PEAK ENERGY, CLIMATE CHANGE, AND THE COLLAPSE OF GLOBAL CIVILIZATION

The Current Peak Oil Crisis

TARIEL MÓRRÍGAN

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GLOSSARY

AEO	Annual Energy Outlook (published by the EIA)
AER	Annual Energy Review (published by the EIA)
anthropogenic	of or related to the influence of human beings; caused or influenced by humans
barrel of oil	159 L (42 U.S. gallons)
BAU	business as usual
bcm	billion cubic meters
biocide	any substance that can destroy living organisms (e.g., pesticides, herbicides, fungicides)
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent (CO_2 plus other GHGs in terms of CO_2 equivalents)
DoD	U.S. Department of Defense
DoE	U.S. Department of Energy
EIA	Energy Information Agency
EOR	enhanced oil recovery
Gb	giga barrels (billion barrels)
Gha	giga-hectare (billion hectares)
GHG	greenhouse gas
ha	hectare (2.47 acres)
HKHT	Hindu-Kush-Himalaya-Tibetan Plateau
IEA	International Energy Administration
IEO	International Energy Outlook (published by the EIA)
km^3	cubic kilometer (1,000,000,000 m^3)
kbpd	kilo barrels per day (1,000 barrels per day)
L	1 liter (0.26 gallons)
LECZ	low elevation coastal zone
m^3	cubic meter (1,000 L)
Mb	mega barrel (million barrels)
mbpd	million barrels per day
Mha	mega-hectare (million hectares)
mitigate	to reduce, lessen, or decrease
Mt	mega tonnes (one million tonnes)
Mtoe	million tonnes oil equivalent

NGL	natural gas liquids
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
permaculture	An approach to designing human settlements and agricultural systems based on the relationships of natural systems found in ecosystems. Patterns occurring in nature are often applied to maximize productivity and minimize work and external inputs of energy and material resources. The intention with permaculture is to create stable, productive, self-sufficient systems that provide for human needs while harmoniously integrating people and human activities with the environment.
tcm	trillion cubic meters
URR	ultimate recoverable reserves
USGS	United States Geological Survey
WEO	World Energy Outlook (published by the IEA)

PREFACE

When I set out to investigate peak oil and energy resources, it was with the intention to either: disprove peak oil theory and/or the predicted timings of when peak oil and energy resources would occur; or to communicate what is peak oil and the potential crisis, if I could not disprove peak oil and its urgency. The deeper I investigated peak oil and energy resource issues, the more it became clear that peak oil was a very severe and imminent crisis.

However, given the possibility of the unprecedented and imminent threats of peak oil and dangerous climate change, the reader should not simply believe one author's analysis and conclusions since the reader can always check the references. Nonetheless, every reader is urged to seriously consider the arguments, evidence, references, and conclusions presented in this analysis. And, when reading, viewing, and listening to other arguments and points of view by other authors consider their methodology, sources, references, and assumptions. In this investigation, a recurring issue is that many assumptions have been made by analysts and societies regarding energy resources and the economic and social systems that rely on them to maintain their functioning. Similarly, many societies generally make grave assumptions about the human carrying capacity of the environment and the severity of climate change in that the magnitude of the crises are generally grossly and inappropriately underestimated. This analysis looks at how peak energy resources and climate change may affect the human carrying capacity of the Earth in the coming decades.

The reader may notice that there are many numbers and units of measurements used in the petroleum and energy science and industry. Part of the challenge of understanding petroleum and energy science and the industries claims is keeping track of all the data and estimates when there are so many different ways that energy resources are measured. An attempt has been made in this analysis to convert as many of these measurements and numbers to as few units as possible in order to facilitate the reader's comprehension of the data and estimates.

Although some readers may find some of these specific figures and estimates relevant for their interests, most readers would do well to simply focus on understanding the order of magnitude of the numbers, figures and estimates. A general idea of the quantities at issue should be sufficient to get an overall understanding of the energy and climate situation. After all, most of these numbers are based on estimates, and estimates of estimates. Furthermore, these data and estimates represent the unresolved aggregation of a variety of accounting and reporting methods. Despite these inconsistencies in the data and estimates, the data are nonetheless useful for providing order of magnitude estimates and probability distributions of quantity and quality of oil and energy resources, demand, and other related matters.

When dealing with uncertainty, one must make decisions without necessarily knowing what the consequences of action or inaction might be. However, at some point action becomes necessary even when uncertainty is still great. There is a saying: If one only knows 50% of the facts, then one should not make a decision or form an opinion. But, if one waits until one has more than 90% of the facts, then it will be too late to act. Given the evidence presented in this analysis, the inherent uncertainty involved should be a cause for alarm and call to action. The peaking of oil will not be accurately predicted until after the fact. If people wait to act until there is more than 90% certainty. Hopefully, I have been able to offer the reader at least 50% of the facts – figuratively speaking.

When one reviews thoroughly the public domain data and claims from various governments, scientists , industry leaders and other organizations, it becomes clear that oil and energy resources will not last much longer. How much longer will their supplies be able to support global demand and the civilizations that depend highly on them is uncertain. However, the evidence suggests that it will be sooner rather than later. How much sooner? The world may likely already be experiencing peak oil and the terminal decline of global oil production. Within the next few years, or even the next few months, oil shortages and unsustainably high oil prices will likely cause the faltering global economy to collapse, and with it modern industrial global civilization. This will likely make it even more challenging for the world to adapt to future dangerous climate changes that are already in the pipeline.

While researching on peak oil and energy resources, I noticed that while there was a great amount of useful and well-written research and information on the issues, but that most of them did not present the findings and state of knowledge in a comprehensive way. Although there are quite a few organizations and publications that do a very good job at bringing together and synthesizing the issues and facts, one still needed to spend a lot of time searching through many different organization publications and websites to put the whole picture together. Although one cannot realistically hope to write a 100% comprehensive review of such overwhelmingly complicated and technical issues as peak production of oil and other energy resources, climate change, and the planet's capacity to sustain human life, This paper is an attempt to synthesize these problems in a concise, but sufficiently-detailed, analysis. Ultimately, this paper is was written to empower people and societies to prepare themselves for the radical changes in the world ahead with the information presented in this analysis. May you find it helpful.

– T.M., October 2010

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Peak Energy, Climate Change, and the Collapse of Global Civilization

The Current Peak Oil Crisis

KEY POINTS

- Peak oil is happening now.
- The era of cheap and abundant oil is over.
- Global conventional oil production likely peaked around 2005 – 2008 or will peak by 2011.
- "Peak oil" refers to the maximum rate of oil production, after which the rate of production enters terminal decline.
- Although there will be oil remaining in the ground when world oil production peaks, the remaining oil will become increasingly difficult and more costly to produce until the marginal financial and energy cost of producing oil exceeds the marginal profit and energy gained.
- Global oil reserve discoveries peaked in the 1960's.
- New oil discoveries have been declining since then, and the new discoveries have been smaller and in harder to access areas (e.g., smaller deepwater reserves).
- Huge investments are required to explore for and develop more reserves, mainly to offset decline at existing fields.
- An additional 64 mbpd of gross capacity – the equivalent of six times that of Saudi Arabia today – needs to be brought on stream between 2007 – 2030 to supply projected business as usual demand.
- Since mid-2004, the global oil production plateau has remained within a 4% fluctuation band, which indicates that new production has only been able to offset the decline in existing production.
- The global oil production rate will likely decline by 4 – 10.5% or more per year.
- Substantial shortfalls in the global oil supply will likely occur sometime between 2010 – 2015.
- Furthermore, the peak global production of coal, natural gas, and uranium resources may occur by 2020 – 2030, if not sooner.
- Global peak coal production will likely occur between 2011 – 2025.

- Global natural gas production will likely peak sometime between 2019 – 2030.

- Global peak uranium will likely occur by 2015 to sometime in the 2020's.

- Oil shortages will lead to a collapse of the global economy, and the decline of globalized industrial civilization.

- Systemic collapse will evolve as a systemic crisis as the integrated infrastructure and economy of our global civilization breaks down.

- Most governments and societies – especially those that are developed and industrialized – will be unable to manage multiple simultaneous systemic crises. Consequently, systemic collapse will likely result in widespread confusion, fear, human security risks, and social break down.

- Economies worldwide are already unraveling and becoming insolvent as the global economic system can no longer support itself without cheap and abundant energy resources.

- This current transition of rapid economic decline was triggered by the oil price shock starting in 2007 and culminating in the summer of 2008. This transition will likely accelerate and become more volatile once oil prices exceed \$80 – \$90 per barrel for an extended time. Demand destruction for oil may be somewhere above \$80 per barrel and below \$141 per barrel.

- Economic recovery (i.e., business as usual) will likely exacerbate the global recession by driving up oil prices.

- A managed “de-growth” is impossible, because effective mitigation of peak oil will be dependent on the implementation of mega-projects and mega-changes at the maximum possible rate with at least 20 years lead time and trillions of dollars in investments.

- Peak oil and the events associated with it will be an unprecedented discontinuity in human and geologic history.

- Adaptation is the only strategy in response to peak oil.

- Mitigation and adaptation are the only strategies for climate change.

- Peak oil crises will soon confront societies with the opportunity to recreate themselves based on their respective needs, culture, resources, and governance responses.

- The impacts of peak oil and post-peak decline will not be the same equally for everyone everywhere at any given time.

- There are probably no solutions that do not involve at the very least some major changes in lifestyles.

- Local and societal responses and adaptation strategies to peak oil and climate change will vary and be influenced based on many factors including: geography, environment, access to resources, economics, markets, geopolitics, culture, religion, and politics.

- The sooner people and societies prepare for peak oil and a post-peak oil life, the more they will be able to influence the direction of their opportunities.

- The peak oil crisis may become an opportunity to recreate and harmonize local, regional, and international relationships and cooperation.

- The localization of economies will likely occur on a massive scale, particularly the localization of the production of food, goods, and services.

- Existential crises will soon confront societies with the opportunity to recreate themselves based on their respective needs, culture, resources, and governance responses.

- If the international community does not make a transcendent effort to cooperate to manage the transition to a non-oil based economy, it may risk a volatile, chaotic, and dangerous collapse of the global economy and world population.

- One of the most important modern technologies to preserve post-peak oil may be the Internet, which can potentially help the world stay connected in terms of communications, information, and Internet technology services even after global transportation services decline.

- Peak oil and energy resources may offer the only viable solution and opportunity for humanity to mitigate anthropogenic climate change on a global scale – by essentially pulling the plug on the engine of the global economy that has driven the climate system to a very dangerous state.

- The success of the Green Revolution of modern industrial agriculture since around 1950 is primarily due to its increased use of fossil fuel resources for fertilizers, pesticides, and irrigation to raise crops. Fossil fuel energy inputs greatly increased the energy-intensiveness of agricultural production, in some cases by 100 times or more.

- Since the advent of the Green Revolution, the global human population has increased from 2.5 billion in 1950 to nearly 7 billion today.

- Global demand for natural resources exceeded planet's capacity to provide sustainably for the combined demands of the global population between 1970 – 1980.

- The global population is projected to grow to around 9.2 billion by 2050.

- Current trends in land, soil, water, and biodiversity loss and degradation, combined with potential climate change impacts, ocean acidification, a mass extinction event, and energy scarcity will significantly limit the human carrying capacity of the Earth.

- Future climate change has the potential to substantially reduce the human carrying capacity of the

Earth by 0.5 – 2 billion people, or more with abrupt climate changes.

- The human carrying capacity of the Earth may be 0.5 – 7.5 billion people by 2050.
- The human carrying capacity of the planet may be 0.5 – 6 billion by 2100.
- Even when greenhouse gas emissions decline after peak oil, climate change will likely continue to be driven by human activities, but in a reduced capacity.
- Moreover, the potential mitigation of climate change due to future energy scarcity will not stop the already committed climate changes that are in the pipeline.
- It is possible that climate negotiations may be abandoned or at least marginalized for a long time (if not permanently) as the crisis of peak oil and economic shock and awe overwhelms the stability and security of every nation.
- It will likely require a concerted and transcendent effort on the part of any remaining international climate negotiators, their governments, and the public to pursue a meaningful international climate policy – much less a binding international climate treaty.
- Based on these estimates, the global population may have nearly reached or already exceeded the planet's human carrying capacity in terms of food production.

EXECUTIVE SUMMARY

“We are in a crisis in the evolution of human society. It's unique to both human and geologic history. It has never happened before and it can't possibly happen again. You can only use oil once. You can only use metals once. Soon all the oil is going to be burned and all the metals mined and scattered.”

– M. King Hubbert[1], geophysicist and energy advisor Shell Oil Company and USGS, 1983

“An additional 64 mbpd of gross capacity – the equivalent of six times that of Saudi Arabia today – needs to be brought on stream between 2007 and 2030.”

– International Energy Agency (IEA)[2], 2008

“Peak oil” refers to the maximum rate of oil production, after which the rate of production enters terminal decline (see Figures 1 and 2). Although there will be oil remaining in the ground when world oil production peaks, the remaining oil will become increasingly difficult and more costly to produce until the marginal financial and energy cost of producing oil exceeds the marginal profit and energy gained.

Peak oil is happening now. The era of cheap and abundant oil is over. Global conventional oil production likely peaked around 2005 – 2008 or will peak by 2011. The peaking of oil will never be accurately predicted until after the fact. Nevertheless, since mid-2004, the global oil production plateau has remained within a 4% fluctuation band (see Figures 20a nd 20b, which indicates that new production has only been able to offset the decline in existing production. The global oil production rate will likely decline by 4 – 10.5% or more per year. Substantial shortfalls in the global oil supply will likely occur sometime between 2010 – 2015.

Global oil reserve discoveries peaked in the 1960's (see Figure 10). New oil discoveries have been declining since then, and the new discoveries have been smaller and in harder to access areas (e.g., smaller deepwater reserves). The volume of oil discovered has dropped far below the volume produced in the last two decades. In total, 507 fields are classified as ‘giant’, and account for 60% of conventional oil production. The top 110 producing oilfields produce over 50% of the global oil supply, and the most productive 10 fields contribute 20%. The top 20 oilfields contribute 27%. Production from 16 of the top 20 producing fields was also in terminal decline in 2007 (see Table 1).

Non-OPEC conventional production is projected to peak around 2010, and thereafter begin to decline. OPEC’s oil production will likely peak within the near-term. Saudi Arabia has more than 20% of the world's proven total petroleum reserves. After 2010, a steady terminal decline in oil production is projected at a depletion rate above 5% per year (see Figure 7). **Huge investments are required to explore for and develop more reserves, mainly to offset decline at existing fields. An additional 64 mbpd of gross capacity – the equivalent of six times that of Saudi Arabia today – needs to be brought on stream**

between 2007 – 2030. Therefore, it is unlikely that global oil production will be able to supply projected global demand within the near future.

Business as usual (BAU) oil demand is projected to increase by 1% per year on average from 2007 – 2030 – from 84.7 million barrels per day (mbpd) in 2008 to 105.2 mbpd in 2030. Under BAU, oil production is projected to grow from 83.1 mbpd in 2008 to 103 mbpd in 2030 (see Figure 15). Undiscovered oil fields account for about 20% of total crude oil production by 2030. In other words, **no one knows whether or how there will be enough oil to supply 20% of total projected crude oil production by 2030**.

The remaining oil is becoming increasingly harder to access and extract, and it is of increasingly lower quality. Therefore, the energy and economic investment required to produce the remaining oil is increasing as the energy yield from reserves is decreasing – i.e., the energy return on investment (EROI) is decreasing. The present EROI for oil is significantly lower than the past EROI for oil; and future EROI for oil will be even lower (see Figure 11).

Conventional oil is a fluid that generally requires minimal processing prior to sale and consumption. Conventional oil from producing fields currently supply approximately 85% of the global liquid fuel mix. Unconventional oil may be found in a variety of reserve formations and viscosities (i.e., thicknesses) that typically require specialized extraction technology (e.g., mining, injection of solvents) and significant processing prior to sale and consumption.

Unconventional oil generally includes extra-heavy oil, oil sands, oil shales, coal-to-liquids (CTL) and gas-to-liquids (GTL). These unconventional oil resources may supply less than 7% of projected global demand by 2030 (see Figure 15). **It is unlikely that unconventional oil resources will be able to significantly replace conventional oil supplies in the future.** The EROI of these unconventional oil resources is lower than that of conventional oil. Unconventional oil resources have greater environmental impacts associated with them, including higher CO_2 emissions. Unconventional oil resources cost at least 2 – 3 times more to produce than conventional oil; so it is likely that oil prices for consumers may increase proportionally (see Table 2, and Figures 12 and 13).

Electricity generation from alternative energy resources (i.e., wind, solar, tidal, geothermal) will not be able to replace oil as a transportation fuel since much of the entire world fleet of automobiles, ships, trains, and aircraft would have to be replaced by electric-powered vehicles. Furthermore, such alternative energy resources cannot replace oil as a petrochemical feedstock.

Most biofuel crops are not feasible for replacing oil on a large-scale due to their enormous requirements for cropland and nutrients (i.e., fertilizers) (see Table 3). The projected share of biofuels in the total global supply of road transport fuels will increase from 1.5% in 2007 to 5% in 2030 assuming BAU (see Figure 15). Biofuels from algae and other microorganisms may potentially be a substitute for petroleum, but high capital and economic costs; and requirements for large areas of land, water, phosphorus and other nutrients (i.e., fertilizers) will likely prevent future algal and microbial oil production from replacing oil on a global-scale. In particular, peak phosphorus resources will severely limit the viability of large-scale algae production.

Furthermore, the peak global production of coal, natural gas, and uranium resources may occur by 2020 – 2030 (see Figure 72), if not sooner. Global peak coal production will likely occur between 2011 – 2025 (see Figures 65 and 66). Global natural gas production will likely peak sometime between 2019 –

2030 (see Figure 68). Global peak uranium will likely occur by 2015 to sometime in the 2020's (see Figures 69 and 70). Since oil is used to produce, distribute, and build and maintain the infrastructure for coal, gas, unconventional oil, nuclear and renewable energy resources, the decline in oil production could very simply bring about declines in the production rates of the other energy resources sooner than the above dates indicate. Peak oil thusly may cause peak energy resources to occur sooner.

Global peak energy will be delayed only if: (1) one or more major new primary energy sources are discovered or developed that are comparable in quantity, quality, and versatility to fossil fuels (especially oil and liquid fuels); (2) significant breakthroughs occur in the quantity, quality, and/or versatility associated with one or more existing primary energy sources; and/or (3) a substantial and sustained decrease in the level of human energy consumption occurs. If either or both of the first two caveats do not occur, then the third caveat must come true, either through a reduction of per capita energy consumption and/or by a decrease in human population.

The conclusions of this analysis are supported by publications and statements made by several national governments, the George W. Bush and Obama administrations, the U.S. Department of Energy (see Figures 8a and 8b), the U.S. and German militaries, leading energy information reporting agencies, the oil industry, the private sector (see Figures 9a and 9b), science, and academia. Part of the reason why the general public are unaware of peak oil is because oil data in the public domain is often misreported, greatly inflated, and sometimes falsified. Contradictions and ambiguity in public data are mainly due to a lack of binding international standards to report oil reserve volume and grade; the conditions at which oil resources may be classified as commercially exploitable reserves; intentional misreporting and falsifying data to further financial and political agendas; lack of transparency and auditing; and uncertainty in technical assessments. The oil resource data and assessments of OPEC (see Figures 3, 4, and 5), information and reporting agencies that monitor the oil industry (including the International Energy Agency (IEA) and the Energy Information Agency (EIA)) (see Figures 8a and 8b), and private industry are also called into question. Buried in caveats and overly optimistic wording (see Figure 15), the estimates and figures of reporting agencies indicate that the global supply of oil will likely not be able to keep up with projected BAU demand, and that great oil supply shortages will likely start to occur within the next few years (see Figures 8a and 8b), if not sooner.

The economic theory on which the economy is based assumes inexpensive and unlimited energy supplies. The global and industrialized economy is based on fractional reserve banking, compound interest, debt-based growth, and compound or unlimited growth. Credit forms the basis of the monetary system. In a growing economy debt and interest can be repaid; in a declining economy they cannot be repaid. Therefore, declining energy flows (i.e., oil) cannot maintain the economic production required to service debt. When outstanding debt cannot be repaid, new credit will become scarce; and economic growth will decline.

Peak oil will have systemic effects throughout the entire global civilization. Global civilization is locked into a very complex and interrelated world economy. **Any attempt to alter significantly the energy and transportation infrastructure and the global economy on which it is based would cause it to collapse – but without an increasing energy supply (i.e., oil), the infrastructure and economy on which our civilization is based cannot survive.** The principle driving mechanisms for a global economic collapse are re-enforcing positive feedback cycles that are non-linear, mutually reinforcing, and not exclusive. A principle initial driver of the collapse process will be growing awareness and action about peak oil. Systemic collapse will evolve as a systemic crisis as the integrated infrastructure and economy of our global civilization breaks down. Most governments and societies – especially those that are developed and industrialized – will be unable to manage multiple simultaneous systemic crises. Systemic collapse will likely result in widespread confusion, fear, human security risks, social break down, changes in geopolitics, conflict, and war. With the collapse of the globalized economy, many communities will have to develop localized economies and food production.

Oil shortages will lead to a collapse of the global economy, and the decline of globalized industrial civilization. Systemic collapse will evolve as a systemic crisis as the integrated infrastructure and economy of our global civilization breaks down. Most governments and societies – especially those that are developed and industrialized – will be unable to manage multiple simultaneous systemic crises. Consequently, systemic collapse will likely result in widespread confusion, fear, human security risks, and social break down. **Economies worldwide are already unraveling and becoming insolvent as the global economic system can no longer support itself without cheap and abundant energy resources.**

This current transition of rapid economic decline was triggered by the oil price shock starting in 2007 and culminating in the summer of 2008. This transition will likely accelerate and become more volatile once oil prices exceed \$80 – \$90 per barrel for an extended time. Demand destruction for oil may be somewhere above \$80 per barrel and below \$141 per barrel. Economic recovery (i.e., business as usual) will likely exacerbate the global recession by driving up oil prices.

A managed "de-growth" is impossible, because effective mitigation of peak oil will be dependent on the implementation of mega-projects and mega-changes at the maximum possible rate with at least 20 years lead time and trillions of dollars in investments. Peak oil and the events associated with it will be an unprecedented discontinuity in human and geologic history.

Adaptation is the only strategy in response to peak oil. Mitigation and adaptation are the only solutions for climate change. Existential crises will soon confront societies with the opportunity to recreate themselves based on their respective needs, culture, resources, and governance responses. If the international community does not make a transcendent effort to cooperate to manage the transition to a non-oil based economy, it may risk a volatile, chaotic, and dangerous collapse of the global economy and world population.

Humanity has already passed the threshold for dangerous anthropogenic interference with the natural climate system. Future climate change has the potential to substantially reduce the human carrying capacity of the Earth by 0.5 – 2 billion people, or more with abrupt and non-linear climate changes. Currently, many nations are dealing with climate change impacts that are resulting from shifts in the onset of seasons; irregular, unpredictable rainfall patterns; uncommonly heavy rainfall; increased incidence of storms; major flood events; and prolonged droughts. Further, changes in temperatures and weather patterns have driven the emergence of diseases and pests that affect crops, trees, and animals. All these climate impacts already have a direct impact on the quality and quantity of crop yields, and the availability and price of food, animal feed, and fiber.

In 2010, the eight month mean (January 2010 – August 2010) global atmospheric concentration of CO_2 was approximately 391 parts per million (ppm) (see Figure 33). The average global atmospheric CO_2 concentration currently increases at a rate of approximately 2 ppm per year. By 2030 and 2050, atmospheric CO_2 concentrations will respectively be at least 431 ppm and 471 ppm or more assuming current BAU emissions trends. **As of 2005, cumulative GHG emissions may have already committed the**

planet to a warming of 2.4ºC (within a range of 1.4º – 4.3ºC) above the pre-industrial mean temperatures. Even if all anthropogenic GHG emissions cease in 2010 (an extremely unlikely scenario), thereby limiting atmospheric CO_2 concentration to 391 ppm, the climate system may have already passed the 2°C threshold for dangerous climate change. As CO_2 concentrations approach 441 ppm a corresponding committed warming of 3.1ºC will occur by 2030 in the absence of strong countervailing mitigation. At the current rate of GHG emissions, a CO_2 concentration of 450 ppm could be reached by around 2040.

A CO_2 concentration of order 450 ppm or greater, if long maintained, would push the Earth toward an ice-free state and that such a CO_2 level likely would cause the passing of climate tipping points and initiate dynamic responses that could be out of humanity's control. Abrupt, non-linear changes are caused by small increases in global climate change that result in large and irreversible environmental changes once climate tipping points are passed. **Anthropogenic GHG emissions are driving the global climate system toward such tipping points earlier than previously predicted. The potential impacts of passing such climate tipping points would be catastrophic, and include** (see Figure 60):

- the disappearance of Arctic summer sea ice (see Figures 50 and 51),
- a major reduction of the area and volume of Hindu-Kush-Himalaya-Tibetan Plateau (HKHT) glaciers, which provide the head-waters for most major river systems of Asia including the Indus, Ganges, Irrawaddy, Mekong, Red, Yangtze, and Yellow rivers (almost 30% of the world's population lives in the watersheds of these rivers) (see Figures 40 and 41),
- ocean acidification (see Figures 52 – 55),
- the deglaciation of Greenland Ice Sheet (see Figure 56),
- the dieback of Amazonian and boreal forests (see Figure 57),
- the shutdown of the Atlantic Thermohaline Circulation (see Figure 58),
- the collapse of West Antarctic Ice Sheet (see Figure 59), and
- a mass extinction event (see Figures 25, 31, and 32).

The catastrophic impacts from these events could include many meters of sea level rise, massive displacement and loss of people and wildlife, severe loss of biodiversity, mass extinction of species and ecosystems, extreme climate events, megadroughts, catastrophic water shortages, and massive famines that could result in chronic economic depressions, political instability, social revolutions, resource wars, overwhelming humanitarian crises, and human rights challenges. Passing climate tipping points would likely cause other severe impacts, such as the release of CO_2 and methane from permafrost and ocean hydrates that would likely cause additional runaway climate feedbacks that could accelerate further climate change.

A target atmospheric concentration of CO_2 of no greater than 350 ppm will likely be needed to prevent the world from passing climate tipping points. However, a target concentration of CO_2 of 300 ppm may be needed to ensure that the climate does not pass the 2ºC threshold. Substantial reductions in anthropogenic GHG emissions post-peak oil, combined with major efforts in carbon sequestration would be necessary to achieve this implausible target. Temperature tipping points for abrupt and non-linear climate changes could be passed within this century, or even in the next decade. Even if climate tipping points are not crossed, committed climate change that is already “in the pipeline” will likely have severe negative impacts on most water resources, food production systems, economies, and ecosystems worldwide.

Since the advent of the Green Revolution in 1950, the success of modern industrialized agriculture is primarily due to its increased use of fossil fuel resources for fertilizers, pesticides, and irrigation to raise crops. Fossil fuel energy inputs greatly increased the energy-intensiveness of agricultural production, in some cases by 100 times or more. In particular, oil has been used on a global industrial scale to:

- produce pesticides and other agrochemicals (herbicides, fungicides, some synthetic fertilizers);
- produce pharmaceuticals and medical supplies for livestock;
- fuel tractors, sprayers and crop dusters, farm equipment, and vehicles to produce food;
- pump and transport water for irrigation;
- make plastic materials for irrigation and other infrastructure;
- transport materials to farms;
- transport food from field to processors, storage, distributors, and consumers; and to
- make plastic materials in which to contain, store, and package food.

In terms of energy resources, the human carrying capacity of the Earth may be even lower based on historical relationships between global population and energy resource use, since the availability of all energy resources may limit the size of the global human population. The consumption of abundant fossil fuel energy has allowed the human population to increase greatly from approximately 0.5 billion before the year 1700 to about 7 billion today (see Figure 72). Until around 1500, the global human population had never exceeded 0.5 billion people (see Figure 24 and 72). By 1800, approximately 1 billion people lived on the Earth at the beginning of the the Industrial Revolution when fossil fuel energy was beginning to be exploited on a large-scale. Since the advent of modern industrialized agriculture around 1950, the global population has increased from 2.5 billion to nearly 7 billion in 2010 (see Figure 24, 61, and 72).

Decreasing energy resources may decrease the global human population that depends on them. Without enormous amounts of energy that oil and other fossil fuel energy resources have supplied for the past two centuries, the human carrying capacity of the Earth may be as low as 0.5 – 2.5 billion people. **Therefore, the total estimated human carrying capacity of the planet is 0.5 – 7.5 billion by 2050, and 0.5 – 6 billion by 2100, assuming that no abrupt and non-linear climate changes, a rapid mass extinction event, a global conflict (e.g., nuclear war) or any other massive environmental catastrophe occurs.** Yet, the projected global human population is 9.2 billion people by 2050. This analysis only considered minimally adequate per capita food and energy supplies. The more resource-intense are the economies and lifestyles of the global population, the lower will be the potential carrying capacity. The human response to peak oil and environmental management practices will be a key factor affecting the potential human carrying capacity of the Earth.

Ironically, peak oil and energy resources may offer the only viable solution for humanity to mitigate anthropogenic climate change on a global scale – by essentially pulling the plug on the engine of the global economy that has driven the climate system to a very dangerous state. Nevertheless, this potential mitigation of climate change will not stop the committed climate changes that are expected to occur in the future, nor will it stop all anthropogenic sources of greenhouse gas emissions altogether.

It is possible that climate negotiations may be abandoned or at least marginalized for a long time (if not permanently) as the crisis of peak oil and economic shock and awe overwhelms the stability and security of every nation. It will likely require a concerted and transcendent effort on the part of any remaining international climate negotiators, their governments, and the public to pursue a meaningful international climate policy – much less a binding international climate treaty.

PART I

PEAK OIL

“The Industrial Revolution was merely the beginning of a revolution as extreme and radical as ever inflamed the minds of sectarians, but the problems could be resolved given an unlimited amount of material commodities.”

– Karl Polanyi, *The Great Transformation*, 1941

"We are on the brink of a new energy order. Over the next few decades, our reserves of oil will start to run out and it is imperative that governments in both producing and consuming nations prepare now for that time. We should not cling to crude down to the last drop – we should leave oil before it leaves us. That means new approaches must be found soon..... The really important thing is that even though we are not yet running out of oil, we are running out of time."

– Fatih Birol[3], chief economist of the International Energy Agency (IEA), 2008

- "Peak oil" refers to the maximum rate of oil production, after which the rate of production enters terminal decline.
- Although there will be oil remaining in the ground when world oil production peaks, the remaining oil will become increasingly difficult and more costly to produce until the marginal financial and energy cost of producing oil exceeds the marginal profit and energy gained.

Peak oil refers to the maximum rate of oil production, after which the rate of production enters terminal decline. Peak oil production usually occurs after approximately half of the recoverable oil in an oil reserve has been produced (i.e., extracted). Peaking means that the rate of world oil production cannot increase, and that oil production will thereafter decrease with time; even if the demand for oil remains the same or increases.

Although there will be oil remaining in the ground when world oil production peaks, the remaining oil will become increasingly difficult and more costly to produce until the marginal financial and energy cost of producing oil exceeds the marginal profit and energy gained. In other words, *peak oil* does not mean that oil will run out (i.e., *oil depletion*) – there will be more difficult to extract oil left in the ground. Rather, *peak oil* refers to the end of abundant and cheap oil on which all industrialized societies and nations depend. This means that nations and societies will effectively run out of oil since production from the remaining oil reserves will become more and more technically and economically unfeasible (i.e., too technically difficult and too expensive).

Production usually increases in a "bell-like" curve toward a peak, and then terminally declines with a long tail afterward. The Hubbert curve is an approximation of the production rate of a resource over time. It is a symmetric logistic distribution curve. It first appeared in *Nuclear Energy and the Fossil Fuels*, a 1956 presentation to the American Petroleum Institute by geophysicist, oil geologist, and professor, Marion King Hubbert, during his tenure at the Shell Oil Company[4]. Hubbert was also a senior research

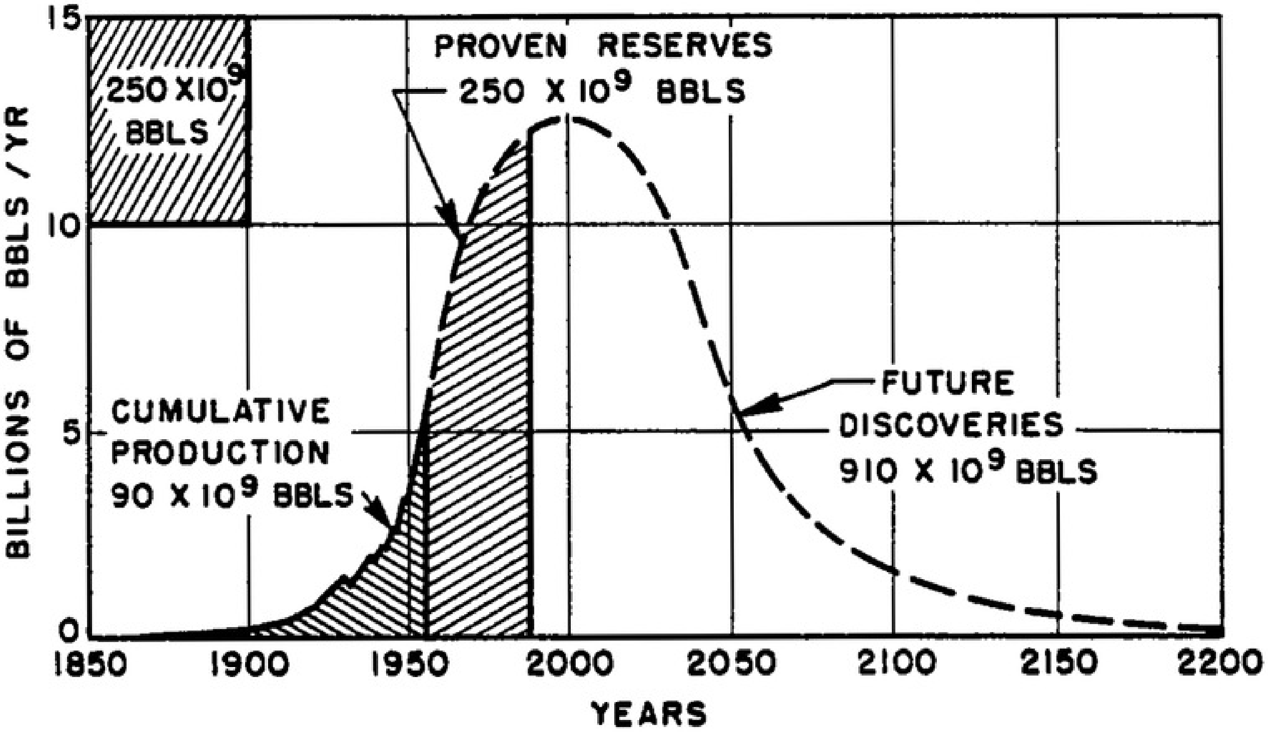


Figure 1: Ultimate crude-oil production based upon initial reserves of 1,250 billion barrels[4]*. Hubbert predicted that global oil production would peak "about the year 2000"*[4]*.This example of a Hubbert Curve is Hubbert's original model of world production trends from 1956. It is skewed based on observed discovery trends and predicted production trends.*

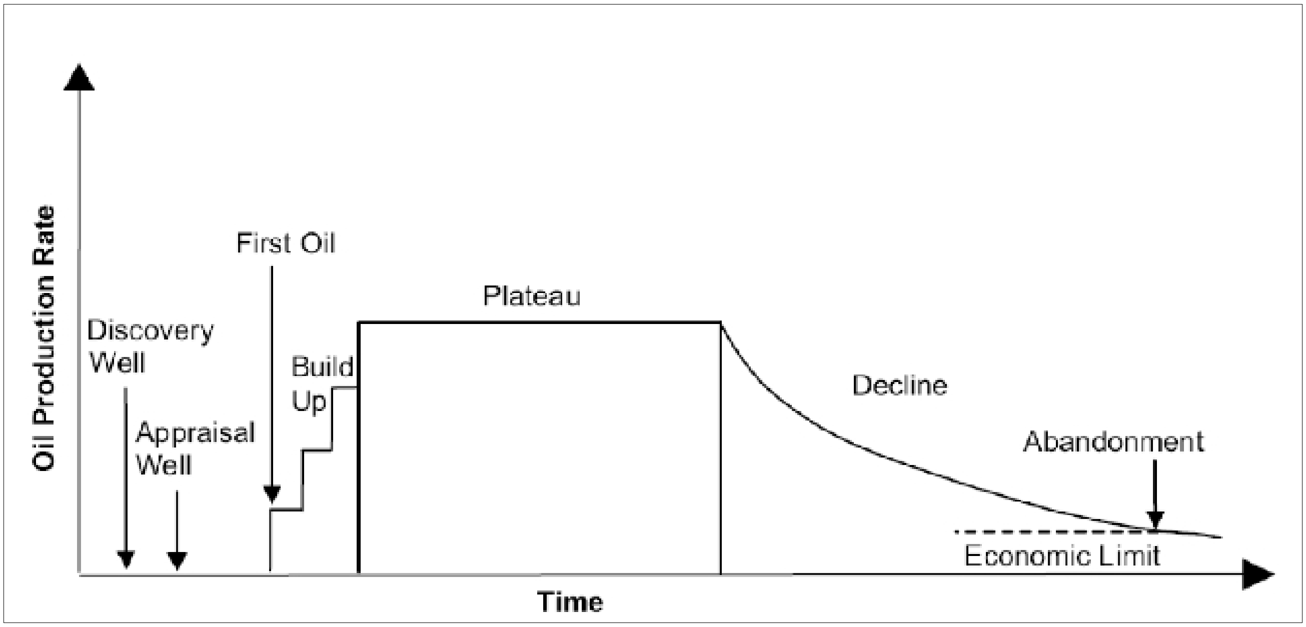


Figure 2: A theoretical production curve, describing the various stages of oil production maturity[5]*.*

geophysicist for the U.S. Geological Survey (USGS). Hubbert applied his model in 1956 to create a curve which accurately predicted that oil production in the contiguous United States would peak around 1970 by basing his calculations on the peak of U.S. oil well discoveries in 1948. Hubbert[4] predicted that global oil production would peak "about the year 2000" (see Figure 1). To illustrate the various stages of oil reserve depletion, Robelius[5] also describes a theoretical oil production curve (see Figure 2), which shows the various theoretical stages of reserve maturity. Note that as the production curve exponentially declines to the right of the curve in Figure 2, it reaches an economic limit (i.e., where net financial loss starts to occur) at which point production is abandoned. At the point of abandonment, production will collapse abruptly rather than decline smoothly to zero production.

Although oil production usually increases in a "bell-like" curve toward a peak before it terminally declines, the "peak" itself can relatively be steep and short-lived before entering decline (as shown in Figure 1) or it can enter a longer more drawn out "plateau" phase (as shown in Figure 2). It may be the case that global oil production will experience a peak plateau phase before it enters terminal decline. Around mid-2004, total global oil production ceased to grow; and new production has only kept global oil production in a relatively flat plateau since then (Figures 20a and 20b). This matter is discussed in more detail in the section *Supply and Demand*, particularly in *Oil Production Decline Rates*.

“Oil fuels the modern world. No other substance can equal the enormous impact which the use of oil has had on so many people, so rapidly, in so many ways, and in so many places around the world.... Alternative energy sources must be compared with oil in all these various attributes when their substitution for oil is considered.”

– Walter Youngquist[6], consulting oil geologist, 2000

- Oil is widely used as a source of energy, especially as a transportation fuel.
- It is used as a feedstock to produce a variety of important materials and chemicals.
- In particular, oil is a key component in the modern industrialized food production system that support nearly 7 billion people today.

The edifice of modern global industrialized civilization is made from oil – and oil is the black blood that flows through it to keep it alive. Oil is widely used as a source of energy, especially as a transportation fuel. It is used as a feedstock to produce a variety of important materials and chemicals. In particular, oil is a key component in the modern industrialized food production system that support nearly 7 billion people today.

Source of Energy and Fuel

Oil is widely used as a source of energy. In 2008, 5.5% of global electricity was generated from oil[8]. In 2008, global consumption of oil totaled 3,502 million tonnes of oil equivalent (Mtoe). Of this total, 61.4% was used for transportation; 9.5% was for industry; 12.9% was for other sectors (including agriculture, commercial and public services, residential, and other sectors); and 16.2% was for non-energy use[8]. Non-energy use includes those oil fuels that are used as raw materials in different sectors, and that are not consumed as a fuel or transformed into another fuel. Non-energy use also includes the use of oil as petrochemical feedstocks (including oil used as feedstock for materials, agrochemicals, and other petroleum products). In 2008, oil represented 41.6% of the global total final consumption of all fuels (e.g., coal, natural gas, etc.) – which totaled 8,428 Mtoe[8]. In the OECD nations in 2008, oil represented 48.7% of total final consumption of fuels[8]. Total final consumption (TFC) is the sum of consumption by different end-use sectors. Backflows from the petrochemical industry are not included in final consumption[8].

