONCLUSION: LEMMINGS-IN-THE-KNOW

Human history more and more becomes a race between education and catastrophe.

- H.G. Wells

It is by now obvious that world oil production faces serious constraints to expanding. Exploration and refining infrastructure is operating at capacity, yet it may not be profitable to invest in capital expansion. New oil discoveries have not offset the yearly depletion of existing fields since the 1980's. Whether or not world oil production will peak in 2005 or 2025 is not the critical question; we have already rolled over to a sellers' market because demand exceeds the rate at which oil can be supplied. With little sign of demand abatement from the US or Europe and skyrocketing demand from China and India, we are drawing down the capital of our oil endowment at an alarming rate. From this point onwards, we can expect supply disruptions, price spikes, and oil shocks.

The petroleum-based world economy has therefore reached a tipping point. Fierce competition for the remaining oil resources will increasingly drive the markets, as well as national and foreign policies. The strategic choices we make now about how the 2nd half of the world's oil should be used will determine how violently and abruptly we descend Hubbert's Peak.

Since a finite resource problem cannot ultimately be solved from the supply side, we must use every tool at our disposal to reduce demand and develop substitute energy sources. Market pricing and oil shocks will undoubtedly play a significant role in demand destruction in the long run. But market solutions will exacerbate distribution inequity and political unrest by excluding all but the wealthy from oil. Cogent government energy policies to allocate oil and reduce demand will be required. The most effective are likely to include combinations of non-price rationing, fuel consumption taxes, and incentives for conservation and alternative energy use.

However, the biggest hurdle to overcome in reducing oil consumption is human nature. Denial is the first recourse, followed by a fighting instinct to preserve the status quo. Cataclysmic perceptual and behavioral shifts will be required before individuals voluntarily reduce their oil consumption. Education and discussion of the issues surrounding peak oil are crucial if we are to manage our inevitable transition away from fossil fuels with any hope of preserving a civilized society.

As for the post-carbon economy, there is currently no viable plan B. A full-scale transition effort is urgently needed. The top priority should be to buy as much time as possible to develop sustainable alternative energy sources. Individuals, villages, states, and governments need to begin investing in mass transit, energy efficiencies and renewable energy. Before they will agree to that, they need to believe that the future value of those investments is worth forgoing other investments or consumption today. Once people grasp the realities of peak oil, a longer investment horizon becomes possible. We must value the world's remaining oil resources as our primary, ever dwindling asset to build the bridge to the future.

The World is too much with us; late and soon.
Getting and spending, we lay waste our powers.

-William Wordsworth

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U.S. Department of Energy (DOE) (www.doe.gov)
U.S. Energy Information Administration (EIA, part of DOE) (www.eia.doe.gov)
U.S. Geological Survey (USGS) (www.usgs.gov)

APPENDIX A

THE WORLD'S GIANT OIL FIELDS

(MATTHEW SIMMONS, 2002)

HUBBERT CENTER NEWSLETTER # 2002/1

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THE WORLD'S GIANT OILFIELDS
*How Many Exist?
*How Much Do they Produce?
*How Fast Are They Declining?

by
Matthew R. Simmons

Volumes of data are readily available on how much oil most countries produce along with data on each country's proven and/or possible reserves. Rarely, though, does data get published on the important individual oilfields making up each country's oil supply. For the past two decades, virtually no data has been released on any of OPEC's key producing oilfields. There is no published data on which of the universe of major oilfields have passed their peak production and are now in decline. There are certainly no published estimates on what these decline rates will become in the future. I have recently completed a lengthy study on the world's current population of giant oilfields. A copy of the full report is available upon request.

This study of giant oilfields does not focus on proven reserves. Instead, it focuses on what these fields now produce each day. I chose to define a giant oilfield as one which now produces in excess of 100,000 barrels per day. (While a field of this size is significant for any oil company, it only represents 1.3% of the world's daily supply.)

What I found, after extensive digging, is that a small percent of the world's oilfields comprise a surprisingly large percent of current daily supply. Almost all of the biggest giant oilfields are old. Many are very old. The new giants found over the past 50 years have been progressively smaller over time, particularly in terms of peak production rates.

There is an urgent need for better data on these critically important fields. It needs to be published on a timely basis so analysts can start tracking their production profiles. Otherwise, future macro-supply forecasts will all be based on estimates that do not even qualify as being "educated." The principal findings of this study of giant oilfields are summarized below.

THE POPULATION OF THE WORLD'S GIANT OILFIELDS

The world's 120 largest oilfields produce close to 33 million barrels a day, almost 50% of the world's crude oil supply. The 62 smallest of these "giant fields" account for 12% of the world's daily oil supply. In contrast, the fourteen largest account for over 20%. The average age of these 14 largest fields is **43.5** years.

Thirty-six giant oilfields that were all discovered more than 40-years ago still collectively produce close to 16 million barrels a day. In contrast, twelve giant oilfields found in the past decade together now produce less than one-tenth of this, or 1.5 million barrels a day, 2% of the world's daily supply. The world clearly has a bi-furcated oil supply in terms of both age of our important oilfields and the number of key fields propping up our production base. Another 20 to 25 new giant fields have been discovered but are still being developed. However, no new field whose development program is now underway is projected to have daily production in excess of 250,000 barrels. In sharp contrast, the world's 19 largest "old giant fields" still produce on average more than 500,000 barrels per day, in spite of an average age of almost 70 years!

Most of the world's true giants were found decades ago. In the past two decades, most oil and gas discoveries have been quite small fields. Occasionally a new billion-plus barrel oilfield is announced. But even these "giant" finds tend to be tiny, in terms of daily production, compared with the giant fields found 50+ years ago. The last four oilfields found with a productive capacity that exceeded one million barrels a day were China's Daqing field discovered in 1959, Western Siberia's Samotlor in 1965, Alaska's Prudhoe Bay in 1968, and Mexico's Cantarell field in 1976. After Cantarell, no new field has come close to this one million barrel a day production level. Only a small group of fields found post-1980 have ever produced 500,000 barrels per day, and many of these new giants are now small producers with natural depletion having taken its toll.

In the decade of the 1990s, more than 400 individually named oilfields were discovered. Only 2.5% of these now produce more than 100,000 barrels per day. In the last two decades, only three giant oilfield discoveries were made, all in the 1980s, whose daily production exceeded 200,000 barrels per day. They are Brazil's Marlim field (530,000 barrels per day), Columbia's Cusiana field (300,000 barrels per day), and Norway's Draugen field (215,000 barrels per day.) I was surprised to learn that so few giant oilfield discoveries with current production levels of 200,000 barrels per day were made in the last 20 years. I would have guessed that the number would be far higher.

Only a handful of deepwater projects are now under development whose peak production will get close to 250,000 barrels per day. Two or three recent onshore Middle East discoveries apparently have multi-billion barrels of probable reserves. But none are close to development. So far, none seem to have the capacity to produce more than 300,000 to 400,000 barrels per day and would only reach this level by 2010 at the earliest. The lengthy elapsed time since the discovery of most of our world's really large fields argues that most new fields will be relatively small daily producers.

Traditionally, the definition of a giant or super-giant oilfield has been a field whose reserves exceed one billion barrels. Super giant fields are generally ones whose reserves exceed five or even ten billion barrels. This definition often gets ambiguous as the reserves for some fields too often get depicted as "total possible reserves" or "oil in place" while other field's reserves size adheres to the strict definition of "proven" and "recoverable reserves." Perhaps it is time for the energy world to change this reserve focus and begin defining giant oilfields in terms of their daily production. This yardstick can be accurately measured, unlike total reserves which are always estimates. For the purposes of this study, my definition of a "giant" is one in which production is at least 100,000 barrels per day.

A 100,000-barrel a day producing oilfield is not a tiny field. It represents a significant asset for even the world's largest oil and gas companies. But a field of this size is only "a drop in the ocean" from the standpoint of the world's overall oil supply of more than 75 million barrels of oil each day. A 100,000-barrel a day field represents only 1.3% of total supply. It takes many of these smaller fields simply to offset even a modest decline in the world's existing production base.

While individual oil field production can be measured, there is surprisingly little public data on what most fields actually produce, including many of the world's giant fields, particularly within all the OPEC countries where most of the true giants are located. There is almost no data on the excess productive capacity for any of these giant fields in terms of "shut-in" or choked back daily supply. There is even less data on what the average decline rates for any of those fields might be. Few supply forecasters have ever attempted to model the future decline rates for these giant fields. The task, if performed, would be daunting as the data needed to create such a model is seriously lacking.

For decades too much of the discussion and analysis of the world's future oil supply has focused on the availability of ample oil reserves. Moreover, this analysis has mostly been done from a "top-down" country-by-country basis. Virtually no analysis has been done on what the production rates of all the giant oilfields might be as the future unfolds, let alone the biggest question of all: what are the current decline rates for these giant fie lds and what are they likely to become over time?

Published estimates of current production rates are available, but not easy to find, for about 45% of the world's population of giant fields, although these particular fields only produce a third of the estimated production volume from all giant fields. I have taken the liberty of "guess-timating" the possible production for the entire group of identifiable giant fields, and I might be off by a considerable margin. Hopefully, this paper might generate some interest in this topic and stimulate the availability of better data on all of these important fields. Key individuals in each region of the world must have detailed knowledge on every one of these fields. I would welcome any feedback for fields I have missed or more important, personal knowledge of what any of these fields actually produce today, or better still what declines each field now experiences.

The world is badly in need of better field-by-field production data. Reliable field-by-field production statistics are only available on a timely basis for the North Sea oilfields. Detailed monthly reports are published for the oilfields in the United Kingdom, Norwegian, and Danish sectors of the North Sea. Outside this region, quality information of any type on the giant oilfields of the world is sparse at best, including even the United States. Field-by-field data does exist for Alaska and the Gulf of Mexico, but it is hard to locate and rarely published. Outside the North Sea and the U.S., locating reliable data on daily field-by-field production for the other non-OPEC producing fields is difficult, and obtaining this data for OPEC oilfields is almost impossible.

OPEC, as the world's most important energy organization, needs to lead an effort to begin creating the same field-by-field data transparency as now exists for the North Sea. If the OPEC producers begin furnishing this data, it will help focus the world's energy planners on the significant expenditure needed in the industry to keep the world's current production base intact. Proper OPEC oil data would likely shatter the current myth that plentiful quantities of cheap oil are abundant throughout the Middle East.

Fortunately, if one is prepared to dig through masses of published data, enough information is available on most of the world's 100,000 barrels per day oilfields to create the probable total universe of these fields. But, the task is extremely time consuming and subject to error. When all existing information is pulled together and properly analyzed, the conclusions reached are enlightening and raise some significant questions on long-term oil supply that have seldom been addressed.

The following table summarizes the probable population of all (or most) oilfields left in the world that now produce more than 100,000 barrels per day. The list is skewed two ways. The bulk of the fields, in total number of fields, is at the lesser end of production volumes. Over half of these fields produce less than 200,000 barrels per day, with an average production of only 130,000 barrels per day. The bulk of the production volumes from these giant fields comes from a small number of mostly old fields.

SUMMARY OF GIANT OILFIELDS

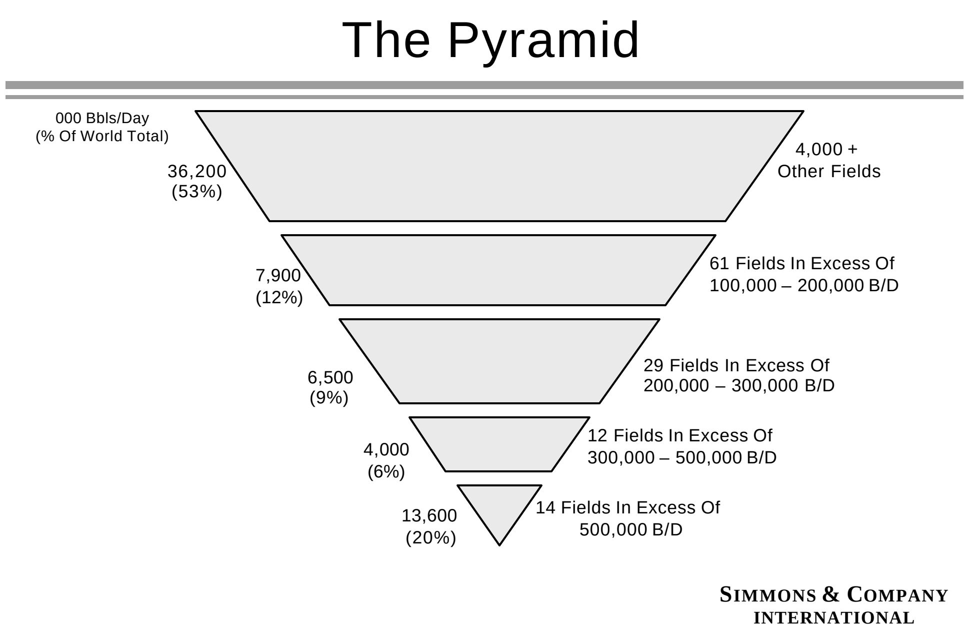
Giant Fields Production Barrels per Day	No. of Fields	Total Production 000 B/D	ERA DISCOVERED					
			Pre-1950's	1950s	1960s	1970s	1980s	1990s
1,000,000 +	4	8,000	2	1		1		
500,000 - 999,000	10	5,900	2	3	3	1	1	
300,000 - 499,000	12	4,100	3	1	6	1	1	
200,000 - 299,000	29	6,450	8	4	6	9	1	1
100,000 - 199,000	61	7,900	5	8	13	13	11	11
TOTAL	116	32,350	20	17	28	25	14	12