Feedstock for Materials

In addition to being an energy fuel source, oil is used as a material feedstock for many products vital to build and support modern industrialized civilization, including:

- diesel, gasoline, aviation fuels, kerosene, propane, and other liquid fuels
- heating oil
- lubricants
- pharmaceuticals and other medical products
- pesticides, herbicides, and other biocides
- plastics and other synthetic materials
- electronics
- synthetic fibers
- adhesives
- tires (approximately seven gallons of oil are required to produce one tire – five gallons are used as feedstock and two gallons supply the manufacturing energy[9])
- asphalt (for roads, runways and other paved surfaces; waterproofing; and roof shingles)
- paraffin wax
- petroleum coke
- other petrochemicals

Decreasing oil supplies, and the concomitant increase in oil prices, will increase the costs of all products that use oil as a feedstock – e.g., medicine, pesticides, plastics. Although some of these oil-based products can be made using non-petroleum based substitutes made from biomass (e.g., plant-based plastics), it could take years to develop and legally approve substitute materials, assuming viable substitutes can be produced on commercial scales. Like the concern about producing biofuels from fuel crops, using biomass to replace petroleum as a feedstock for modern industrial goods would have the adverse effect of using cropland that could otherwise be used to grow food crops or to conserve natural ecosystems (e.g., forests), which would also cause an increase in food prices and environmental degradation.

Food Production and Distribution

Around 1945 – 1950, the Green Revolution had started – this was the beginning of modern oil-based industrial agriculture. Since then, oil has been used to produce pesticides and other agrochemicals (synthetic fertilizers are made from natural gas, but are often applied using oil-powered vehicles); to fuel tractors, farm equipment, and vehicles to produce food; to transport water and materials to farms; to transport food from field to processors, storage, distributors, and to consumers; and to make plastic materials in which to package the food.

Modern industrial agriculture has allowed the human population to increase at a very high exponential rate since 1950, when the global population is estimated to have been about 2.5 billion people[10,11] (see Figure 61). By 2000, the global human population had increased to around 6 billion people. In 2010, the human population is nearly 7 billion (i.e., 6.8 billion)[10]. By 2030, the global population is projected to increase to about 8 billion people assuming BAU[12]. One of the differences between 2.5 billion people in

1950 and 7 billion people in 2010 is oil. Although other fossil fuel energy resources are important for increasing and supporting the global human population, oil is vital since it supports modern industrial agriculture (i.e., feedstock for pesticides, transport fuel). However, peak global oil production may result in peak fossil fuel production, which together with climate change may limit the human carrying capacity of the planet to between 0.5 – 7.5 billion people by 2050 (see *Human Carrying Capacity* for a discussion on the role of oil in modern industrial agriculture).

Defining and Measuring Conventional and Non-Conventional Hydrocarbon Reserves

"...conventional easy oil is peaked but there's plenty of oil and gas yet to be had and the technology is developing or is already here to make it possible to bring oil sands to market, later to bring oil shale to market through technology..."

– John D. Hofmeister[13], President of Shell Oil America, 2007

- Conventional oil is a fluid that generally requires minimal processing prior to sale and consumption.
- Conventional oil from producing fields currently supply approximately 85% of the global liquid fuel mix.
- Unconventional oil may be found in a variety of reserve formations and viscosities (i.e., thicknesses) that typically require specialized extraction technology (e.g., mining, injection of solvents) and significant processing prior to sale and consumption.
- Unconventional oil generally includes extra-heavy oil, oil sands, oil shales, coal-to-liquids (CTL) and gas-to-liquids (GTL).
- These unconventional oil resources may supply less than 7% of projected global demand by 2030.

The Petroleum Resources Management System defines conventional and unconventional oils in the following way[14]:

"Conventional resources exist in discrete petroleum accumulations related to a localized geological structural feature and/or stratigraphic condition, typically with each accumulation bounded by a downdip contact with an aquifer, and which is significantly affected by hydrodynamic influences such as buoyancy of petroleum in water. The petroleum is recovered through wellbores and typically requires minimal processing prior to sale.

"Unconventional resources exist in petroleum accumulations that are pervasive throughout a large area and that are not significantly affected by hydrodynamic influences (also called "continuous-type deposits"). Examples include coalbed methane (CBM), basin-centered gas, shale gas, gas hydrates, natural bitumen, and oil shale deposits. Typically, such accumulations require specialized extraction technology (e.g., dewatering of CBM, massive fracturing programs for shale gas, steam and/or solvents

to mobilize bitumen for in-situ recovery, and, in some cases, mining activities). Moreover, the extracted petroleum may require significant processing prior to sale (e.g., bitumen upgraders)."

In other words, conventional oil is a fluid that is generally found in rather discrete underground accumulations, or reserves, that are accessible for extraction through wellbores. Conventional oil generally requires minimal processing prior to sale and consumption. On the other hand, unconventional oil may be found in a variety of reserve formations that typically require specialized extraction technology (e.g., mining, injection of solvents) and significant processing prior to sale and consumption (e.g., tar sands, shale oil).

Unless otherwise stated, in this analysis, unconventional oil includes extra-heavy oil, oil sands, oil shales, coal-to-liquids and gas-to-liquids (see *Unconventional Oil Reserves* for further discussion and analysis of unconventional oil resources). Neither conventional nor unconventional oil include vegetable oil derived from biomass or other biofuels.

However, there is a category of oil which, though considered conventional, can be extracted only using new technologies which are not yet fully developed and/or involves pioneering work in frontier areas, such as ultra-deepwater. This category of "conventional oil produced by unconventional means" includes oil recovered from currently unopened areas of the Arctic seas, from new marine deepwater and ultra-deepwater resources, and from additional oil recovered from new enhanced oil recovery (EOR) projects. There are very large uncertainties about the amount of economically recoverable resources in this category and this "conventional oil produced by unconventional means" is often not included in estimates of ultimately recoverable resources. For instance, this category of oil is not included in the latest figures from the U.S. Geological Survey. Although no systematic estimates for each of the various components of this category are included in this report, Figure 13 provides a broad illustration of their potential quantities. Furthermore, additional oil resulting from reserves growth is customarily included in conventional oil, except where the reserves growth derives from new EOR projects[2].

Oil Data Is Inaccurate

Chapter 4

"Reserves are confused and in fact inflated. Many of the so called reserves are in fact resources. They're not delineated, they're not accessible, they're not available for production."

– Sadad al-Husseini[15], a former executive of Saudi Aramco, 2007

"Reliance on IEA reports has been used to justify claims that oil and gas supplies will not peak before 2030. It is clear now that this will not be the case and the IEA figures cannot be relied on."

– John Hemming[16], UK Member of Parliament, 2009

- Oil data in the public domain is often misreported, greatly inflated, and in some cases falsified.
- Contradictions and ambiguity in public data are mainly due to a lack of binding international standards to report oil reserve volume and grade; the conditions at which oil resources may be classified as commercially exploitable reserves; intentional misreporting and falsifying data to further financial and political agendas; lack of transparency and auditing; and uncertainty in technical assessments.
- The oil resource data and assessments of OPEC, oil information and reporting agencies, and private industry are also called into question.
- Buried in caveats and overly optimistic wording, the estimates and figures of reporting agencies (e.g., the International Energy Agency (IEA)) indicate that the global supply of oil will likely not be able to keep up with projected BAU demand, and that great oil supply shortages will likely start to occur within the next few years, if not sooner.
- Conventional oil proven reserves should be revised downward to 850 – 900 Gb from 1200 – 1300 Gb.

Misreporting, Falsifying Data, Uncertainty, and Lack of Standards and Transparency

Looking at the published oil reserves, one can easily get the impression that there are vast amounts of oil left in the ground to be extracted. It could be easy to assume that there is no way that peak oil production should be a concern in the next few decades. However, a careful reading of published oil reserves and projected oil production shows that they really are written in a overoptimistic (at best) and misleading (at worse) manner. In fact, a careful reading of the published public domain oil data, oil reserves, and projected production reveals clear evidence that suggests that oil data in the public domain is greatly inflated, and that global oil discoveries of reserves, reserve capacity, and total and projected production has already peaked or will peak in the near-term. Contradictions and ambiguity in public data are mainly due to a lack of binding international standards to report oil reserve volume and grade; the conditions at which oil resources may be classified as commercially exploitable reserves; intentional misreporting and falsifying data to further financial and political agendas; lack of transparency and auditing; and uncertainty in technical assessments[17]. Buried in caveats and overly optimistic wording, the data clearly indicates that the global supply of oil will not be able to keep up with projected BAU demand, and that great oil supply shortages will likely occur in the near-term (i.e., within the next few years, if not sooner).

There is no harmonized system of defining and classifying oil resources; and the way those resources are measured in practice differs widely by country and by jurisdiction. There is no internationally agreed benchmark or legally binding standard as to how much proof is required to demonstrate the existence of a discovery, nor about the assumptions to be used to determine whether discovered oil can be produced profitably. This is a partially due to different reporting systems that are designed for different purposes. For instance, standards for financial reporting, such as the U.S. Securities and Exchange Commission (SEC) rules, are often the strictest, which results in the lowest estimates. Whereas the requirements for companies to release information on resources and reserves differs significantly. Reserve audits are not universally required, practiced, or published. Although some oil companies, including international oil companies, use external auditors and publish the results, most national oil companies do not (often justifying their lack of transparency due to state or trade secrets). These lack of standards and transparency create significant uncertainty about how much oil can reasonably be expected to be produced commercially in the long-term[2].

There are a range of opinions regarding the volume and grade (i.e., quality) of oil remaining in reserves. Publicly available data is produced from surveys conducted by the journal *World Oil*, the *Oil and Gas Journal*, and the Organization of the Petroleum Exporting Countries (OPEC) Secretariat[17]. However, these sources tend to provide optimistic high range estimates since they do not question surveyed reserve estimates, as compared to independent parties who assess reporting methodology. Possibly, they do not question these estimates because they may be considered outside of their jurisdiction and politically sensitive[17]. For example, data published by the OPEC Secretariat has never been subject to independent audit[18], and it is generally considered inaccurate, but it is still included in public data unquestioned[2,19,20].

Some energy information agencies (e.g., the International Energy Agency (IEA), the U.S. Energy Information Administration (EIA)) acknowledge sources of reporting errors described by independent analyses as caveats to the published figures, but continue to present their main oil resource estimates based on these spurious publicly available data. For example, the IEA's *World Energy Outlook 2008* (WEO 2008) states[2] “the world is far from running out of oil; remaining oil and natural gas liquid proven reserves totaled 1200–1300 Gb by the end of 2007...though most of this increase has come from revisions made in the 1980’s in OPEC countries rather than new discoveries”.

Independent analyses demonstrate a consensus among authors that reserve estimates published by reporting and information agencies are likely to be exaggerated and over-inflated. According to these authors[2,5,21-23] conventional oil reserves should be revised downward to 850 – 900 Gb from 1200 – 1300 Gb, and production is predicted to terminally decline between 2010 – 2015.

Public domain data consistently reports growth in annual reserve estimates despite simultaneously reporting that oil consumption has exceeded additional discovery reserve volumes of conventional oil. The IEA[2] reports, "The volume discovered has fallen well below the volume produced in the last two decades." Net negative withdrawals from reserves have consistently occurred since 1980 (and first occurred in 1972), which indicates that conventional oil reserves have been in steady decline[17]. Since 2007, the volume of oil produced has exceeded the volume discovered by a factor of three – and this trend is expected to widen[17].

Due to these different data and standards, and since reports and reporting agencies use different definitions and measures of oil supplies, the numbers and estimates of oil supply and demand may vary somewhat throughout this analysis depending on which data sources are used. Although these numbers vary, they still are useful for developing a workable range of estimates and projections for this analysis.

Organization of the Petroleum Exporting Countries (OPEC)

Political and financial objectives can provide incentives to misreport reserves. The most well known instance of misreporting occurred in the 1980's during the Organization of the Petroleum Exporting Countries (OPEC) "fight for quotas" (see Figures 3 and 4). Several of the OPEC countries adjusted their reserves upward in the 1980's without any new oil discoveries, during a time when OPEC was discussing how production quotas should be allocated. Misreporting likely occurred because OPEC nations agreed to

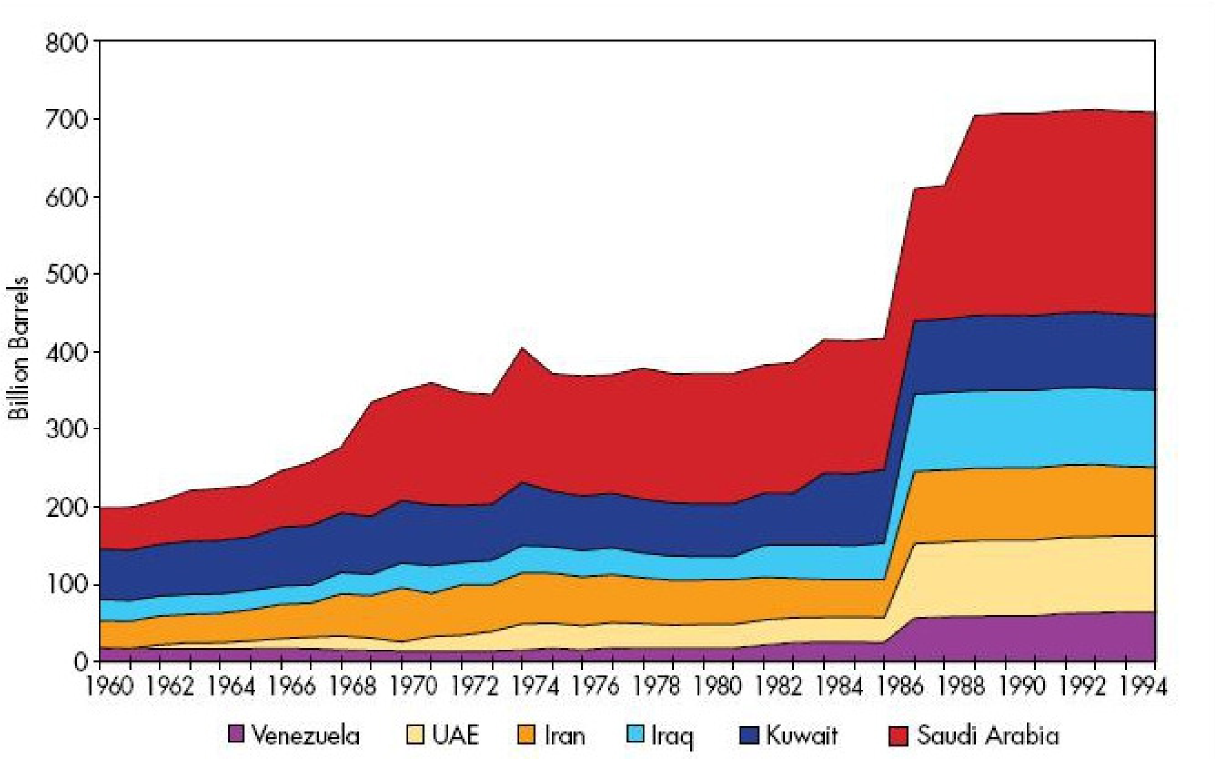


Figure 3: OPEC official proved oil reserves[24]. Note: the dramatic simultaneous increase in reported oil reserve volumes by OPEC in the 1980's.

set export quotas in proportion to reserve volumes. This may have provided OPEC nations with a strong incentive to inflate reported reserve data to increase market share and revenue[2]. It was understood that having higher reserves would be beneficial when quotas were assigned, so each OPEC country in turn raised its reserves.

Further support for this argument comes from a statement by the IEA in its *World Energy Outlook 2008* [2], "the world is far from running out of oil; remaining oil and natural gas liquid (NGL) proven reserves totaled 1200 – 1300 Gb by the end of 2007 (including about 200 Gb of Canadian oil sands)...though most of this increase has come from revisions made in the 1980's in OPEC countries rather than new discoveries"[2]. Global oil and natural gas liquids (NGL) proven reserves supposedly have almost doubled since 1980. As suggested in the previous quote, most of the increase in reserves has come from revisions made in the 1980's in OPEC countries rather than from new discoveries (see Figures 3 and 4); and that modest increases have continued since 1990, despite rising consumption[2]. Figure 4 also shows that – in addition to a relatively flat, but slightly increasing reserve volume curve – OPEC 11 nations simultaneously reported smaller reserve estimate increases around 1993 – 1996, and again around 2001 – 2002.

The discrepancy of OPEC's "increased" reserve figures is not accounted for in public data. These misreported figures add between 287 – 300 Gb to global oil reserve figures[19,26]. Data published by the OPEC Secretariat has never been subject to independent audit[18], and it is generally considered inaccurate, but it is still included in public data relatively unquestioned[2,19,20].

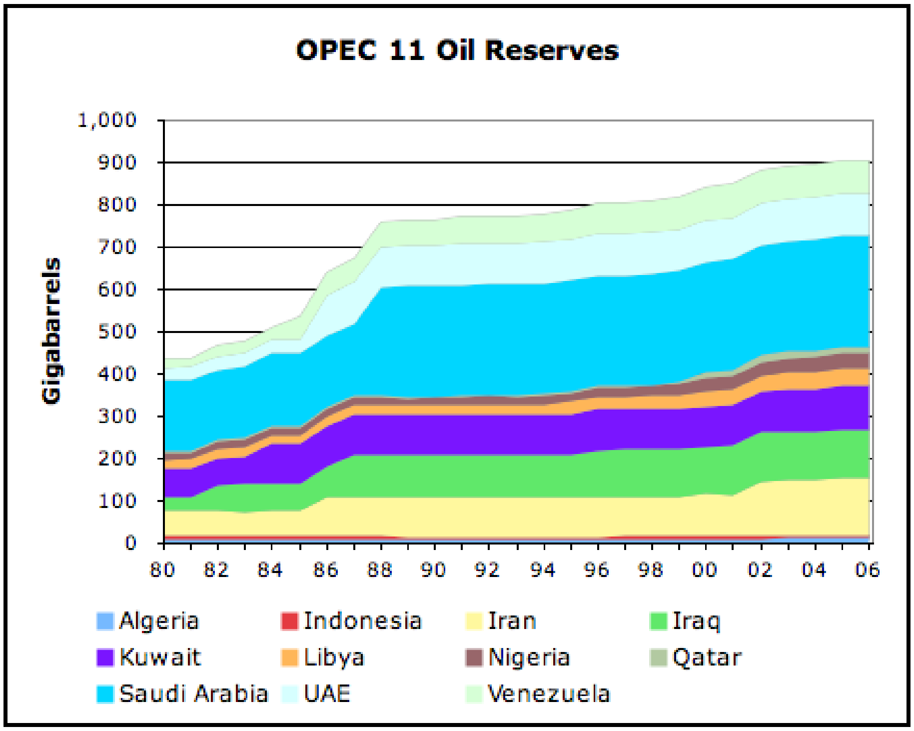


Figure 4: OPEC 11 oil reserves[25]. Note: the dramatic simultaneous increase in reported oil reserve volumes by OPEC in the 1980's.

Furthermore, OPEC claims it has adequate spare capacity and that OPEC spare capacity is set to rise, settling in the medium-term at just over 6 mbpd assuming BAU[27]. However, the actions of OPEC nations indicate that they may not have this spare capacity. When oil prices were much higher in 2008 than they are now, OPEC did not make use of all of the spare capacity that they supposedly had (see Figure 5)[2,19,20].

The of history of IEA estimates of future productive capacity for OPEC 10 shows that that the estimates have tended to decrease over time, which also raises questions about current OPEC productive capacity estimates (see Figure 6). Each year, from the 2006 to the 2009 report, the IEA's *Mid Term Oil and Gas Market Reports* lower the estimated capacity down by approximately 2 mbpd. In 2010, the capacity estimates increased slightly mainly due to increased capacity of Iraq[28,29].

As of January 2009, Saudi Arabia officially had about 266.7 Gb of oil reserves, which is more than 20% of the world's proven total petroleum reserves[31]. Although oil production in the Ghawar oil field peaked in 1980 at about 5.6 kbpd, it supposedly produced 5.1 kbpd in 2007 (see Table 1), which was equal to 7% of global conventional oil production in 2007 [2]. Saudi Arabia’s historical crude oil production indicates that production peaked at 9.6 mbpd in 2005 (see Figure 7). In 2008, crude production was 9.3 mbpd. In 2009,

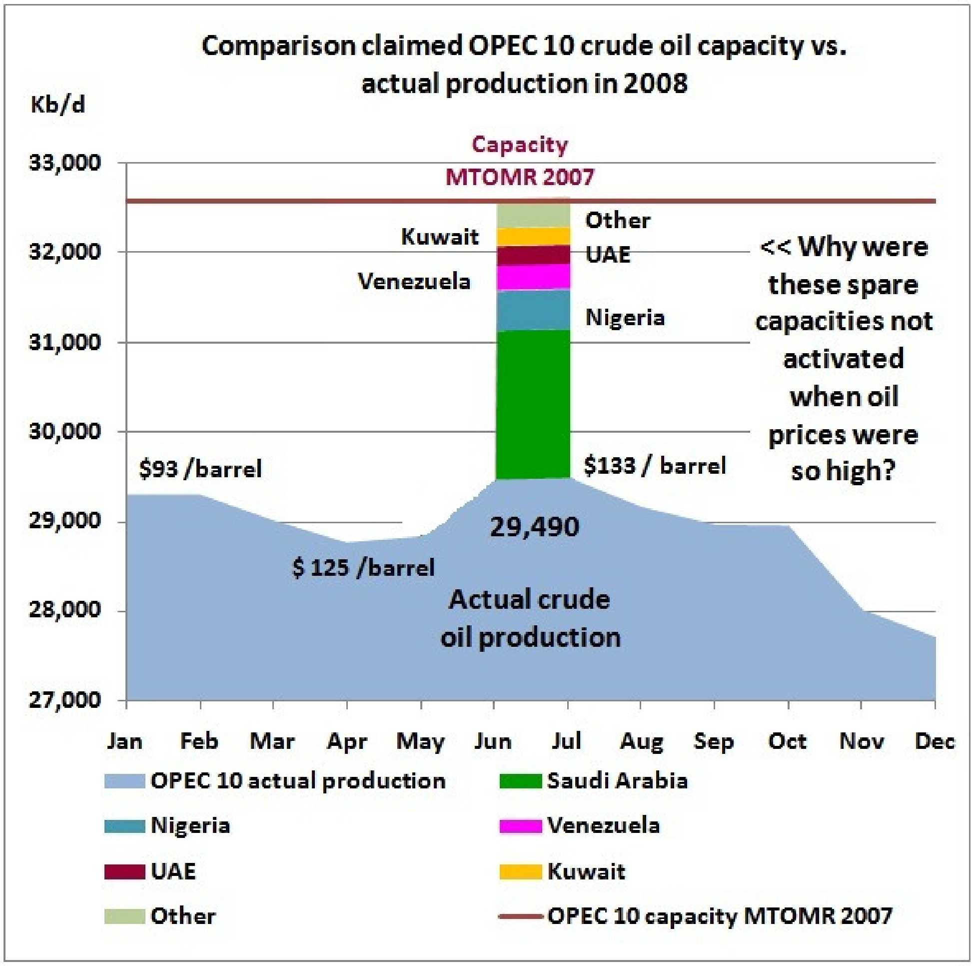


Figure 5: Comparison claimed OPEC 10 crude oil capacity versus actual production in 2008 [28,29]. MTOMR 2007

refers to the IEA's Mid Term Oil and Gas Market Report 2007 [30].

it was projected to drop to 8.1 mbpd; then, increase in 2010 to 8.5 mbpd. After 2010, a steady decline in oil production is forecast[32]. In July 2008, the depletion rate was above 5% per year. However, depletion rates could be less than 5%, if good reservoir management of large fields is applied[32]. In July 2010, King Abdullah of Saudi Arabia announced that he had ordered all oil exploration to cease supposedly "in order to keep the earth's wealth for our sons and grandsons[33]." King Abdullah's proclamation might be an admission that Saudi Arabia has no more oil to find.

Logically, OPEC reserves should be declining in recent years, since their oil is extracted while virtually no new fields are discovered or added. OPEC spare capacity may be significantly lower than is published. These OPEC nations have consistently reported constantly increasing reserve volumes since they increased their reserve estimates in the 1980's (see Figure 4). In other words, not only did OPEC nations inflated their reported reserve volumes in the 1980's, they also have consistently reported increasing reserve volumes since the 1980's despite continuously extracting oil from those reserves. Therefore, it may be highly appropriate and precautionary to assume that 287 – 300 Gb of claimed global oil reserve figures are indeed overstated and misreported.

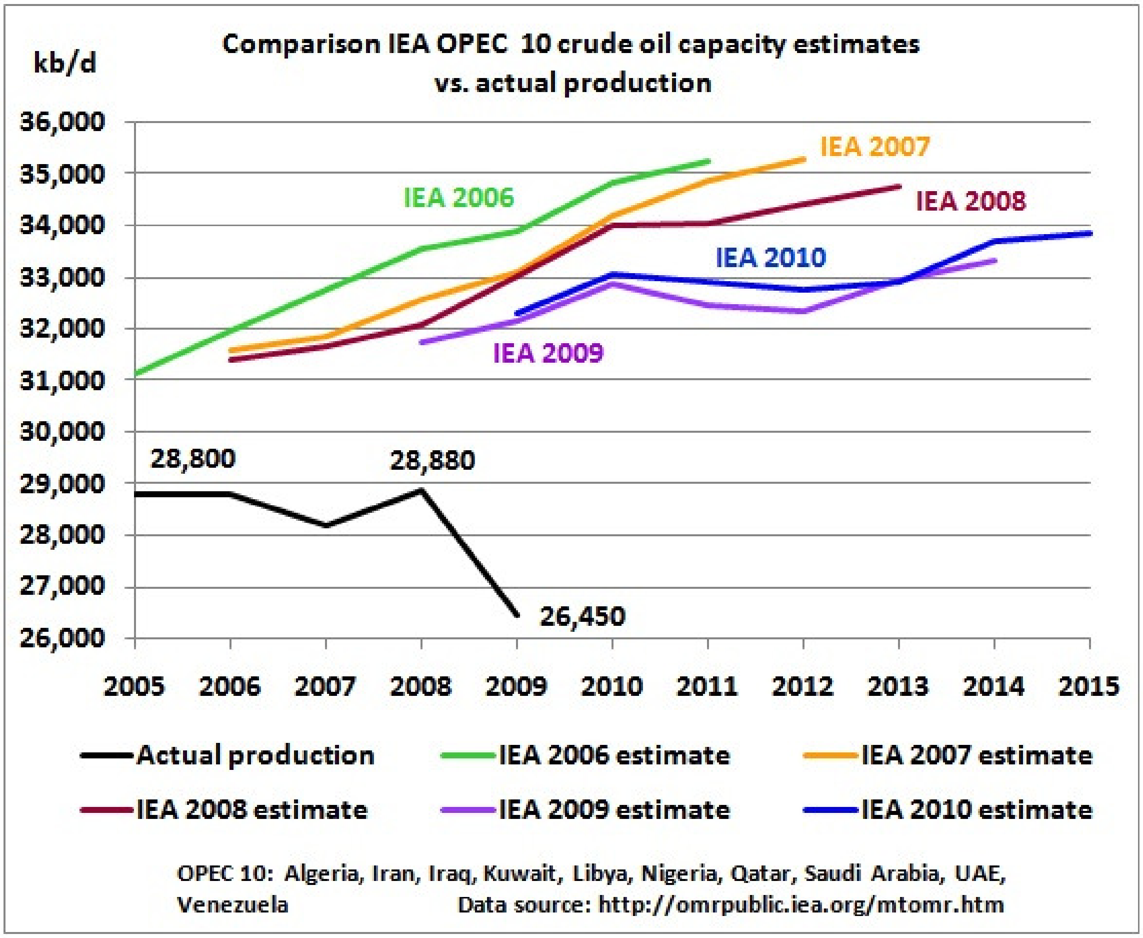


Figure 6: Comparison of IEA OPEC 10 crude oil capacity estimates versus actual production[28,29]*. IEA 2006–2010 refers to the IEA's Mid Term Oil and Gas Market Reports for the years 2006–2010, respectively.*

Information and Reporting Organizations

In addition to the lack of transparency and reporting standards, the oil resource assessments of information and reporting agencies that monitor the oil industry (e.g., the International Energy Agency (IEA) and the Energy Information Agency (EIA)) are also called into question. Political pressure and economic agendas may have corrupted these organizations' abilities to honestly and reasonably analyze and publish their resource assessments.

The International Energy Agency

In the past couple years, the International Energy Agency (IEA) has been accused of falsifying its assessments. The IEA is an intergovernmental organization that acts as energy policy advisor to 28 member nations. Founded during the oil crisis of 1973 – 1974, the IEA's initial role was to coordinate measures in times of oil supply emergencies. Over time, the IEA's mandate has broadened to incorporate the "Three E's" of balanced energy policy making: energy security, economic development and environmental protection. The IEA's current work focuses on climate change policies, market reform, energy technology collaboration and outreach to the rest of the world, especially major consumers and producers of energy like China, India, Russia and the OPEC countries[34].

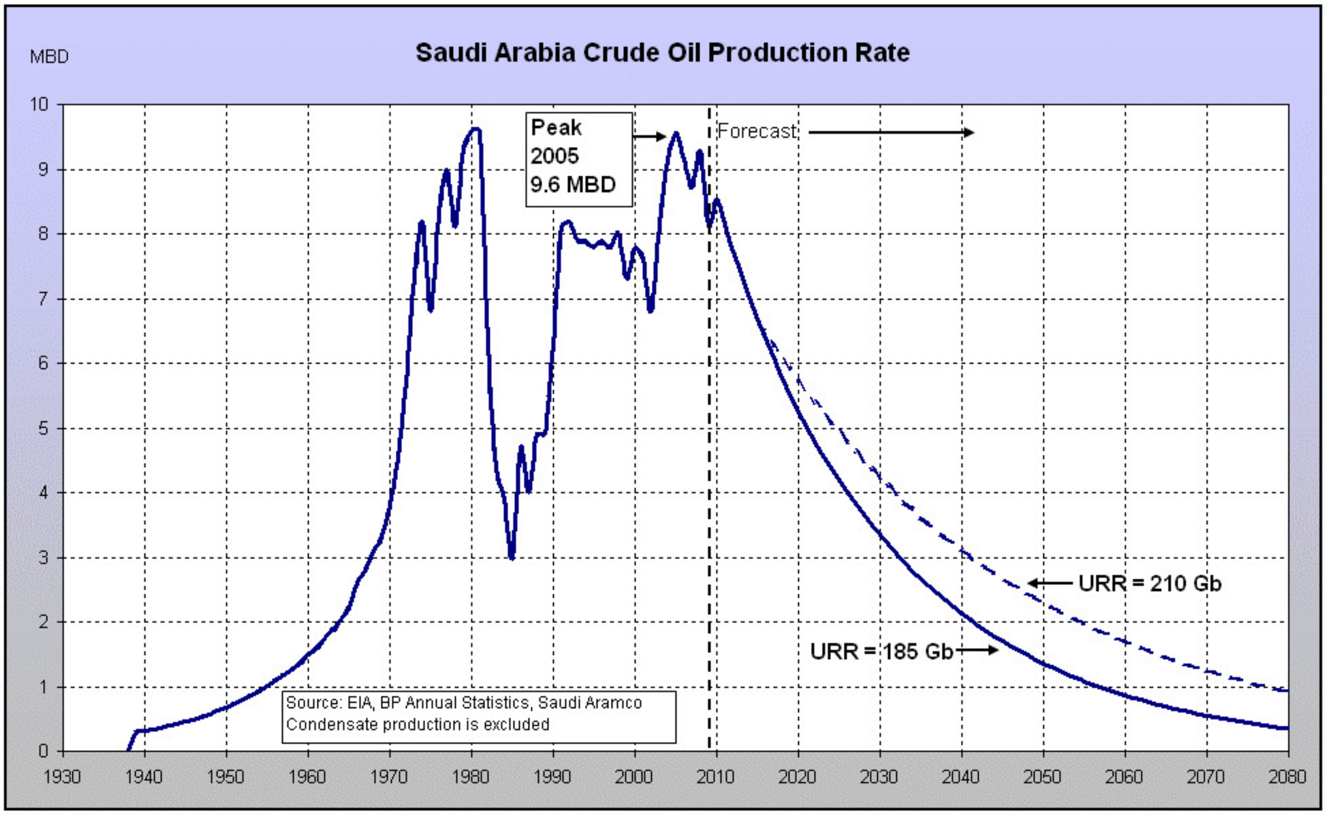


Figure 7: Saudi Arabia crude oil production to 2080 [32].

According to an anonymous senior official at the International Energy Agency, who was interviewed by a journalist at The Guardian (a British newspaper), the world is much closer to running out of oil than official estimates admit[16]. The whistleblower alleges the IEA has been deliberately underplaying an imminent oil shortage for fear of triggering panic buying. The IEA official also claims the U.S. played an influential role in encouraging the IEA to underplay the rate of production decline from existing oilfields while exaggerating the chances of discovering new oil reserves. The allegations raise serious questions about the accuracy of the IEA's *World Energy Outlook 2008* and *2009* on oil demand and supply, which is used by the British and many other governments to inform their national energy and climate change policies.

The official[16] questioned the prediction in the *WEO 2008* that oil production can be increased from 83 mbpd in 2008 to 105 mbpd by 2030 [2]. Although the *WEO 2009* lowered this projection from 105 mbpd to 103 mbpd by 2030 [35], this relatively small decrease may also be inflated. "The IEA in 2005 was predicting oil supplies could rise as high as 120m barrels a day [mbpd] by 2030 although it was forced to reduce this gradually to 116m and then 105m last year," said the IEA source, who asked to remain unidentified for fear of reprisals inside the industry. "The 120m figure always was nonsense but even today's number is much higher than can be justified and the IEA knows this...Many inside the organisation believe that maintaining oil supplies at even 90m to 95m barrels a day would be impossible, but there are fears that panic could spread on the financial markets if the figures were brought down further. And the Americans fear the end of oil supremacy because it would threaten their power over access to oil resources," he added[16].

A second senior IEA source, who has now left the organization but also asked to remain anonymous, said a key rule at the IEA was that it was "imperative not to anger the Americans", but the fact was that there was not as much oil in the world as the IEA reported. "We have [already] entered the 'peak oil' zone. I think that the situation is really bad," he added[16].

Furthermore, IEA sources who had contacted the Guardian also say that Fatih Birol, the chief economist at the IEA, has increasingly been facing questions about the figures by people inside the organization[16].

Kjell Aleklett, professor of physics and energy resources at Uppsala University, Sweden, claimed that the IEA's *WEO 2009* was a "political document" developed for consuming nations with a vested interest in low prices[36]. Aleklett said he had experiences similar internal worries about the IEA[36],

"The Organisation of Economic Cooperation and Development [OECD] gave me the task of writing the report, Peak Oil and the Evolving Strategies of Oil Importing and Exporting Countries. *This report was one of those discussed at a round-table meeting that was held in the IEA's conference room in Paris. At that opportunity, in November 2007, I had a number of private conversations with officers of the IEA. The revelations now reported in the Guardian [referring to an earlier article[16]] were revealed to me then under the promise that I not name the source. I had earlier heard the same thing from another officer from Norway who, at the time he spoke of the pressure being applied by the USA, was working for the IEA."*

The IEA recognizes the importance of its own reported figures, boasting on its website[37]: "The World Energy Outlook is the flagship publication of the International Energy Agency. It has long been recognised as the authoritative source of global long-term energy market analysis." Previously, the IEA also claimed on its website[16], "The IEA governments and industry from all across the globe have come to rely on the World Energy Outlook to provide a consistent basis on which they can formulate policies and design business plans."

The British government, among others, frequently uses IEA statistics rather than any of its own to argue that there is little threat to long-term oil supplies[16]. John Hemming, the Member of Parliament who chairs the all-party parliamentary group on peak oil and gas, said the leaked claims confirmed his suspicions that the IEA downplayed how rapidly the world was running out of oil, and that this oil decline had profound implications for the energy policy of the British government. He also claimed that he had been contacted by some IEA officials who were displeased with the British government's lack of independent skepticism over oil predictions. "Reliance on IEA reports has been used to justify claims that oil and gas supplies will not peak before 2030. It is clear now that this will not be the case and the IEA figures cannot be relied on," said Hemming[16].

Furthermore, the IEA has admitted that much of its previous assessments are not based on actual data, but simply on assumptions. In the *WEO 2007*, the IEA[38] estimated a weighted average observed decline rate from oilfields currently in production of around 3.7% per year in their Reference Scenario (BAU) to 2012. Yet, in the *WEO 2008*, the IEA estimated the global average oil production decline rate to be 6.7%[2], which is a major change from the 2007 estimate. In 2008, British journalist, George Monbiot[39], interviewed the chief economist of the IEA, Fatih Birol, about the IEA's their global oil supply and demand forecasts in the then newly published *WEO 2008*. Monbiot asked Birol about why the IEA made this major revision in its *WEO 2008*. Birol responded by stating that the year 2008 was the first time the IEA had assessed the 798 largest oilfields in the world to see how they were going to decline – and they estimated that the global average was 6.7%. Monbiot then asked Birol on what was the 3.7% estimate in the *WEO 2007* based. Birol responded[39],

"It was mainly an assumption, a global assumption about the world's oil fields. This year [2008] we look at the country-by-country, field-by-field, and we look at also onshore and offshore. It was very, very detailed. And, last year it was the assumption, and this year it was the finding of our study [sic]." In other words, the WEO 2007 *estimate of 3.7% was based on assumptions, whereas the* WEO 2008 *estimate of 6.7% was based on data. When Monbiot asked why the IEA had not done this research based on data before 2008, Birol replied, "In fact, nobody has done that research. And, this research we have done this year is the first time in the world. And, this is the first publicly available data in that respect [sic]."*

Monbiot[39] also asked Birol why the IEA dramatically re-forecast the likely price of oil in 2030 from $62 per barrel (in the *WEO 2007*) to $120 per barrel (in the *WEO 2008*; in real year-2007 dollars). Birol replied, "Investment needs are much higher than we thought in the past." Nevertheless, the estimated price for oil in 2030 nearly doubled in the *WEO 2008* from the *WEO 2007*. Therefore, the need for investment to continue producing oil must be significantly higher than reported in 2007.

Yet, Fatih Birol admitted that the energy industry's ability to supply future oil demand was declining. Birol added[39], "In this book [*WEO 2008*], we are asking for a global energy revolution. The reason why we are asking for an energy revolution is prepare everybody for difficult days and difficult times. I think we should be very careful that we make our policies ranging from the efficiency policies to research and development to get the new technologies in place in a timely manner [sic]."