	GIANT FIELDS' PRODUCTION '000 Barrels Per Day							Total Production
	Pre-1950s	1950s	1960s	1970s	1980s	1990s	%	000 B/D
1,000,000 +	5,700	1,100	0	1,200	0	0	25%	8,000
500,000 - 999,000	1,500	1,700	1,600	600	500	0	18%	5,900
300,000 - 499000	900	300	2,300	300	300	0	13%	4,100
200,000 - 399,000	1,700	900	1,400	2,000	200	200	20%	6,400
100,000 - 299,000	550	1,100	1,700	1,700	1,500	1,400	25%	7,950
	10,350	5,100	7,000	5,800	2,500	1,600	100%	32,350
Percentage of Total	32%	16%	22%	18%	8%	5%		100%

GIANT OILFIELDS AS A PERCENTAGE OF THE WORLD'S OIL SUPPLY

For the past decade, many of the finest energy think-tanks have noted, with some relief, how diverse the world's oil supply now is, with almost 80 countries making up the global 68-million barrels per day crude oil supply. Natural Gas Liquids (NGLs) and refinery processing gains make up the other 7 million barrels per day of total supply.

The diversity myth is shattered once these giant oilfields are analyzed. The reality is that 14 **old** individual oilfields make up more than 20% of the world's total supply, so the supply base is anything but diverse. Schematically, the following inverted pyramid reflects how this supply is allocated from Super Giant fields at the bottom to a profusion of tiny oilfields at the top, highlighting how critical giant fields are to the global oil supply.



Most of these giant fields are old. Each successive decade's new discoveries have been smaller than their predecessors. The average production from the generation of giant fields discovered prior to 1950 and still producing in 2001 is 5 times greater than that of the fields discovered over the last decade. The steady decline in average production by giant fields found in each decade over the past 50 years is dramatic testament that the adage "most large oilfields get found first" is still alive and well.

World's 2000 Oil Supply
(Million barrels per day)

	Total Production B/D	GIANT FIELDS Number	Daily Production	Percentage of Total
OPEC				
Middle East				
Saudi Arabia	8.00	7	7.35	92%
Iran	3.65	10	1.85	51%
Iraq	2.55	5	2.45	96%
UAE	2.20	7	2.10	95%
Kuwait	1.75	3	1.55	89%
Neutral Zone	0.60	1	0.30	50%
Qatar	0.65	3	0.50	77%
Total	**19.40**	**36**	**16.10**	**83%**
Rest of OPEC				
Nigeria	2.00	--		
Libya	1.30	7	0.85	65%
Algeria	0.80	2	0.35	44%
Venezuela	2.90	10	1.70	59%
Indonesia	1.20	2	0.40	33%
Total	**8.20**	**21**	**3.30**	**40%**
Total OPEC	**27.60**			
Non-OPEC				
North America	11.40	17	3.70	32%
Europe	6.40	10	2.00	31%
FSU	7.90	12	2.15	27%
Asia	6.30	7	2.75	44%
Latin America	3.70	4	1.20	32%
Middle East	1.90	4	0.50	26%
Africa	2.80	5	0.65	23%
Total	**40.40**	**59**	**12.95**	**32%**
Total Crude*	**68.00**	**116**	**32.35**	**48%**

* NGLs and refinery processing gains adds another 7.5 million barrels per day

Source: 2000 Total Production: IEA   Giant Oilfield Data: Matthew Simmons

It is also remarkable how many key producing oil countries of the world still rely on a handful of giant fields for the bulk of their production. Even the U.S., with the most producing fields in the world and the largest population of producing wells, still gets more than 1.5 million of our 5.8 million barrels per day oil supply from only nine fields. Three of these nine fields' ages are close to, or even exceed, 100 years!

Saudi Arabia apparently has only seven giant fields, but they produce more than 7.3 million of its total 8 million barrel a day oil output. Iraq's 5 giant fields account for 96% of its output. Kuwait's 3 giant fields are almost 90% of its output. Nigeria is the only OPEC producer with no fields currently producing in excess of 100,000 barrels per day.

WILL THESE GIANT FIELDS DECLINE?

With production from giant fields providing such a significant share of the world's oil supply, it seems important to understand the decline rates each of these fields now experience and to determine what future decline rates are likely to be. Unfortunately, there is little publicly available data for even the most visible of these giant fields to make an educated guess at this important statistic.

There is ample data showing that giant oilfields do ultimately peak and then begin to decline. All the giant fields of Texas are classic illustrations of this. Prudhoe Bay, Cusiana, or the entire population of the North Sea's true giant fields also demonstrate not only that large fields decline but also that production declines rapidly once it peaks.

Saudi's Ghawar field, still by far the largest producing field the world has ever known, might last another 100 years. But, the field might also have already peaked. That no public data is available to shed any light on this issue places a giant question mark over the supply from this field. Someday even a field as large as Ghawar will begin its decline. If its decline rate comes close to those experienced by the North Sea fields or Prudhoe Bay, it would take a global drilling boom to find enough smaller fields merely to replace lost Ghawar oil supply.

Sooner or later, most of the world's current population of giant fields will all be in decline. If the world's future supply needs to result from new fields that are getting progressively smaller, it could require more than 3,000 new oilfields to be found and developed over the next 10 years, compared to slightly more than over 400 named new oilfields that were discovered in the past decade.

Until there is far better transparency on the world's giant oilfield production data and decline rates, the world can only guess at its future oil supply. There is an urgent need for better data on all these key fields.