When Monbiot asked Birol what would happen if that global energy revolution doesn't take place, Birol replied, *"Then, we will have much more difficult days than we had last summer, in 2008 summer* *[preceding the global economic crisis of 2008] in terms of high prices, first of all. This is the economic effect. And, there are also some other implications. For example, there will be a huge transfer of wealth from the consuming nations – from OECD countries, from Asia – to very few number of countries. And, of course, this transfer of wealth may have many implications under energy sector and beyond...The argument I put forward is, I believe, is a valid one. And, what I believe, is a strong one. And, maintained by facts and figures [sic].”*

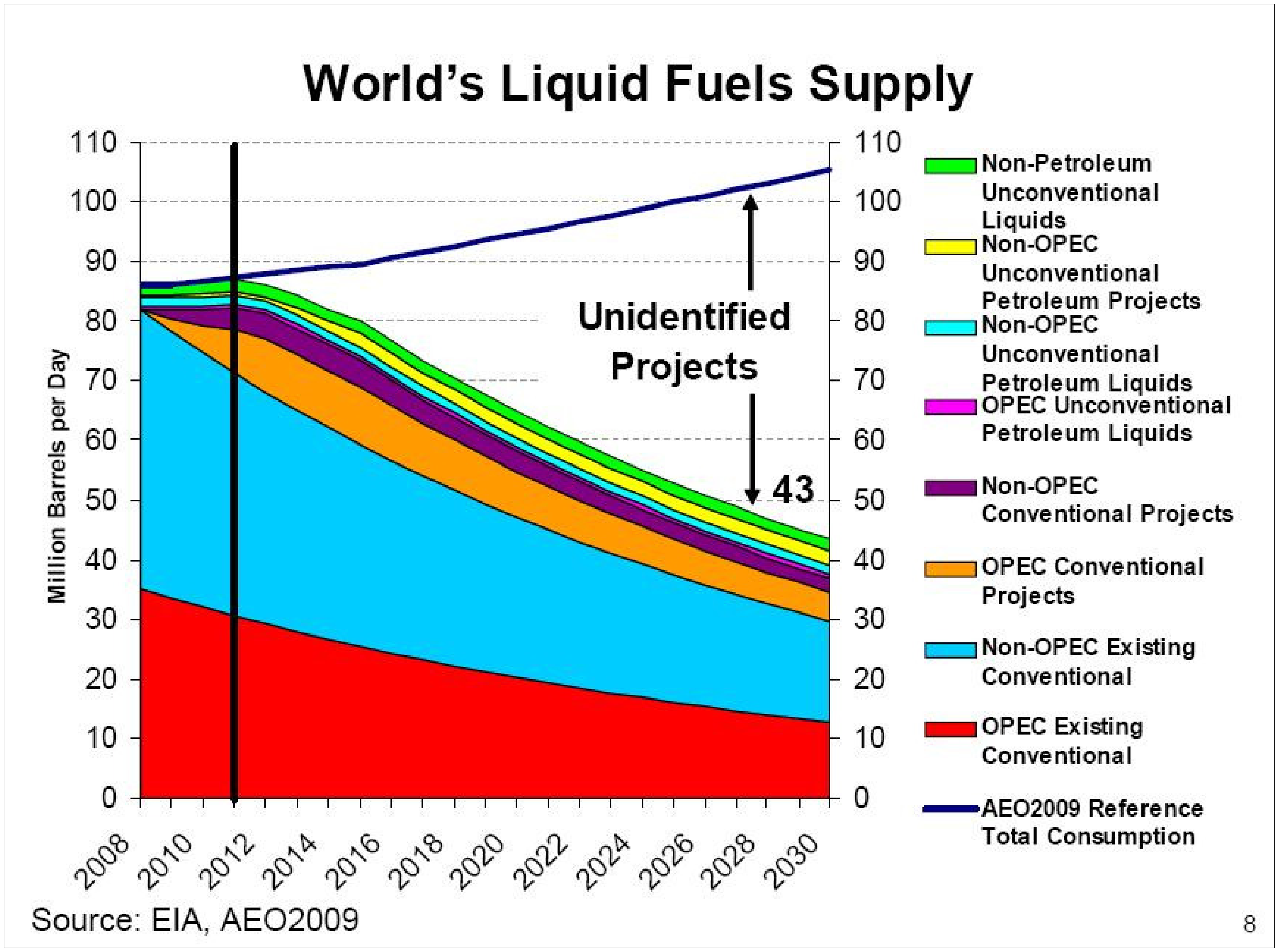
The U.S. Department of Energy

Perhaps one of the more confounding instances supporting peak liquid fuels supply within the next few years comes from the U.S. Energy Information Administration. Glen Sweetnam, former director of the International, Economic and Greenhouse Gas division of the Energy Information Administration (EIA) at the U.S. Department of Energy (DoE), admitted in an interview that “a chance exists that we may experience a decline” of world liquid fuels production between 2011 – 2015, “if the investment is not there”[40]. Until April 2010, Glen Sweetnam was the main official expert on the oil market in the Obama administration[41]. He also headed the publication of the DoE’s annual *Annual Energy Outlook* (*AEO*) and *International Energy Outlook* (*IEO*), which are considered a couple of the most influential annual energy reports for the outlook of the U.S. and international energy markets, respectively. Until recently, he was also vice president and principal at Houston-based Lukens Energy Group[41]. In April 2010, Sweetnam was transferred to the post of senior director for energy at the U.S. National Security Council, where he is now under direct authority of the White House[40,42].

In the same interview[40], Sweetnam also admitted that the solution to the issue of knowing when, where, and in what quantities additional sources of oil should be put into production is “unidentified”. Further, he indicates a possible decline of liquid fuels production between 2011 – 2015 could be the first stage of the “undulating plateau” pattern, which will start “once maximum world oil production is reached”, followed by the possibility of a near-term and unexpected fall of global liquid fuels production. As discussed in the following section *Supply and Demand*, a peak in global conventional oil production so far occurred in 2005 – 2008; and since then global production has demonstrated an undulating plateau pattern (see Figures 20a and 20b). Therefore, Sweetnam's projection may have already started to occur as early as 2005.

Sweetnam held a round-table meeting of oil economists on April 7, 2009 in Washington, D.C.. During the meeting, he made a presentation in which there appeared a graph in the presentation document showing that the DoE is expecting a significant decline in the total of the global liquid fuels supplies after 2011 [40,43] (see Figure 8a). The graph labels as “unidentified” the additional liquid fuel supply projects required to supply a gap that is projected to grow after 2011 between increasing global demand and the decline of oil supplies that the DoE projects will start in 2011 – 2012. Furthermore, the IEA projects that the post-peak production decline rate will be 2% per year – decreasing from 87 mbpd in 2011 to 80 mbpd in 2015 – while global demand for liquid fuels is projected to increase to 90 mbpd by 2015. Therefore, the “unidentified” additional liquid fuels projects would need to supply a 10 mbpd gap between liquid fuels supply and demand in less than 5 years. It should be noted, 10 mbpd is roughly equivalent to the liquid fuels production rate of Saudi Arabia. Therefore, the world would need the equivalent of at least another Saudi Arabia by 2015 to offset global liquid fuels production decline. According to the presentation and the transcript of this round-table meeting, many oil producing regions are projected to experience production declines before 2015 [40].

Although this admission of peak oil by 2011 by the DoE might seem alarming, what makes it particularly disconcerting is that although Sweetnam's chart cites the EIA's *Annual Energy Outlook 2009* as the source of Figure 8a, no such chart appears in the publication, nor in the *AEO 2008*, the *AEO 2010*, the *IEO 2008*,



Source: EIA, AEO2009

Figure 8a: World's liquid fuels supply. At a round-table meeting of oil economists on April 7, 2009 in Washington, D.C., Glen Sweetnam made a presentation in which there appeared a graph, "World's Liquid Fuels Supply" (shown in the figure above), in the presentation document showing that the U.S. Department of Energy (DoE) is expecting a significant decline of the total of the global liquid fuels supplies after 2011 [43]*. At the time, Sweetnam was the director of the International, Economic and Greenhouse Gas division of the Energy Information Administration (EIA) at the DoE. He claims that global liquid fuels production will likely decline between 2011 – 2015, if investment in liquid fuels projects does not occur*[40]*. If that investment does not occur, the gap that is projected to grow after 2011 between increasing global demand and the decline of oil supplies will grow over time, causing severe liquid fuels shortages. Until April 2010, Glen Sweetnam was the main official expert on the oil market in the Obama administration. The slide cites the EIA's* Annual Energy Outlook 2009 *(*AEO2009*) as the source of this graph, but the* AEO2009 *does not have such a graph. Rather, the* AEO2009 *presents an overly optimistic outlook for oil production, and does not discuss the rapid decline in oil production shown in the graph above.*

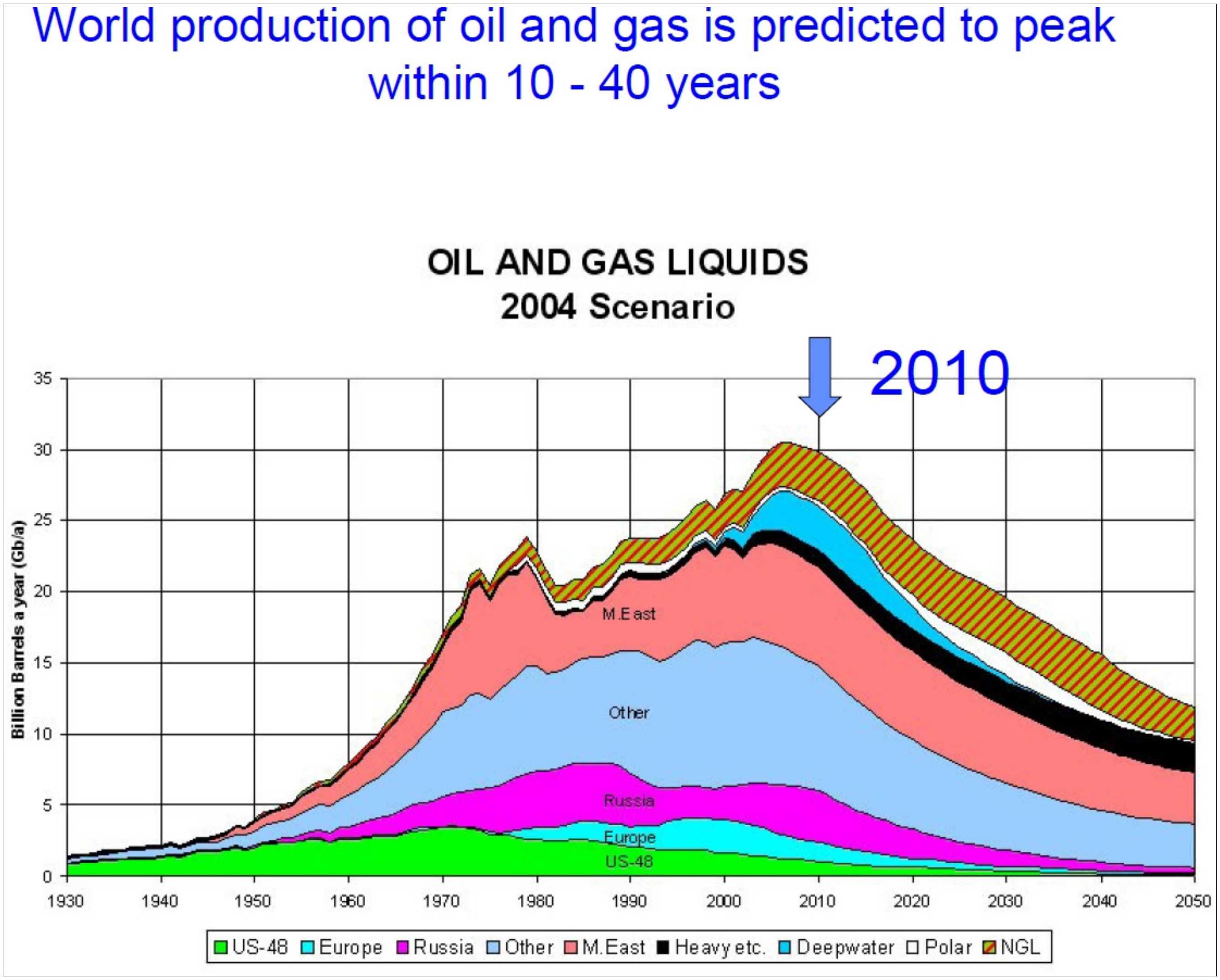


Figure 8b: Oil and gas liquids 2004 scenario. "World production of oil and gas is predicted to peak within 10 – 40 years". In March 2005, the U.S. Secretary of Energy, Steven Chu, presented on a hypothesis of an imminent decline in the global production of liquid fuels while he was director of the Lawrence Berkeley National Laboratory, a U.S. Department of Energy National Laboratory[47]. In his presentation, Chu indicated that peak oil and gas liquid fuels production would occur around 2005, and then decline rapidly starting in 2010, which he clearly indicated in his presentation slide shown in the figure above.

or the IEA's *WEO 2009* (in case EIA was a typographical error for IEA)[31,35,44-46]. On the contrary, the *AEO 2009* projects that total liquid fuels production in 2030 will be 105.4 mbpd in its reference case (i.e., BAU), and 119.3 mbpd in its low oil price scenario (i.e., $50 per barrel of oil). Even in its high oil price scenario (i.e., $200 per barrel of oil), the *AEO 2009* projects a limit of 88.9 mbpd by 2030. Yet, according to Sweetnam's graph in Figure 8a, global liquid fuels production could be less than 45 mbpd without the "unidentified" oil projects' contribution. Clearly, the graph that Sweetnam used was referenced incorrectly to the *AEO 2009*. It seems unlikely that the graph originally appeared in an older unpublished internal draft of the *AEO 2009* given the optimistic projections of all the recent *AEO* reports. Furthermore, Sweetnam's graph does not match the graphic style of either the *AEO* or *IEO* reports.

There is no clear evidence explaining this discrepancy. When Matthieu Auzanneau, a journalist for Le Monde, asked U.S. Department of Energy Secretary, Steven Chu, and the political staff of the DoE to comment on Glen Sweetnam's statement, they replied with a "no comment"[42]. Sweetnam was the director of the International, Economic and Greenhouse Gas division of the EIA at the U.S. DoE; and he was one of the heads of the *International Energy Outlook* and the *Annual Energy Outlook* (both of which share the same data, information, and authors). Presumably, Sweetnam had access to the same data and analyses that the *AEO 2009* authors had. However, it is uncertain whether the *AEO 2009* authors had the same information that Sweetnam had. Without further evidence, one can only speculate as to why this discrepancy occurred. Perhaps, the DoE has a public face and a private face in which the public receives one set of information and special interests have access to another? Sweetnam's graph and warnings may reflect insider knowledge of the energy market. His opinions may not represent the official opinion of the U.S. DoE and the U.S. government.

Another important figure in the DoE is the U.S. Secretary of Energy, Steven Chu, Nobel Laureate in Physics in 1997. Chu is also aware of the issues of global peak oil production. In March 2005, Chu presented on a hypothesis of an imminent decline in the global production of liquid fuels while he was director of the Lawrence Berkeley National Laboratory, a U.S. Department of Energy National Laboratory[47]. In his presentation, Chu indicated that peak oil and gas liquid fuels production would occur around 2005, and then decline rapidly starting in 2010, which he clearly indicated in his presentation slide shown in Figure 8b.

At that time, David Fridley, an expert on oil economics, worked under Chu. In an interview given in 2009, Fridley claims[48], "[Chu] was my boss...He knows all about peak oil, but he can't talk about it. If the government announced that peak oil was threatening our economy, Wall Street would crash. He just can't say anything about it."

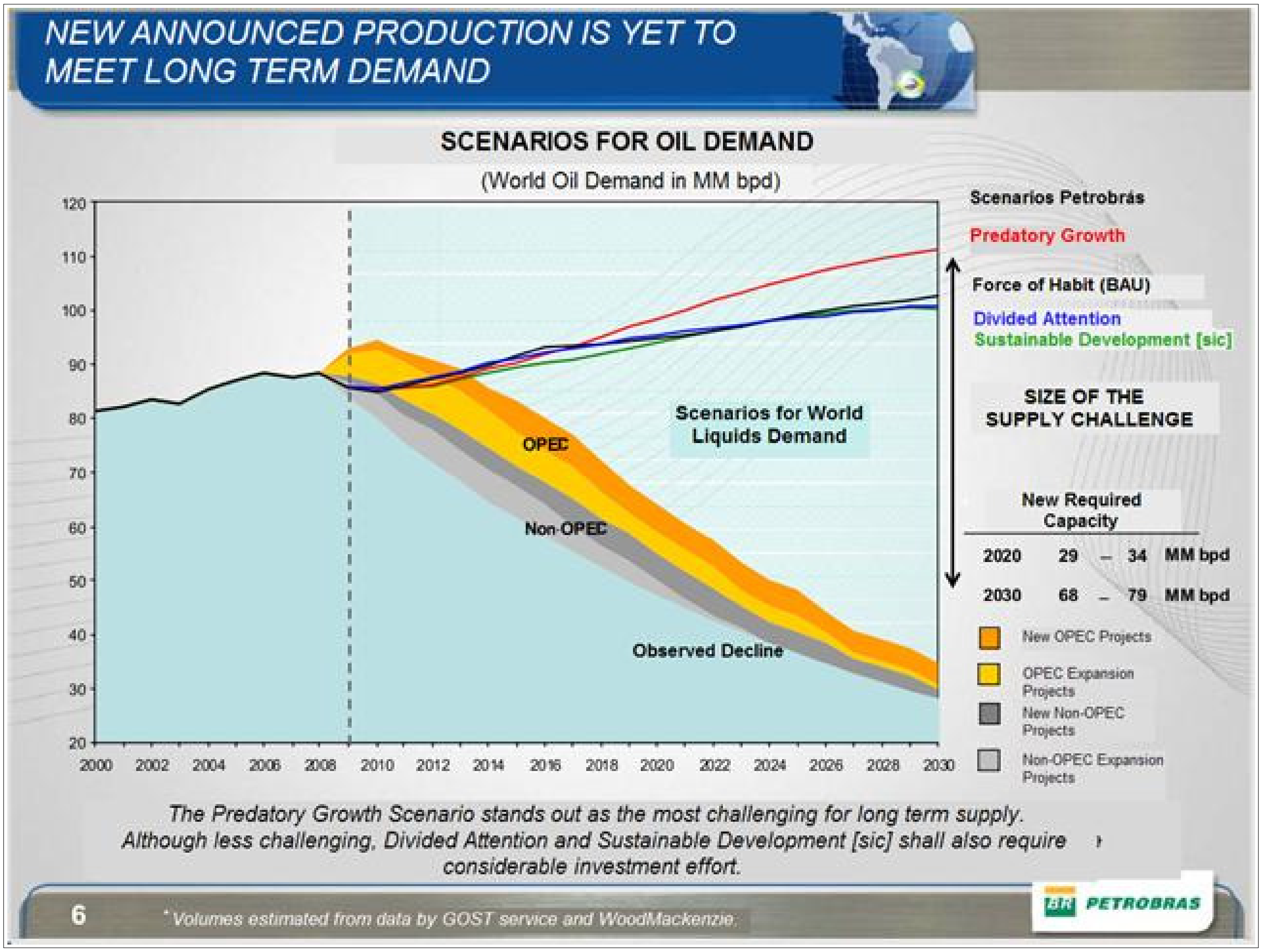
It is interesting to note that Chu based his projections for peak oil on the calculations of Colin Campbell, an expert oil industry geologist, who supposedly based his estimates on the confidential data of the consulting firm Information Handling Services[49,50] (IHS) (see below for more about IHS). The data and estimates of IHS on the global oil reserves are significantly less than those published in the public domain[50].

In 2005, *Peaking of World Oil Production: Impacts, Mitigation, and Risk Management* was written for the U.S. Department of Energy. Also called the *Hirsch Report*, after the name of the lead author, Robert Hirsch, the report examined the time frame for the occurrence of peak oil, the necessary mitigating actions, and the likely impacts based on the timeliness of those actions. Robert Hirsch has been a manager of petroleum exploratory research at Exxon, a senior staff member at the RAND Corporation, and director of the U.S. research program on nuclear fusion energy. In an interview in 2010 [42], Robert Hirsch claimed that after his 2005 report was published, the people in the DoE with whom he was working told him not to work on peak oil anymore, and not talk about it.

Hirsch added that the people who instructed him to stop discussing and working on peak oil were high-level in the laboratory; and that they were receiving their instructions from higher authorities on the political side of the DoE. After completing the work the authors of the *Hirsch Report* did on the 2005 study and on the follow-up in 2006, the DoE headquarters "completely cut off all support for oil peaking and decline analysis"[42]. Further, the people that Hirsch worked with at the National Energy Technology Laboratory were also told to stop working on peak oil and to stop discussing the matter. Hirsch adds[42], "It has not changed. I have friends who simply won't talk about it now. So I have to assume that they are receiving the same kind of instructions."

Private Industry

In some cases, proprietary rights and trade secrets of private firms can create a lack of transparency and distort public data. For instance, the data and estimates of Information Handling Services (IHS) Inc., an information service provider, on the global oil reserves are significantly less than those published in the public domain. Yet, access to IHS data and reports are restricted. IHS reports are protected by strict copyright protections. The price to oil companies, major banks, and other clients for annual access to IHS analysis is supposedly very expensive, but the actual price is confidential. A statistician at the l'Institut Français du Pétrole (IFP) claims that the price is €1 million per year[50].



NEW ANNOUNCED PRODUCTION IS YET TO MEET LONG TERM DEMAND

SCENARIOS FOR OIL DEMAND

(World Oil Demand in MM bpd)

Scenarios Petrobrás

Predatory Growth

Force of Habit (BAU)

Divided Attention

Sustainable Development [sic]

SIZE OF THE SUPPLY CHALLENGE

New Required Capacity				
2020	29	–	34	MM bpd
2030	68	–	79	MM bpd

- 🟧 New OPEC Projects
- 🟨 OPEC Expansion Projects
- ■ New Non-OPEC Projects
- □ Non-OPEC Expansion Projects

The Predatory Growth Scenario stands out as the most challenging for long term supply. Although less challenging, Divided Attention and Sustainable Development [sic] shall also require considerable investment effort.

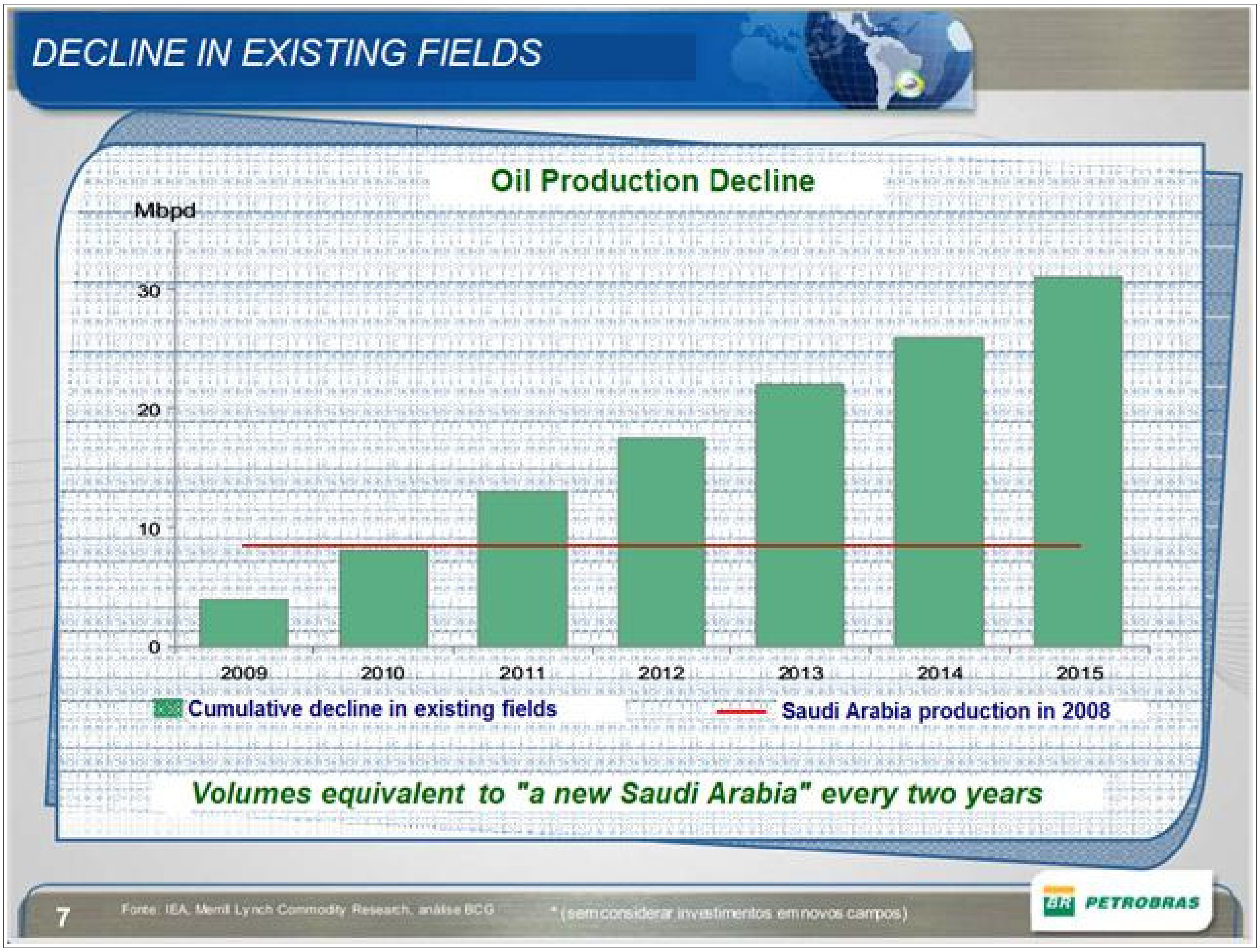
6

* Volumes estimated from data by GOST service and WoodMackenzie.

PETROBRAS

Figure 9a: A presentation slide (slide 6) showing a possible peak in global oil production around 2010 as presented by José Sergio Gabrielli de Azevedo, the CEO of Petroleo Brasileiro SA (a.k.a., Petrobras), Brazil's state-controlled oil company[51]. The slide shows world oil capacity peaking in 2010 due to oil capacity additions from new projects being unable to offset world oil decline rates.

Lack of transparency can be abused and fraud committed. For example[52-55], in 2004, Royal Dutch Shell overstated its oil and gas reserves by 20%. Shell announced it had agreed to the settlement for non-U.S. investors without admitting any wrongdoing. The lawsuit resulted in the payment of $450 million to non-American shareholders in 2007 to settle investors' claims related to its 2004 reserve crisis. The 2004 reserve scandal prompted the departure of several top executives, including chairman Sir Philip Watts. Shell was also fined a total of £82.7 million by U.S. and UK regulators. As a consequence of the scandal, Shell also abolished its twin board structure that investors complained lacked clarity and accountability. This lack of clarity and accountability may have contributed to the reserves scandal.



DECLINE IN EXISTING FIELDS

Oil Production Decline

🟩 Cumulative decline in existing fields

Saudi Arabia production in 2008

Volumes equivalent to "a new Saudi Arabia" every two years

Fonte: IEA, Merril Lynch Commodity Research, análise BCG

* (sem considerar investimentos em novos campos)

Figure 9b: A presentation slide (slide 7) showing a cumulative decline in existing fields over time; as presented by José Sergio Gabrielli de Azevedo, the CEO of Petroleo Brasileiro SA (a.k.a., Petrobras), Brazil's state-controlled oil company[51]*. According to slide 7, the world needs one Saudi Arabia every two years just to keep production constant.*

Oil industry executives have recently made public statements about peak oil production occurring in the near-term. José Sergio Gabrielli de Azevedo is the CEO of Petroleo Brasileiro SA (a.k.a., Petrobras), Brazil's state-controlled oil company. In December 2009, Gabrielli gave a presentation[51] in which slide 6 shows global oil capacity (including biofuels) peaking in 2010 due to oil capacity additions from new projects being unable to offset global oil decline rates (see Figure 9a). In his presentation, Gabrielli states that the world would need the equivalent of one Saudi Arabia every two years to offset future world oil decline rates. The observed decline rate is approximately 5.1% per year. On slide 7 in his presentation, Gabrielli plots cumulative decline in existing fields over time. According to slide 7, the world may need one Saudi Arabia every two years just to keep production constant (see Figure 9b).

Similarly, other oil company executives have recently made statements of peak oil supplies occurring in the near-term. For instance, Sadad al-Husseini, former Aramco executive, states that global oil production is on a peak production plateau[15]. Christophe de Margerie, CEO of Total, does not believe that global oil production will ever exceed 89 mbpd[56]. Global oil production in 2010 is around 86 – 87 mbpd.

For over two years, Chevron had a series of "easy oil is over" advertisements as part of its *willyoujoinus* campaign. The advertisements are signed "Dave" (i.e., David O'Reilly, chairman of Chevron). The advertisements include the statement[57]: "The world is currently burning 2 barrels of oil for every barrel of new oil discovered." Another statement is[57]:

"Energy will be one of the defining issues of this century, and one thing is clear: the era of easy oil is over...Many of the world's oil and gas fields are maturing. And new energy discoveries are mainly occurring in places where resources are difficult to extract – physically, technically, economically, and politically."

Therefore, it seems that some in the energy industry, including at least some of the executives, are aware of peak oil being a near-term event, rather than something that may happen in the distant future.

Oil Discoveries

Chapter 5

“The world is currently burning 2 barrels of oil for every barrel of new oil discovered.”

– Chevron Corporation[57], *willyoujoinus* advertising campaign, 2005 – 2010

“Energy will be one of the defining issues of this century, and one thing is clear: the era of easy oil is over...Many of the world's oil and gas fields are maturing. And new energy discoveries are mainly occurring in places where resources are difficult to extract – physically, technically, economically, and politically.”

– Chevron Corporation[57], *willyoujoinus* advertising campaign, 2005 – 2010

- Global oil reserve discoveries peaked in the 1960's.
- New oil discoveries have been declining since then, and the new discoveries have been smaller and in harder to access areas (e.g., smaller deepwater reserves).
- The volume of oil discovered has dropped far below the volume produced in the last two decades.
- In total, 507 fields are classified as ‘giant’, and account for 60% of conventional oil production.
- The top 110 producing oilfields produce over 50% of the global oil supply.
- The top 20 producing oilfields contribute 27%.
- The most productive 10 fields contribute 20%.
- Production from 16 of the top 20 producing fields was in terminal decline in 2007.

Historically, the widening gap between oil discoveries and production can be almost entirely attributed to reduced discovery rates (see Figure 10). Global oil reserve discoveries peaked in the 1960's. Oil discoveries declined from an average of 56 Gb per year in the 1960's to 13 Gb per year in the 1990’s. The number of discoveries fell sharply in the 1990's, after they peaked in the 1980's. New oil discoveries have been declining, and the the new discoveries have been smaller and in harder to access areas (e.g., smaller deepwater reserves)[2].

In the last two decades, the volume of oil discovered has dropped far below the volume produced (see Figure 11). However, in the near future this gap between oil discoveries and production could widen further by projected declines in production from the relatively few fields that support global supply. World oil reserves are unevenly distributed between 70,000 fields[2]. The majority of crude oil production comes from a small number of very productive fields – mostly super-giant and giant oilfields.

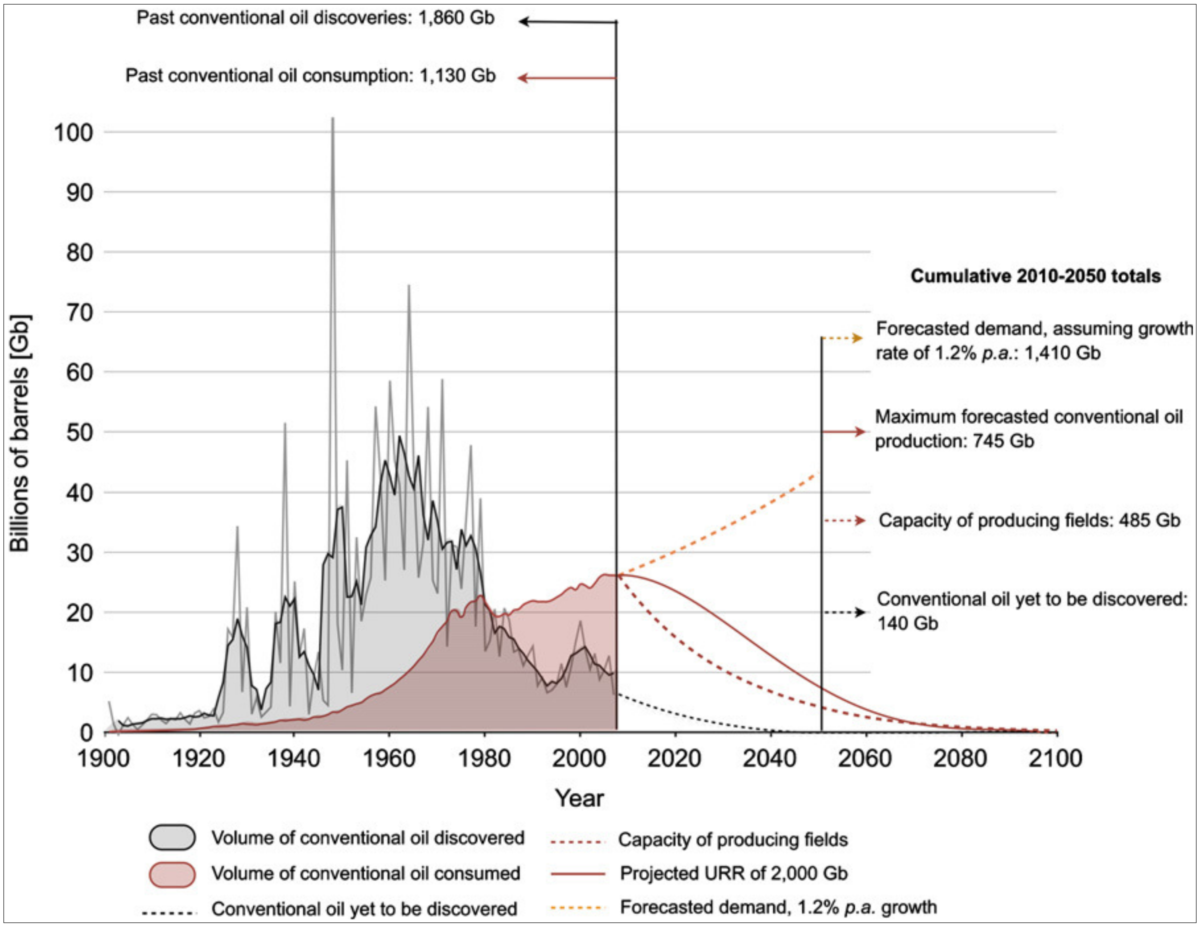
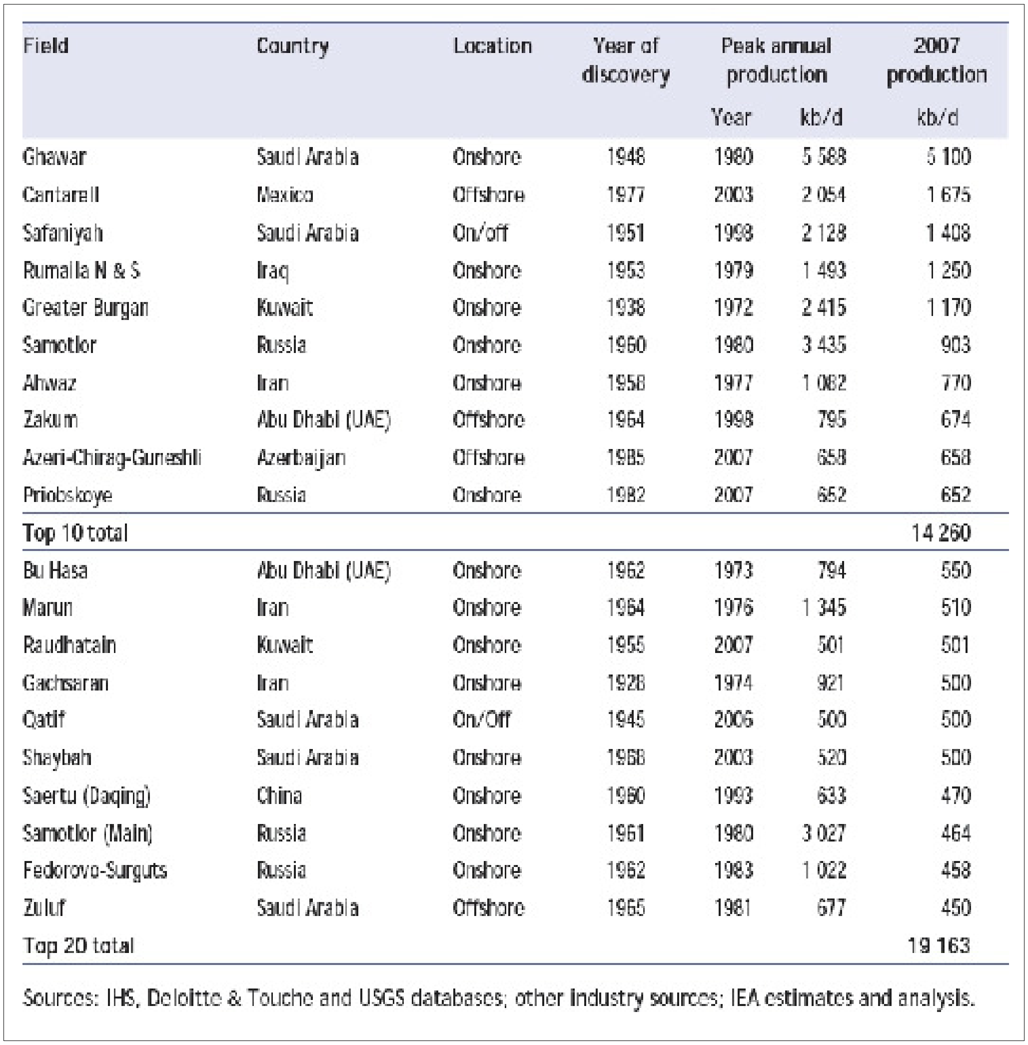


Figure 10: Annual backdated 2P conventional oil discovery, conventional oil consumption, and forecasted production and discovery[2,19,58,59 as cited in 17].

The IEA defines a *super-giant* as an oilfield with initial 2P (i.e., proven plus probable) reserves of at least 5 Gb; a *giant* as a field with initial reserves of 500 million barrels to 5 Gb; a large field contains more than 100 million barrels[2]. In total, 507 fields are classified as *giant*, and account for 60% of conventional oil production[5]. The top 110 producing oilfields produce over 50% of the global oil supply (more than 100 kbpd each); the top 20 oilfields contribute 27% (about 19.2 mbpd); and the most productive 10 fields contribute 20% (approximately 14 mbpd in 2007). All of the 20 largest producing oilfields are super-giants, of which Ghawar (140 Gb of initial reserves) is by far the largest (see Table 1). The Ghawar oilfield in Saudi Arabia supposedly produced 5.1 kbpd in 2007, which was equal to 7% of global conventional oil production[2]. A very large number of small fields, approximately 70,000 in total, presently produce just under 50% of global production (each producing less than 100 kbpd)[2]. Of the 507 giant oil fields, 430 are in production[5], of those 261 are in decline[60]. In 2007, production from 16 of the top 20 producing fields was also in terminal decline (see Table 1)[2].

Very few giant oil fields have been found since the early 1980's, and the last of the super-giants was found in the 1960's[61]. Figure 10 shows the peak of conventional oil discovery occurred in the early 1960's. The year 1948 experienced the most discoveries, with finds totaling 107 Gb – including the Ghawar oilfield (world’s largest and most productive field ever discovered) in Saudi Arabia. In 1985, Azeri-Chirag-Guneshli was the last of the top 20 producing fields to be discovered. Priobskoye in Russia was found in 1982; Canterell in Mexico in 1977; and all the others between 1928 – 1968 [2] – which suggests that the chances of finding fields of similar size are remote.

Table 1: The world's 20 biggest oilfields by production[2].



Field	Country	Location	Year of discovery	Peak annual production		2007 production
				Year	kb/d	kb/d
Ghawar	Saudi Arabia	Onshore	1948	1980	5 588	5 100
Cantarell	Mexico	Offshore	1977	2003	2 054	1 675
Safaniyah	Saudi Arabia	On/off	1951	1998	2 128	1 408
Rumalia N & S	Iraq	Onshore	1953	1979	1 493	1 250
Greater Burgan	Kuwait	Onshore	1938	1972	2 415	1 170
Samotlor	Russia	Onshore	1960	1980	3 435	903
Ahwaz	Iran	Onshore	1958	1977	1 082	770
Zakum	Abu Dhabi (UAE)	Offshore	1964	1998	795	674
Azeri-Chirag-Guneshli	Azerbaijan	Offshore	1985	2007	658	658
Priobskoye	Russia	Onshore	1982	2007	652	652
Top 10 total						**14 260**
Bu Hasa	Abu Dhabi (UAE)	Onshore	1962	1973	794	550
Marun	Iran	Onshore	1964	1976	1 345	510
Raudhatain	Kuwait	Onshore	1955	2007	501	501
Gachsaran	Iran	Onshore	1928	1974	921	500
Qatif	Saudi Arabia	On/Off	1945	2006	500	500
Shaybah	Saudi Arabia	Onshore	1968	2003	520	500
Saertu (Daqing)	China	Onshore	1960	1993	633	470
Samotlor (Main)	Russia	Onshore	1961	1980	3 027	464
Fedorovo-Surguts	Russia	Onshore	1962	1983	1 022	458
Zuluf	Saudi Arabia	Offshore	1965	1981	677	450
Top 20 total						**19 163**

Sources: IHS, Deloitte & Touche and USGS databases; other industry sources; IEA estimates and analysis.

Energy Return On Investment (EROI)

"All the easy oil and gas in the world has pretty much been found. Now comes the harder work in finding and producing oil from more challenging environments and work areas."

– William J. Cummings[62], Exxon-Mobil company spokesman, 2005

- The energy return on investment (EROI) is the ratio between the amount of energy expended to obtain a particular energy resource and the amount of usable energy acquired from that resource.
- The remaining oil is becoming increasingly harder and more costly to access and extract, and it is of increasingly lower quality.
- The present EROI for oil is significantly lower than the past EROI for oil; and future EROI for oil will be even lower.

Although the world is far from running out of oil, the remaining oil is becoming increasingly harder to access and extract, and it is of increasingly lower quality. Therefore, the energy and economic investment required to produce the remaining oil is increasing as the energy yield from reserves is decreasing – i.e., the energy return on investment (EROI) is decreasing. EROI is the ratio of the energy delivered or produced by a process to the energy used directly and indirectly in that process. When the EROI ratio is greater than unity (i.e., greater than 1), a net positive energy yield is gained. When the EROI is less than unity, a net negative energy is gained (i.e., there is a net energy loss). An EROI of unity means that no energy is gained or lost. The higher the EROI, the more units of energy are gained for every one unit invested. In particular, the present EROI for oil is significantly lower than the past EROI for oil; and future EROI for oil will be even lower. For example, U.S. domestic oil production's EROI decreased from about 100:1 in 1930, to 40:1 in 1970, to about 14:1 today[63] (see Figure 11). In other words, for every one unit of energy invested in producing oil in 1930, 100 units of energy could be gained from the oil. But today, for every one unit of energy invested in producing oil, only 14 units of energy can be gained from the oil. In the past century, the EROI has declined by an order of magnitude. Figure 11 also compares the EROI of a variety of energy resources, in addition to oil resources. Depending on a variety of factors (e.g., design, quality, operating conditions, maintenance) some of the technologies represented in Figure 11 may get higher or lower energy yields than shown – but overall, the graph offers a general idea of the scales of energy being considered.