The Author: Matthew R. Simmons

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The Oilman's Column #10- by L. F. Ivanhoe

A. PUT YOUR MONEY WHERE YOUR GAS TANK IS

Environmentalists argue eloquently that if our narrow-minded government and the greedy oil companies could just see our national fuel needs unselfishly, then cheap energy would gush forth from someplace and solve the world's problems. (Where do I get in line?) I only wish that such utopian views were possible. Unfortunately our globe now consumes more than a trillion (million million) gallons of crude oil each year, with the United States burning up one quarter thereof – more than 55 percent of which is imported. Simply put, if Americans do not want any oil activity on U.S. lands and seas, then we had all better be willing to reduce our oil use dramatically. Any American who is really concerned about his children's welfare should put his money where his mouth is and pay a more realistic gasoline tax of say $1.50 per gallon as in the other industrialized countries. (Europeans now pay $3.00/gallon gas tax.) Increasing our fuel tax would not only promote conservation, but would raise billions in revenues. Other taxes (income, sales, etc.) could be reduced to offset total tax burdens.

B. GASOLINE TAXES

Our politicians get elected on the "good news" of low gasoline prices – not on the "bad news" of high gas taxes. The economic logic is irrefutable for increasing the U.S. Federal gasoline tax – a 50-cent tax (much less than in Europe) would bring in $50 billion per year, which would pay for much of our oil trade deficit. But such an unpopular tax should not be expected until a real national emergency occurs. A gasoline tax increase is still a political no-no, due to the vehement objections of two groups of voters – namely: those who buy gasoline, and those who sell it.

C. $4/BARREL = 10¢/GALLON

There are 42 U.S. gallons in a barrel of oil. A price increase of $4/barrel represents a 10¢/gallon increase…virtually nil to the average U.S. consumer. Few Americans outside the oil industry are aware of how critical a $4/barrel ($0.10/gallon) price difference can be to the many small U.S. oil field operators and to many producing nations – namely the difference between bankruptcy and survival. Taxes are much/most of gasoline's price all over the world.

H.C. NEWSLETTER

The M. KING HUBBERT CENTER FOR PETROLEUM SUPPLY STUDIES
located in the Department of Petroleum Engineering
Colorado School of Mines
Golden, Colorado

The Hubbert Center has been established as a non-profit organization for the purpose of assembling and studying data concerning global petroleum supplies and disseminating such information to the public.

The question of WHEN worldwide oil demand will exceed global oil supply is stubbornly ignored. The world's oil problems, timing and ramifications can be debated and realistic plans made only if the question is publicly addressed. A growing number of informed US and European evaluations put this crisis as close as now to 2014. The formation of this center is to encourage a multi-field research approach to this subject.

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APPENDIX B

OIL AND GAS MEGAPROJECTS
(2006 UPDATE)

(CHRIS SKREBOWSKI
PETROLEUM REVIEW – APRIL 2006)

Prices holding steady, despite massive planned capacity additions

Petroleum Review *regularly updates its listing of the upcoming so-called 'megaprojects'. The aim of the listing is to attempt to answer the question as to whether sufficient oil is being developed to meet likely requirements going forward, writes* Chris Skrebowski.

This latest update of the megaprojects database shows that both Canada and the Opec producers plan major significant new capacity additions by the end of the decade.

The *Petroleum Review* database – based on public sources of information – now identifies some 21.3mn b/d of new capacity due onstream by 2010. Of this total, some 10.3mn b/d is to come from Opec producers and nearly 11mn b/d from non-Opec producers.

The significant increase in the planned future capacity in the database is the result of Opec publishing a comprehensive listing of its future projects (see **www.opec.org**) and of a number of Canadian tar sands projects being announced, as well as the inclusion of the smaller projects down to peak flows of 50,000 b/d.

In overall terms, the outlook for future supply appears somewhat brighter than even six months ago – possibly as a result of high prices being sustained and triggering investment decisions.

However, before concluding that the pressure is off and oil prices will now ease back, it is worth examining what happened in 2005.

The projects that actually come onstream in 2005 had a notional capacity of around 2.6mn b/d. [Capacity additions are allocated by year and time of start-up – so this total includes increments from fields that started up in earlier years, and the amount of new capacity added in 2005 adjusted for start-up date.] However, the actual increase in 2005 supply was just 1.05mn b/d (according to IEA's *Oil Market Report*, Febuary 2006). The explanation is the loss of capacity through depletion and the loss of capacity caused by the Gulf of Mexico hurricanes.

For the Opec producers, the gross capacity addition in 2005 was 1.16mn b/d and the net addition was 1.02mn b/d. The 140,000 b/d difference is mainly due to the loss of capacity in the various Opec states that was not covered by the normal infill drilling and well workovers. It is assumed that, with most Opec producers operating flat out, there has been little or no change to the spare capacity largely held by Saudi Arabia.

In the case of the non-Opec producers, which all operate at capacity, the gross addition in 2005 of 1.42mn b/d yielded a net addition of just 30,000 b/d (IEA *Oil Market Report*, February 2006). The Gulf of Mexico hurricanes cost the system the equivalent of 278,000 b/d on an annualised basis. The remaining 1.1mn b/d is accounted for by the erosion of non-Opec capacity (see *Petroleum Review*, August 2005). Virtually all of the capacity erosion occurred in the OECD countries. According to the IEA's figures, in 2005 all the itemised OECD producers had a lower production in 2005 than in 2004. Collectively, OECD output fell by 0.95mn b/d in 2005.

Looking forward to the 2006–2010 period, the situation should improve, as in each year over 3mn b/d of gross new capacity is due onstream. However, this total will be eroded by four possibly predictable and one unpredictable factors.