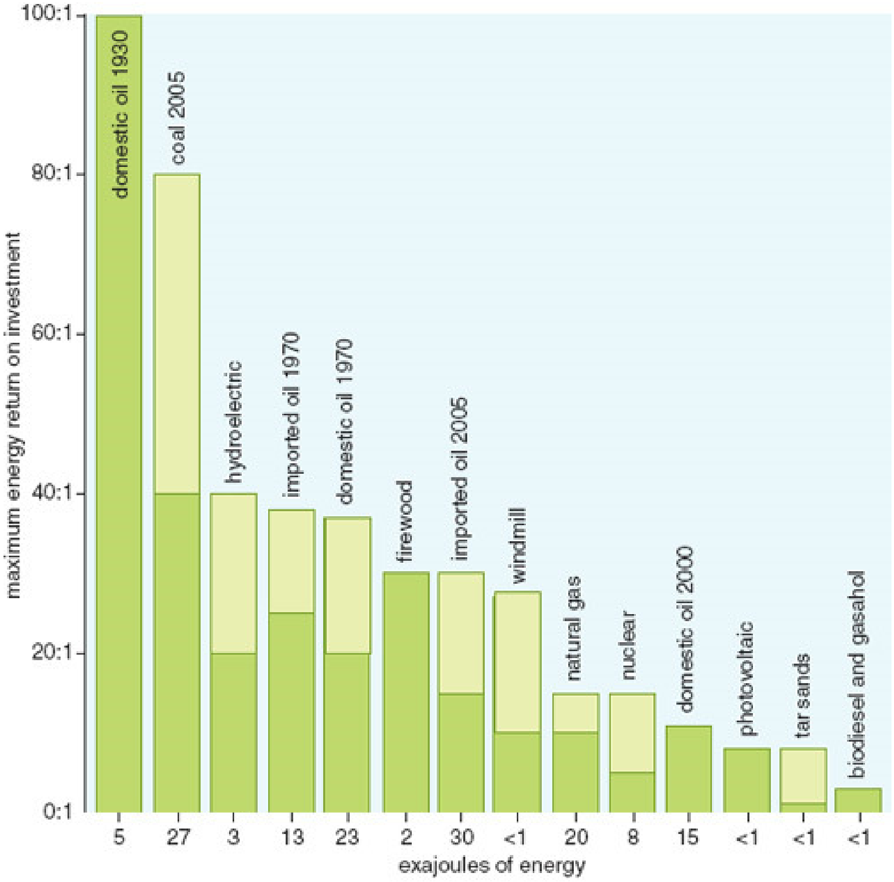


Figure 11. Energy return on investment (EROI). The EROI is the energy cost of acquiring an energy resource; one of the objectives is to get out far more that you put in. Domestic oil production's EROI has decreased from about 100:1 in 1930, to 40:1 in 1970, to about 14:1 today. The EROI of most "green" energy sources, such as photovoltaics, is presently low. (Lighter colors indicate a range of possible EROI due to varying conditions and uncertain data.) EROI does not necessarily correspond to the total amount of energy in exajoules produced by each resource[63].

"The growth rate of supplies of "easy oil", conventional oil and natural gas that are relatively easy to extract, will struggle to keep up with accelerating demand. Just when energy demand is surging, many of the world's conventional oilfields are going into decline."

– Jeroen van der Veer[64], CEO, Royal Dutch Shell, 2007

- Conventional oil from producing fields currently supply approximately 85% of the global liquid fuel mix.
- The ultimately recoverable resources (URR) of conventional oil amount to 3,500 Gb.
- One-third – about 1,100 Gb – of this total 3,500 Gb has been produced up to now.
- Remaining onventional oil proven reserves, Canadian oil sands reserves, and natural gas liquids supplies should be revised downward to 850 – 900 Gb from 1,200 – 1,300 Gb.
- Undiscovered oil resources account for the other third of the remaining recoverable oil – about 1,100 Gb.
- Since "undiscovered oil resources" have not yet been discovered (i.e., it is not known if the oil actually exists), and since oil discoveries have been declining since the 1960's, it is unlikely that the remaining "undiscovered oil resources" will be discovered in any significant amount.
- Therefore, there may only be about 850 – 900 Gb of recoverable conventional oil and natural gas liquids resources remaining.

The ultimately recoverable resources (URR) of the world's conventional oil amount to 3,500 Gb – not including approximately an additional 500 Gb that might come from new sources not yet assessed and the application of new technologies. This category of resources includes initial proven and probable reserves from discovered fields (see the *Appendix 1* for definitions of reserve estimates), reserves growth and economically recoverable oil that has yet to be found[2]. Only one third – about 1,100 Gb – of this total 3,500 Gb has been produced up to now[2]. The IEA claims that the remaining global proven reserves of oil and natural gas liquids were approximately 1,200 – 1,300 Gb (including about 200 Gb of Canadian oil sands) at the end of 2007 [2]. These reserves supposedly have almost doubled since 1980. The IEA claims that most of the increase in reserves has come from revisions made in the 1980's in OPEC countries rather than from new discoveries; and that modest increases have continued since 1990, despite rising consumption[2]. As discussed in *Oil Data Is Inaccurate*, OPEC's reserves claims are spurious. Therefore, the actual reserve volume may be lower than stated.

Undiscovered oil resources account for about a third (about 1,100 Gb) of the remaining recoverable oil. Since “undiscovered oil resources” have not yet been discovered (i.e., it is not known if the oil actually exists), and since oil discoveries have been declining since the 1960’s, it is unlikely that the remaining third of “undiscovered” oil resources will be discovered in any significant amount in the near- or medium-term, if ever. Any undiscovered reserves that might be found will not be developed and put into production for many years since discovery and development require several years to realize, assuming that such reserves are economically profitable and investment can be financed. Any remaining undiscovered reserves will likely be lower in quality and the harder to extract, which will require a greater amount of investment for a lower return (see Figures 12 and 13). Ignoring undiscovered oil reserves from the accounting would reduce the world's URR to about 2,300 Gb of oil, of which half have already been produced. Since peak oil production usually occurs after approximately half of the recoverable oil in an oil reserve has been produced, this would indicate that global oil production has peaked or will peak soon.

However, as discussed in the previous section regarding OPEC's misreporting its reserves and how the IEA and EIA have misreported oil data and estimates, independent analyses demonstrate a consensus among some authors that reserve estimates published by reporting and information agencies are likely to be exaggerated and over-inflated. According to these authors[2,5,21-23] conventional oil reserves should be revised downward to 850 – 900 Gb from 1,200 – 1,300 Gb. Using reported 2P figures, Owen et al.[17] also estimate that global reserve figures should be revised downwards from 1,200 – 1,300 Gb to 850 – 900 Gb

Adjusting for acknowledged errors and misreported figures, and assuming that the contribution of remaining undiscovered oil resources is negligible, the world may be left with approximately 850 – 900 Gb of oil exploitable in the ground – and not 2,200 Gb. If correct, this would suggest that the world oil production has likely peaked or will peak in the near-term. About 1,100 Gb of this total 2,200 Gb has been produced up to now. That leaves half remaining. Halfway is when production peaks. This would suggest that we are currently within the period of peak oil production, if the “undiscovered oil” indeed does not exist. Since recovery factors for oil are less than 100%, it is possible that even this remaining amount of oil is not completely exploitable for future demand.

Unconventional Oil

"It is pretty clear that there is not much chance of finding any significant quantity of new cheap oil. Any new or unconventional oil is going to be expensive."

– Lord Ron Oxburgh[65], a former chairman of Royal Dutch Shell, 2008

- Unconventional oil resources include extra-heavy oil, oil sands, oil shales, gas-to-liquids (GTL) and coal-to-liquids (CTL).
- The global supply of unconventional oil is projected to increase from 1.7 mbpd in 2007 to 8.8 mbpd in 2030.
- These unconventional oil resources may supply less than 7% of projected global demand by 2030.
- These projections are based on significant assumptions of BAU and other factors.
- It is unlikely that unconventional oil resources will be able to significantly replace conventional oil supplies in the future.
- The EROI of these unconventional oil resources is substantially lower than that of conventional oil.
- Unconventional oil resources have greater environmental impacts associated with them, including higher CO_2 emissions.
- Unconventional oil resources cost at least 2 – 3 times more to produce than conventional oil; so it is likely that oil prices for consumers may increase proportionally.
- High prices will likely make unconventional oil resources economically nonviable in the future.

Increasing Oil Production Costs

The IEA[2] projects that unconventional oil – including extra-heavy oil (excluding that from Venezuela), oil sands, chemical additives, gas-to-liquids and coal-to-liquids – will be an important fuel source for offsetting declining oil production from existing fields and new conventional oilfields and from NGLs. The agency projects that the global supply of unconventional oil will increase from 1.7 mbpd in 2007 to

8.8 mbpd in 2030. In total, these projected unconventional oil supplies would only add 7.1 mbpd to global oil supplies by 2030, as compared to 2007 production. These unconventional oil resources would supply less than 7% of projected global demand by 2030. Oil production from oil sands, with Canada making the largest contribution, is projected to increase from 1.2 mbpd in 2007 to 5.9 mbpd in 2030. Gas-to-liquids (GTL) production is projected to increase from about 50 kbpd in 2007 to 650 kbpd in 2030. Coal-to-liquids (CTL) production would increase by 1 mbpd. However, the IEA[2] stresses that these projections are based on significant assumptions, especially those for GTL and CTL, given the uncertainties about future technology choices and the resulting mix of fuels; the development of the technologies; how production costs will change relative to alternative ways of producing the resources; and future environmental constraints.

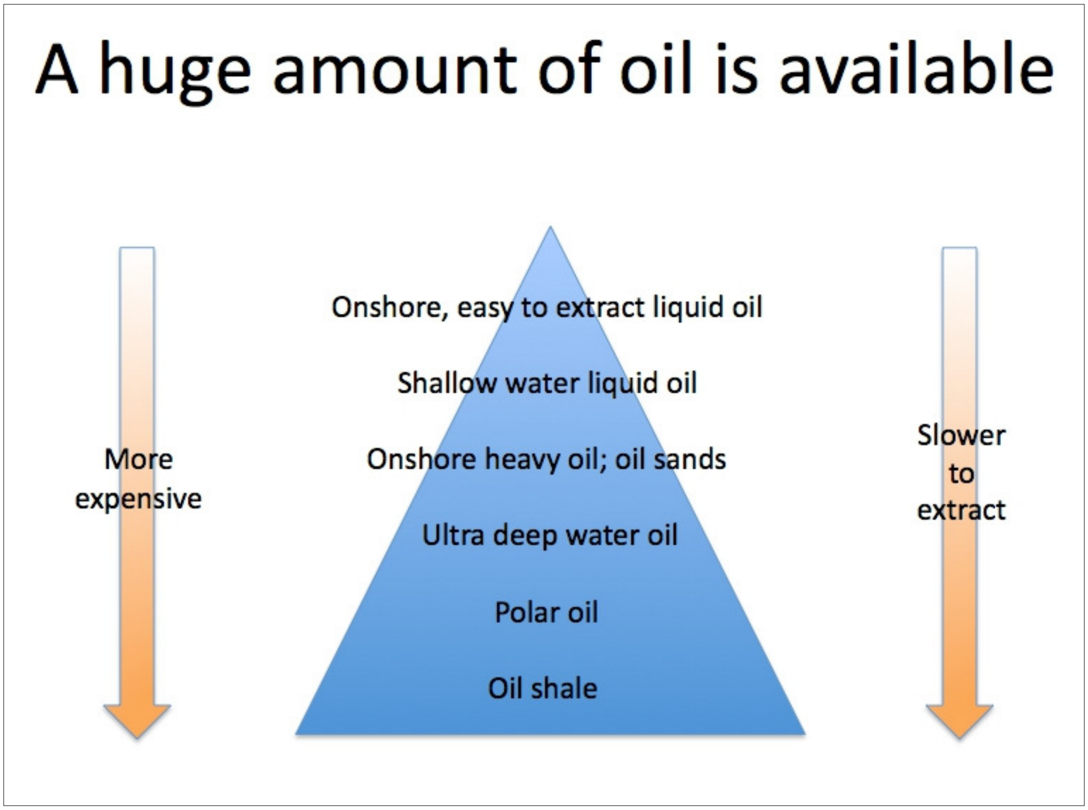


Figure 12: Diagram depicting increasing costs and challenges of extracting unconventional oil resources. Although there may be huge amounts of oil potentially available, they become increasingly harder and more expensive to extract until they are not viable to produce[66].

The total production cost for oil includes the cost of finding and adding new reserves, plus the cost of extracting the oil or other fossil materials (e.g., bitumen, gas, coal). Production costs are the costs to produce the oil. Oil prices are how much oil sells for on the market. In order to make a profit, oil prices have to be more than the production costs. Consequently, production costs affect the price of oil. Figure 13 shows a long-term oil-supply production cost curve (approximate per barrel production cost for oil resources) based on IEA ultimate recoverable reserves (URR) estimates[2]. The long-term oil-supply cost curve plots the potential long-term contributions from conventional oil resources (including those defined above as conventional oil produced by unconventional means) and unconventional resources (including

GTL and CTL) against their current associated production costs. The IEA[2] estimates that the total long-term conventional oil resource base (including proven, probable and undiscovered resources) is approximately 2,200 Gb. Including unconventional oil, the total long-term potential oil resource base is around 6,500 Gb[2]. This potential resource base increases to 9,000 Gb, if GTL and CTL are also included in the estimate[2]. However, as discussed below, much of the unconventional oil resources may not be recoverable for a variety of reasons.

Although the long-term oil-supply cost curve represents the production costs of various forms of oil, it is also indicative of potential oil prices. Oil prices are determined by production costs, supply, demand, price manipulation by industry and governments, and market sentiment toward oil futures contracts, which are traded by oil hedgers (e.g., transportation companies) and heavily by speculators. Even though oil production costs do not solely determine the price of oil, production costs represent a theoretical minimum price for oil, assuming that producers intend to profit financially. Therefore, as oil production costs increase over time, so will oil prices. As such, the long-term oil-supply cost curve offers an idea of how much oil prices could potentially rise in proportion to oil production costs (see Figure 13 and Table 2).

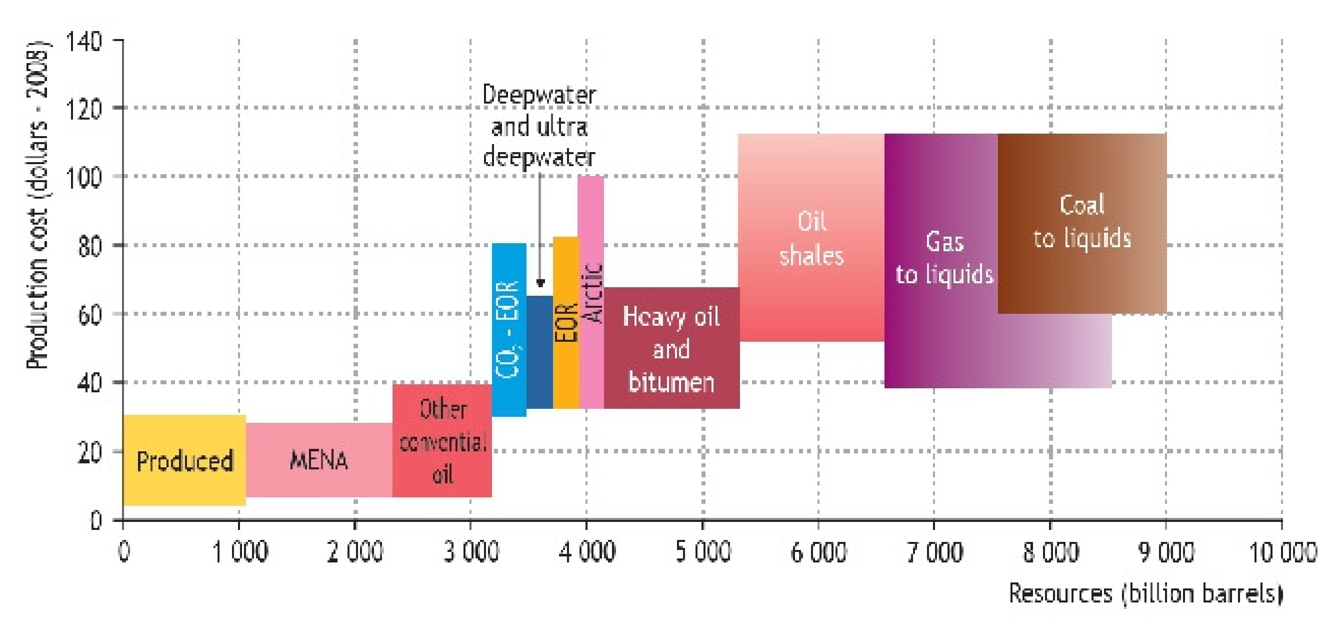


Figure 13: Long-term oil-supply cost curve. The curve shows the availability of oil resources as a function of the estimated production cost. Cost associated with CO_2 emissions is not included. There is also a significant uncertainty on oil shales production cost as the technology is not yet commercial. MENA is the Middle East and North Africa. The shading and overlapping of the gas-to-liquids and coal-to-liquids segments indicates the range of uncertainty surrounding the size of these resources, with 2.4 trillion barrels shown as a best estimate of the likely total potential for the two combined[2].

As oil resources become increasingly more difficult to access and lower in oil quantity and quality, production costs increase (see Figures 12 and 13). This is related to the issue of decreasing energy returns on investment (EROI) – where continuously dwindling quantities of oil of decreasing quality become progressively harder to access while oil demand is continuously increasing. At some point, production costs will be so expensive that they will drive oil prices high enough to destroy oil demand. Beyond this point, either oil prices will have to decrease below the price choke point (as they did during the oil price shock in the summer of 2008), or the market will collapse as oil becomes prohibitively expensive to produce or purchase. In the former instance, oil prices would eventually rebound (as they did in 2008 after the summer price shock) and increase until demand is destroyed again. Eventually, this volatility can happen only so many times until oil prices can no longer drop below the choke point. At this point, the market collapses. For further discussion about oil prices and demand, see *Oil Prices and Demand Destruction*.

Table 2: Approximate per barrel production costs for remaining oil resources[2].

Remaining potentially economically recoverable resources	Approximate production costs per barrel
conventional oil	\$10 – \$40
CO_2-EOR (enhanced oil recovery)	\$30 – \$70
other EOR (enhanced oil recovery)	\$35 – \$80
deepwater and ultra-deepwater	\$40 – \$65
Arctic	\$40 – \$100
oil sands and extra-heavy oil	\$40 – \$80
oil shales	\$50 – \$120
gas-to-liquids	\$40 – \$120
coal-to-liquids	\$60 – \$120

Given that these unconventional and “conventional using non-conventional methods” oil resources cost at least 2 – 3 times more to produce than conventional oil, it is likely that oil prices for consumers will increase proportionally. Furthermore, the EROI of these unconventional oil resources is lower than that of conventional oil, which means that great quantities of unconventional oil will need to be produced in order to yield the same amount of energy that fuels contemporary demand. These unconventional oil resources also have greater environmental impacts associated with them than conventional oil, including higher CO_2 emissions. Consequentially, unconventional oil resources may become even more expensive, if environmental policies increase the costs to produce and consume them. Note, the minimum production costs for unconventional oil are approximately equal to the maximum production cost of conventional oil. Therefore, it seems unlikely that future oil prices will decrease much below current prices, if at all ever. Indeed, the evidence indicates that the end of the era of cheap oil ended in 2004 – 2005, and that future oil will become increasingly expensive over time.

Oil Sands

Oil sands are also called *bituminous sands* and *tar sands*. *Bitumen* is a tar-like form of crude oil that is often found in deposits containing significant amounts of sand. The bitumen must be headed or diluted before it will flow. Bitumen typically is lower quality than conventional crude oil (e.g., bitumen contains more sulphur, metals and heavier hydrocarbons). The IEA[2] projects that oil sands projects globally will increase by 4.7 mbpd by 2030. Alberta, Canada accounts for the largest share of global oil sands production. Oil production from Canadian oil sands is projected to increase from 1.2 mbpd in 2007 to 5.9 mbpd in 2030 [2].

Producing oil sands is very environmentally invasive and destructive[2]. Oil sand production also requires high inputs of water and energy (typically from natural gas). If an oil sand deposit is near the surface, the surface vegetation and landscape on it is cleared, and the deposit is strip-mined using giant power shovels and dump trucks. The bitumen is extracted using hot water and caustic soda. The extracted bitumen is then upgraded (or diluted) with lighter hydrocarbons before it can be transported to a refinery. Between 2 – 4.5 barrels of water are used to produce each barrel of synthetic crude oil (SCO) in an ex-situ mining operation. Despite recycling, almost all of the water ends up in tailings ponds.

Drilling is required when oil sand deposits are located deeper than about 75 m. Long horizontal or multilateral wells are used, if the viscosity of the reserve is relatively low or can be reduced sufficiently for the oil to flow to the surface. Recovery factors are typically less than 15%. In situ viscosity-reduction technologies are currently used for highly viscous oils, including cyclic steam stimulation injection (CSS) and steam-assisted gravity drainage (SAGD). Some technologies in development include a vapor extraction process that uses hydrocarbon solvents instead of steam to increase oil mobility. Theoretical recovery factors range from 20 – 70%, depending on the technology applied. In SAGD operations, 90 – 95% of the water is recycled, but about 0.2 barrels of ground water are used per barrel of bitumen produced[67].

Oil sands production is very energy intensive. The National Energy Board[67] projects that natural gas use for oil sands production will increase from 0.7 billion cubic feet per day in 2005 to 2.1 billion cubic feet per day in 2015. Although Canada has natural gas resources, this enormous rise in natural gas demand will be difficult to meet. Natural gas production in Canada peaked in 2001 [68]. The current capacity of the natural gas infrastructure and production will be insufficient to supply this projected demand. Furthermore, the costs for producing gas will likely increase proportionally the costs for producing oil sands since natural gas prices are coupled to crude oil prices[69]. Given the enormous energy inputs required to produce oil sands, the EROI is relatively low as compared to conventional crude oil. One estimate of the EROI of oil sands is about 5.2:1 [69].

Although more than 50 Gb (less than 2 years of current global oil demand) are projected to be developed to 2030, only about 30 Gb (about 1 year of current oil demand) would come from projects that are already sanctioned, planned, or at the feasibility study stage. Furthermore, the IEA projections of oil sands production are uncertain due to environmental and resource constraints, especially energy and water needs and CO_2 emissions[2]. Given this uncertainty and that future oil sands production may be limited, it is unlikely that oil sands will be able to offset the decline in conventional oil production.

Extra-Heavy Oil

Bitumen and extra-heavy oil are closely related types of petroleum that differ mainly by their flow rates. Sometimes *extra-heavy oil* is referred to as *oil sands*. Extra-heavy oil is more fluid than bitumen, but extra-heavy oil is also too heavy to transport by pipeline or process in normal refineries. The Orinoco Belt in Venezuela has a large deposit of extra heavy oil, which is considered to be one of the largest oil sands deposit in the world, after the Athabasca oil sands in Alberta, Canada. The estimated producible reserves of the Orinoco Belt are 513 Gb[70].

Estimates of Venezuelan extra-heavy oil reserves and production are often included in conventional oil data rather than unconventional oil figures since Venezuela generally classifies its extra-heavy oil as conventional crude oil[2]. Therefore, Venezuelan extra-heavy oil production is not included in the estimate of extra-heavy oil supplies in this analysis. The IEA[2] projects that extra-heavy oil production outside Venezuela will likely occur mainly in Kuwait and in a few isolated projects in Brazil, Italy, Vietnam – in total, possibly reaching more than 0.7 mbpd by 2030 (less than 0.5% of projected global demand in 2030).

The U.S. Geological Survey[70] estimates that there is between 380 – 652 Gb of technically recoverable heavy oil in the Orinoco Oil Belt Assessment Unit (AU) of the East Venezuela Basin Province. Optimistically, the USGS claims that the Orinoco Oil Belt AU contains one of the world's largest recoverable oil accumulations, second to Saudi Arabia. However, this comparison does not mention that the quality of Venezuela's extra-heavy oil sands is inferior to that of Saudi Arabia's crude oil. However, the USGS[70] admits,

"No attempt was made in [its] study to estimate either economically recoverable resources or reserves within the Orinoco Oil Belt AU. Most important, these results do not imply anything about rates of heavy oil production or about the likelihood of heavy oil recovery. Also, no time frame is implied other than the use of reasonably foreseeable recovery technology."

So, the estimate of 380 – 652 Gb of technically recoverable heavy oil in the Orinoco Oil Belt that the USGS offers is at best a maximum theoretical yield. The economically recoverable resources or reserves will be less than the maximum theoretical resources depending on recovery factors, which range from 15 – 70%[70]. Since the world would need the oil reserves of at least six Saudi Arabia's to supply projected global demand by 2030 [2], the global supply of oil cannot rely on extra-heavy oil production to support projected BAU demand any more than it can rely on oil sands.

Oil Shale

Production of shale oil started in the 1830's. Oil shale production peaked globally in 1980 at about 45,000 tonnes per year. Production dropped to 16,000 tonnes per year in 2004, with more than 70% of the supply from Estonia[2] (see Figure 14). The IEA estimates that the recoverable reserves of oil shales is about 1,000 Gb. The U.S. has the largest oil shale resources (over 60% of the global total), followed by Brazil, Jordan, Morocco and Russia[2].

Oil shales are rocks that contain a large proportion of solid organic compounds (*kerogen*) from which liquid hydrocarbons can be extracted. While oil resources, such as crude oil or oil sands, originate from the biodegradation of hydrocarbons into oil, the heat and pressure in oil shale deposits have not yet transformed the kerogen in oil shale into petroleum. Kerogen requires more processing to use than crude oil, which increases its cost as a crude-oil substitute. The EROI for oil shales is also very low. For instance, preliminary energy balances of a Royal Dutch Shell oil shales project at Mahogany Ridge indicate an EROI of 3:1 – 4:1 [2]. Oil shale production costs are estimated to be in the range of $50 – $120 per barrel. The potential to improve oil shale production technology are very uncertain due to a lack of major commercial projects. Consequently, the IEA[2] does not expect oil shales to make any significant contribution to global oil supply before 2030. Furthermore, a carbon penalty would increase significantly the production cost since oil shale extraction is extremely energy and carbon intensive[2].

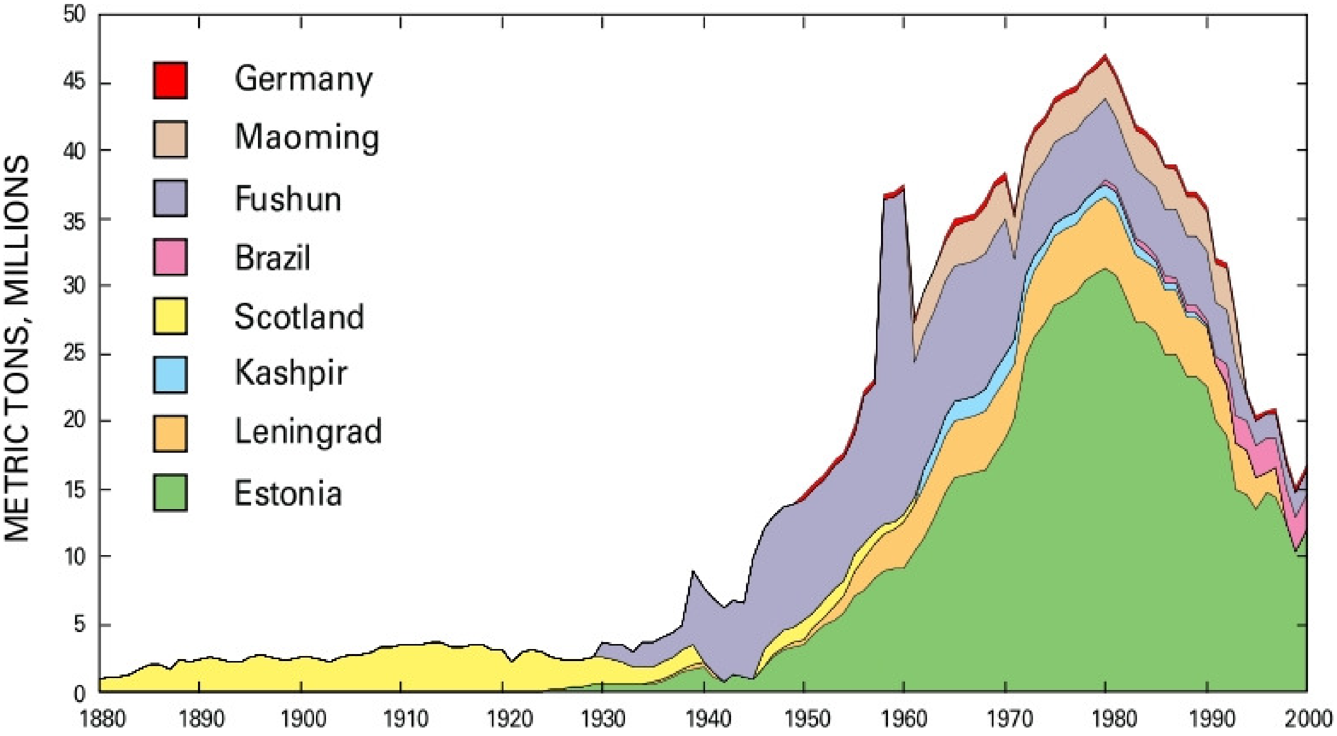


Figure 14: Production of oil shale in millions of metric tons from 1880 – 2000 [71].

Gas-to-Liquids

Gas-to-liquids (GTL) technology involves converting natural gas into liquid fuels that have longer-chain hydrocarbons, such as diesel fuels. GTL production is projected to increase from about 50 kbpd in 2007 (less than 0.1% of global demand) to 650 kbpd in 2030 (less than 0.5% of projected global demand in 2030). However, the IEA[2] stresses that these projections are based on significant assumptions due to uncertainties about the development of future technologies, how production costs will change, and future environmental constraints. GTL is a very capital-intensive chemical process that involves more complex engineering and operation as compared with NGLs. The long-term prospects for GTL production mainly depend on costs. Although production costs have decreased from $120,000 per barrel per day of capacity in the mid-1950's to less than $40,000 in 2000, costs have increased recently due to a surge in capital and operating costs that has affected all sectors of the oil and gas industry, and due to the higher cost of the gas feedstock[2]. Current GTL technology requires 8,000 – 10,000 cubic feet of gas for each barrel of GTL diesel produced. GTL production costs per barrel range from $40 – $90, depending on the price of the feedstock gas[2]. As such, the long-term development of the GTL industry is uncertain[2].

Since global gas production will likely peak sometime between 2019 – 2030 (see section *Peak Gas*), and since peak gas production has already occurred in many nations and regions, natural gas resources will become increasingly scarce and more expensive as various demands for gas (e.g., for heating, energy production, GTL, synthetic fertilizer production) compete for the remaining resources. This may cause production costs and market prices for GTL to become prohibitively expensive in the future, thereby substantially reducing or eliminating their effective contribution to the global portfolio of liquid fuels. Given the IEA's projections and uncertainties of GTL potential contribution to global liquid fuel demand, declining gas supplies, and increasing production costs, GTL will likely not contribute much to future global liquid fuel supplies.

Coal-to-Liquids

Coal-to-liquids (CTL) involves the indirect conversion of coal to oil products through gasification and Fischer-Tropsch synthesis processes that have been carried out commercially for many decades. Despite the established technology, global CTL production continues to be limited as CTL production has been uneconomic until recently, primarily due to the large amounts of energy and water required for production processes, the high cost of developing CTL plants, and volatile oil and coal prices. Although the IEA[2] projects that global CTL production will likely increase from 0.13 mbpd in 2007 to 1.1 mbpd in 2030, the agency admits that the uncertainties surrounding the potential of CTL resources are very large, because of technical, economic and environmental considerations[2]. CTL processes have very high CO_2 emissions. Each barrel of oil produced by CTL emits 0.5 – 0.7 tonnes of CO_2. For instance, a 50 kbpd plant emits an average 11 Mt of CO_2 per year. Future carbon emissions regulations and taxes would increase the production costs for CTL[2].

Since global coal production will likely peak sometime between 2011 – 2030 (see *Peak Coal*), coal resources will become increasingly scarce and more expensive as various demands for coal (e.g., for heating, energy production, CTL) compete for the remaining resources. This may cause production costs and market prices for CTL to become prohibitively expensive in the future, thereby substantially reducing or eliminating their effective contribution to the global portfolio of liquid fuels. Given the IEA's projections and uncertainties of CTL potential contribution to global liquid fuel demand, declining natural gas supplies, and increasing production costs, CTL will likely not contribute much to future global liquid fuel supplies.

"An additional 64 mbpd of gross capacity – the equivalent of six times that of Saudi Arabia today – needs to be brought on stream between 2007 and 2030."

– International Energy Agency (IEA)[2], 2008

"...even assuming more effective conservation measures, the world would need to add roughly the equivalent of Saudi Arabia's current energy production every seven years."

– U.S. Joint Forces Command[72], Department of Defense, 2010

"If they don't have a lot of additional oil to put on the market, it is hard to ask somebody to do something they may not be able to do."

– President George W. Bush[73], speaking about Saudi Arabia, 2008

- Business as usual (BAU) oil demand is projected to increase by 1% per year on average from 2007 – 2030.
- This demand growth represents an increase from 84.7 million barrels per day (mbpd) in 2008 to 105.2 mbpd in 2030.
- Under BAU, oil production is projected to grow from 83.1 mbpd in 2008 to 103 mbpd in 2030.
- Undiscovered oil fields account for about 20% of the projected of total crude oil production by 2030. In other words, no one knows whether or how there will be enough oil to supply 20% of the projected total crude oil production by 2030.
- Non-OPEC conventional production is projected to peak around 2010 and then begin to terminally decline thereafter.
- OPEC's oil production will likely peak within the next few years, if it has not already peaked.
- Saudi Arabia has more than 20% of the world's proven total petroleum reserves. After 2010, a steady terminal decline in oil production is forecast at a depletion rate above 5% per year.
- Huge investments are required to explore for and develop more reserves, mainly to offset decline at existing fields.
- An additional 64 mbpd of gross capacity – the equivalent of six times that of Saudi Arabia today –

needs to be brought on stream between 2007 – 2030 to supply projected BAU demand.

- Therefore, it is unlikely that global oil production will be able to supply projected global demand within the near future.

- A terminal 3 – 5% per year decline rate for post-peak global oil production would have devastating economic consequences.

- After 2010, the range of estimated global average oil production decline rates is at least 4 – 10.5%.

- The decline curve assumption regarding the future oil production is a set of three assumptions:

    - the first assumption is that the EROI of remaining oil is not adequately considered; and thus the net energy available to the economy and society will decline at a faster rate than the actual production curve suggests;

    - global production and demand models assume that all the oil produced will be available to the entire global market, even though oil producers will likely prioritize domestic consumption in order to maintain their economies and national security; and

    - oil production decline curves tend to assume that as oil production declines societies can continue to afford to use technical resources to find, develop, extract, and refine the remaining oil; and that the financing and price stability will be available for such investment.

- The decline curve assumption may be very misleading since declines in oil production undermine the ability of society to produce, trade, and use oil (and other materials and energy fuels) in a re-enforcing positive feedback loop.

- Therefore, the actual oil production decline rates (4 – 10.5%) may greater than projected; and they may be abrupt and non-linear, if the global economy collapses.

- Assuming BAU, oil prices are projected to reach \$100 – \$108 per barrel by 2020 and \$115 – \$133 per barrel by 2030 (in real 2008 dollars).

- Demand destruction for oil may be somewhere above \$80 per barrel and below \$141 per barrel.

- The global and industrialized economy is based on fractional reserve banking, compound interest, debt-based growth, and compound and unlimited growth. The economic theory on which the economy is based assumes unlimited energy supplies. Declining energy flows (i.e., oil) cannot maintain the economic production required to service debt. When outstanding debt cannot be repaid, new credit will become scarce.

- Although the global economy was set to falter due to financial over-extension, corrupt financial practices and pursuing unlimited debt-based economic growth, the dramatic rises in oil prices since 2004 and the oil price shock of the summer of 2008, probably contributed to triggering the economic collapse of 2008.

- Economic recovery would stimulate oil demand and thereby increase oil prices. Therefore, economic recovery (i.e., BAU) will likely exacerbate the global recession by driving up oil prices.

- Given that many nations and their citizens are insolvent and on the brink of debt default – especially the OECD – another oil shock and/or permanent increase in oil prices would likely push the global economy and many nations over the cliff edge into economic collapse.

Oil Production and Demand

Due to different data sources and standards, and since reports and reporting agencies use different definitions and measures of oil supplies, the numbers and estimates of oil supply and demand may vary somewhat throughout this analysis depending on which information sources are used. Although these numbers vary, they still are useful for developing a workable range of estimates and projections for this analysis.

Global

The EIA projects that global liquid fuels consumption in the *International Energy Outlook 2010* (*IEO 2010*) Reference case (i.e., BAU) increases from 86.1 mbpd in 2007 to 110.6 mbpd in 2035 [74]. However, the *IEO 2010* assumes that growing global GDP will drive this increase in liquid fuels demand, The EIA projects that world GDP will increase by 3.4% per year from 2007 – 2020 and 3.1% per year from 2020 – 2035 [74]. Given the current global economic crisis, such a high rate of GDP growth seems unlikely in the short-term.

BAU oil demand in the IEA's *WEO 2009* Reference Scenario is projected to increase by 1% per year on average from 2007 – 2030 – from 84.7 mbpd in 2008 to 105.2 mbpd in 2030 [35]. Demand is expected to have dropped sharply in 2009 in response to the economic crisis that started in 2008, but then recover progressively from 2010 assuming that the world economy pulls out of recession. The non-OECD nations, especially Asia and the Middle East, account for nearly all of the demand growth over the period from 2007 – 2030, where 42% of the overall increase comes from China alone[35]. However, it is unclear why the IEA expects near zero demand growth in industrialized OECD countries.

According to the EIA's BAU projections[74], global liquid fuels production will increase from 85 mbpd in 2007 to 111 mbpd in 2035, including the production of both conventional liquid supplies (e.g., crude oil and lease condensate, NGLs, and refinery gain) and unconventional supplies (e.g., biofuels, oil sands, extra-heavy oil, coal-to-liquids, gas-to-liquids, and shale oil).

Under BAU, in the *WEO 2009* the IEA projects oil production to grow from 83.1 mbpd in 2008 to 103 mbpd in 2030 [35], which is slightly lower than the 2030 estimate of 103.8 mbpd given in the *WEO 2008* [2] (see Figure 15). Included in this projection, global unconventional oil production increases from 1.8 mbpd in 2008 to 7.4 mbpd in 2030 [35]. Undiscovered oil fields account for about 20% of total crude oil production by 2030 (see Figures 15 and 16)[2]. However, since undiscovered oil fields have not been proven to exist, the contribution of undiscovered oil to the global oil supply is highly speculative at best, if not misleading.

From 2008 – 2030, the average shortfall of oil supply compared to demand is approximately 2 mbpd, which cumulatively equals about 16 Gb over the IEA's projection period. It is unclear how the world would be able to compensate for this significant shortfall in oil supplies. Considering that 20% of projected global oil production is to be supplied by undiscovered oil resources by 2030, the global shortfall in oil may be quite substantial, even if half or most of the undiscovered oil is discovered and produced. If the crude oil from "fields yet to be developed" (denoted by the light blue area in Figure 15) are not developed and put into production within the coming years, then the shortfall in global oil supplies may be enormous by 2030.