- Project slippage – over recent years project slippage has averaged around two to three months, although some projects have seen delays running into years. Even two to three months equates to around a 20% shortfall in any one year. The capacity is not lost, but moves forward. This has the effect of smearing out the new capacity so the increment in any one year is lower, but

continued on p31

	2005	2006	2007	2008	2009	2010
Opec new capacity	1,160	1,520*	1,420*	1,320*	2,240*	2,235*
Non-Opec capacity	1,416	1,865*	2,320*	1,886*	1,710*	1,035*
Total new capacity	**2,576**	**3,385***	**3,740***	**3,206***	**3,950***	**3,270***
Capacity erosion	1,226	1,400	1,600	1,750	1,800	1,850
Net new capacity	**1,350**	**1,985**	**2,140**	**1,456**	**2,150**	**1,420**
Gulf of Mexico loss	300					
Net Net	**1,050**	**1,037****	**1,300****	**1,866****	**1,622****	**1,189****

**assumes no slippage and no capacity shortfall; **assumes 20% slippage and 10% capacity shortfall*

All calculations Petroleum Review

Table 1: Capacity additions and capacity erosion, 2005–2010

Project	Location	Operator	Oil peak flows (kb/d)	Gas peak flows (mn cf/d)	Reserves (mn b)	Partners and shareholdings
Onstream 2006						
Opec countries						
AOR-E Delta	Nigeria	ExxonMobil	110			
Asab upgrading	Abu Dhabi	ADNOC	100			
Bu Hasa, Sahil project	Abu Dhabi	ADNOC	180			ADCO 100%
Darkhovin Ph2	Iran	Eni/Naftiran	+110			Eni 60% (on behalf of NIOC), Naftiran Intertrade (NICO) 40%
Dolphin, Al Khalij	Qatar	QP/Total	100			
EA	Nigeria	Shell	+50			
Erha	Nigeria (OPL 209)	ExxonMobil	150		500	ExxonMobil 56.25%, Shell 43.75%
Ghawar Haradh Ph3 (33° API)	S Arabia onshore	Saudi Aramco	+300 (2Q2006)			Saudi Aramco 100%
In Amenas (cond)	Algeria	BP/Statoil	50			
NEB Ph1 project****	NE Abu Dhabi	ADNOC	+110			ADNOC 100%?
South Pars Ph6 and 8 (cond)		Statoil	120			
South Pars oil layer (Ahwaz)		NIOC	250			
Non-Opec countries						
ACG Ph2 West Azeri	Azerbaijan	BP	+300 (2007)		5800	BP 34.14%, Unocal 10.28%, Socar 10%, Inpex 10%, Statoil 8.56%, ExxonMobil 8%
ACG (cont)						TPAO 6.75%, Devon 5.62%, Itochu 3.92%, Delta Hess 2.72%
Albacora Leste (P50)	Brazil	Petrobras	180 (2006)		700mn boe	Petrobras 90%, Repsol 10%
Atlantis	Gulf of Mexico	BP	150		675 boe	BP 56%, BHP 44%
Benguela-Belize (BBLT1)	Angola	Chevron	100 (2007)		400	Chevron 31%, Agip 20%,Total 20%,Sonangol 20%, Galp 9%
Buzzard	UKCS	Nexen	100 (2007/2008)		550	Encana 43%, Intrepid Energy 30%, BG Group 22%, Edinburgh Oil & Gas 5%
Cachalote	Brazil	Petrobras			800	
Chinguetti Ph1	Mauritania offshore	Woodside	75		123	Woodside 47.39%, Hardmn Res 19%, SMdH 12%, BG 10.23%, Premier 8.13%, Roc Oil 3.25%
Dalia	Angola	Total	240		1,600	Total 40%, BP 16.67 %, Statoil 13.33%, ExxonMobil 20%
Enfield (+Laverda/Vincent)	Australia NW Shelf	Woodside	100		363	Woodside Petroleum 60%, Mitsui 40%
Foster Creek	Canada Northern Alberta		115 (2015)			
Golfinho Module I (28-40°API)	Brazil (Espirito Santo)	Petrobras	100 (2007)		450	Petrobras 100%
Jubarte 1 Ph1 (P34)	Brazil B60 Santos	Petrobras	60 (2006)		540	Petrobras 100%?
Surmont (heavy oil by SAGD)	Canada Northern Alberta	ConocoPhillips	100 (2012)			ConocoPhillips 50%, Total 50%
Syncrude Ph3	Athabasca, Canada	Canadian Oil Sands	100			Canadian Oil Sands 32%, Imperial Oil 25%, Petro-Canada 12%, Nexen ?%, others ?%
Tengiz/Kololev expansion*	Kazakhstan	Chevron	+150	100	7,000	Chevron 50%, ExxonMobil 25%, KazMunaiGaz 20%, LukArco 5%
Thunder Horse (inc North)	Gulf of Mexico	BP	250 (2008)	200	1,500 boe	BP 75%, ExxonMobil 25%
Upper Salym, Vadelyp	Khanty-Mansiisk	Shell/Evikhon	60 (2009)		800	Salym Petroleum Development (SPD): 50% Shell, 50% Evikhon
Onstream 2007						
Opec countries						
Abu Hadriya/Khursaniyah/Fadhili	S Arabia onshore	Saudi Aramco	+500	250	4,500, 500, 950	Saudi Aramco 100%
Block 208 El Merk fields	Algeria	Anadarko	125			Anadarko 100%?
Idd al Shargi N and S Dome	Qatar	Occidental	65			
Khursaniyah NGLs	S Arabia onshore	Saudi Aramco	300			
Corocoro Ph1	Venezuela offshore	ConocoPhillips	75		450	ConocoPhillips 32.5%, PdVSA 35%, Eni 26%, Opic 6.5%
Rag e Safid-Bangestan	Iran onshore	Qeshm	150			
Ras Gas (cond)	Qatar	ExxonMobil	50			
Sabriya	Kuwait onshore	KOC	50			
Salman, Faroozan, Daroud	Iran onshore	Total, Petro Iran	150			
Non-Opec countries						
ACG Ph2 East Azeri	Azerbaijan	BP	+300 (2007/2008)		5,800	TPAO 6.75%, Devon 5.62%, Itochu 3.92%, Delta Hess 2.72%
Espadarte RJS-409	Brazil	Petrobras	100			
Golfinho Module II (28-40°API)	Brazil (Espirito Santo)	Petrobras	100 (2007/2008)		450	Petrobras 100%
Greater Plutonio (6 fields)	Angola block 18	BP	240		800	BP 50%, Shell 50%
Kikeh	Malaysia offshore Sabah	Murphy Oil	120 (2009)		530	Murphy 80%, Petronas Carigali 20%
Lobito-Tombuco (BBLT 2)	Angola	Chevron	+100 (2008)	400+		Chevron 31%, Agip 20%,Total 20%,Sonangol 20%, Galp 9%
Long Lake (tar sands)	Canada, N Alberta	Nexen	70		1,900	Nexen 50%, OPTI Canada 50%
Mangala and Aishwariya	India onshore Rajastan	Cairn Energy	80–100	600		Cairn Energy 70%, ONGC 30%
Peng Lai Ph2	China Bohai Bay PL19-3	ConocoPhillips	190 (2009)	800		CNOOC 51%, ConocoPhillips 49%
Polvo (BM-C-8)	Brazil, Campos basin	Devon Energy	50	50mn b+		Devon Energy 60%, SK Corporation 40%
Roncador II (FPU P52)	Brazil	Petrobras	180 (2008)		2,700 (tot)	Petrobras 100%
Roncador III (P54)	Brazil	Petrobras	180 (2008)		2,700 (tot)	Petrobras 100%
Rosa (tieback to Girassol)	Angola block 17	Total	250, net+40		300	Total 40%, Esso 20%, BP 16.67%, Statoil 13.33%, Norsk Hydro 10%
Sakhalin 2	Russian Far East	Shell	+120			
Vankorskoye 2 fields	Russia Siberia	Shell/TFE PSA	216		1,700 boe	
Onstream 2008						
Opec countries						
Agbami	Nigeria OPL 216, 217	Chevron	230	800		Chevron 68.15%, Petrobras 13%, Statoil 18.85%
Akpo	Nigeria OML 130	Elf Nigeria (Total)	180		590	Total 24%, NNPC ?%, Petrobras ?%, Sapetro ?%
AKG later phases (cond)	Qatar	ExxonMobil	90			
Al Rayyan	Qatar	Occidental	50			
Berkine block 405b (cond)	Algeria	First Calgary	50			
Bosi Oil	Nigeria	ExxonMobil	110			
Hawiyah NGLs	S Arabia onshore	Saudi Aramco	370			Saudi Aramco 100%
Jeruk	Indonesia, offshore Java	Santos	50	170 boe		Sampang PSC: Santos 45%, Singapore Petroleum Co (SPC) 40%, Cue Energy 15%
Nuayyim (Arab Super Light 50°)	S Arabia onshore	Saudi Aramco	100		1,000	Saudi Aramco 100%
Qatargas II (cond)	Qatar	ExxonMobil	160			
Ras Gas (cond/LPG)	Qatar	ExxonMobil	150			
Shaybah and Central fields expn	S Arabia onshore	Saudi Aramco	+300			Saudi Aramco 100%
Non-Opec countries						
ACG Ph3 (Gunashli)	Azerbaijan	BP	+200 (2009)		5,800	See under Ph1 in 2006
Horizon Ph1 (tar sand)	Canada, N Alberta	CNR	240		3,300	CNR ???