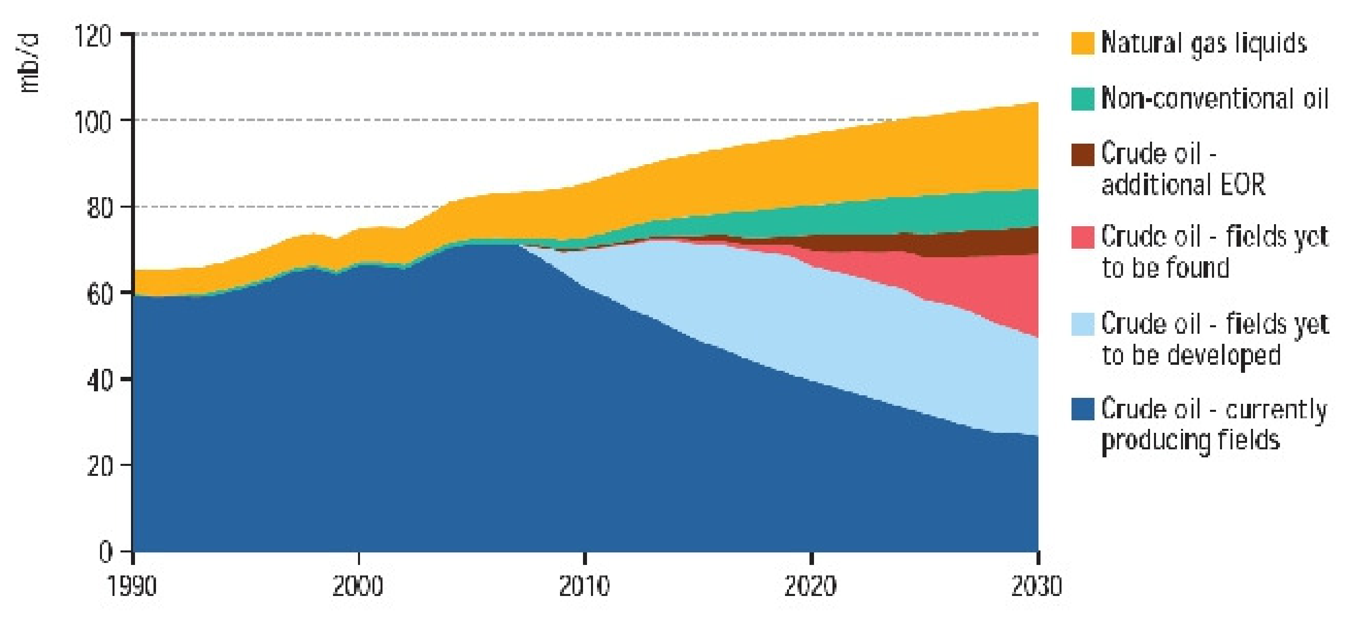


Figure 15: World oil production by source in the IEA's WEO 2008 *Reference Scenario*[2]*. The red wedge denoting "crude oil - fields yet to be found" increases the upward trend of the overall production curve above it to about 103 mbpd by 2030, which allows this supply curve to nearly match the IEA's projected rate of oil demand of 105.3 mbpd by the same year. Compare Figure 15 with Figure 16.*

Non-OPEC conventional production (crude oil and NGLs) is projected to peak around 2010 and then begin to decline thereafter. Oil production has already peaked in most non-OPEC countries[35] (see Figure 17). Oil production is expected to peak in most of the other non-OPEC nations before 2030 [35]. For instance, the U.S. lower 48 oil production peaked in 1970 – 1971 (see Figure 18). In 1956, Hubbert successfully predicted that oil production from the U.S. lower 48 states would peak between 1965 – 1970 [4]. In 1970, when U.S. production of crude oil and natural gas plant liquids peaked at 11.3 mbpd, net imports were 3.2 mbpd (see Figures 18 and 19). In 2009, production was 7.2 mbpd, and net imports were 9.7 mbpd[45] (see Figure 19).

The oil crisis of 1973 – 1974 that was initiated by the oil embargo imposed by Organization of Arab Petroleum Exporting Countries (OAPEC) coincided with peak oil production in the U.S. and other oil producing countries around that time. Another oil crisis was initiated by the Iranian Revolution in 1979. These two oil crises demonstrated how dependent a country, like the U.S., had become on oil imports less than a decade after reaching peak domestic oil production. During the 1970's and early 1980's, oil prices increased roughly 6 times amid oil price volatility (see Figure 23)[61]. Oil prices increased by about 3-fold in 1973 – 1974, and then by another 2-fold in 1979 – 1980 in constant dollars[61]. Furthermore, economic growth declined in most oil importing nations after the impact of the first oil shock and following the supply disruptions of 1973 – 1974 and 1979 – 1980 [61]. Assuming that future economic activities continue to drive BAU, growing oil demand and decreasing domestic production will require oil-importing nations to further increase their imports. As global supplies of oil decline in the future, the importing economies will be challenged to supply their domestic oil demand without reducing consumption and securing supplies in an increasingly competitive oil market. This in turn likely lead to a long-term economic decline for those countries. The economic decline of the U.S. and other major OECD states would ultimately lead to a long-term decline in the global economy.

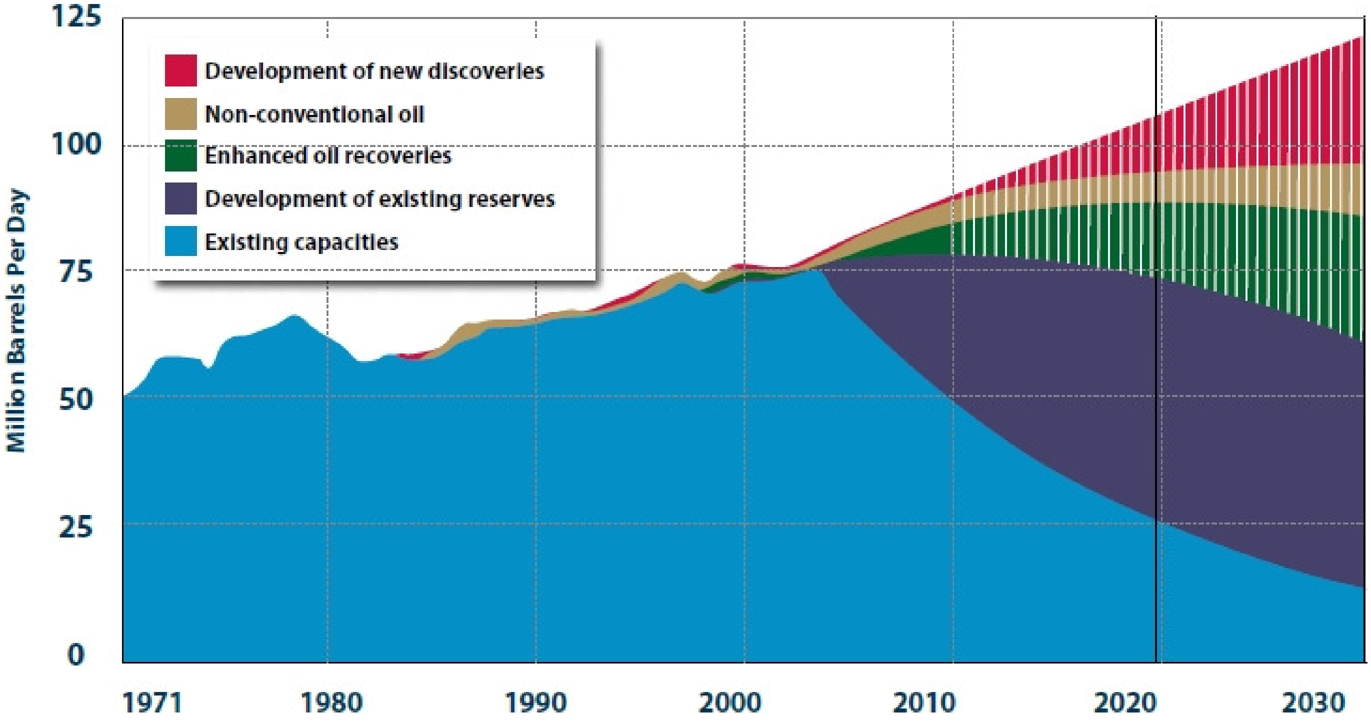


Figure 16: Future world oil production based on the IEA's WEO 2008 Reference Scenario, as published in the U.S. Joint Forces Command's Joint Operating Environment 2010 [72]*. Figures 15 and 16 are essentially showing the same production curves. However, Figure 16 places the production curve of undiscovered oil resources (the red curve denoting "development of new discoveries") on the top of the other production curves in the graph, rather than in the middle as in Figure 15. In this way, Figure 16 makes it easier to visualize what future oil production might be like, if the contribution from undiscovered oil resources is ignored. However, the "development of existing reserves" (the dark blue curve) still may give the impression that future oil production will be relatively high. Nonetheless, substantial investments would be necessary for the "development of existing reserves".*

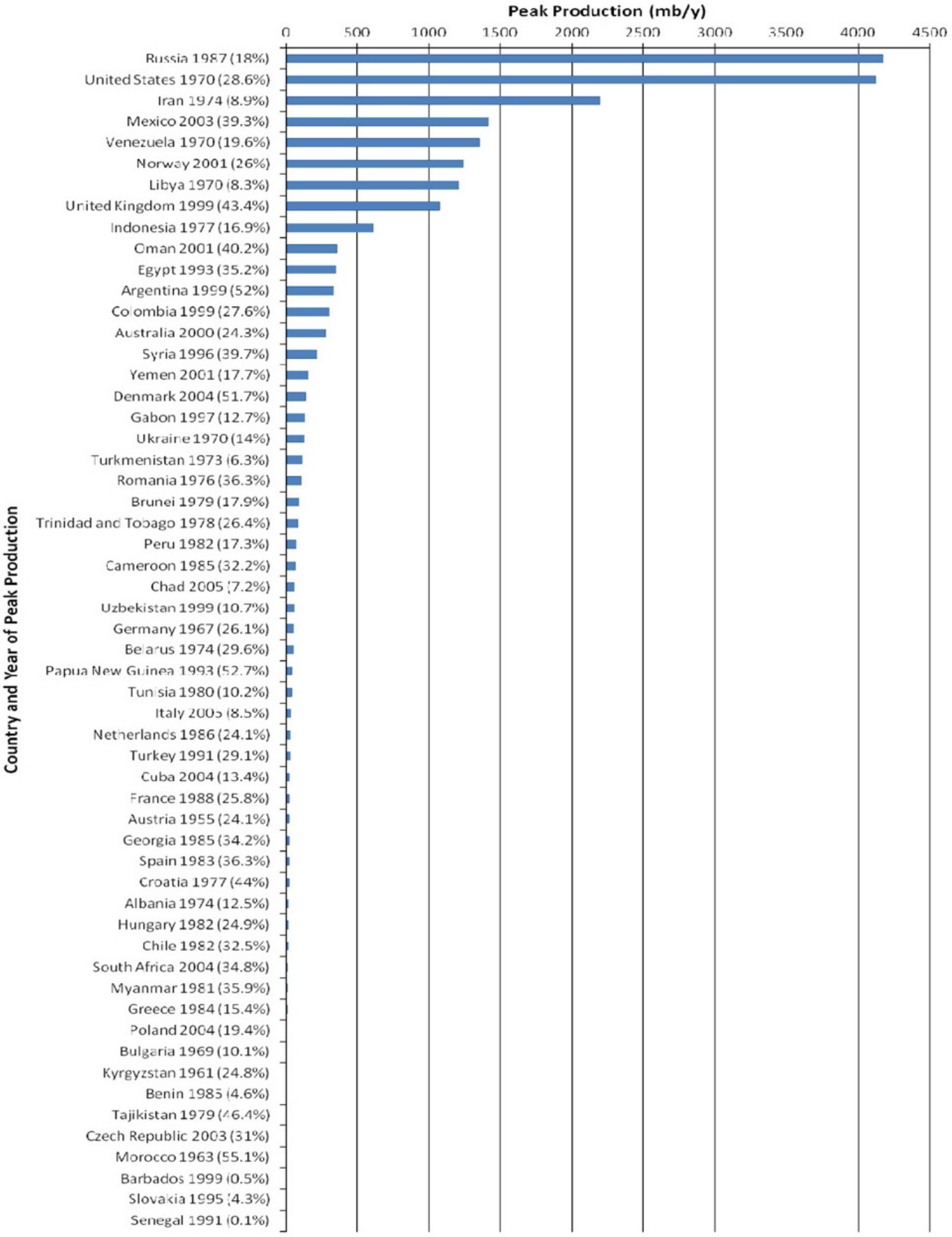


Figure 17: The expanding group of post-peak oil producing countries. The year of peak production for conventional oil and estimated percentage of the USGS estimate of URR (including allocated reserve growth)

produced by the date of peak are shown. In some cases (e.g. Poland), peak production may be primarily the result of economic and political factors rather than physical depletion, and some countries (e.g. Iran) may subsequently be able to increase production above the previous peak[75,76 as cited in 77].

OPEC

The IEA assumes that most of the projected increase in oil production will come from members of OPEC, because the information agency claims that OPEC holds the bulk of remaining proven oil reserves and ultimately recoverable resources[35]. Assuming BAU, their collective output of conventional crude oil, natural gas liquids (NGLs), and unconventional oil (primarily gas-to-liquids) is projected to increase from 36.3 mbpd in 2008, to about 40 mbpd in 2015, and nearly 54 mbpd in 2030 [35]. The IEA's *WEO 2008* Reference Scenario (i.e., BAU) projects that Saudi Arabia would remain the world's largest oil producer throughout the projection period with the nation's oil output increasing from 10.2 mbpd in 2007 to 15.6 mbpd in 2030 [2]. OPEC's share of global oil production would increase from 44% in 2009 to 52% in 2030 [35]. This projected increase in OPEC's share of global oil production is due to OPEC's collective output of conventional crude oil, natural gas liquids (NGLs) and unconventional oil (mainly gas-to-liquids), which is projected to increase from 36.3 mbpd in 2008 to almost 54 mbpd in 2030 [35], *assuming that there are no major disruptions in supply and that the requisite investment occurs*[2]. Furthermore, there is an additional caveat to the BAU projections presented in the WEO 2008 Reference Scenario[2]:

"These projections call for huge investments to explore for and develop more reserves, mainly to combat decline at existing fields. ***An additional 64 mbpd of gross capacity – the equivalent of six times that of Saudi Arabia today – needs to be brought on stream between 2007 and 2030.*** *A faster rate of decline than projected here would sharply increase upstream investment needs and oil prices."*

These caveats and assumptions on which these BAU projections are based do not provide for a credulous forecast by the IEA. These projections are further undermined by the fact that OPEC reserve and production figures and data are misreported and highly over-exaggerated, as discussed in the previous section in *Oil Data Is Inaccurate*.

The U.S. Department of Defense supports the concern posed by the IEA's caveats by stating[72]:

"To meet climbing global requirements, OPEC will have to increase its output from 30 MBD [mbpd] to at least 50 MBD [mbpd]. Significantly, no OPEC nation, except perhaps Saudi Arabia, is investing sufficient sums in new technologies and recovery methods to achieve such growth. Some, like Venezuela and Russia, are actually exhausting their fields to cash in on the bonanza created by rapidly rising oil prices...A severe energy crunch is inevitable without a massive expansion of production and refining capacity. While it is difficult to predict precisely what economic, political, and strategic effects such a shortfall might produce, it surely would reduce the prospects for growth in both the developing and developed worlds..."

Saudi Arabia

Matthew Simmons[78], energy advisor to George W. Bush, analyzed more than 200 scientific papers published by scientists working on Saudi Arabian oil production. Based on his review of these papers, Simmons came to the conclusion that reservoirs in Saudi Arabia were at an advanced stage of depletion, and that the reserves were significantly overstated. As of January 2009, Saudi Arabia officially claimed it had about 266.7 Gb of oil reserves, which is more than 20% of the world's proven total petroleum reserves[79]. Although oil production in the Ghawar oil field peaked in 1980 at about 5.6 kbpd, it supposedly produced 5.1 kbpd in 2007 (see Table 1), which was equal to 7% of global conventional oil production in 2007 [2]. Saudi Arabia's historical crude oil production indicates that the nation's production peaked at 9.6 mbpd in 2005 (see Figure 7). In 2008, crude production was 9.3 mbpd. In 2009, it was projected to drop to 8.1 mbpd; then, increase in 2010 to 8.5 mbpd. After 2010, a steady terminal decline in oil production is forecast[32]. In July 2008, the depletion rate was above 5% per year[32].

Iraq

OPEC[80] claims that Iraq has 115 Gb in proven crude oil reserves. Assuming that all of that oil is there and that it is 100% recoverable, 115 Gb of oil would be completely consumed by global demand in about 3.7 years, if Iraq was the only source of oil. In other words, Iraq could only delay peak oil from occurring for another 3.7 years in the best but improbable case. In October 2010, Oil Minister Hussain al-Shahristani[81] claimed that Iraqi proven oil reserves are now 143 Gb. Given that OPEC's reports on its oil reserves are suspect, this recent claim of increased oil reserves should be accepted cautiously. However, even with 143 Gb of oil, 115 Gb of oil would be completely consumed by global demand in about 4.6 years assuming that it all could be recovered.

Regardless of whether it is 115 Gb or 143 Gb, Iraq can only produce and export large quantities of its oil only if its oil infrastructure operates at a reasonable capacity. However, Iraq's oil infrastructure may be completely inadequate to support much of its intended oil production and exports[84]. Currently, Iraq is in a hurry to build export infrastructure, but not just to have capacity for increased oil production. The current oil pipelines could break at any moment, which would cause an economic and environmental disaster that would greatly impact Iraq, neighboring countries, and the global oil market. Shutting down 1.6 mbpd of Iraqi oil exports would likely cause an immediate spike in global oil prices[84]. A massive oil spill could also likely strain relations with neighboring countries. A pipeline rupture would be an environmental disaster that could send oil into the waters of Iran, Kuwait, and Saudi Arabia.

The pipelines that export most of Iraq's oil were built in 1975 and were supposed to last only 20 years without any major inspections and upgrades. Now, the pipelines are 15 years past their functional life and were last inspected in 1991 when pipeline corrosion forced a 75% reduction in safe exporting capacity, because excessive corrosion that had deteriorated the pipeline walls in some cases by 76%[84]. According to a study[84] commissioned by the U.S. Army Corps of Engineers and conducted by Foster Wheeler, a global engineering and energy conglomerate, the Iraq's oil infrastructure is at risk of failing at any time. Supporting this claim Deputy Oil Minister Ahmad Shamma[84] stated, "We are afraid of anything happening to them...We are not putting any more pressure on them, touch wood."

The export pipelines are long overdue for replacement. A full integrity evaluation of the existing pipelines

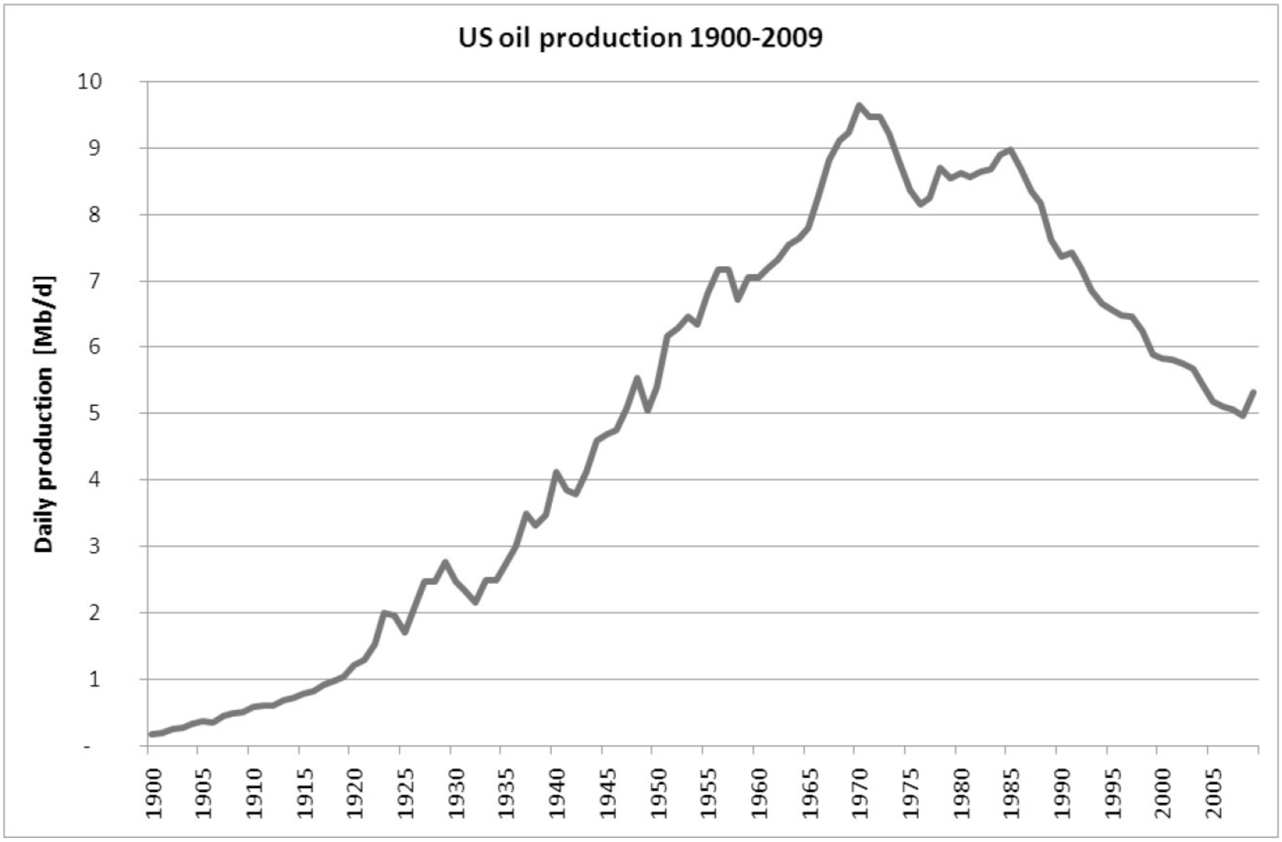
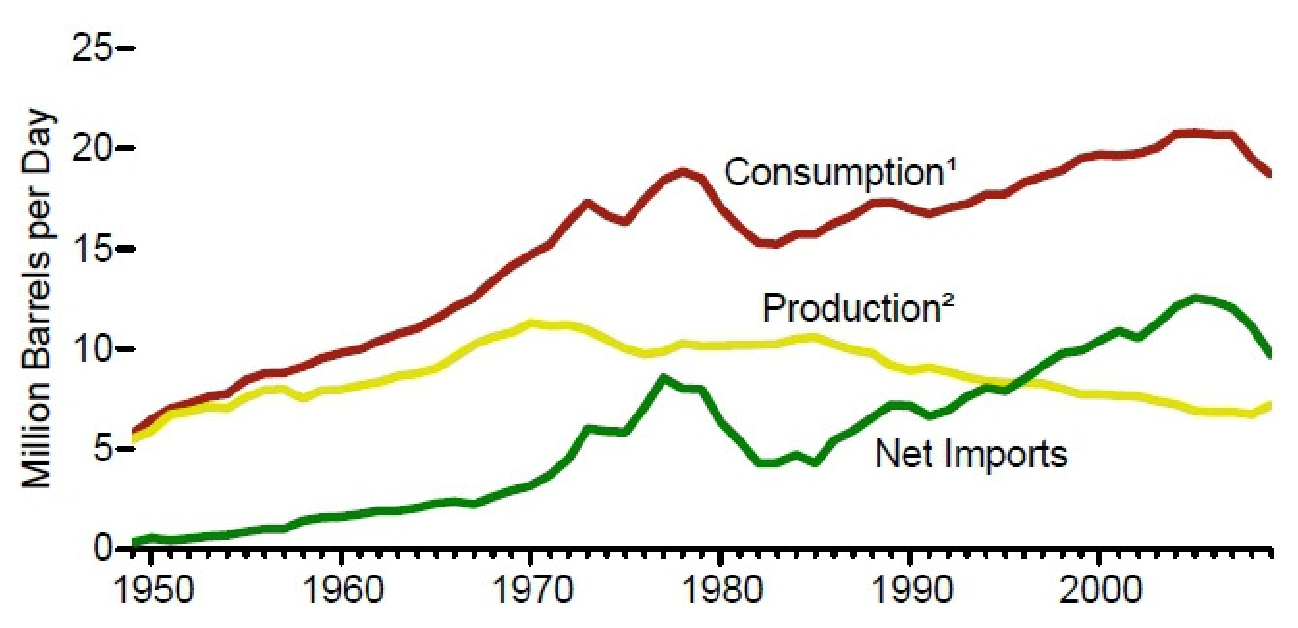


Figure 18: Historical production of oil in the USA from 1900 – 2009 [82].

will be required, if the pipelines are to continue in service. Without this assessment, the condition of the pipelines are considered critical. However, no such assessment has been made[84]. According to the Foster Wheeler assessment[84], "If this average corrosion rate has continued linearly, the pipeline should have lost containment by now." Furthermore, the pipelines cannot be repaired or even inspected until alternative export routes are built, due to the risk of rupturing the pipelines.

Although shutting down the southern pipelines would be the best option environmentally, it would likely cause a major economic depression in a war-torn nation that depends on crude oil export revenues for over two-thirds of GDP in 2009 [85], and relies on its southern pipelines to sell about 75% of its oil[84]. Although new export outlets that are planned to come online by the end of 2012, Iraq will be extremely hard-pressed to meet increasing export demands and while creating alternate export routes before the current pipelines fail in such a short time[84]. Although the Iraq Oil Ministry has a stated goal of more than 12.5 mbpd of production capacity within seven years, new export routes have yet to be established and existing pipelines in the north of the country also need to be restored[84]. Therefore, the future of Iraq's oil production and its potential to supply global oil demand is at best speculative.

Therefore, if OPEC spare capacity is misreported and reserve figures are highly over-exaggerated by 300 Gb, and if some of the 20% of the world's production of proven total petroleum reserves located in Saudi Arabia are in a state of decline (including the 7% of global proven reserves that are in the Ghawar oilfield), and if oil production and exports in Iraq are insufficient to supply global demand in the near- to long-term; then it is unlikely that OPEC's share of global oil production would increase to 54 mbpd by



¹ Petroleum products supplied is used as an approximation for consumption.
² Crude oil and natural gas plant liquids production.

Figure 19: Petroleum overview of the United States[83]*. When U.S. petroleum production peaked at 11.3 mbpd in 1970, net imports stood at 3.2 mbpd. By 1996, net imports exceeded production. In 2008, production was 6.7 mbpd, and net imports were 11.0 mbpd.*

2030 to supply over 50% of the projected BAU demand through to 2030. Indeed, it may be very unlikely that OPEC will be able to support much of the global oil demand through 2030 given the IEA's caveats for OPEC that:

1. "huge investments" are needed for exploration and development;
2. "the equivalent of six times that of Saudi Arabia today" needs to be brought on stream between 2007–2030; and given that
3. global rates of oil reserve discovery peaked in the 1960's and declined exponentially since then (see Figure 10); and that
4. future reserve discoveries will likely be smaller, of lower grade, in harder to access locations, and therefore more costly to produce.

Undiscovered Oil

Under BAU, the IEA projects oil production to grow from 83.1 mbpd in 2008 to 103 mbpd in 2030 [35]. Global demand for oil is projected to increase from 84.7 mbpd in 2008 to 105.2 mbpd in 2030 [35]. This difference between the projected supply and demand would leave a substantial gap of about 2 mbpd in 2030. However, undiscovered oil fields account for about 20% of total crude oil production by 2030 [2] (see Figure 15), or about 20 mbpd in 2030. Without the 20 mbpd contribution of undiscovered reserves, the 2030 gap in global oil supply would be approximately 22 mbpd. Presumably no one knows whether the

20 mbpd of undiscovered reserves exists. Conveniently or unintentionally, the undiscovered reserves in Figure 15 are placed in the middle of the world oil production curve graph, which visually increases the entire world oil production curve to 103 mbpd – almost exactly the oil production rate necessary to supply projected global demand. Compare the IEA's graph in Figure 15 with the graph in Figure 16 published by the Joint Forces Command of the U.S. Department of Defense. Figure 16 is based on the IEA's estimates. In Figure 16, the curve for "new discoveries" (a.k.a., undiscovered oil resources) is placed on the top (in red) of the total oil production curve, rather than in the middle, which allows one to better visualize how much less future oil production might be without the inclusion of undiscovered oil resources. In this graph, global oil production is much less than 100 mbpd by 2030, if "new discoveries" are ignored.

The placement of the undiscovered oil projections in the graph may give some people the impression that there will be plenty of oil in the future. If the 20 mbpd of undiscovered oil is ignored, but assuming that all the other oil resources are exploitable, then the world oil production curve becomes relatively flat at approximately 83 mbpd after 2005, the year that global oil production may have peaked and entered the current undulating plateau (see Figures 20a and 20b). If the 20 mbpd of undiscovered oil is ignored, and assuming that the other projected oil resources (both conventional and unconventional) are not fully exploitable, then the world oil production curve (see Figure 15) would enter a terminal decline at approximately 83 mbpd within several years after 2005. One way or another, without having the undiscovered oil resources to supply demand, it is likely that global oil production may have peaked or will do so soon.

Oil Production Decline Rates

It is possible, if not highly likely, that by 2010 – 2011 the world will experience a serious shortage of oil supply as peaking oil production begins to fall short of current and future demand. Conventional oil from producing fields currently supplies approximately 85% of the global liquid fuel mix[17]. According to Hirsch[86], "A relatively monotonic, terminal 3 – 5% per year decline rate for world oil production would have devastating economic consequences, unless mitigation implementation was initiated well before the onset of decline."

Around mid-2004, total global oil production ceased to grow; and new production has only kept global oil production in a relatively flat plateau since then (Figures 20a and 20b). After 2010, the range of estimated global average oil production decline rates is 4 – 10.5% [2,17,87-92]. These production decline rates would result in a cumulative gap between BAU demand and declining production rates of about 925 Gb over the period 2010 – 2050 [17] (see Figure 21). Even at a modest decline rate of 4.07%, current sources of liquid fuels (i.e., crude oil from producing fields, unconventional oil, NGLs) will only have the capacity to supply just over 50% of BAU demand by 2020; which implies that the remaining 50% will have to be supplied by sources that are not in production today[17].

However, the global average decline rate could increase to around 10.5% or more per year by 2030, as all regions undergo a decrease in average field size (the average decline rate for oilfields smaller than giant-sized is at least 10.4% or greater) and as most regions experience a shift in production to offshore fields (the average decline rate for offshore and deepwater oilfields is at least 7.3% to 13.3%, respectively)[2]. Some countries will require a significant increase in upstream investment just to offset decline. For instance, the increase in decline rate is particularly high in North America, where the natural decline rate (i.e., the production decline rate without EOR) increases from about 14% to 17%[2]. Lack of infrastructure and investment will constrain the ability for future global oil production capacity growth. The U.S. Department of Defense states[72]:

"The central problem for the coming decade will not be a lack of petroleum reserves, but rather a shortage of drilling platforms, engineers and refining capacity. Even were a concerted effort begun today to repair that shortage, it would be ten years before production could catch up with expected demand… A severe energy crunch is inevitable without a massive expansion of production and refining capacity."

All of these global oil production decline rates tend to assume a smooth linear downward exponential curve. As discussed in the following section, this decline curve assumption of a smooth terminal decline in global oil production may be overly optimistic and misleading. Instead, the post-peak global oil supply may experience an abrupt non-linear collapse following a brief transition period as a smooth production decline curve.

Decline Curve Assumption

Both, oil production models (like those shown in Figures 1, 8a, 8b, 9a, and 72) and the estimates of post-peak oil production decline rates discussed in the previous section make a critical assumption – that the post-peak oil production indicated by the right-hand downward slope of the production curve will decline smoothly until production reaches zero or some economic limit. These models and estimates can leave one with the impression that all of the post-peak oil resources will be available to the global economy after production peaks. Based on these assumptions, one might conclude that the remaining global supply of oil will smoothly and gradually become increasingly scarce as production declines. Such assumptions would not be correct.

Furthermore, there are a few other critical assumptions often made regarding future oil production[96]. The first assumption[96] inadequately considers the energy return on investment (EROI) of remaining oil resources, except indirectly and incompletely through estimates of production costs and future oil prices. Since future oil reserves will become increasingly smaller, more inaccessible and of lower quality (e.g., unconventional oil), the EROI for these remaining oil supplies will be lower. Therefore, the net energy available to the economy and society will decline at a faster rate than the actual production curve suggests.

Second, global production and demand models assume that all the oil produced will be available to the entire global market[96]. The nations with largest growth rates of oil consumption are oil producers who will have preferential access to there own declining reserves[96]. They will likely prioritize domestic consumption in order to support and grow their economies, avoid social unrest, maintain government legitimacy, and for national security (e.g., to fuel military and basic services). Oil sold on the global market will likely be sold to wealthier and/or politically favored nations or organizations. Consequently, it is likely that the available oil on the global market will decline more rapidly than the overall decline in global production.

Third, even if declining EROI and domestic consumption by producer states are accounted for, production models assume a stable economy and infrastructure[96]. In most of the modeling[17], oil production curves are

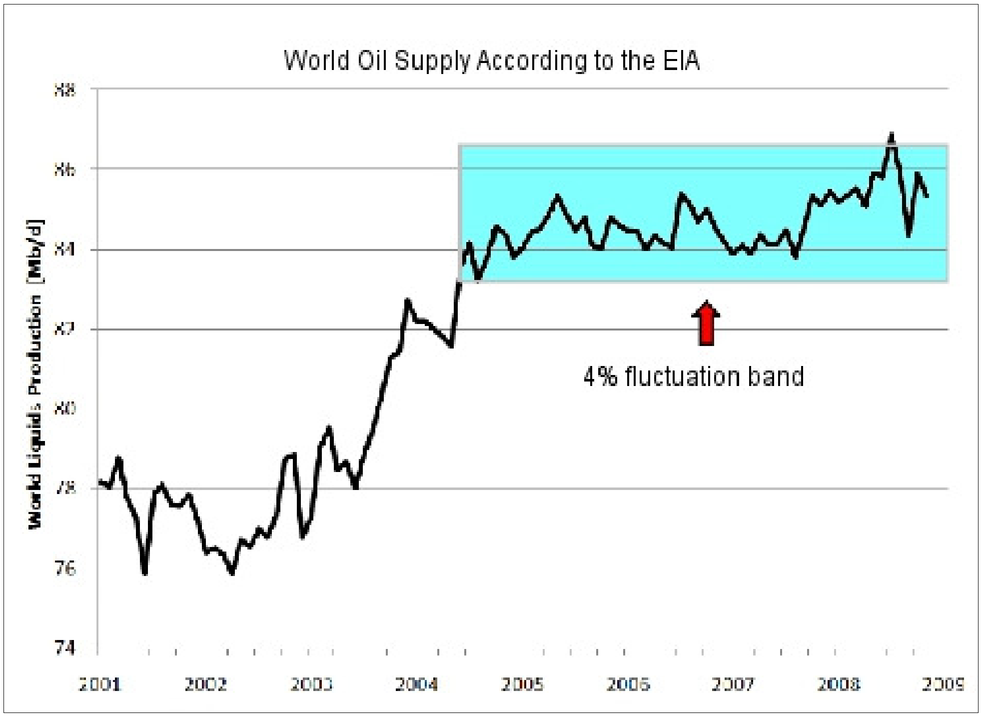


Figure 20a: World oil supply according to the EIA. World liquid fuels production from January 2001 to November 2008. Since mid-2004, production has stayed within a 4% fluctuation band, which indicates that new production has only been able to offset the decline in existing production[93].

derived from proven reserves (1P) or proven plus probable (2P) (see *Appendix 1* for further definitions of oil reserves). Proven reserves (1P) are based on current production costs and available technology. Proven plus probable reserves (2P) are based on assumptions about the development of future technology and economic growth, which might allow consumers to pay higher prices (i.e., increase consumers' willingness to pay). Therefore, oil production decline curves tend to assume that as oil production declines societies can continue to afford to use technical resources to find, develop, extract, and refine the remaining oil; and that financing and price stability will be available for such investment. These production models ignore the interdependent feedback between oil production (i.e., oil supply) and the economy[96].

Korowicz[96] calls this set of three assumptions the *decline curve assumption*. The decline curve assumption may be very misleading since declines in oil production undermine the ability of society to produce, trade, and use oil (and other materials and energy fuels) in a re-enforcing positive feedback loop. Energy flows, especially from oil, through the global economy will likely be unpredictable, volatile, and vulnerable to sudden and severe collapse. Declining oil production and decreasing oil EROI suggests that much of the oil and other energy resources (e.g., coal, natural gas, unconventional oil) that are assumed to be available to the global economy will remain in the ground (i.e., will not be produced) since economic and financial systems, real purchasing power, and energy infrastructure will not be available to extract and consume them. Therefore, if the global economy collapses, estimated oil production decline rates (4 – 10.5%) may be greater than projected, and may be abrupt and non-linear.

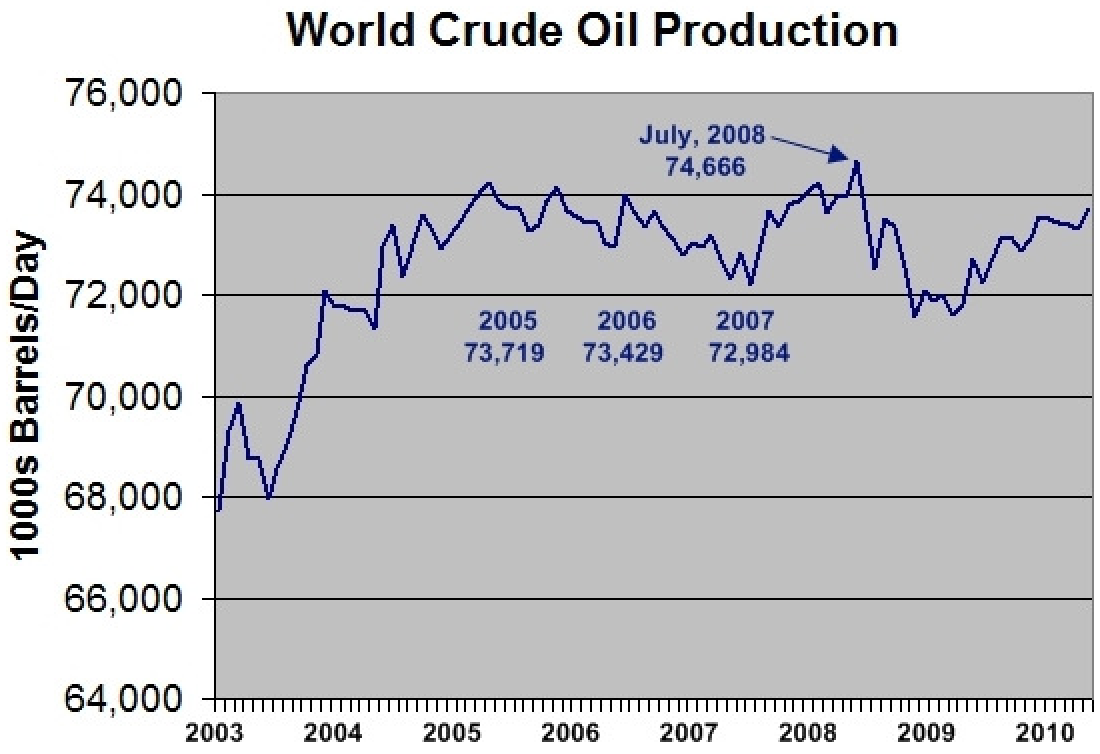


Figure 20b: EIA data for global conventional oil production[94]*. The average world production through July is 73.426 mbpd in 2010.*

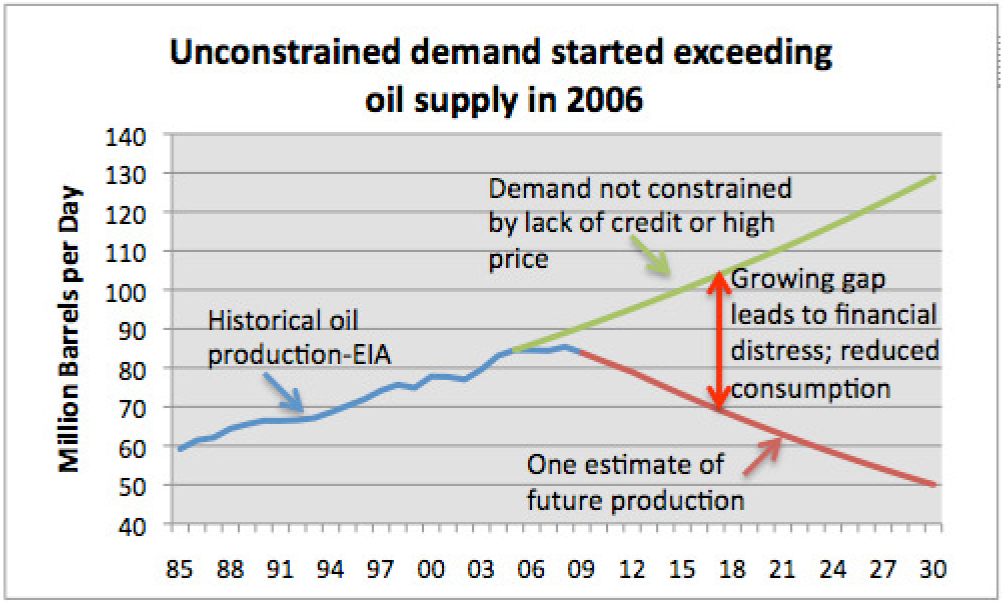


Figure 21: Unconstrained demand started exceeding oil supply in 2006 [95] with historical data from the EIA.