Table 2: Future oil field projects with a peak production capacity of over 50,000 b/d

Project	Location	Operator	Oil peak flows (kb/d)	Gas peak flows (mn cf/d)	Reserves (mn b)	Partners and shareholdings
Jackpine Mine Ph1	Canada, N Alberta		200 (10)			
Joslyn Ph1 & 2	Canada, N Alberta		100 (14)			
Kashagan Ph1	Kazakh Caspian	Agip (Eni)	450 (2009/2010)	1,500	13,000 (tot)	Eni/Total/ExxonMobil/Shell 18.52% each, ConocoPhillips 9.26%, Inspex 8.33%,KMG 8.33%
Kizomba C	Angola	ExxonMobil	200		1,000	ExxonMobil 40%, BP 26.66%, Eni 20%, Statoil 13.33%
Marlim Leste (P53)	Brazil, Campos Basin	Petrobras	140 (2008)	6mn cm/d	150	Petrobras 100%
Marlim Sul Module 2 (P51)	Brazil	Petrobras	180		2,679 boe (tot)	Petrobras 100%
Moho-Bilondo	Congo (Haute Mer permit)	Total	90			Total 53.5%, Chevron 31.5%, Societe Nationale de Petroles du Congo (SNPC) 15%
Sunrise Thermal project	Canada, N Alberta		200			
Su Tu Trang (White Lion)15-1	Vietnam Cuu Long Bas	ConocoPhillips	100?	220		Petrovietnam 50%, ConocoPhillips 23.25%, KNOC 14.25%, SK Corp 9%, Geopetrol 3.5%
Shenzi	Gulf of Mexico	BHP Billiton		100		BHP Billiton ?%, BP ?%
Stybarrow	Australia offshore	BHP Billiton	80		60–90	BHP Billiton 50%, Woodside Petroleum 50%
Tahiti	Gulf of Mexico	Chevron	125	70	400–500mn boe	Chevron 58%, Statoil 25%,Shell 17%
Onstream 2009						
Opec countries						
Al Shaheen expansion	Qatar offshore	Maersk Oil	+225			Maersk Oil, QPC
Azadegan (southern part)***	onshore Iran	Inspex, NIOC	125		2,500–3,000	Pedco 25%, Japanese interests 75% (Inspex ?%, Japex ?%, JNOC ?%, Tomen ?%)
Corocoro Ph2	Venezuela offshore	ConocoPhillips	+45		450	ConocoPhillips 50%, PdVSA 24%, Eni 26%
Khurais	S Arabia onshore	Saudi Aramco	1,200		3,000	Saudi Aramco 100%
Qatar GTL (Ph1)	Qatar	Qatar Shell Gas	165 (cond)	800		Qatar Petroleum ?%, Shell ?%
Rhourde El Baguel	Algeria	Sonatrach	100			
South Pars Ph9 and 10 (cond)	Iran	NIOC, LG	80 (cond)			
Upper Zakum redevelopment	Abu Dhabi	ExxonMobil	+200			ExxonMobil to 28%
Non-Opec countries						
BC10 Block 74	Brazil Espirito Santo	Shell? Petrobras?	80		400	Petrobras 35%, Shell 35%, ExxonMobil 30%
Frade	Brazil	Chevron	100 (2010)		300	Chevron 42.5%, Petrobras,?%, Nissho Iwai ?%
Karachaganak Ph3 and 4	Kazakhstan	Eni and BG	+200?			Eni 32.5%, British Gas 32.5%, Chevron 20%, Lukoil 15%
Kearl project Ph1	Canada, N Alberta	Imperial Oil	100			Imperial Oil ?%, ExxonMobil ?%
Muskeg River	Canada, N Alberta		140			
Onstream 2010						
Opec countries						
Al-Shaheen expansion	Qatar	Maersk Oil	+300			
Cepu block (Banyu Urip)	Indonesia Offshore	ExxonMobil (TBC)	170	20	700 in block	ExxonMobil 45%, Pertamina 45%, Indonesian government 10%
Jeruk	Indonesia, offshore Java	Santos	100		170 boe	Sampang PSC: Santos 45%, Singapore Petroleum Co (SPC) 40%, Cue Energy 15%
Kushk-Hosseineh	Iran onshore		300		1,500+	
'Project Kuwait' (Northern fields)	Kuwait onshore	KPC/ Oilco group	+450			Fields involved: Raudhatain, Ratqa, Abdali and Sabriyah
Shaybah (Ph2)	S Arabia onshore	Saudi Aramco	+200			Saudi Aramco 100%
Usan/Ukot/Tongo	Nigeria (OPL 222)	Elf Nigeria (Total)	175		480+	Elf Nigeria 20%, Chevron 30%, ExxonMobil 30%, Nexen 20%
Non-Opec countries						
Albacora (complementary)	Brazil	Petrobras	100			
Golfinho (FPSO 3)	Brazil	Petrobras	100?			
Jubarte Ph2 (P57)	Brazil B60 Santos	Petrobras	60 (2010)		540	Petrobras 100%?
Kashagan Ph2	Kazakh Caspian	Agip (Eni)	+450 (2012)	1,500	10,000 (tot)	Eni/Total/ExxonMobil/Shell 18.52% each, ConocoPhillips 9.26%, Inspex 8.33%, KMG 8.33%
Roncador IV (FPSO P55)	Brazil	Petrobras	150			
Uvatskoye	Russia Siberia	TNK-BP	200			
Onstream 2011						
Opec countries						
Bonga SW + Aparo	Nigeria (OML 118)	Shell+Chevron	175		1,000	Shell 55%, ExxonMobil 20%, Total 12.5%, Eni 12.5%
Manifa (Arab Heavy 28° API) Ph1	S Arabia offshore	Saudi Aramco	300			Saudi Aramco 100%
Qatar GTL Ph2	Qatar	Qatar Shell Gas	100 (cond)			Qatar Petroleum ?%, Shell ?%
Yadavaran	Iran onshore	NIOC/CNPC?	300		3,000	NIOC 80%, ONGC 20%
Non-Opec countries						
Marlim Sul III (FPSO P56)	Brazil	Petrobras	100			
Marlim Sul IV (semi, tba)	Brazil	Petrobras	100			
Papa Terra (DC-20) (14°-17° API)	Brazil	Petrobras	200?		700–1000	Petrobras 62.5%, Chevron 37.5%
Onstream 2012						
Opec countries						
Azadegan Ph2 (Northern part)***	onshore Iran	NIOC/Japan	110		2,500–3,000	NIOC, Japanese interests
Non-Opec countries						
Horizon Ph3 (tar sand)	Canada, N Alberta	CNR	+122		3,300	CNR ???
Kashagan Ph3	Kazakh Caspian	Agip (Eni)	+300(2016)	1,500	10,000 (tot)	Agip/Total/ ExxonMobil/Shell 20.37%, ConocoPhillips 10.19%, Inspex 8.33%
Onstream 2013						
Opec countries						
Manifa (Arab Heavy 28° API) Ph2	S Arabia offshore	Saudi Aramco	+300			Saudi Aramco 100%
Manifa (Arab Heavy 28° API) Ph3	S Arabia offshore	Saudi Aramco	+400			Saudi Aramco 100%
Potential Projects						
Opec countries						
Anaran block (4 fields)	onshore Iran	Norsk Hydro	100		1,000	Norsk Hydro 75%, Lukoil 25% (PSA?)
Arash	Iran in Gulf	NIOC			683 boe	
Hamrin	Iraq onshore (South)	SOC	60			
Khurmala Dome	Iraq onshore (Kirkuk area)	NOC	100			
Majnoon	Iraq onshore	SOC	360		12,100	
Minagish EOR project	Kuwait onshore	KOC	100			
Neutral Zone expansion	Saudi/Kuwaiti on/offshore		+150			