Peak production of other energy and material resources – e.g., coal, natural gas, uranium, phosphorus – is expected to occur within the next couple decades, if some of them have not already peaked (see *Peak Energy Resources* and *Peak Phosphorus*). The production of other energy and material resources on an industrial scale depends on a stable and inexpensive supply of oil to fuel the machinery, technology, infrastructure and labor to find, develop, extract, process, distribute, and use these various resource products. Peak resource production is based on BAU estimates, which are based on the assumption that oil production will not decline during the projection period. Since oil is used to produce these other resources, it is likely that peak oil production will cause peak production of other energy and material resources to occur sooner than projected. Consequently, this would accelerate the collapse of the global economy and limit societies willingness to pay for oil.

Oil Prices and Demand Destruction

Oil prices have dramatically increased since 2004 (see Figures 22 and 23). Oil prices have been volatile since then. In 2008, oil prices increased to $92 per barrel, and then rose to a record $141 per barrel in early July 2008. After spiking to $141 per barrel in July 2008, oil prices collapsed to $33 per barrel by the end of the year, which was the lowest price level since summer 2004 [27] (see Figure 22). Since 2009, oil prices have fluctuated between $70 – 86 per barrel. Assuming BAU, oil prices are projected to rebound with the economic recovery to reach $100 per barrel by 2020 and $115 per barrel by 2030 (in real 2008 dollars)[35]. As a result, OECD countries as a group are projected to spend on average close to 2% of their GDP on oil and gas imports through to 2030 [35]. In the *IEO 2010* [97] Reference case (i.e., BAU), the price of light sweet crude oil (the highest quality oil) in the U.S. (in real 2008 dollars) is projected to rise from $79 per barrel in 2010, to $108 per barrel in 2020, and $133 per barrel in 2035.

The global and industrialized economy is based on fractional reserve banking, compound interest, debt-based growth, and compound or unlimited growth. The economic theory on which the economy is based assumes unlimited energy supplies. Credit forms the basis of the monetary system. In a growing economy debt and interest can be repaid; in a declining economy they cannot be repaid. Therefore, declining energy flows (i.e., oil) cannot maintain the economic production required to service debt. When outstanding debt cannot be repaid, new credit will become scarce[96].

Although the global economy was set to falter due to financial over-extension, corrupt financial practices and pursuing unlimited debt-based economic growth, the dramatic rise in oil prices since the start of 2007, followed by the oil price shock of the summer of 2008, probably triggered the economic collapse (a.k.a. the "Economic Crisis of 2008" or the "Great Recession"). Just as the rise in oil prices choked the global economy so did the subsequent global financial crisis, the ensuing global recession, and the drastic slowdown of economic activity choke oil demand[27]. This situation illustrates the coupling between the economy and oil supplies.

The IEA and EIA forecasts oil prices to increase to $115 by 2030 [35] and $133 by 2035 [97]. However, such oil price projections assume that people will be able to afford oil at prices above $80. Based on the economic events since 2008, demand destruction for oil may be somewhere above $80 per barrel and below $141 per barrel. Assuming that peak oil has occurred, or will occur in the near-term, it is unlikely that oil prices will decrease to their pre-2005 levels – especially since future oil resources will be more costly to produce (see Figure 13).

The global recession reduced oil demand and concomitant oil prices. Economic recovery will stimulate oil demand and thereby increase oil prices. Therefore, economic recovery (i.e., BAU) will likely exacerbate the global recession by driving up oil prices. Given that many nations and their citizens are insolvent and on the brink of debt default another oil shock and/or permanent increase in oil prices would likely push the global economy and many nations over the cliff edge and into economic collapse.

Strategic Petroleum Reserves

Strategic petroleum reserves are oil stockpiles or inventories held by national governments and private industry in order to maintain energy, economic, and national security during energy shortages and crises. Strategic petroleum reserves are generally stockpiles of crude oil, and therefore require refining.

The IEA was formed after the 1973 – 1974 oil crisis. Energy security is a primary IEA activity. IEA member countries are required to maintain oil stockpiles or strategic petroleum reserves as part of the IEA's emergency response system[98]. Altogether, IEA member countries hold about 4.1 Gb of public and industry oil stocks, of which around 1.4 Gb are held by governments and specialized agencies for emergency purposes. The remaining reserves are held by the oil industry.

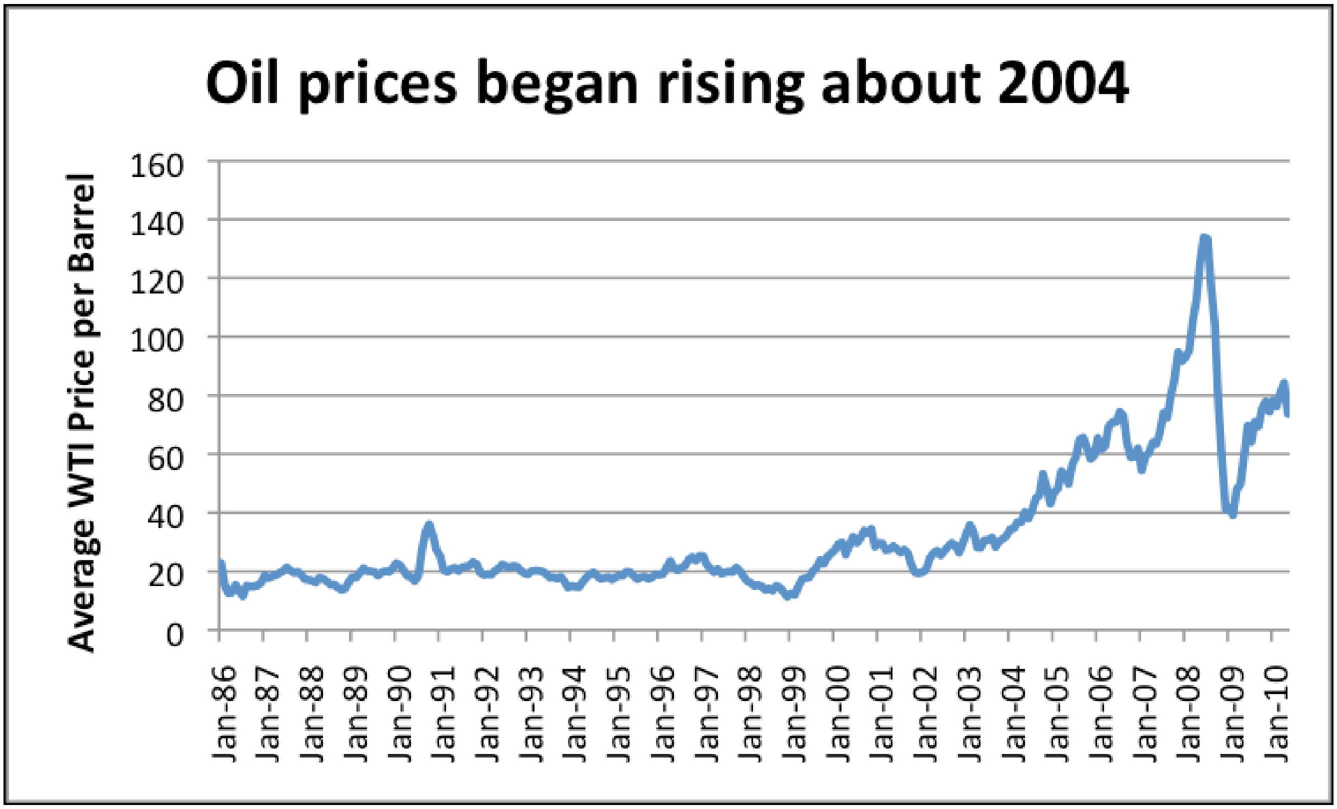


Figure 22: Average monthly West Texas Intermediate (WTI) spot prices from 1986 – 2010, based on Energy Information Administration (EIA) data[95].

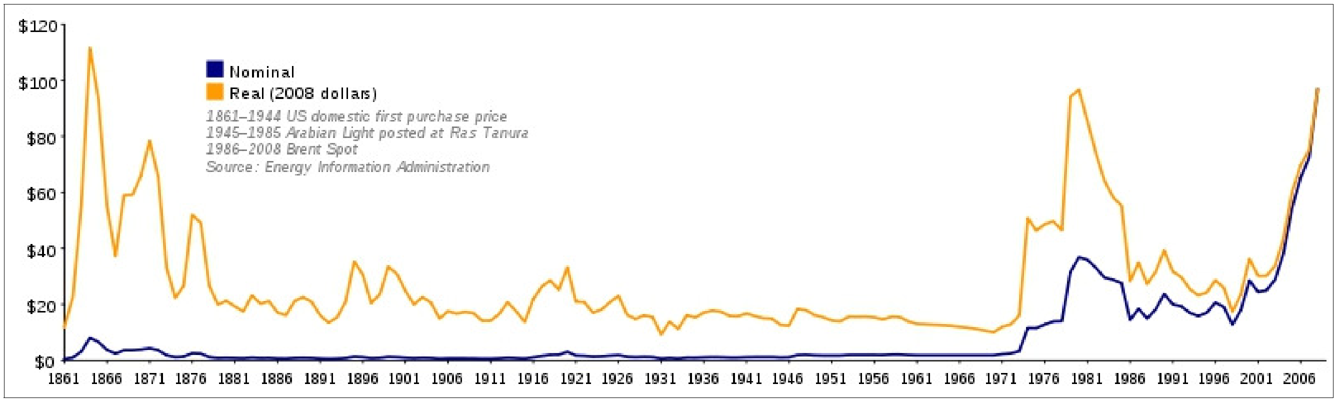


Figure 23: Oil Prices from 1861 – 2007 [100].

In 1974, the IEA emergency response mechanism was established in its International Energy Program (IEP) Agreement which obligates its member countries to hold oil stocks equivalent to at least 90 days of net oil imports of the previous year; to implement domestic measures to manage a major oil supply disruption; and to share available oil with other member countries. Only net-exporter member countries of the IEA are exempt from the reserve requirement: Canada, Denmark, Norway, and the United Kingdom. Nonetheless, both Denmark and the UK have recently created strategic reserves to comply with European Union requirements[98].

The U.S. supposedly has the largest strategic petroleum reserve in the world. According to U.S. Department of Energy's Strategic Petroleum Reserve Project Management Office[99], the U.S. Strategic Petroleum Reserve Inventory was full as of December 27, 2009 at 726.6 million barrels of crude oil – 292.6 million barrels in sweet crude and 434 million barrels in sour crude oil.

By the Council Directive 68/414/EEC of 20 December 1968, all 27 members of the European Union are also required to have a strategic petroleum reserve within the territory of the EU equal to at least 90 days average daily internal consumption. Similarly, many nations have their own oil stockpiles. Few nations have enough oil reserved for a supply of 90 days or more. Most have less than a 90 day supply, if any at all. None of them are known to have a year or more of supply.

In the best case, it seems that the world would only have a few months of oil supplies in case of a severe supply disruption. Therefore, strategic petroleum reserves and other such oil stockpiles will not be enough to delay the onset of peak oil or to mitigate a post-peak oil decline. Most likely, these strategic reserves will be used for emergency responses and rationing, maintaining some basic services and industry, security, defense, and other military activities.

"...the supply-demand fundamentals seem consistent with the view now taken by market participants that the days of persistently cheap oil and natural gas are likely behind us."

– Ben S. Bernanke, Chairman of the U.S. Federal Reserve[101], 2006

"By 2012, surplus oil production capacity could entirely disappear, and as early as 2015, the shortfall in output could reach nearly 10 MBD [mbpd]."

– U.S. Joint Forces Command [72,102], Department of Defense, 2008 and 2010

- Peak oil is occurring now.
- Peak oil production likely occurred in 2005 – 2008 or will occur by 2011.
- Thereafter, global oil production will likely begin a terminal decline starting by the end of 2010 – 2011.
- Since mid-2004, the global oil production plateau has remained within a 4% fluctuation band, which indicates that new production has only been able to offset the decline in existing production.
- The peaking of oil will not be accurately predicted until after the fact.

Peak Oil Production

Peak conventional oil production will likely occur anytime between 2005 – 2008 or will occur by 2011. Thereafter, global conventional oil production will likely enter an undulating plateau phase; followed by a terminal decline that will likely start by the end of 2010 – 2011 [2,7,17,103,104]. The peaking of oil will not be accurately predicted until after the fact. Nevertheless, since mid-2004, the conventional oil production plateau has remained within a 4% fluctuation band (see Figures 20a and 20b), which indicates that new production has only been able to offset the decline in existing production[79,93]. This plateau in conventional oil production has occurred despite steadily increasing oil demand. In 2005, global conventional oil production reached a peak at around 73.7 mbpd. In 2008, global conventional oil production peaked at around 74.7 mbpd[94]. Campbell and Heapes[103] estimate that the peak production of conventional oil passed in 2005, and that the peak of all liquids (excluding natural gas) will occur around 2010. The authors' estimates support the projections made by other authors[7,17,59].

High-level authorities in the U.S. Department of Energy (DoE) have also stated that a peak in global oil production may occur within the next few years. Glen Sweetnam, former director of the International, Economic and Greenhouse Gas division of the Energy Information Administration (EIA) at the U.S. Department of Energy (DoE) claims that global liquid fuels production will likely decline between 2011 – 2015, if investment in liquid fuels projects does not occur[40]. If that investment does not occur, the gap that is projected to grow after 2011 between increasing global demand and the decline of oil supplies will grow over time, causing severe liquid fuels shortages. This decline in liquid fuels supply was shown in a presentation given by Sweetnam in 2009 (see Figure 8a) (see *U.S. Department of Energy* in *Oil Data Is Inaccurate* for more details regarding Glen Sweetnam and the DoE's peak oil claims). Until April 2010, Glen Sweetnam was the main official expert on the oil market in the Obama administration[41].

Similarly, U.S. Secretary of Energy Steven Chu presented on a hypothesis of an imminent decline in the global production of liquid fuels in March 2005 [47]. In his presentation, Chu indicated that peak oil and gas liquid fuels production would occur around 2005, and then decline rapidly starting in 2010, which he clearly indicated in his presentation slide shown in Figure 8b (see *U.S. Department of Energy* in *Oil Data Is Inaccurate* for more details regarding Steven Chu and the DoE's peak oil claims).

Predictions of global peak oil production have also recently been issued by the U.S.. In early 2010, the U.S. Joint Forces Command of the U.S. Department of Defense issued its *Joint Operating Environment 2010* [72] which warns, “By 2012, surplus oil production capacity could entirely disappear, and as early as 2015, the shortfall in output could reach nearly 10 MBD [10 mbpd].” Remarkably, the *Joint Operating Environment 2008* published two years ago already presented the same diagnosis, word for word[102], “By 2012, surplus oil production capacity could entirely disappear, and as early as 2015, the shortfall in output could reach nearly 10 MBD.” The report also stated[102], “The implications for future conflict are ominous. If the major developed and developing states do not undertake a massive expansion of production and refining capabilities, a severe energy crunch is inevitable.”

A German military report written by military analysts in the Future Analysis department of the Bundeswehr Transformation Center states[105] that “some probability that peak oil will occur around the year 2010 and that the impact on security is expected to be felt 15 to 30 years later…[there will be] partial or complete failure of markets… [including] shortages in the supply of vital goods could arise.. A restructuring of oil supplies will not be equally possible in all regions before the onset of peak oil.” The document was leaked by *Der Spiegel* in September 2010. The document is said to be in draft stage and to consist solely of scientific opinion, which has not yet been edited by the Defense Ministry and other government bodies.

The UK Industry Task Force on Peak Oil and Energy Security predicts[106] that “...as early as 2012/2013 and no later than 2014/2015, oil prices are likely to spike, imperilling economic growth and causing economic dislocation.” The task force is comprised of top UK executives and energy experts. The British government, including energy minister Lord Hunt, staged a closed-door summit meeting with the taskforce on March 22, 2010 [107]. The government intended to develop an action plan to contend with a near-term peak and to “calm rising fears over peak oil.”[107].

The New Zealand Parliament released a report[108] of the global oil market stating that “Oil is ‘the lifeblood of modern civilisation’.” and that “...another supply crunch is likely to occur soon after 2012 due to rising demand and insufficient production capacity".

Chatham House[109], which was commissioned by Lloyd's, a major specialist insurance market, says that "an oil crunch is likely in the short to medium term" and "appears likely around 2013". However, the report relies too heavily on high-tech alternatives to oil and natural gas as a transition fuel to mitigate peak oil in the future.

Some oil industry executives and industry reports estimate that peak oil production will likely occur sometime between 2012 – 2015 [104,106,110]. Other sources forecast peak oil production to occur by 2020, or after 2030 [2,104]. However, these higher estimates (after 2015) tend to be based on assumptions of huge investments and on publicly available data that is not adjusted for reporting errors and misreporting. Therefore, it is likely that these reports are overly optimistic as to when peak oil will occur.

As discussed in the previous section, Saudi Arabia has more than 20% of the world's proven total petroleum reserves[79]. Saudi Arabia's historical crude oil production indicates that the nation's production peaked at 9.6 mbpd in 2005 (see Figure 7). In 2008, crude production was 9.3 mbpd. In 2009, it was projected to drop to 8.1 mbpd; then, increase in 2010 to 8.5 mbpd. After 2010, a steady decline in oil production is forecast[32]. In July 2008, the depletion rate was above 5% per year[32]. Since oil production in Saudi Arabia may enter into a terminal decline in 2010, and since OPEC nations have consistently misreported their reserves by about 300 Gb since the 1980's, it is likely that OPEC will not be able to support the need for growing global oil production in the near-term. Since 20 – 50% or more of global oil production from OPEC may possibly be in decline, and since non-OPEC reserves (which represent the other half of the world's oil reserves) are already in post-peak decline, it is possible that global oil production may enter in terminal decline within the next few years – quite possibly as early as 2010.

Further supporting this argument, the IEA[2] implicitly claims that peak oil production will occur starting around 2010, if their caveat[2] for the required "huge investments to explore for and develop more reserves, mainly to combat decline at existing fields" by 2010 does not occur, because "an additional 64 mbpd of gross capacity – the equivalent of six times that of Saudi Arabia today – needs to be brought on stream between 2007 and 2030." The IEA[2] adds to this caveat, "A faster rate of decline than projected here would sharply increase upstream investment needs and oil prices." The U.S. Joint Forces Command supports the IEA's claim by stating[72] that "...even assuming more effective conservation measures, the world would need to add roughly the equivalent of Saudi Arabia's current energy production every seven years."

Insufficient Capacity

In general, the BAU projections offered by the IEA are highly questionable since they are based on critical assumptions. Conventional oil production rates will (at best) maintain current capacity and will likely not increase until 2030 (see Figure 15), assuming continuing development of known crude oil reserves, the discovery and development of new crude oil fields, and the application of EOR[2]. This caveat is a vitally important one since the IEA expects global gross capacity additions to supply demand growth and output declines from existing fields until 2010, which would only increase spare capacity modestly. After 2010, capacity additions from current projects decline significantly. This is largely a consequence of the upstream development cycle in which many new projects will likely be sanctioned in the next two or three years as oil companies complete existing projects and move on to new ones[2].

However, the gap between projects currently being developed and what will be required to keep pace with increasing demand will widen sharply after 2010 (see Figure 21). Approximately 7 mbpd of additional capacity will be required by 2015 (over and above the capacity that is already in the pipeline from current projects), most of which will need to be sanctioned by 2010. Yet, most of the required capacity has not yet been approved[2]. The IEA admits that the immense scale of the required investment raises questions about whether all of the projected necessary additional capacity will actually occur. If actual capacity additions fall short of this amount, spare production capacity would not be able to supply demand and "oil prices would undoubtedly rise – possibly to new record highs"[2].

Based on the IEA[2,35] caveats requiring "huge investments" and "continuing development" of oil production capacity, it is very possible that a post-peak terminal decline in oil production may occur in 2010 or shortly thereafter. According to the agency's recent report[35], global energy investment has fallen since 2008 as a result of a tougher financial environment, weakening demand for energy, and lower cash flow. All these factors have been exacerbated by the economic crisis that started in 2007 – 2008 after the oil price shock. Energy companies are developing fewer oilfields, and cutting back spending on refineries, pipelines and power stations. Many ongoing projects have been delayed, and many planned projects have been postponed or canceled. Most oil companies have announced cutbacks in capital spending, as well as project delays and cancellations, primarily as a result of lower cash flow. The IEA estimates that global upstream oil and gas investment budgets for 2009 had been reduced by about 19% compared with 2008, which is a reduction of over $90 billion. Oil sands projects in Canada account for the majority of the suspended oil capacity. Therefore, it seems unlikely that oil production and distribution capacity will be sufficient to supply growing oil demand, even if current oil resources are adequate to supply demand. Therefore, peak oil production is also related to the maximum production capacity – without the capacity the oil cannot be produced, and without substantial oil resources no one will invest in capacity to get the marginal quantities.

Why No Warning? Chapter 11

"This is a societal issue, there is no 'other' to blame, but the responsibility belongs to us all."

– David Korowicz[96], 2010

"...if you spend some time looking at peak oil, if you're a reasonably intelligent person, you see that catastrophic things are going to happen to the world. We're talking about major damage, major change in our civilization. Chaos, economic disaster, wars, all kinds of things that are, as I say, very complicated, non-linear. Really bad things. People don't like to talk about bad things."

– Robert Hirsch[42], director of fusion research at the U.S. Atomic Energy Commission, 2010

"[Steven Chu, U.S. Secretary of Energy,] knows all about peak oil, but he can't talk about it. If the government announced that peak oil was threatening our economy, Wall Street would crash. He just can't say anything about it."

– David Fridley[48], oil economist who worked under Steven Chu, 2009

- It is likely that many different actors in the political, industrial, and economic elite with different motivations and agendas contribute to this lack of public warning.
- Many, if not most, of the actors (including policy-makers, industry, the public) involved may be unaware of the situation, and may be acting on wrong information and the assumption that there are plenty of oil and energy resources and that business as usual is possible.
- Various incidences of misreporting and discrepancies have been perpetuated for a long time.
- Nevertheless, some warnings have been published by some government agencies, the military, academia, industry, and the private sector.
- Mainstream media seems to offer no or marginal coverage of the issues.
- Ultimately, society is responsible for the lack of warning, preparation, and response – the public and the market have not been paying attention to oil supplies and assumed unlimited economic growth.
- One reason in particular for motivating the lack of warning by status quo interests might be that a principle initial driver of the collapse process will be growing awareness and action about peak oil. If any national government announces that peak oil is threatening the economy, the market would

crash, and the economy would collapse sooner.

- Admitting peak oil will also have geopolitical consequences.

Given the risk and consequences of a global peak oil crisis, one might ask: "*Why has the public not been warned about peak oil?"* Although this is a very important question to answer, it is beyond the scope of this analysis to determine why it is so. Determining the reasons for this lack of warning would require an extensive investigation into the matter. Any attempt to determine in this analysis the motivations for the lack of warning and a public discourse would be speculation. It is likely that many different actors in the political, industrial, and economic elite with different motivations and agendas contribute to this situation. Some of them may involve various agendas for political and economic gains. Many, if not most, of the actors (including policy-makers and people in the relevant industries) involved may be unaware of the situation and may be acting on wrong information, the assumption that there are plenty of oil and energy resources, and/or that BAU is possible. *Ultimately, "this is a societal issue, there is no 'other' to blame, but the responsibility belongs to us all. What we require is rapid emergency planning coupled with a plan for longer-term adaptation."*

As discussed in the sections *Oil Data Is Inaccurate* and *When Will Oil Peak?*, various incidences of misreporting and discrepancies have been perpetuated for a long time. Nevertheless, it was also discussed how various government agencies have published warnings and reports on the matter. For instance, the U.S. Department of Defense and the U.S. Department of Energy both have issued multiple reports and clear warnings on the matter in just the past few years. Likewise, to various extents the governments of the UK and New Zealand and the German military have also issued warnings, but have only just begun to discuss peak oil publicly among policy-makers. Furthermore, a substantial amount of research on peak oil and energy resources is available in the academic literature, some of which is cited in this paper. Some industries have also made statements, published reports, and offered clear warnings about near-term peak oil. Yet, despite these reports and announcements, policy-makers, government leaders, and the mainstream media have essentially not addressed the issue or brought it to the public discourse. Why the message was not broadcast through global society despite these various public warnings would require much more investigation and speculation at this point in this analysis.

However, there may be one reason in particular motivating the lack of warning by status quo interests: A principle initial driver of the collapse process of society will be growing awareness and action about peak oil. If any national government announces that peak oil is threatening the economy, the market would crash, and the economy would collapse sooner. In addition to a market panic that would accelerate economic collapse, social and political unrest would likely ensue, which would also accelerate economic collapse. This presents an ethical problem: Not warning people is not fair nor will it avoid the inevitable problem of collapse. Yet, warning the public would cause likely the problem to occur sooner with possibly the same results. Unfortunately, there had been several decades to have prepared for peak oil. Starting sooner would have offered the possibility for the world to gradually and harmoniously make the transition to a non-petroleum economy.

Furthermore, announcing peak oil might also cause more social unrest and delegitimize various governments and institutions, because the public may believe that their governments failed to protect the interests of their nations and citizenry either by willful deceit, corruption, and/or incompetency. Governments and their agencies might also be seen as colluding with large corporations and private interests, especially with the oil and energy industries. Whether true or not, public sentiments that national governments helped to facilitate or were otherwise involved in the global-scale economic fraud and economic recklessness perpetuated by the financial and industrial sectors (i.e., Wall Street) would further delegitimize governments and foment unrest.

Admitting peak oil will also have geopolitical consequences. Oil producing nations might lose geopolitical power, if the international community realizes that they will no longer be reliable suppliers due to declining production rates. Private investment might also decline as investors look elsewhere to make their investments. Nations with resources may become targets of new political and economic alliances and/or resource competition and wars. Considering that a rapid reduction in the global population may occur in response to oil and energy scarcity and economic decline post-peak oil, a public warning about peak oil may cause a general panic as individuals, communities, and nations react to protect and secure their lives, livelihoods, and resources against a potential dieoff event and upheaval.

Although the above discussion is speculative, it does offer some plausible reasons to explain why no large-scale public warning about peak oil has occurred. Nefarious political and economic motivations aside, authorities in the know may be caught in a terrible dilemma: Announcing peak oil may be akin to shouting “Fire!” in a crowded theater, except that the burning theater has no exits.

As stated above, why and how peak oil will occur without any public warning or preparation is ultimately “a societal issue, there is no 'other' to blame, but the responsibility belongs to us all.” Whatever might be the motivations and reasons for not issuing a warning and offering prudent leadership on preparing for peak oil, it is clear that there is insufficient time to mitigate and prepare for peak oil and economic decline. Even if a government or industry surprised the world and released previously undisclosed new energy resources and/or technologies overnight, it would likely take years or decades and trillions of dollars to implement it on a commercial scale and to change the global energy infrastructure and economy. Therefore, it seems that a peak oil shock will be unavoidable and will come without much public warning.

Mitigating Peak Oil

Chapter 12

"Our ignorance is not so vast as our failure to use what we know."

– M. King Hubbert, geophysicist and energy advisor Shell Oil Company and USGS

"I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait until oil and coal run out before we tackle that."

– Thomas Edison[111], 1931

- It will take at least 20 years to change modern civilization over to a non-oil-based economy and infrastructure; which would cost trillions of dollars and would still result in a massive global economic decline.
- A managed “de-growth” is impossible, because effective mitigation of peak oil will be dependent on the implementation of mega-projects and mega-changes at the maximum possible rate.
- Electricity generation from alternative energy resources (i.e., wind, solar, tidal, geothermal) will not be able to replace oil as a transportation fuel since much of the entire world fleet of automobiles, ships, trains, and aircraft would have to be replaced by electric-powered vehicles.
- These alternative energy resources will likely be needed to supply electricity demand as other fossil fuels reach peak production in the near future.
- Such alternative energy resources (i.e., wind, solar, tidal, geothermal) cannot replace oil as a petrochemical feedstock.
- The projected share of biofuels in the total global supply of road transport fuels will increase from 1.5% in 2007 to 5% in 2030 assuming BAU.
- Most biofuel crops are not feasible for replacing oil on a large-scale due to the huge requirements for cropland and nutrients (i.e., fertilizers).
- Biofuels from algae and other microorganisms may potentially be a substitute for petroleum, but high capital and economic costs; and requirements for large areas of land, water, phosphorus and other nutrients (i.e., fertilizers) will likely prevent future algal and microbial oil production from replacing oil on a global-scale. In particular, peak phosphorus resources will severely limit the viability of large-scale algae production.

Mitigating Peak Oil

It will take at least 20 years to change modern civilization over to a non-oil-based economy and infrastructure. Implicit in making the transition away from an oil-based economy is the adoption of alternative energy technologies and non-oil based materials to substitute for petrochemicals. For example, platics can be made from plant-based materials instead of petroleum. Yet, even with 20 years, the change to a non-oil-based economy and infrastructure would cost trillions of dollars and would still result in a massive global economic decline[61]. A managed “de-growth” is impossible, because effective mitigation of peak oil will be dependent on the implementation of mega-projects and mega-changes at the maximum possible rate. Specifically[61]:

- Waiting until global oil production peaks before taking crash program action leaves the world with a significant liquid fuel deficit for more than 20 years.

- Initiating a mitigation crash program 10 years before global oil peaking would help considerably, but it still leaves a liquid fuels shortfall roughly a decade after the time that oil would have peaked.

- Initiating a mitigation crash program 20 years before peaking appears to offer the possibility of avoiding a global liquid fuels shortfall for the forecast period. However, the change to a non-oil-based economy and infrastructure would cost trillions of dollars and would still result in a massive global economic depression.

- The obvious conclusion from this analysis is that with adequate, timely mitigation, the costs of peaking can be minimized, but not avoided. If mitigation is too little, too late; the global supply-demand balance will be achieved through massive demand destruction (i.e., shortages), which would translate to significant economic hardship.

In other words, nations will need at least 20 years before peak oil occurs to make the transition away from an oil-based economy and society. Even with 20 years preparation time, significant economic disruption will likely occur. At least 10 years will be necessary to minimize, but not to avoid, severe economic disruption. Assuming that the estimates of the timing of peak oil are correct, there may be no more than 1 year (or less) left to initiate mitigation crash programs to avoid severe economic and social disruption. Clearly, this is would do little to mitigate a massive economic collapse and social disruption.

In particular, the impacts of peak oil on the transportation sector are perhaps the largest, but not the only concern, because transportation powered by cheap and convenient liquid fuels essentially make the world's economies move and function. Using automobiles as an example, the following is a discussion of the order of magnitude of what would be required to change the global energy infrastructure in only part of the transportation sector. The global fleet of passenger light-duty vehicles (not including heavy cargo trucks and other types of large vehicles) is projected to increase from an estimated 770 million vehicles in 2007 to 1.4 billion in 2030 [35]. Therefore, about 600 million more cars and the infrastructure to support them will need to be produced in order to supply projected BAU demand by 2030. Improving the energy and material-use efficiencies of technology and infrastructure (e.g., transportation, plastics, other products made from oil) would require years and massive financial investments to accomplish.

Societies particularly dependent on automobiles will be very affected by declining oil production. In the

U.S., one-half of the year-1990 model cars were projected to remain on the road 17 years later in 2007. At normal replacement rates, consumers will spend an estimated $1.3 trillion (year-2003 dollars) from 2005 until about 2015 – 2020 to replace only one-half the domestic stock of automobiles. The median lifetime of light trucks is 16 years. At current replacement rates, one-half of the 80 million light trucks will be replaced in the next 2014 – 2019 at a cost of $1 trillion. The median lifetime of the 7 million heavy trucks (including buses, highway trucks, and off-highway trucks) in the U.S. is 28 years. At normal replacement levels, one-half of the domestic heavy truck stock will be replaced by in the next 2020 – 2025 years at a cost of $1.5 trillion[61]. By 2020 – 2025, the U.S. will have to spend nearly $4 trillion dollars to replace its domestic automobile fleet just to replace aging vehicles assuming BAU, according to this estimation. This price estimate does not include costs for maintaining, expanding, and replacing energy and transportation infrastructure. And, this $4 trillion dollars is only the cost for one nation's automobile fleet – and trains, boats, aircraft, and other vehicles and engines have not been considered.

Although the replacement of global vehicle capital stock with energy efficient and alternative energy-using engines (e.g., electric- or biofuel-powered engines) would potentially help reduce oil demand and change the domestic vehicle fleet to non-oil based fuel system, the normal replacement rates of automobiles would require at least 10 – 20 years and cost trillions of dollars. It would be impossible to assume that people could afford to replace, or even retrofit, tens of millions of vehicles in the U.S. – much less nearly 800 million light-duty vehicles plus other heavier vehicles worldwide – even assuming that their are enough material resources to rebuild the global fleet. It is also not prudent to suppose that governments' can sponsor or otherwise subsidize affordable "crash programs" to accelerate normal vehicle replacement schedules to incorporate higher energy efficiency and/or alternative energy technologies into the transportation sector.

Even if the owners of the global automobile fleet had the financial resources and the will to replace their oil consuming vehicles, it is important to remember that automobiles also require large inputs of oil to build them – plastic components (used to decrease vehicle weight to improve energy efficiency) and electronics are made from oil feedstocks, and there are about 7 gallons of oil used to make each tire[9]. Replacing approximately 770 million light-duty vehicles in the world (assuming each vehicle only has 4 tires each) would require roughly 513 million barrels of oil just for the tires alone. And eventually, those tires will have to be replaced as they wear down from use. Similarly, the rest of the transportation sector (e.g., trains, ships, aircraft) would have to be replaced or retrofitted to perpetuate this current economic paradigm.

Alternative Energy Sources

The IEA[112] projects that the use of non-hydro renewable energy technologies (including solar, wind, tidal and wave, and geothermal, and bio-energy) will increase by 2030 assuming BAU, mostly in electricity power generation. The share of non-hydro renewables in total power output is projected to increase from 2.5% in 2007 to 8.6% in 2030. The share of hydropower may decrease from 16% to 14% by 2030.

Alternative energy resources, such as solar and wind energy, are not practical replacements for liquid fuels. Although solar, wind, tidal, and geothermal energy resources will be useful for many applications, it is currently too expensive to produce at very large scales and the technology is still developing. Furthermore, these alternative energy sources are limited by geographical and environmental factors that constrain their potential development. For instance, photovoltaics require sunlight; wind turbines require consistently strong winds; hydropower requires large bodies of water, tidal requires access to marine coastlines; and geothermal requires specific geological environments.

Since solar, wind, and tidal are variable energy sources – i.e., they only work when the sun is shining, the wind is blowing, or the ocean is active – energy storage technology must be developed and made cost-efficient to store surplus energy to meet later demand on a large-scale. Furthermore, an entirely new energy infrastructure (e.g., a new power grid) would be required to distribute all of these potential energy sources, assuming that the entire transportation fleet could be retrofitted or replaced with electric vehicles. Converting the transportation sector to an alternative energy-based system would require many years and would be tremendously expensive, if it was feasible to do so.

Moreover, alternative energy would likely be needed for other applications such as for electricity generation as the production of other fossil fuel resources peaks. And so, using alternative energy sources to power much or all of the world's transportation sector does not seem to be a practical or even possible solution to peak oil. Neither can these alternative energy sources replace oil as a material feedstock for such things as plastics and pesticides.

Additionally, hydrogen fuel cell technology cannot replace energy resources. The name “hydrogen fuel cells” is somewhat misleading. Hydrogen fuel cells are not an energy source, they are an energy battery. That is to say, the hydrogen in fuel cells store energy that is put into them through electrochemical processes. The hydrogen is not burned and consumed like fossil fuels. It simply undergoes a chemical reaction in which energy stored in the bonds of hydrogen molecules release their energy. In order to recharge the battery, energy (e.g., from an electrical outlet) must be supplied. Therefore, hydrogen fuel cells do not create energy, they store and release energy.

Biofuels

The IEA[35] projects that share of biofuels in the total global supply of road transport fuels will increase from 1.5% in 2007 to 5% in 2030 assuming BAU. The IEA[35] projects that the global biofuels supply will increase from 0.7 mbpd in 2007, to 1.6 mbpd by 2015, and 2.7 mbpd by 2030 assuming BAU. Nearly 25% of this projected increase would come from second-generation biofuel technologies. For example, second-generation biofuels for aviation may enter the market around 2020, but economic challenges and problems of scaling up facilities for commercial production will likely limit biofuels production to only about 80 kbpd by 2030, which is equal to 1% of aviation energy demand[35].

Most of the increased use of biofuels in 2007 – 2008 occurred in the OECD, primarily in Europe and North America[35]. However, the IEA[35] does not expect that the recent increase in biofuels production will continue in the near-term. Many nations are reconsidering their biofuels blending targets because of concerns about the impacts on food prices of diverting crops to biofuels; questions about the amount of the greenhouse gas emissions savings and emissions associated with changing to biofuels; and doubts about the environmental sustainability of biofuels. Furthermore, relatively low oil prices have reduced the profitability of biofuel production and imposed substantial financial challenges on many biofuel refineries. Investment in new plants has plummeted while many existing biofuel plants are operating at well below capacity[35].

As oil prices increase, biofuel production may become more economically viable in the future. However, if high oil prices are required to make biofuel production economically viable, then it is possible that biofuels may be too expensive to supply global demand unless the price for producing biofuels decreases significantly.

Another critical factor may prevent biofuels from replacing petroleum as an energy source. Biofuel crops require an enormous amount of cropland devoted for their production, which competes with food crop production. Of the 13.2 billion hectares (Gha) of the global total land area, more than 10% (1.5 Gha) are currently used to produce arable crops and over 25% (3.5 Gha) are in pasture for meat, milk and fabric (e.g., wool, leather) production from grazing animals. Biofuel crops, which supply 1.5% of global oil demand, are currently grown on about 1% of total agricultural land[2].

The impact of biofuel production on land and water resources varies with local agroclimatic conditions and policies. Biofuel production is very water intensive. The quantity of irrigation water used for global biofuel production is approximately 44 km^3, which is equivalent to 2% of all irrigation water[12]. Water demand for biofuel production depends on the type of crop grown. An average of approximately 2,500 L of water is required to produce 1 L of liquid biofuel under current production conditions. This is approximately equivalent to the average amount of water required to produce food for one person for one day. Yet, regional variations can be significant depending mainly on the relative proportion of irrigation in biofuel crop production. For instance, the amount of irrigation water used for biofuel production is 2% in China, 3% in the United States, but negligible in Brazil and the EU[12]. Therefore, water supplies can be a major constraint on increased energy crop production in some regions. The exception to this may be biofuels made from algae, which can be grown on marginal land or in water. However, even algal biofuels require significant amounts of land and water to produce oil on a large-scale. Algal biofuels are discussed in the following section.

Biofuels production costs can vary depending on the feedstock (e.g., corn, switch grass, algae), conversion process, scale of production, and geographical location[113]. Most biofuel crops are insufficient for replacing oil on a large-scale for several reasons. Biofuels generally have a low energy return on investment (EROI) (see Figure 11). They also generally require substantial fossil fuel inputs, including fuel and synthetic fertilizers and pesticides). Producing and processing biofuel crops can also cause substantial environmental degradation. Biofuel crops require a lot of cropland, perhaps with the exception of microbial biofuel crops like algae (see Table 3). However, one of the most relevant constraints on using biofuels to substitute for oil is that biofuel crops require a lot of nutrients to grow, particularly phosphorus, nitrogen and potassium. Nutrient supplies will always be a limiting factor for all biomass production, even for algae and other microbial biofuel stocks.

Algae Biofuel

Algae are simple, photosynthetic aquatic organisms that convert sunlight, water, nutrients, and carbon dioxide to algal biomass. Microalgae have more rapid growth rates than terrestrial plant crops. There is much interest in the prospect of producing biofuels and material feedstocks from algae to replace oil. Algae can be converted to bio-oil, bioethanol, biodiesel, bio-hydrogen, and bimethane. Algae may be the only known source of renewable biofuel that might be able to supply a significant part of the global

Table 3: Comparison of estimated biodiesel production efficiencies from vascular plants and microalgae[115] as modified with rounding from 116.

Biodiesel feedstock	Area needed to meet global oil demand (in million hectares) (Mha)	Area required as a percent of total global land (%)	Area required as a percent of total arable global land (%)
Cotton	15,000	101	757
Soybean	10,900	73	552
Mustard seed	8,500	57	430
Sunflower	5,100	34	258
Rapeseed/canola	4,100	27	207
Jatropha	2,600	17	130 (0)[a]
Oil palm	820	5.5	41
Microalgae (10 g/m^2/day, 30% TAG)	410	2.7	21 (0)[b]
Microalgae (50 g/m^2/day, 50% TAG)	49	0.3	2.5 (0)[b]

[a] Jatropha is mainly grown on marginal land.
[b] Zero area required as a percent of total arable global land, assuming that microalgal ponds and bioreactors are located on non-arable land.

demand for transport fuels and some material feedstock (e.g., for the production of plastics)[113].