Table 2: Future oil field projects with a peak production capacity of over 50,000 b/d

Project	Location	Operator	Oil peak flows (kb/d)	Gas peak flows (mn cf/d)	Reserves (mn b)	Partners and shareholdings
Ramin	Iran near Ahwaz	NIOC			1,500	
Sincor II	Venezuela	Total	180			
Subbah-Luhais	Iraq onshore (South)	SOC	80			
Tomoporo (23° API)	Venezuela	PdVSA	250?		1,000	PdVSA, but private investors to 49%
West Qurna Ph2	Iraq onshore	SOC	650		11,300	
Non-Opec countries						
BC-2	Brazil Campos basin	Total				
BS-4	Brazil offshore	Shell				
Block 09-03	Vietnam Cuu Long bas	Petrovietnam	100+?		300–400	
Block 18 West (3 fields)	Angola block 18	BP			250–300	
Block 31 North E – Plutao+3 dev	Angola block 31	BP			500 in block 31	BP 26.67%, ExxonMobil 25%, Sonangol 20%, Statoil 13.33%, Marathon 10%, Total 5%
Block 31 S-Ceres/Palas/Juno	Angola block 31	BP			500 in block 31	BP 26.67%, ExxonMobil 25%, Sonangol 20%, Statoil 13.33%, Marathon 10%, Total 5%
Block 32- Perpetua et al	Angola block 32	Total			4 discoveries	Total 30%, Marathon 30%, Sonangol 20%, ExxonMobil 15% and Petrogal 5%
Borealis	Canada, N Alberta		100			
Christina Lake	Canada, N Alberta		250			
Chinook BM-C-7	Brazil Campos basin	Kerr McGee			250–450 boe	Kerr-McGee 50% Petrobras 50%
Filanov	Caspian, Russian sector	Lukoil	100+		600	Lukoil 100%
Fort Hills oilsands	Canada, N Alberta	Petro-Canada	190		2,800	Petro-Canada 55%, UTS Energy Corp 30%, Teck Cominco 15%
Great White	Gulf of Mexico	Shell			500–1000 boe	Shell ?%
Jackpine Mine Ph2	Canada, N Alberta					
Kearl project Ph2 and 3	Athabasca, Canada	Imperial Oil	200			Imperial Oil ?%, ExxonMobil ?%
Kebabangan	Malaysia Blk J off Sabah	ConocoPhillips			200–300	Block J: Petronas Carigali 20%, ConocoPhillips 40%,Shell 40%
Kharampur	Russia	Rosneft			4,900 boe	
Kharyaga	Russia Siberia	Total PSA			5,200	
Khvalynskoye	Russian Caspian	Lukoil/KazMgaz			17(c)36mn t (o)	
Kizomba D	Angola block 15	ExxonMobil				
Kurmangazy	N Caspian (Russ/Kaz)	Rosneft/KMG	600?		7,000	Rosneft 25%, other Russian 25%, KazMunaiGaz 25%, Total 25% (tbc)
Lungu	China Tarim basin	Petrochina			500	
Marimba Leste (FPS-Semi)	Brazil Campos basin	Petrobras				
Marimba Leste (FSO)	Brazil Campos basin	Petrobras				
Northern Lights oil sands project	Canada Northern Alberta	Synenco	100			Synenco 60%, Sinopec 40%
Northern Territories 4flds	Russia, Timan-Pechora	Lukoil, ConocoPhillips			990	
Stybarrow	Australia Exmouth basin	BHP Billiton	100		90	BHP Billiton 50%, Woodside Petroleum 50%
Su Tu Vang (Golden Lion) 15-1	Vietnam Cuu Long basin	ConocoPhillips	100?		400?	Petrovietnam 50%, ConocoPhillips 23.25%, KNOC 14.25%, SK Corp 9%, Geopetrol 3.5%
Suncor (tarsands) expansion	Canada		100			
Talanskoye	Russia Siberia	Surgutneftegas			832	
Tiof	Mauretania	Woodside			298	
Tsentralnoye block	Russia/Kazakh Caspian	Lukoil/Kazakhoil			3,800	TsentrKaspneftegaz JV: Kazakhoil 50%, Lukoil and Gazprom 50%
Val Gamburtsev	Russia Siberia	Yukos/Sibneft			600	
Verkhnechonsknoye	Eastern Siberia	TNK-BP?			1,500	
Voyageur	Canada, N Alberta		250			
Yalamo-Samur	Russia/Azeri Caspian	Lukoil			3,750 boe	
Yuri Korchagin	Russian Caspian	Lukoil			879 boe	
Yuzhno-Shapinskoye	Russia Siberia	SeverTek			500	Lukoil Fortum
Su Tu Nau (Brown Lion)	Vietnam Block 15-1	ConocoPhillips				PetroVietnam 50%, ConocoPhillips 23.3%, KNOC 14.2%, SK Corp 9%, Geopetrol 3.5%