Industrial bioreactors (i.e., algae production systems) for algal cultures include open ponds, photobioreactors, and closed systems. Closed systems are substantially more expensive than open ponds, they have significant operating challenges, and they cannot be scaled-up more than about a 100 m^2 (i.e., 0.01 ha) for individual reactor units[113]. In addition to yielding more oil than other biofuel crops, algae also can be grown in many different environments including on marginal land and in salt water and sewage. The advantage of this is that algae does not need to be grown on cropland[113]

Algal cultures can consist of a single or several algae species optimized for producing specific products. Nevertheless, Scott et al.[114] suggest an upper oil yield limit to algae. Since estimates for algal growth are based on laboratory experiments or pilot-scale trials, the maximum productivity at a large-scale using current technology is unlikely to exceed 45,000 L per ha per year (283 barrels of oil per ha per year) of biodiesel[114]. Demirbas[113] estimates that the per unit area yield of oil from algae is roughly between 8,100 – 32,400 L per ha per year (51 – 204 barrels of oil per ha per year), which is about 7 – 31 times greater than the next highest yielding biofuel crop, palm oil. Based on Demirbas' estimate, in order to supply the current global demand for oil (approximately 31 Gb per year in 2010), 155 – 620 Mha of the surface area of the planet (either terrestrial or aquatic surface area) per year would be required for algae production in ponds and other types of bioreactors. This area does not include the area required for the associated infrastructure (e.g., facilities, pipelines, roads, refineries). Table 3 compares various land requirments for grow biodiesel crops. Although biodiesel is a specific type of oil product (e.g., as compared to bioethanol), it gives a general idea of the scale of land use requirements.

If algae could only be grown on arable land, then growing algae as a biofuels crop would be impractical since it would require 10 – 41% of the global total area of arable land (see *Arable Land*). However, algae can be grown in ponds, lakes, water channels, and in the ocean. High nutrient waste water containing nitrogen and phosphate salts from domestic, agricultural, and industrial sources can be added directly to algal growth media. This can lower the cost of algae production, while simultaneously treating waste water. Furthermore, salt water, either from saline aquifers or sea water, can be used for algae production. Using salt water can reduce the risk of competition for freshwater resources for other purposes[113].

Although nutrients for growing algae can be supplied from water runoff from local land areas (e.g., agricultural runoff) or from water from sewage and water treatment facilities, algae will still require an enormous input of nutrients. Nutrients, such as phosphorus, must be supplied in large excess because the added phosphates complex with metal ions, which prevents all of the added phosphorus from being available for uptake by algal cultures. For instance, sea water supplemented with commercial nitrate and phosphate fertilizers and other micronutrients is commonly used for growing marine microalgae[113]. Therefore, using algae as a biofuels source would likely require large quantities of fertilizers to support enormous cultures of algae grown for commercial production. For example, although algae may be able to produce 10 – 20 times more biodiesel than rapeseed, algae require 55 – 111 times more nitrogen fertilizer (i.e., 8 – 16 tons per ha per year)[113]. Such large amounts of nitrogen and phosphorus could cause considerable environmental damage, while diverting fertilizer supplies from food and other crop production to algae production.

Although some nutrients (e.g., nitrogen and phosphorus) found in algal waste can be recycled after the oils have been extracted, an initial investment of nutrients will be required to start up algae production. In effect, the algae will act to sequester nutrients such as phosphorus in their biomass. One of the limiting nutrients for algal growth is phosphorus. Phosphorus is an element necessary for all life. Phosphorus is one of the three major nutrients required for plant growth: nitrogen (chemical symbol N), phosphorus (P), and potassium (K). Phosphorus is often a limiting nutrient in natural ecosystems, in which the supply of available phosphorus limits the size of the population possible in a given ecosystem[117].

Most phosphorus is obtained from mining phosphate rock[117]. Phosphorus is also obtained from deposits of guano[117]. Peak global phosphorus production likely occurred in 1989 [117,118] or will occur by 2033 [119] (see *Peak Phosphorus*). Therefore, the capacity to produce biofuels from algae may be constrained by global supplies of phosphorus.

In order to estimate the input of phosphorus to produce enough biofuel to replace current global oil demand in 2010 (i.e., 86.6 mbpd), the nutritional requirements of algae must be considered. The minimal nutritional requirements of algae can be estimated using the approximate molecular formula of microalgal biomass that is $CO_{0.48}H_{1.83}N_{0.11}P_{0.01}$ – also written as $C_{100}O_{48}H_{183}N_{11}P_1$ [120]. At a minimum, phosphorus accounts for approximately 1% of the total molecular weight of algal biomass. However, in addition to needing to supply enough phosphorus to meet the minimum nutritional requirements for algal biomass, enough phosphorus must also be supplied to keep the phosphorus concentrations in the algal growth media (e.g., nutrient-rich water) at an optimum level. For the sake of this estimation, only the minimum phosphorus by molecular weight will be considered, and not the quantity needed to keep the phosphorus concentrations in the algal growth media at an optimum level.
Current oil demand is about 31 Gb per year in 2010. The equivalent of one tonne (t) of oil is contained in

7.3 barrels of oil. Therefore, the global demand for oil is about 4.3 Gt per year. Assuming optimistically that the oil yield of all biofuel algae species is high (i.e., 50% of biomass is oil), and that all of this oil is 100% recoverable from the algae and the refining processes, then about 8.6 Gt of algae would have to be produced per year to supply current oil demand. Thus, approximately 86 Mt per year of phosphorus would need to be supplied to grow all of this algae.

Commercial phosphate rock typically contains 26 – 34% of P_2O_5 (phosphorus pentoxide). Reserves of phosphate rock with lower concentrations of P_2O_5 also exist, but they are more economically and energetically costly to extract and produce. For this estimation, all phosphate rock is optimistically assumed to be of relatively high quality – i.e., 34% P_2O_5. Therefore, in order to supply 86 Mt of phosphorus per year, approximately 575 Mt of phosphate rock per year would be necessary.

According to the USGS[121], global production of phosphate rock was 158 Mt in 2009, which was 3 Mt less than what was globally produced in 2008. However, USGS figures are often inflated or distorted since they often use outdated or misreported government and industrial data. More likely, the peak of global phosphorus production likely occurred in 1989 [117,118], or will occur by 2033 [119], at a production rate of about 160 Mt per year[117-119]. Regardless of the timing of peak phosphorus, it is clear that using at minimum 57.5 Mt per year of phosphate rock to produce algal biomass for fuel and as material feedstock (e.g., to make plastics) is not a plausible option since appropriating about 36% of global phosphate rock production from food production would likely lead to a chronic global food supply crisis. Since it is likely that more phosphorus would be needed to grow so much algal biomass, 575 Mt of phosphate rock per year is the minimum requirement for global algae production to replace petroleum.

Once phosphorus supplies are exhausted, phosphorus will need to be recycled (e.g., by using methods of composting, soil conservation, manure, composting toilets) in order to avoid a massive global food security crisis. However, if phosphorus is sufficiently recycled throughout all sectors of the economy, including agriculture, then significantly less phosphates would be available in runoff and waste water for algal biomass production. In turn, this would likely stimulate demand for phosphate rock fertilizers for algae production. And once again, the problem of supplying enough phosphorus to produce algal fuel remains a problem.

Even if phosphorus supplies were not a limiting factor for algal biofuel production, economic costs will likely limit the development a global capacity to produce algal biofuels to replace current or future oil demand. According to Oilgae[122], an algae fuels industry organization, the costs of setting up and operating a photobioreactor for algae cultivation are much higher than for open ponds, but photobioreactors offer higher efficiency and oil yields. Although open ponds cost approximately $100,000 per ha in capital costs, photobioreactors cost about $1 – 1.5 million per ha, which is 10 times more than for open ponds. However, photobioreactors provide yields that are 3 – 5 times higher than for open ponds.

Assuming optimistically that all algae cultivation reactors cost only $100,000 per ha in capital costs, and that only 155 Mha of surface area would be required for algae production, then it would cost about $15.5 trillion dollars in capital costs to set up global algae fuel capacity. In comparison, the world GDP in in 2009 was about $58 trillion dollars[123]. This figure only considers the upfront capital costs of reactors, and not their operating costs, nor the capital and operating costs of developing refineries, processing facilities, and associated infrastructure. Nor, does this estimate consider the costs (if any) of retrofitting or replacing the global transportation fleet with engines that can run on algae biofuel products. Considering that the global economy is declining in a recession triggered by dramatic oil price increases, it is unlikely that enough investment for algae reactors, refineries, and other facilities and infrastructure will be available in the near future.

Even if the requisite facilities and infrastructure are economically viable, the costs of producing and refining algae fuels is still high. For example, Oilgae[122] estimates that the current production costs for algae based biodiesel is about $18 per gallon, if photobioreactors are used. This figure is for the production cost of algae biodiesel; the consumer price would be higher than this estimate.

Closed reactor systems may only be able to compete with crude oil at $800 per barrel, an economically impractical price to consider for large markets. Solix Biofuels has developed technologies to produce oil derived from algae, but it costs about $1,378 per barrel, or $32.81 per gallon[124]. Therefore, open systems may be the only economic solution for large-scale algae production for now[125].

Despite algae requiring large inputs of nutrients (especially phosphorus) and capital, algae might have the potential to become a competitive source of biofuel on a large scale in some economies sometime in the future. The European Algae Biomass Association claims that turning laboratory experiments into industrial-scale production of algal fuels would take another 10 – 15 years (until around year 2019 – 2024)[126]. The U.S. Department of Defense supports the development of algal fuel as part of its mission for the U.S. military to supply half of its fuel from renewable energy sources by 2016. The U.S. Defense Advanced Research Projects Agency (DARPA)[127] claims that its research projects have already produced oil from algae at a production cost of $82 per barrel. Now, DARPA plans to start large-scale refining of algal oil into jet fuel, at a production cost of less than $126 per barrel. DARPA also claims that a larger-scale refining operation that would produce 1.2 Mb per year would start production in 2013. However, the projects are projected to only yield 9.7 barrels of oil per ha per year from the algal farm.

Although the U.S. military and the private industrial sector may become successful at producing algal fuel economically on a large-scale, it still will require vast areas of the planet and enormous capital costs to develop a national or global-scale algal fuel capacity, including the costs for production, refining facilities and infrastructure. Even if DARPA (or any other organizations or firms) is able to develop a large-scale algal fuel production facility by 2013, it still will require at least several more years to expand production to supply national and international markets. Even if oil yields turn out to be high, and the finances to develop commercial production and an algae-based economy become available, large-scale algae production is still years away and the nutrient resources (especially phosphorus) is limited in supply.

There is also the potential for the development and implementation of genetically-modified microorganisms (e.g., bacteria) to produce high yields of oil products. However, like microalgae, any potential oil-producing organism will still require large amounts of nutrients, including phosphorus, on a similar scale as that of algae. Therefore, any potential biofuel crop will have to compete with the same resources that are necessary for food production and to maintain the life that supports ecosystems. And, as with the case of algae, large-scale microbial biofuel production may come too little too late to avoid the worst impacts of global post-peak oil production.

Given the physical constraints and the economic and technological uncertainties regarding algae and microbial production, algal and microbial biofuels can at best be considered a wildcard that may be a partial solution for energy independence and security for some actors (e.g., states, private sector), but nonviable for the others without adequate wealth, resources or access to algae and microbial biofuel markets. Nevertheless, large-scale algae and microbial biofuel production may come too little too late to avoid the worst impacts of peak oil.

The Consequences of Peak Oil

Chapter 13

"The era of procrastination, of half-measures, of soothing and baffling expedients, of delays, is coming to a close. In its place we are entering a period of consequences..."

– Winston Churchill, 1936

"Getting in and to try to understand the problem in some kind of detail is I think impossible because it's very non-linear...And people may behave rationally, or they may strike and go out in the streets. There may be political chaos! When that happens, the police have to get out and then, you know, wars may happen. It gets very messy."

– Robert Hirsch[42], director of fusion research at the U.S. Atomic Energy Commission, 2010

- Peak oil will have systemic effects throughout the entire global civilization.
- Global civilization is locked into a very complex and interrelated world economy.
- Any attempt to alter significantly the energy and transportation infrastructure and the global economy on which global civilization is based would cause it to collapse – but without an increasing oil and energy supply the infrastructure and economy on which our civilization is based cannot survive.
- The principle driving mechanisms for a global economic collapse are re-enforcing positive feedback cycles that are non-linear, mutually reinforcing, and not exclusive.
- A principle initial driver of the collapse process will be growing awareness and action about peak oil.
- Systemic collapse will evolve as a systemic crisis as the integrated infrastructure and economy of our global civilization breaks down. Most governments and societies – especially those that are developed and industrialized – will be unable to manage multiple simultaneous systemic crises.
- Systemic collapse will likely result in widespread confusion, fear, human security risks, social break down, changes in geopolitics and markets, conflict, and war.
- With the collapse of the globalized economy, many communities will have to develop localized economies and food production.

Systemic Collapse and the Decline of Global Civilization

Peak oil will have systemic effects throughout our entire global civilization. Korowicz[96] explains that the contemporary world is based on:

"...a globalising, integrated and co-dependant global economy evolved with particular dynamics and embedded structures that have made our basic welfare dependent upon delocalised 'local' economies. It has locked us into hyper-complex economic and social processes that are increasing our vulnerability, but which we are unable to alter without risking a collapse in those same welfare supporting structures. And without increasing energy flows, those embedded structures, which include our expectations, institutions and infrastructure that evolved and adapted in the expectation of further economic growth cannot be maintained."

In other words, not only is our civilization locked into a very complex and interrelated world economy, any attempt to significantly alter it and the energy and transportation infrastructure and the global economy on which it is based would cause it to collapse – but without an increasing oil energy supply, the infrastructure and economy on which our civilization is based cannot survive.

A comprehensive analysis of the implications and potential consequences of a peak in global oil production is beyond the scope of this paper. Therefore, this particular topic will not be discussed at great length here. Instead, the reader is urged to read David Korowicz's[96] report, *Tipping Point: Near-Term Systemic Implications of a Peak in Global Oil Production – An Outline Review. Tipping Point* provides a very clear and straightforward analysis of the implications and consequences of a peak in global oil production. Nevertheless, along with this analysis, it is worth summarizing the integrated collapse mechanisms and the possible consequences of peak oil as discussed by Korowicz.

The principle driving mechanisms for a global economic collapse are re-enforcing positive feedback cycles[except where noted, adapted from 96]:

- Declining oil and energy flows will increase economic costs and reduce global economic production. Reduced global production will undermine society's ability to produce goods and services, to trade, and to produce and use energy, which will further reduce economic production.

- The global and industrialized economy is based on fractional reserve banking, compound interest, debt-based growth, and compound or unlimited growth. The economic theory on which the economy is based assumes unlimited energy supplies. Credit forms the basis of the monetary system. In a growing economy debt and interest can be repaid. In a declining economy they cannot be repaid. Therefore, declining energy flows cannot maintain the economic production required to service debt. When outstanding debt cannot be repaid, new credit will scarce.

- In 2008, oil represented 41.6% of the global total final consumption of all fuels (e.g., coal, natural gas, etc.)[8]. Of this total, 61.4% was used for transportation; 9.5% was for industry; 12.9% was for other sectors (including agriculture, commercial and public services, residential, and other sectors); and 16.2% was for non-energy use[8].

- The major petroleum products many people are familiar with include petrol, aviation fuels, kerosene, diesel, lubricating oils and bitumen. However, refined oil also serves as a petrochemical feedstock for the production of plastics, synthetic rubber, pharmaceuticals, pesticides, electronics, packaging, fabrics, dyes, adhesives and paint. Therefore, oil not only provides the fuel for the growth of the global economy, it also provides many of the materials that support societies and from which modern civilization is built. A shortage of oil will result in shortages of plastics, electronics, pharmaceuticals, and other oil-based products necessary to build and support modern civilization.

- Society's localized needs and welfare have become very dependent on hyper-integrated globalized supply-chains (e.g, industrial, agricultural, water, energy). The system-wide functioning of global supply-chains is supported by monetary confidence and bank intermediation. The money in our economies holds no intrinsic value; it is backed by debt. When the economy is destabilized, deflation and hyper-inflation risks will also destabilize the monetary system. Furthermore, the banking system as a whole must become insolvent since their assets (i.e., loans) cannot be repaid.

- The failure of globalized supply-chains will collapse world trade. In developed and industrialized societies, regional and local economies will breakdown since few goods and services are produced locally, but rather are imported and outsourced from the global economy. Therefore, the more complex and globalized the systems and inputs are on which modern societies rely, the more are societies at risk from a systemic collapse.

- The global economy and supply-chains are also highly dependent on the operation of highly co-dependent critical infrastructure (e.g., energy, transportation, water, waste, food, finance, telecommunications, and Internet technologies). A systemic failure in one part of the infrastructure may cause cascading failure in the others. This infrastructure depends on continual re-supply of energy, materials, short-lifetime components; complex highly resource intensive and specialized supply-chains; large economies of scale; and the operation of the monetary and financial system. The interdependence of infrastructure is likely to cause rapidly increasing risks of systemic failure.

- Since the Green Revolution started after World War II, the modern industrial agricultural system has become highly dependent on fossil fuel inputs (particularly oil and natural gas), the delocalization of food sourcing, and small just-in-time inventories. The failure of the modern food production system could result in rapidly evolving food security risks in both developed and developing countries. At risk is food production, the ability to link surpluses to deficits (i.e., distribute food from source to consumer), collapsed purchasing power, and the ability to monetize market transactions.

- Peak oil is likely to cause a general peak in energy production and use (e.g., coal and gas generated electricity) (see *Peak Energy Resources*). The ability to develop new energy production and maintain existing energy infrastructure will likely be severely compromised. Massive energy demand and supply collapses will likely cause further decay of energy infrastructure and limit the ability to rebuild it.

- The collapse mechanisms described above are non-linear, mutually reinforcing, and not exclusive. In other words, the above collapse mechanisms are interrelated, can happen simultaneously, can occur very suddenly and rapidly, and can cause and accelerate the occurrences of any of the other collapse mechanisms.

- A principle initial driver of the collapse process will be growing awareness and action about peak oil and a growing awareness about the rapid decline of the financial sector and global economy. Investors will likely try to extract themselves from “virtual assets” (e.g., bond, equities, market funds, and cash) and convert them into “real assets” (e.g., property, precious metals, tools) before the system collapses. However, the nominal value of virtual assets likely far exceeds available real assets. Therefore, the confirmation of peak oil (e.g., by official and market action, and mainstream media discourse), fear, market panic, and market decline will drive a positive feedback in financial markets will accelerate systemic collapse.

- Systemic collapse will evolve as a systemic crisis as the integrated infrastructure and economy of our global civilization breaks down. Most governments and societies, especially those that are developed and industrialized, will be unable to manage multiple simultaneous systemic crises. Consequently, systemic collapse will likely result in widespread confusion, fear, human security risks, human rights abuses, and social break down. □

In addition to Korowicz's points:

- Peak oil will manifest itself with increased oil prices. Increased oil prices starting in 2007 and culminating in the summer of 2008 triggered the “Economic Crisis of 2008” the following quarter. Given that many nations and their citizens are insolvent and on the brink of debt default, the next oil price shock and/or permanent increase in oil prices may push the global economy into complete insolvency and collapse.

- Large transfers of wealth will likely flow from oil consuming nations to oil producing nations, until such time that oil producing nations reduce their exports for domestic consumption and/or due to lack of resources.

- The effects of global collapse will not be homogenous. Rather each region, nation, and community will be affected based on local and regional circumstances. Therefore, adaptation strategies will vary by circumstances and the environment. Geography, available natural resources, and access to trade routes will be important factors. Those societies with access to energy resources may be able to maintain some semblance of modern industry and civilization. Many people will likely have to live in pre-industrial conditions, with some relics of the industrial age to various extents.

- Many communities will have to develop localized economies and food production with the collapse of the globalized economy.

- The collapse of the globalized economy will likely cause mass displacement and migration. Societies with access to resources will likely be targets of resources wars, especially for energy, food, water, and material resources. Economic and social collapse will likely cause political instability, revolutions, failed states, social unrest (i.e., riots and civil wars), increased crime, military action, and other conflicts in some areas. Conflicts using nuclear weapons by both states and non-state actors is possible.

- Beliefs in cultural and social values, religion, economics, politics, and other institutions will likely be questioned by much of the masses. This is an opportunity for societies to endeavor to make a better and more secure world for themselves. It is also an opportunity for various political and social movements to lead people to do very terrible things. Everyone is responsible for shaping their respective societies and the world order. Everything is on the table.

- National and sub-national governments and boundaries may change significantly – with some political institutions and boundaries being created, altered, or disappearing. International and inter-regional geopolitics will likely be radically changed. Some regions may be ungoverned by any state authority. Old geopolitical alliances and conflicts based on oil resources will likely change. Resource and power grabs among nations and transnational corporations will greatly affect future geopolitics and international trade.

- It would take at least 20 years to change modern civilization over to a non-oil-based economy and infrastructure, which would still result in a massive global economic depression[61]. Therefore, a managed "de-growth" of the economy is impossible, because effective mitigation of peak oil will be dependent on the implementation of mega-projects and mega-changes at the maximum possible rate with at least one or two decades lead time[61]. With adequate, timely mitigation, the costs of peaking can be minimized, but systemic collapse cannot be avoided without the very rapid introduction of some radical new advanced technologies.

Governance Responses

Although social and governance responses to peak oil will vary due to local and regional circumstances, Friedrichs[128] compares three possible governance responses to peak oil and economic decline based on historical case studies of North Korea, Cuba, and other nations: *predatory militarism*, *totalitarian retrenchment*, and *socioeconomic adaptation*. Other responses are also possible, such as populist regimes.

Nations inclined to use military solutions may follow a strategy of *predatory militarism* to secure resources and economic stability. For instance, the United States, Europe and China might resort to a strategy of predatory militarism to secure access to resources elsewhere in the world. Although China's military capacity may not permit it to secure resources very far abroad, China may attempt to secure access to oil, gas, and other resources in Central Asia and in the seas around its coast[128].

When North Korean access to oil and other resources delivered from the Soviet Union was disrupted after the fall of the Soviet Union in 1990, elite privileges to resources were preserved at the expense of starving hundreds of thousands of North Korean citizens. Nations with a strong authoritarian tradition may follow a North Korean path of *totalitarian retrenchment* in which the ruling political and economic elites of a nation preserve their status and access to resources by suppressing and controlling their populations through authoritarian means. Democratic societies can also destabilize and fall under tyrannical regimes, as demonstrated during the history of the 20th Century[128].

Cuba was also challenged by a disruption of deliveries of oil from the Soviet Union. Cuba adapted to its own "peak oil" crisis after the fall of the Soviet Union in 1990, and the U.S. embargo left it without enough oil imports to sustain an oil-based industrialized economy. As a result of large declines in domestic food production and food imports, Cuba experienced food shortages in 1993 – 1994. In 1993, as a form of *socioeconomic adaptation* Cuba implemented an unprecedented set of reforms in agriculture that included breaking up most large state farms into production cooperatives, while opening farmers markets where farmers could sell surplus output (i.e., crop production beyond quotas farmers had to sell to the state) at free market prices. These policy changes resulted in gradual recovery in the agriculture sector[128].

Although Cuba experienced a great socioeconomic crisis for several years, there was no mass starvation event comparable to the one experienced in North Korea. Rather, the central government of Cuba implemented policy in which Cubans were supported by the decentralization of food production and economic activities, by social networks, and by non-industrial methods of production to adapt to energy, agrochemical, and food scarcity. However, with over 11 million people to support on an island nation, Cuba has become increasingly dependent on food imports to feed its population. Cuba's total food and agricultural imports nearly doubled between 2000 – 2006 [129]. Currently, Cuba imports about 80% of the food it rations to the public[130].

Although the Cuba government is of an authoritarian disposition, its response to its domestic oil and food crisis was significantly different than that of North Korea's totalitarian retrenchment. Nonetheless, as Cuba demonstrates, the different reactive strategies of societies are not exclusive. Nations that adopt a strategy of socioeconomic adaption, such as Cuba did after its oil imports were cut, potentially may be an optimal and more fair path to follow to protect human security and rights than predatory militarism and totalitarian retrenchment.

People may be able to mitigate and adapt to the effects of peak oil by reverting to localized, community-based economies that do not require the high energy inputs that are required for industrialized societies. Socioeconomic adaptation would be easier to implement for people in societies in which individualism, industrialism, and mass consumerism are not part of the cultural norm, especially where subsistence lifestyles have been practiced for generations. Socioeconomic adaptation would be more challenging to implement for people in developed and industrialized societies in which individualism, industrialism, and mass consumerism have been part of the cultural norm and way of life for generations[128].

There could also be other reactive strategies to the effects of Peak Oil. For example, the mobilization of national sentiment could result in populist regimes[128]. Depending on the society and government, and on how Peak Oil affects them, any of the above reactive strategies could be adopted in any combination as circumstances allow. For example, Nazi Germany could be described as being governed under a regime of predatory militarism, imperialism, totalitarian retrenchment, and corporatism. As an ominous note, such a governance regime was in part a result of the economic collapse and chronic economic depression affecting Germany during the early 20th Century.

"One of the biggest issues on the table now is climate change – global warming. Related concerns are going to have to give way to the urgent needs of immediate human existence after world oil production begins to decline. Our economies cannot flourish with very high-priced liquid fuels that are in deepening shortage. Massive, rapid, serious mitigation will be required. We can't do everything at once, which means that global warming efforts and the dreams of a renewable energy future are going to have to be secondary to the urgent, large need to regain some sort of reasonable economic equilibrium."

– Robert Hirsch[42], director of fusion research at the U.S. Atomic Energy Commission, 2010

- It is possible that climate negotiations may be abandoned or at least marginalized for a long time (if not permanently) as the crisis of peak oil and economic shock and awe overwhelms the stability and security of every nation.

- It will likely require a concerted and transcendent effort on the part of any remaining international climate negotiators, their governments, and the public to pursue a meaningful international climate policy – much less a binding international climate treaty.

- Two main arguments against pursuing an international climate policy will likely be made:

    - the peak oil shock and the associated collapse of societies and the global economy will be a more pressing issue; and

    - climate change will no longer be a concern since most oil demand will have been destroyed which will cause GHG emissions to decline sharply.

- However, future climate changes that are already in the pipeline will require adaptation and possibly further mitigation by societies.

- The international community and climate negotiators urgently need to review and reconsider the science and data regarding climate change and energy supplies.

- If this reassessment and discourse does not occur, not only will the international climate negotiations be ineffective, if it is not entirely destined to failure, human security and the stability of every society will be gravely threatened by these systemic crises.

Regarding climate change and climate policy, there is an ultra-critical assumption that the scientific and international community, and the climate negotiators are making: Economic and emissions projections generally assume that there is an unlimited or nigh-limitless supply of oil and other fossil fuels to fuel unlimited economic growth and development[131]. The IEA projects that the rise in emissions of greenhouse gases in their Reference Scenario (i.e., BAU) will cause a doubling of the concentration of those GHGs in the atmosphere by the end of this century, committing the world to an eventual global average temperature increase of up to 6°C[2]. Global peak oil production likely occurred in or will likely occur by 2005 – 2011 (with global oil supply shortages predicted by 2011 – 2015), and that global demand for oil is growing rapidly. Therefore, it is probable that BAU (e.g., continued economic growth, environmental degradation, and GHG emissions) beyond the next few years will be impossible as the global oil-based economy enters a rapid and permanent decline. Therefore, the international community is assuming that anything resembling business as usual is actually possible.

Given that some levels of government are already aware of peak oil (e.g., the U.S. and UK) (see *Oil Data Is Inaccurate*), it may be possible that some of the paltry Copenhagen Accord pledges and resistance to develop progressive climate policy may reflect insider knowledge that energy supplies, and hence GHG emissions and other human activities that contribute to climate change, will indeed decline in the near-term. In which case, international climate negotiations may merely be a symbolic activity by some, but not all, actors in order to maintain an illusion of economic and political stability to further their various political and economic agendas.

With peak oil, there is a high probability that our integrated and globalized civilization is on the verge of a rapid and near-term collapse. Once peak oil production causes the collapse of the global economy and threatens the lives and livelihoods of countless billions of people, it is possible that climate negotiations may be abandoned or at least marginalized for a long time (if not permanently) as the crisis of peak oil and rapid economic decline overwhelms the stability and security of every nation. In this context, the greatest threat to having successful and meaningful climate negotiations may not be the self-interested motivations and political impasse of the international community, but rather the possible panic and lack of political will that will likely ensue once peak oil and economic shock and awe takes effect. In this case, it will likely require a concerted and transcendent effort on the part of any remaining international climate negotiators, their governments, and the public to pursue a meaningful international climate policy – much less a binding international climate treaty.

Two main arguments against pursuing an international climate policy will likely be made: (1) the peak oil shock and the associated collapse of societies and the global economy will be a more pressing issue; and (2) climate change will no longer be a concern since most oil demand will have been destroyed which will cause GHG emissions to decline sharply. Unfortunately, the rhetoric of these arguments may be accepted to the detriment of future climate negotiations and global society.

Regarding the first argument: Although the peak oil crisis will become a very important short- and medium-term priority, climate change will continue to affect every part of the world in the short- to long-term. Climate change will continue to threaten water, food, and ecosystem security throughout the world as resources become scarce due to fuel scarcity, economic depression and societal collapse. Capacity building and humanitarian relief will be limited or unavailable with scarce energy supplies and economic resources.

Regarding the second argument: Even though GHG emissions will likely decline substantially after peak oil production enters a terminal decline, they will not cease entirely. Some oil, other fossil fuels, and biomass will be consumed by the institutions (e.g., military, basic services, etc.) and societies that can afford and secure the remaining expensive energy supplies. In addition, coal, natural gas, and other hydrocarbon fuels will continue to be used as an energy source – albeit on a more limited scale – until the production of those resources peaks and declines in the next couple decades or so. Furthermore, land use and deforestation caused by human activities and climate change will likely continue to contribute to GHG emissions depending on how much the remaining human population exploits the environment.

The international climate negotiations and any potential climate policy thus far are based on very serious and erroneous assumptions about the physical constraints of the planet Earth, its resources, and carrying capacity because:

1) proposed targets for atmospheric GHG concentrations and global temperature rise are much too high to prevent catastrophic climate change. The target atmospheric GHG concentration is around 450 ppm CO_2e, which will likely commit the planet to an average global temperature increase of at least 2 – 3.1°C or more;

2) the intentions and commitments of the international community are woefully insufficient to seriously mitigate dangerous anthropogenic climate change;

3) the competing and conflicting economic and social agendas of most nations are in complete conflict with the supportive capacity of a stable climate system – and therefore, ultimately their own national interests; and

4) the international community is making the calamitous assumption that there is enough global oil and fossil fuel supplies to continue fueling their various agendas for unlimited economic growth and development (i.e., business as usual), and that this presumed unlimited fossil fuels supply will contribute to future GHG emissions.

The international community and climate negotiators urgently need to review and reconsider the science and data regarding climate change and energy supplies. Then, they need to have a truly honest discussion on how to realistically manage the two impending and unprecedented crises confronting the world – peak oil and climate change. If this reassessment and discourse does not occur, not only will the international climate negotiations be ineffective, if not entirely destined to fail, human security and the stability of every society will be gravely threatened by these systemic crises.

Ironically, peak oil may be the only practical solution to mitigate climate change on a global scale. While the international community continues to argue over whether and how to address the challenge of climate change, peak oil may effectively “make the decision” for people. Essentially, peak oil and energy resources may “pull the plug” on anthropogenic GHG emissions and other climate change inducing human activities. Global society had the opportunity for many decades to reduce its GHG emitting fossil fuel consumption and to reduce the activities that cause anthropogenic climate change in a controlled and well-managed way. Now, it seems that these reductions in fuel consumption and human activities will be forced on global society by the physical limits of the planet on which everyone depends. Unfortunately, as peak oil production initiates the collapse of the global economy, the human response may not occur in a controlled and well-managed way.

PART II

HUMAN CARRYING CAPACITY

“It is an aberration. For most of human history the population doubled only once every 32,000 years. Now it's down to 35 years. That is dangerous. No biologic population can double more that a few times without getting seriously out of bounds. I think the world is seriously overpopulated right now. There can be no possible solutions to the world's problems that do not involve stabilization of the world's population.”

– M. King Hubbert[1], geophysicist and energy advisor Shell Oil Company and USGS, 1983

Food Chapter 15

"Must it not then be acknowledged by an attentive examiner of the histories of mankind, that in every age and in every State in which man has existed, or does now exist
That the increase of population is necessarily limited by the means of subsistence,
That population does invariably increase when the means of subsistence increase, and,
That the superior power of population is repressed, and the actual population kept equal to the means of subsistence, by misery and vice."

– Thomas Robert Malthus[132]. *An Essay on the Principle of Population*, 1798

"The fact that hunger was increasing even before the food and economic crises suggests that present solutions are insufficient and that a right-to-food approach has an important role to play in eradicating food insecurity."

– United Nations Food and Agriculture Organization (FAO), The State of Food Insecurity in the World[133], 2009

- The success of the Green Revolution is primarily due to its increased use of fossil fuel resources for fertilizers, pesticides, and irrigation to raise crops.

- Since the advent of the Green Revolution, the global population has nearly tripled from nearly 2.5 billion to 7 billion people between 1950 – 2010.

- Global demand for natural resources exceeded planet's capacity to provide sustainably for the combined demands of the global population between 1970 – 1980.

- Annually, 1 billion people experience chronic hunger; this is nearly 14% of the global human population.

- Approximately 85 million people suffer from acute hunger, which causes them to starve slowly and waste away.

- Approximately 50% of the global human population suffers chronically from some form of malnourishment from either or a combination of a scarcity of calories, protein, or micronutrients.

- About 2.2 – 4.5 billion people experience insufficient protein and calorie intake and are deficient in some essential micronutrients.

- Yet, as billions of people suffer from hunger and malnutrition, over 1 billion people are overfed, overweight, and obese. Furthermore, millions of newly affluent people globally are increasingly eating more meat and consuming more calories

- The global population is projected to increase 9.2 billion people by 2050, which may cause the global food demand to increase 2 – 3 times by 2050, assuming the continued BAU per capita increase in food consumption.

The success of the Green Revolution is primarily due to its increased use of fossil fuel resources for fertilizers, pesticides, and irrigation to raise crops. Fossil fuel energy inputs greatly increased the energy-intensiveness of agricultural production, in some cases by 100 times or more[134]. Plant breeding was mainly focused on designing plants that could tolerate high levels of fertilizer use while improving food crop yields. The Green Revolution was technologically suited to the special circumstances of relatively level arable (i.e., plowable) land with sufficient water resources for irrigation and fertilizer[134]. However, the Green Revolution has been implemented in an environmentally and energetically unsustainable way. Industrial agriculture technology has substantially increased soil erosion, polluted water resources. Increased pollution and agrochemical use has caused significant public health and environmental problems.

Ultimately, the challenge of ensuring global food security and other global issues – such as population growth, climate change, and diminishing water and energy resources – are interconnected in a complex and mutually reinforcing way. By 2050, the global human population is projected to be 9.2 billion[135]. Two obvious and important questions are: Whether and how can 9 billion people be healthily, equitably, and sustainably fed in the the future assuming BAU? However, two other more critical and relevant questions to answer are: Whether and how can the current global population of nearly 7 billion people be healthily, equitably, and sustainably fed in the near- and long-term as oil and other energy resources peak and decline? If 7 billion people cannot be supported by the planet’s carrying capacity, then anymore surely cannot be sustained well.

Food scarcity has always affected the human species as recurring series of acute, regional and unanticipated events (e.g., wars, weather and climate events such as droughts)[134]. At nearly 7 billion, the current global human population is of an unprecedented size (see Figure 24). The modern industrialized global economy and national and international policies fail to produce and distribute surplus food to the entire human population. This failure of the global economy to produce and distribute food to so many people has allowed chronic hunger and famine to become nearly continuous and global in scale. Annually, 1 billion people experience chronic hunger[136]. This is nearly 14% of the global human population. Currently, 850 million people (12% of the global population) suffer from hunger every day[137,138]. Approximately 10% of these 850 million people (85 million people) suffer from acute hunger, which causes them to starve slowly and waste away[138]. More than 9 million people starve to death per year or otherwise die of diseases their malnourished bodies cannot resist[136].

Approximately 50% of the global human population suffers chronically from some form of malnourishment from either or a combination of a scarcity of calories, protein, or micronutrients[136]. About 2.2 – 4.5 billion people experience insufficient protein and calorie intake and are deficient in the micronutrients folate, iron, iodine, vitamin A, and zinc[136]; deficiencies of which can stunt and interfere with physical and mental development. Moreover, these malnourished people suffer from anemia, blindness, brain damage, cretinism, goiter, and they die early of cancer, malaria, measles, and other diseases[136].

Yet, as billions of people suffer from hunger and malnutrition, over 1 billion people are overfed, overweight, and obese. Furthermore, millions of newly affluent people globally are increasingly eating more meat and consuming more calories[136].

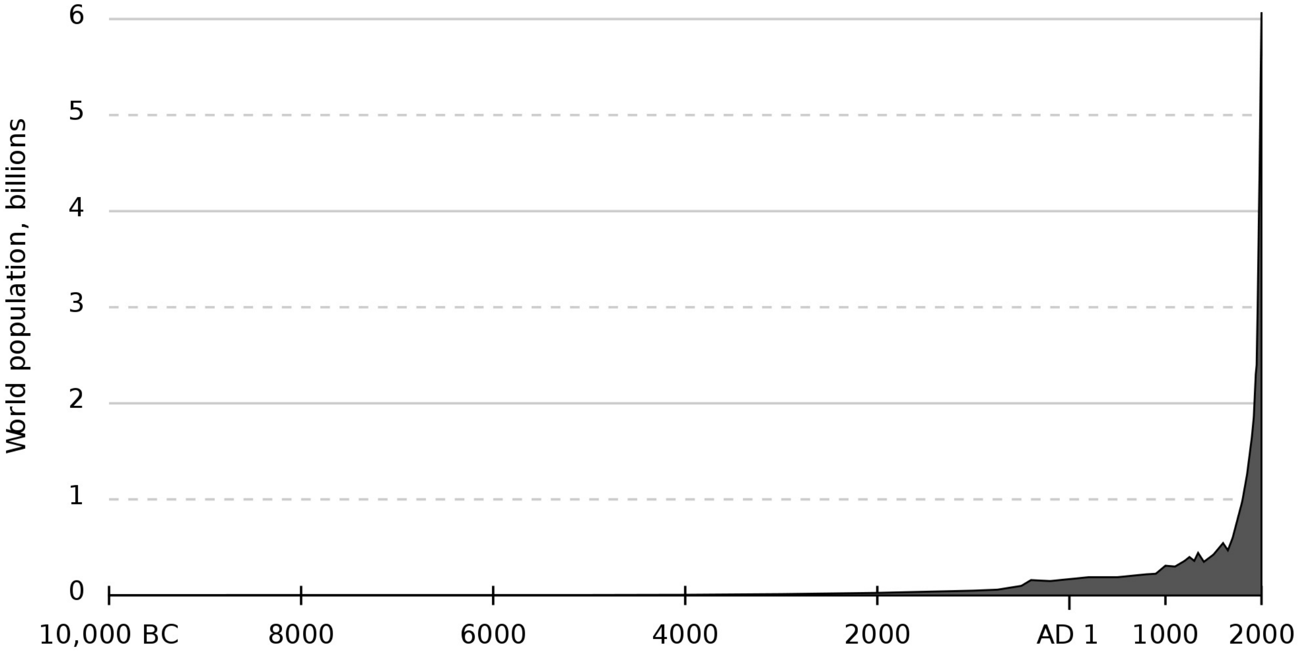


Figure 24: World population over time (data from the lower estimates at census.gov)[141].

The global population is projected to increase 9.2 billion people by 2050 [135]. Considering this increase in population, global food demand may increase 2 – 3 times by 2050, assuming the continued BAU per capita increase in food consumption[136]. Since the advent of the Green Revolution, the global population more than doubled – increasing from nearly 2.5 billion to 6 billion people between 1950 – 2000. By 2011, the global human population is projected to be 7 billion, which would be nearly a tripling of the global population since 1950.

Global demand for natural resources exceeded planet’s capacity to provide sustainably for the combined demands of the global population between 1970 – 1980 [139]. During the 20th Century, the human population overwhelmed and dominated most of the planet’s ecosystem services, and decimated much of the planet’s life and biodiversity, as people have co-opted and taken control of significant parts of the planet’s biological, geological, chemical, and atmospheric resources and cycles[136,140].

During the past 50 years, the human species has changed the structure and functioning of ecosystems and the biophysical and chemical systems of the planet more rapidly and extensively than at any time in human history, primarily to supply rapidly growing demands for food, fresh water, building materials, fiber, energy fuel, and other natural resources. These unprecedented changes have resulted in a substantial and largely irreversible loss in the diversity and abundance of life on Earth[140]. Yet, despite dominating, altering, and damaging the planet's ecological and biophysical systems, billions of people remain malnourished and hungry. Increasing food demand coupled with decreasing carrying capacity likely means that the planet will not be able to support future human resource demands. Without improved systems of food production and distribution combined with sustainable population management, chronic and perpetual hunger will likely increase and worsen in the future.