limited production from 12/2004, Vadelyp 2006; ** 250,000 b/d 2007–2009; * 5,000mn barrels for field; **** Al Dhabiya, Rumaitha, Shanaget*

Table 2: Future oil field projects with a peak production capacity of over 50,000 b/d

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growth extends further forwards.

In tight and inflationary markets, for virtually everything to do with oil field development projects, delays are more likely to increase than decrease. Canadian tar sands projects are particularly vulnerable as gas supply, water supply, carbon dioxide emissions and manpower issues are not fully resolved. Some of the Opec new capacity targets also look aggressive.

- Supply shortfalls – peak production levels will be decreased by normal maintenance and operational factors. Some fields will disappoint and a few will give pleasant surprises. Some industry insiders suggest that total peak flows should be reduced by around 10% to reflect these realities.
- Capacity erosion or depletion will increase as more countries reach the point where their production declines year-on-year. Over the next few years China, Mexico, Malaysia, India and Brunei will move into decline. All the evidence shows that depletion tends to speed up rather than slow down – the North Sea being a good example.
- After the exceptional demand growth seen in 2004, the general view is that it will be slower as continuing high prices restrict demand. The latest IEA estimates for 2006 demand growth have been revised down from 1.78mn b/d to 1.49mn b/d (IEA *Oil Market Report*, March 2006). It is virtually impossible to predict demand growth, but for the purpose of analysis, around 1.5mn b/d could be used.
- Wars, revolutions and hurricanes are all likely to reduce supply, but are quite unpredictable. The effects can also be surprisingly long-lived. The IEA does not envisage 2004 production levels in the Gulf of Mexico being reattained before 2007 or even 2008. And this assumes there won't be significant further hurricane damage.

If all the factors reducing new capacity come into play, makets will remain tight and prices high. Only if new capacity flows into the system rather more rapidly than of late, will there be any chance of rebuilding spare capacity and softening prices. (See **Table 1**.) ●

Petroleum Review *is always pleased to receive comments and corrections on the megaprojects analysis. The subject is both contentious and productive of strong emotions, but the compilation of a viable analysis is important to both the oil industry and the wider oil using community. Any help or comments on the analysis would be gratefully received. Furthermore, in filling our role as reporters on the industry, we would be pleased to print other analyses. We would also welcome letters to the Editor.*

ACRONYMS AND ABBREVIATIONS

ASPO	Association for the Study of Peak Oil
bbl	barrel(s). One barrel of oil = 42 US gallons
BOE	barrel of oil equivalent
BP	British Petroleum
bpd	barrels per day
BTU	British Thermal Unit. The quantity of heat required to raise the temperature of one pound of water from 60° to 61°F at a constant pressure of one atmosphere.
CEO	Chief Executive Officer
CIA	Central Intelligence Agency
CPI	Consumer Price Index
CTL	coal to liquid
DOE	U.S. Department of Energy
EIA	Energy Information Administration, part of U.S. Department of Energy
EOR	enhanced oil recovery, using techniques such as horizontal, multi-branched wells, water or steam injection wells, CO2 fracturing, etc.
EROEI	energy return on energy invested. Sometimes called EROI.
Gbd	billion barrels/day (Giga = 10^9).
GCL	gas condensate liquids
GDP	gross domestic product
GNP	gross national product
GPI	genuine progress indicator
GTL	gas to liquid

IEA	International Energy Agency, the Paris-based institution charged with energy security policy for its 26 member countries. The IEA authorizes releases from members' strategic petroleum reserves.
IMF	International Monetary Fund
IOC	international oil company
LNG	liquified natural gas
mbd	million barrels per day (sometimes written mmbd)
MIT	Massachusetts Institute of Technology
NETL	National Energy Technology Laboratory (part of DOE)
NGL	natural gas liquids
NIMBY	Not In My Back Yard
NOC	national oil company
OECD	Organization for Economic Cooperation and Development
OPEC	Organization of Petroleum Exporting Countries
Q or Quad	a quadrillion (10^{15}) BTUs of energy
R&D	research and development
ROI	return on investment
SEC	U.S. Securities and Exchange Commission
URR	ultimate recoverable reserves
USGS	United States Geological Survey