In order to estimate the human carrying capacity of the Earth, the question of quality of life versus quantity of life must be addressed. Although it is beyond the scope of this paper to produce very precise estimates of the human carrying capacity of the Earth, the following section offers a general order of magnitude estimate of the planet's carrying capacity based on supplying human food requirements and the potential global food production capacity. In other words, the following section estimates how many people the world might be able to sustainably feed nutritionally adequate diets. This estimate serves to provide a theoretical order of magnitude upper bound to global human population. Therefore, the focus of this estimate is on the quantity of human life, rather than on the quality of life beyond that of eliminating hunger and providing everyone with an at least adequate and diverse diet. In order to estimate the carrying capacity of the planet, the following additional factors that limit human population will be considered: human food requirements, availability of cropland, water, energy, phosphorus (a crop nutrient), and the effects of climate change on these factors. To a lesser extent, the issues of health and food waste will also be discussed briefly.

Arable Land

Chapter 16

“A nation that destroys its soils destroys itself.”

– Franklin D. Roosevelt, former U.S. President

- Arable land is land that can be plowed to produce crops.
- Approximately 37% of the planet’s land surface is used as cropland and pasture. About 30% is unusable for cropland (e.g., ice caps, mountains, deserts, urbanization). The remaining 32% of the Earth’s surface is forest of various degrees of density.
- Approximately 0.5 ha per capita is the minimum land requirement for a diverse and adequate diet of animal and plant food products.
- In 1960, when the global human population numbered only 3 billion, approximately 0.5 ha was available globally per capita.
- In 1999, only 0.22 ha of cropland per capita was available worldwide.
- The average quantity of cropland per capita in the U.S. has declined to 0.48 ha in the past decades.
- By 2050, lack of arable land due to land degradation and population growth might mean that there will not be food for between 0.5 – 3 billion people of the projected 9.2 billion global population assuming business as usual.

In order to estimate the Earth’s carrying capacity for the human population, the global human food requirement must be estimated. Wolf et al.[142] estimate per capita food requirements for three different food consumption patterns: a vegetarian diet, a moderate diet and an affluent diet. Although these diets satisfy minimum daily caloric intake and daily protein requirements, their composition is different. Whereas a vegetarian diet does not include meat, affluent diets consist of relatively high consumption of meat and dairy products; moderate diets include some meat and dairy products. The authors made the diets comparable, by expressing them in grain equivalents, which refer to the amount of dry weight in grains needed as raw material for consumed products (i.e. dairy and meat products). Since grains account for 80% of global human calorie consumption (directly, or indirectly via livestock), grain production and consumption are useful indicators for food security[143]. Wolf et al. estimate that the average daily consumption in grain equivalents per adult for the vegetarian, moderate and affluent diet was respectively 1.3 kg, 2.4 kg, and 4.2 kg (dry weight) in grain equivalents – or, 475 kg, 877 kg, 1,534 kg (dry weight) in grain equivalents per adult person per year.

Approximately 0.5 ha per capita is the minimum land requirement for a diverse and adequate diet of animal and plant food products[144]. Although this estimate makes certain assumptions about climatic and soil conditions, and about the level of technology and agricultural practices used, it offers a rough but useful general estimate for global per capita cropland requirements.

However, not every person in the world has access to the equivalent of 0.5 ha of food producing land. In 1960, when the global human population numbered only 3 billion, approximately 0.5 ha was available globally per capita for the production of a diverse, nutritious diet of plant and animal products[145]. In 1999, only 0.22 ha of cropland per capita was available worldwide[145], which is about half the per capita amount of cropland currently available in the United States. Nonetheless, the average quantity of cropland per capita in the U.S. has declined to 0.48 ha in the past decades, which is less than the critical cropland area necessary for diverse food production[145].

In some regions, the available land is even less than 0.48 ha per capita. For instance, the current available cropland in China is only 0.08 ha per capita (see Table 4). This relatively small amount of cropland provides the Chinese people with a predominantly vegetarian diet[145], which is supplemented with food imports. A total of 1,400 kg per capita per year of agricultural product is produced to feed each American, while the average food supply in China is only 800 kg per year per capita[145] – which corresponds to an affluent diet (U.S.) and a moderate diet (China) as defined by Wolf et al.[142].

Table 4: Resources used and/or available per capita per year in the U.S., China, and the world to supply basic human needs[136].

Resources	**U.S.**	**China**	**World**
Cropland (ha)	0.48	0.08	0.22
Pasture (ha)	0.79	0.33	0.52
Forest (ha)	0.79	0.11	0.59
Total (ha)	2.78	0.45	1.97
Water (million liters)	2.0	0.46	0.60
Fossil fuel oil equivalents (liters)	9,500	1,400	2,100

The Chinese have likely reached or exceeded the production limits of their agricultural system. The dependence of China on large inputs of fossil fuel based fertilizers and biocides (e.g., pesticides, fungicides) compensate for shortages and the degradation of cropland, severely eroded soils, and a limited water supply. Moreover, China currently imports large quantities of grain in order to supply domestic demand; and it is expected to continue to increase grain imports in the near future due to land and water shortages. All of these factors indicate that severe food production problems may occur in China in the near future[145].

However, the U.S. may also risk severe food shortages in the future, since the U.S. may only be able to supply food for 200 million people without food imports and high energy inputs (i.e., oil)[146]. Post-peak oil, the U.S. may also be challenged by an unprecedented food shortage crisis, if it cannot secure enough food for its population in the long-term.

In terms of calories, more than 99.9% of the human food supply comes from the land, while less than / 0.01% comes from oceans and other aquatic ecosystems[147]. Of the total world land area – approximately 13 billion hectares (Gha) – the percentages in use are over 10% for cropland; more than 26% for pasture land; 32% for forest land; 9% for urban; and 21% for other areas. Most of the other remaining 21% of the total land area is unsuitable for cropland, pasture, and/or forests because the soils are too infertile or shallow to support plant growth or the climates and regions are too harsh, too cold, dry, steep, stony, or wet[134].

Most of the suitable cropland is already is in use. More than 10% (1.5 Gha) of the total world land area (13 Gha) is currently used to produce arable crops, and over 26% (3.4 Gha) are used as pasture to produce meat, milk and fiber from grazing animals[136]. From the start of the Green Revolution in 1950 until 1999, the area of land dedicated to crops increased globally from 1.2 Gha (about the combined total land area of China and India) to 1.5 Gha (about the total land area of the Russian Federation)[136].

Arable land is land that can be plowed to produce crops. Although all arable land can potentially be cropland, not all cropland is arable (i.e., plowable). In order to plow, the land must be relatively flat and clear of landscape features (e.g., trees, stones). In many areas, crops are harvested or gathered by hand (e.g., on slopes and in forests). Since estimates of agricultural production tend to only consider arable land, but generally not non-arable cropland, only arable cropland is considered for the purposes of this analysis. Only considering arable land will be sufficient here for producing a rough order of magnitude estimate of the potential human carrying capacity of the Earth.

By 2050, the global human population is projected to be 9.2 billion[135] from about 6.8 billion in 2010 [10]. Yet, global food demand is projected to double by then[136]. In order to supply a doubling of food demand by 2050, global crop yields would nearly have to double without an increase in the area of cropland. Otherwise, if crop yields per area land do not change, the area of land dedicated to food production would have to double to about 3 Gha.

The area of cropland globally is increasing at a rate of 5 – 8 million ha (Mha) per year from the conversion of forested and other wildland[136]. Schade and Pimentel[136] offer a rather thorough analysis and estimates of the potential human carrying capacity of the planet in terms of potential cropland and food production. Their analysis, reviewed below, provides a rough estimate of carrying capacity that is worth including in this analysis. The authors estimate that by 2050 global demand for arable land will increase by 200 – 750 Mha, which means that between 1.7 – 2.25 Gha of arable land will be needed by 2050. From 1950 – 1995, global grain yields per acre increased an average greater than 2% per year. Since 1995, the growth in grain yields has declined. An additional 200 Mha of cropland would likely be required to supply global BAU food demand assuming that crop yields increase 0.3% per year and that per capita consumption does not change (particularly by the newly affluent who are consuming more meat and more calories). An additional 750 Mha would likely be required to supply global BAU demand assuming that crop yields average 1% per year and that food consumption doubles by 2050, which may be the more likely BAU scenario.

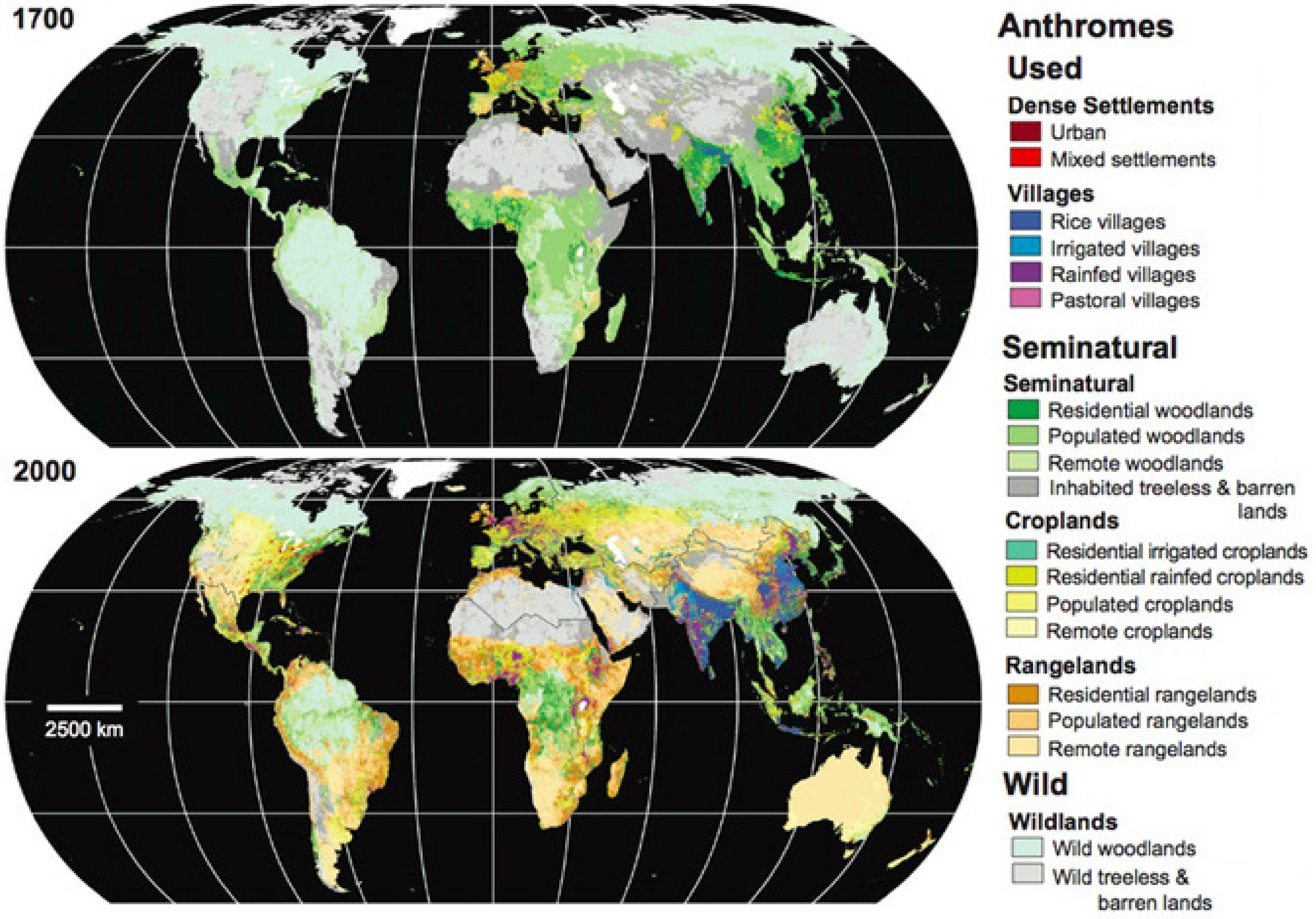


Figure 25: A comparison of anthropogenic biomes (anthromes) for years 1700 and 2000 [148]*. Biomes are climatically and geographically defined as similar climatic conditions on the Earth, such as communities of plants, animals, and soil organisms.* Biomes *are often referred to as* ecosystems*. Examples of biomes include deserts, Mediterranean forests, woodlands, and scrub, tropical and subtropical coniferous forests, temperate coniferous forests, wetlands, tundra, and so on. Examples of anthropogenic biomes include croplands, urban areas, and other human-dominated landscapes.*

Table 5: Land deficit and human dieback (9.2 billion people projected in 2050)[136].

	Land farmed now (billion ha) (Gha)	**Additional land needed (billion ha) (Gha)**	**Land available (billion ha) (Gha)**	**Deficit (billion ha) (Gha)**	**Ratio: deficit versus total land needed**	**Deficit as a percent (%)**	**Billion people into which this percent translates (%)**
Best Case	1.5	0.6	0.5	0.1	0.1 : 2.1	5	0.46
Worst Case	1.5	1.2	0.3	0.9	0.9 : 2.7	33	3.1

However, the above estimates for projected cropland demand assume that the quality of arable land will remain constant. Yet, the quality of arable land does not remain constant since modern industrialized agriculture generally degrades and erodes soil; diminishing returns on fertilizer and pesticide use reduce crop yields; and declining phosphorus and natural gas production will reduce the future supply of fertilizers[136]. Therefore, more arable land will likely be required, even if the global human population and its consumption habits remain the same.

Within the past 1,000 years, agricultural activities have degraded and destroyed approximately 2 Gha of once productive land (about the combined total land area of the Russian Federation and India)[136] (see Figure 25), which is more than the current 1.5 Gha globally cultivated (about the total land area of the Russian Federation). Most of this soil degradation and loss has occurred since the beginning of industrial agriculture. Over 60% of this soil damage is complete and irreversible, or at the least the damage would cost greatly to recover[136].

Since 1960, a third of global cropland has been abandoned because it has been degraded beyond use[136,144]. Approximately 10 Mha of arable land is destroyed each year[136]. At a rate of 10 Mha per year of soil loss during the period from 2010 – 2050, an additional 0.4 Gha of natural lands will need to be put into agricultural production just to continue supplying current food demand; not counting the projected additional 0.1 – 0.3 Gha of arable land that will be lost by 2050 due to the abandonment of drylands and the development of human settlements and infrastructure[136]. Therefore, in addition to the 1.7 – 2.25 Gha projected to be in production by 2050, at least 0.4 Gha of additional arable land will also need to be put into production by then – which increases the total required cropland to between 2.1 – 2.65 Gha by 2050.

However, the Earth may not be able to supply enough land to support human demand. Ignoring impacts on biodiversity, ecosystems, the environment and the carbon cycle, 2.4 Gha of land globally would be at least moderately suitable for wheat, rice and maize production[136]. However, Schade and Pimentel[136] estimate that there may be only about 2.0 Gha ultimately available.

Approximately 37% of the planet's land surface is used as cropland and pasture, and about 30% is unusable for cropland (e.g., ice caps, mountains, deserts, urbanization). The remaining 32% of the Earth's surface is forest of various degrees of density. More than 90% of all available land that might potentially be converted to cropland is currently tropical forest and rangeland in Africa and South America, which leaves little in Asia, Europe, and North America. However, the soil quality of the land in these low-latitude regions is limited for agriculture and pasture since tropical soils are thin and are easily degraded and eroded – between 5 – 15 Mha per year of tropical soil are lost[136].

In addition to the limited amount of remaining arable land, the remaining soil is also of lower quality. Cultivated land and the land already lost to degradation and erosion are the planet's most fertile[149]. These remaining arable lands are increasingly unsuitable for agriculture, because they are either too wet, dry, steep, sandy, thin; the use of these croplands for agriculture would rapidly degrade their soils; the costs to put these lands into production would be too prohibitive; or they lack road access to markets[136].

Perhaps only 0.3 – 0.5 Gha of the 1.8 Gha of land that is considered even remotely arable can produce any food at a reasonable production cost. However, the soil would only briefly support substantial food production before the soil becomes too degraded[136]. This lack of arable land leaves a shortfall of about 0.1 – 0.9 Gha by 2050. This means that by 2050, there will likely not be food for between 0.5 – 3 billion people of the projected 9.2 billion global population assuming BAU (see Table 5). In other words, the planet might only be able to provide enough arable land to support 6.2 – 8.7 billion people assuming BAU.

The analysis and estimates thus far assume that current high energy inputs (e.g., irrigation, agrochemicals, and energy resources) will increase proportionally and will be sustainable in the future. However, the implausibility of these assumptions will be discussed and the estimates of carrying capacity will be further developed in the following sections.

Irrigated Land

Chapter 17

"Steadily increasing demand for agricultural products to satisfy the needs of a growing population, and the desire for a more varied diet, continues to be the main driver behind water use."

– United Nations World Water Assessment Programme (WWAP)[150], 2009

- Globally irrigation accounts for 70% of all human water use and for 85% of water consumption.
- Using irrigation to produce food can require enormous quantities of water and energy (i.e., fossil fuel energy) to extract, distribute, and apply the fresh water using pumps and other irrigation technologies.
- Irrigated cropland is on average 3.3 times more productive than rain-fed land.
- Approximately 18% of the world's cropland is irrigated.
- Irrigated cropland produces about 40% of the global food supply.
- By 2050, a shortage of irrigated cropland may leave a total of 760 million people without enough food due to soil degradation and population growth.

Globally, irrigation accounts for 70% of all human water use and for 85% of water consumption[151]. Water that is "consumed" is no longer available for other uses. Using irrigation to produce food can require enormous quantities of water and energy to extract, distribute, and apply the fresh water using pumps and other irrigation technologies. Pimentel[151] estimates that 15% of the total energy expended annually for all crop production in the U.S. is used to pump irrigation water. For instance, corn (maize) crops, which are cultivated on half of U.S. irrigated land, can require approximately 1,000 mm of irrigated water when grown in arid regions This amount of water is the equivalent to 10,000 m^3 or 2.6 million U.S. gallons per hectare (ha). It requires about 13 barrels of oil equivalent (boe) (or about 20.5 million kilocalories (kcal)) of energy to pump this amount water from a depth of only 30.5 m (100 feet) and apply it. When irrigation water is pumped from a depth of 100 m, the energy cost increases to more than 32 times the energy cost of surface water used for irrigation[151]. The total energy input of 13 boe per ha for irrigated corn is more than 2.5 times the approximately 5 boe per ha (8.2 million kcal) required for the same yield of rain-fed corn. Similarly, irrigated wheat requires more than 3 times the energy needed to produce rain-fed wheat[152].

Irrigated cropland is on average 3.3 times more productive than rain-fed land[136]. Approximately 18% (275

Mha) of the world's 1.5 Gha of cropland is irrigated. This 18% of global cropland produces about 40% of the global food supply[153]. However, the proportion of cropland that is irrigated varies by nation. For instance, about 50% of the food produced in China and India is grown on irrigated land[153]; whereas 16% of the food produced in the U.S. is grown on irrigated land[154]. Since the 18% of the world's cropland that is irrigated is about 3.3 times as productive as rain-fed land, this irrigated land is equivalent to about 891 Mha of rain-fed land, which makes the 1.5 Gha of combined cropland (both irrigated and rain-fed) equivalent to 2.1 Gha of rain-fed land.

By 2050, at least 350 Mha will need to be irrigated to produce enough food to support the global population[136]. The average increase in irrigated land from the 1950's to the 1990's was 1.5% per year[150]. However, this rate of increase has been in decline since then. The average projected increase in irrigated land from 1998 until 2030 is 0.6% per year[150] (see Figure 62). Kendall and Pimentel[155] project that the fraction of land irrigated in 2050 will be 18%, assuming BAU based on the assumption that historical trends in the expansion of irrigation will continue – and 17% in the pessimistic case, and 19% in the optimistic case. Yet, 4 – 10 Mha per year of irrigated land are lost to erosion, salinization, and waterlogging[136]. Conservatively using the lower estimate, the loss of 4 Mha per year of cropland means that 160 Mha of irrigated land will likely need to be abandoned by 2050. This increases the total irrigated land requirement by 2050 from 350 Mha to 510 Mha.

However, not all cropland can be irrigated. In addition to the 275 Mha of currently irrigated cropland, approximately an additional 150 Mha is considered suitable for irrigated food production[136]. Therefore, a total of 425 Mha of cropland is available for irrigation. This leaves an 85 Mha deficit of irrigated land by 2050, which is equivalent to about 281 Mha of rain-fed land. After adjusting for previously considered land deficits to avoid double counting, this deficit of 281 Mha of rain-fed land equivalent becomes 195 Mha rain-fed land equivalent. Schade and Pimentel[136] estimate that this shortage of cropland would leave a total of 760 million people without enough food by 2050. Food deficits from deficient irrigated land will especially impact the more intensively irrigated and highly populated nations (e.g., China, India). After adding this deficit of irrigated land to the previous estimates of rain-fed land, there will likely not be enough food for between 1.2 – 4 billion people of the projected 9.2 billion global population by 2050 assuming BAU. In other words, based on the analysis so far, the planet might only be able to provide enough arable and watered land to support 5.5 – 7.7 billion people assuming BAU.

Including the assumption that agricultural methods do not improve, future croplands will likely be of decreasing quality as soil degradation and increasing production and input (e.g., agrochemicals) costs accelerate[136]. Irrigated cropland (not counting rain-fed land) will lose the capacity to produce food for an additional 40 million people every year after 2050. At this rate of soil loss an additional 2 billion people will suffer from food shortages by 2100 when the human population is projected to be 9.1 billion (within a projected range of 5.5 – 14 billion)[156]. Therefore, global food production will be able to only feed 3 – 6 billion people of projected 9 billion (or 5.5 – 14 billion), which would leave the remaining 3 – 6 billion people (or up to 11 billion) to suffer from hunger and malnourishment by 2100.

Although the above estimates of potentially available cropland account for losses due to soil degradation and the lack of suitable arable land, they assume that water supplies will remain constant in the future. However, water supplies change over time due to changes in environmental conditions (e.g., changes in precipitation and climate patterns) and human influences (e.g., consumption patterns, policy), as discussed in the following section. Changes in the availability of water for food production will further affect the human carrying capacity of Earth.

"Water use has been growing at more than the rate twice of population increase in the last century."

– United Nations Food and Agriculture Organization (FAO) and UN-Water[157], 2010

- In 1995, human activities already appropriate an estimated 54% of the global surface water that is potentially available.
- By 2025, humans may use 70% of the global surface water that is potentially available.
- Irrigated agriculture accounts for 70% of global water withdrawals.
- Since food production is expected to double by 2050, water demand will also likely double assuming business as usual and current irrigation practices.
- At least 2 billion people suffer some form of malnutrition; more than 1 billion people lack access to safe drinking water; and over 3 billion lack adequate sanitation.
- There are nearly 4 billion cases per year of water-borne diseases in developing countries, which cause 2 – 6 million of them to die each year.
- By 2030, more than 5 billion people (of over 8 billion) may still be without access to adequate sanitation.
- In 2005, 2.4 billion were living in water stressed conditions.
- By 2025, the number of people expected to live in water stressed conditions is projected to be 5 billion people (of 7.5 billion).
- By 2025, about 1 billion people are projected to live in water scarce conditions.

The previous discussion about the potential global environmental human carrying capacity assumes that there will be enough water resources available to grow all the necessary food for the global population. Since food production is expected to double by 2050, water demand will also likely double assuming BAU and current irrigation practices[158].

The vast majority of the Earth's water resources are salt water – only 2.5% of water resources are fresh water (see Figure 26). Approximately 70% of the fresh water available globally is frozen in the icecaps of Antarctica and Greenland. This leaves the remaining 30% (equal to only 0.7% of total water resources worldwide) available for consumption. From this remaining 0.7%, about 87% is allocated for agricultural purposes[159].

In total, the amount of freshwater available for human consumption ranges between 12,500 – 14,000 cubic kilometers (km^3) per year[160]. Total global freshwater use is estimated to be about 4,000 km^3 per year[150]. An additional 6,400 km^3 of rainwater is used "directly" in agriculture. Most (99%) of the 4,000 km^3 per year in water use is supplied by withdrawals from renewable water sources, either by surface water or groundwater. Less than 1% (about 30 km^3 per year) of the water use is supplied by non-renewable (fossil) aquifers[150].

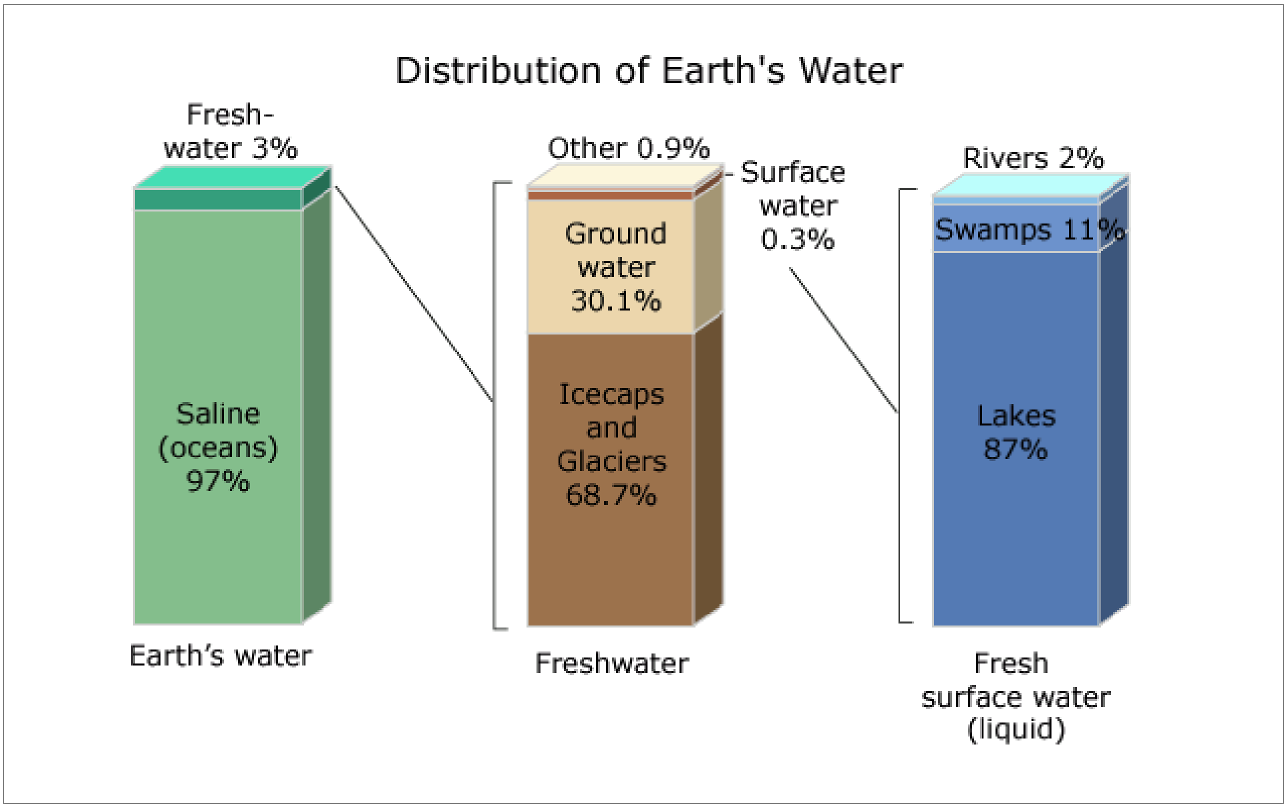


Figure 26: Distribution of Earth's water. About 0.00009% of the total global water available is surface water; and about 0.009% is groundwater[161].

As the global human population grew from 2.5 billion in 1950 to 6.5 billion at the beginning of the 21st Century, food production growth far exceeded population growth, irrigated area doubled, and water withdrawals tripled[150]. Irrigated agriculture currently covers 18% of cultivated land (275 Mha) and accounts for 40% of global food production[150].

Irrigated agriculture accounts for 70% of global water withdrawals – whereas industrial use (including energy generation) accounts for 20% of total water use; and domestic use accounts for about 10%[150]. Although irrigation accounts for 70% of all global human water use, it accounts for 85% of water consumption (i.e., water that is no longer available for other uses)[136]. In 1995, human activities already appropriate an estimated 54% of the global surface water that is potentially available[162]. By 2025, humans may use 70% of the global surface water that is potentially available[163]. Considering that water demand may double by 2050, about 75% of the global population may live in water scarce conditions by then[136].

Since double the volume of surface water used currently will not be available for future demand, much of this water will have to come from underground sources, such as aquifers[136]. Currently, aquifers across the world are being drained rapidly as growing global population and increasingly affluent lifestyles demand more water. Many of the largest grain-producing regions have experienced substantial declines in the volumes of their aquifers, which threatens aquifer longevity and water and food security[136].

Despite the appropriation of surface waters and the extraction of groundwater reserves, billions of people still do not have access to basic water supplies and services for drinking, hygiene and sanitation, and food production to support their daily needs. About 30% of the global population experiences water shortages; about 20% (1.2 billion people) live in areas of physical water scarcity; and 25% (1.6 billion people) live in a developing country that lacks the necessary infrastructure to distribute water from rivers and aquifers to supply demand[164]. At least 2 billion people suffer some form of malnutrition; more than 1 billion people lack access to safe drinking water; and over 3 billion lack adequate sanitation[150]. There are nearly 4 billion cases per year of water-borne diseases in developing countries, which cause 2 – 6 million of them to die each year[136]. By 2030, more than 5 billion people (67% of a global population of over 8 billion) may still be without access to adequate sanitation[150].

More people will require more water in order to produce more food, fiber, industrial crops, and livestock and fish. Food and feed crop demand may nearly double in the next 50 years. The four main factors driving water scarcity are: (1) population growth; (2) increasing urbanization (which will focus the demand for water among a more concentrated population); (3) increasing per-capita consumption as the world becomes more developed; and (4) climate change (which will generally change the quantity, quality and distribution of global freshwater resources)[159]. The magnitude of the changes in water resources due to climate change is still uncertain. And, the changes in water resources will vary from one region to another. In particular, semi-arid regions will probably experience an increase in the variability of precipitation, which will result in more frequent periods of drought[165]. The impacts of climate change on food and water resources is discussed further below in *Climate Change*.

However, water scarcity is a relative term in that it depends on the demand for water. In order to estimate the human carrying capacity of the environment, the minimum human requirements for water must be considered. The absolute minimum volume of water necessary for human survival is 2 – 4.5 L per capita per day for drinking purposes[166]. The water requirement for drinking water, hygiene, sanitation, bathing, food preparation and cooking (but not food production), and other domestic needs ranges between 27 – 100 L per capita per day[134].

The WWAP[150] estimates that the daily water requirement to support human diets range from 2 – 5 m^3 (2,000 – 5,000 L) of water per person per day[150]. Although an average person requires about 1,800 – 2,300 kcal per day, 2,800 kilocalories (kcal) per person is a threshold for food security[150]. The WWAP[150] suggests that 1 liter of water is needed to produce 1 kcal of food, as a rule of thumb. This is about 2.8 m^3 of water per capita per day, which equals approximately 1,000 m^3 of water per capita per year required just for food production. However, protein-rich diets (i.e., high meat consumption) require significantly more water than do vegetarian diets. For instance, meat production requires 8 – 10 times more water than cereal production[150]. Energy flow efficiency in the food chain is very low – about 10% for herbivores and 20% for carnivores. For example, about 10 kcal of grass are required to produce 1 kcal of beef[150].

Postel[158] estimates that a person requires at least approximately 1,700 m^3 of water per year to supply all of an individual's water needs, including for food production[158]. People are considered living in water stressed conditions when they have access to less than 1,700 m^3 of water per capita per year[158]. Below this level, there is generally not enough water available to supply the demands of households, cities, and industries; to dilute pollution; to supply ecosystems and ecological functions; and to produce enough food for the population. In 1995, 1.4 billion people lived in water stressed conditions[136]. Ten years later, 2.4 billion were living in water stressed conditions in 2005 [136]. By 2025, the number of people expected to live in water stressed conditions is projected to double to 5 billion people (i.e., about 67% of the projected population of 7.5 billion)[136].

People are considered living in water scarce conditions when their average annual water supply is 1,000 m^3 or less per capita[158]. By 2025, about 1 billion people (about 13% of the projected global population of 7.5 billion) are projected to live in water scarce conditions[136].

The estimated amount of freshwater available worldwide for human consumption ranges between 12,500 – 14,000 km^3 per year[160]. Assuming the minimum requirement of water is 1,700 m^3 of water per capita per year, and assuming optimistically that the amount of freshwater available for human consumption is 14,000 km^3 per year – then the human carrying capacity of the planet may be constrained to roughly 8 billion people assuming that no large-scale technology is used to secure or create more freshwater resources (e.g., desalination of sea water). The global population may be 8 billion by 2030 assuming BAU growth. If this water would be distributed equally, then these 8 billion people would each only have the minimum annual requirement for water.

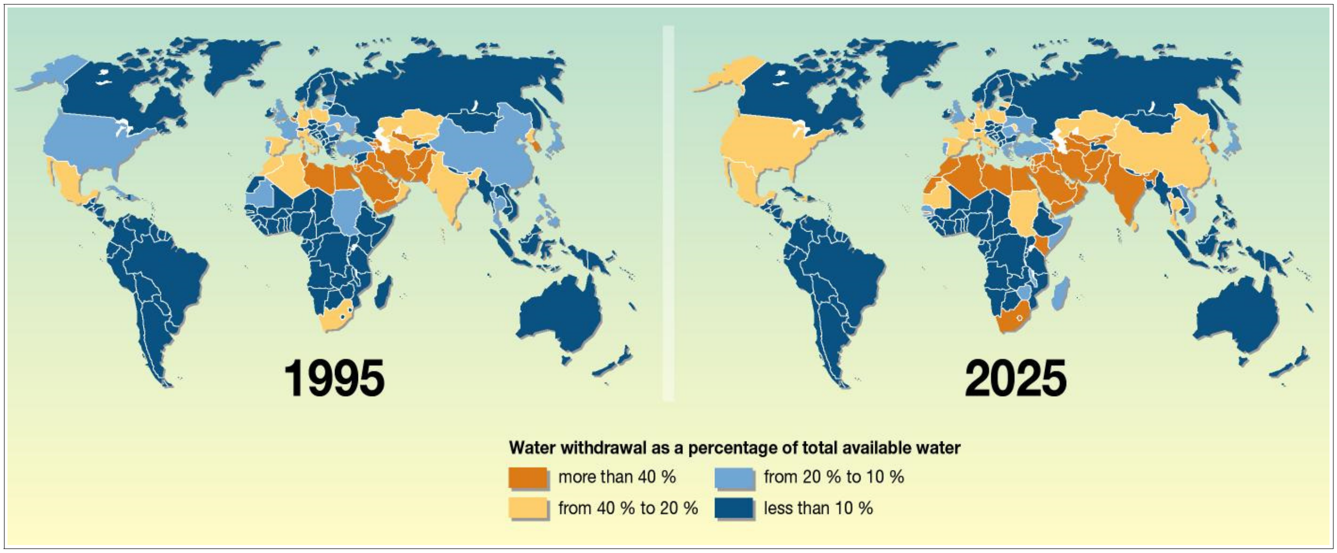


Figure 27: Comparing water withdrawal as a percentage of total available water by country between 1995 and 2025 [160].

However, many nations in Africa, the Middle East, western Asia, and some eastern European countries have lower than average quantities of freshwater resources available to their populations (see Figure 27). Due to rapid population growth, the potential water available for the global population decreased from 12,900 m^3 per capita per year in 1970 to 9,000 m^3 in 1990, and to less than 7,000 m^3 in 2000[160]. The availability of global freshwater resources is projected to decrease to 5,100 m^3 per capita per year by 2025, which would be enough to meet individual human needs if it were distributed equally among the global population[160]. The global average water withdrawal is 600 m^3 per capita per year. However, as Figure 27 illustrates, water resources and water demand vary from place to place. Water withdrawals per person range from 20 m^3 per year in Uganda to more than 5,000 m^3 per year in Turkmenistan. Water withdrawals are highest in arid and semi-arid regions, and are lowest in tropical countries[150]. In areas where water demand is high and supplies are low (e.g., arid and semi-arid regions), water stress and scarcity may afflict the population. Whereas in areas of great water supply compared to the demand (e.g., some tropical and high latitude regions) a surplus of water resources may exist.

Agriculture accounts for most of global water demand. Increasing competition for the remaining water resources will further compromise agricultural productivity, because food crops require great volumes of water. For example, in the U.S. corn (maize) transpires 6 million liters per ha (6,000 m^3 per ha) of water and the soil evaporates an additional 1 – 2.5 million liters per ha (1,000 – 2,500 m^3 per ha) during a single growing season[152].

Globally, farmers are losing water access to wealthier urban areas, municipalities and industries. And, as the global population and wealth per capita continues to grow, the water demand of households and industries may double in the future[136]. Some water-scarce nations (e.g., Algeria, China, Egypt, Israel, Mexico, Saudi Arabia, Yemen) have already started importing great quantities of ‘‘virtual water’’ by importing food[136]. Importing food can be less costly than domestic production since it requires about a 1,000 kg of water to produce 1 kg of grain[136]. This strategy will increasingly become the only alternative for poor nations with rapidly growing populations[137]. Developing nations may import between 2 – 3 times as much food in 2030 as they did in 2000 [136]. Since so many people live in developing societies, this projected increase in food imports will strain the limits of global food production. For instance, China’s food imports have been steadily increasing, and they are projected to increase to 200 million tons of grain by 2030, which would require most of the world’s food exports[136].

Increasing global demand for food will greatly magnify global dependence on high food productivity in the world’s major breadbasket regions, and on the continuance of a benign geological, meteorological, and political climate. However, only seven countries produce substantially more food than they consume: Argentina, Australia, Canada, France, Thailand, and United States[136]. About 193 nations must import at least some of their food[146]. Some nations (e.g., China, Egypt, Mexico, Nigeria) whose populations are rapidly increasing imports must import more food each year[136]. Since nearly 40% of the projected 2025 global population will live in countries whose water supplies are too limited for food self-sufficiency, dependence on grain imports is bound to increase[158]. As oil shortages and economic decline raise energy, transportation and food prices, the food security of nations that depend on food imports will be further threatened.

Groundwater overpumping and aquifer depletion challenge many of the world’s most important food producing regions – including the north plain of China, the Punjab of India, parts of Southeast Asia, areas of north Africa and the Middle East, and the western United States[162]. Declining water tables indicate limits on the capacity to expand future groundwater use, and that a portion of the world’s current food supply cannot be considered a reliable contributor to the world's long-term food supply since it depends on unsustainable water withdrawals. For example, as recently as 1994, Saudi Arabia was producing nearly 5 million tonnes of wheat by extracting nonrenewable groundwater. Then, when fiscal problems caused the government to reduce the subsidies that had propped up this unsustainable wheat production, Saudi grain output dropped 62% in two years, falling to 1.9 million tonnes by 1996 [158].

Many of the world's major rivers are being also overexploited, which suggests that greatly increasing agricultural water supplies will be difficult[158]. In Asia, where much of the world population growth and additional food needs will occur, many rivers are completely tapped out during the dry season when irrigation is essential[158]. Effectively, no water is discharged to the sea during much of the dry season in many river basins in Asia – including the Ganges and most rivers in India, the Huang He (Yellow River in China), the Chao Phraya (Thailand), and the Amu Dar'ya and Syr Dar'ya (in the Aral Sea basin)[158]. The Nile River and the Colorado River (in southwestern North America) discharge little or no freshwater to the sea in most years[162].

Although increasing water productivity and water use efficiency are crucial for future water scarcity challenges, the total amount of available freshwater may substantially limit the carrying capacity of the planet. As discussed about, the estimated amount of freshwater available worldwide for human consumption ranges between 12,500 – 14,000 km^3 per year[160]. Assuming the minimum requirement of water is 1,700 m^3 of water per capita per year, and assuming optimistically that the amount of freshwater available for human consumption is 14,000 km^3 per year – then the human carrying capacity of the planet may be constrained to roughly 8 billion people assuming that no large-scale technology is used to secure or create more freshwater resources (e.g., desalination of sea water). The global population may be 8 billion by 2030 assuming BAU growth. If this water would be distributed equally, then these 8 billion people would each only have the minimum annual requirement for water. Therefore, the limit on the carry capacity in terms of water resources may be less than 8 billion, assuming that everyone in the world would like to live with an at least adequate supply of water rather than the minimum for survival.

So far, this discussion of water resources has not considered how climate change may affect water resources in the future. Indeed, this section has only assumed BAU with the current climate regime. Climate change impacts on water and the human carrying capacity of the environment will be discussed in a following section.

“There are no substitutes for phosphorus in agriculture.”

– United States Geological Survey[167], 2009

- Phosphorus is an element necessary for all life. Phosphorus is one of the three major nutrients required for plant growth: nitrogen (N), phosphorus (P), and potassium (K).
- Global phosphorus production most likely peaked in 1989. If global phosphorus production has not yet peaked, it will likely do so by 2033.
- The quality of remaining phosphate rock is decreasing and the production costs are increasing.
- Global reserves will start to run out within 50 – 100 years.
- Once phosphorus supplies are exhausted, phosphorus will need to be recovered and reused in order to avoid a massive global food security crisis. There are no substitutes for phosphorus in agriculture.
- In 2007 – 2008, the price of phosphate rock increased dramatically worldwide due to increased agricultural demand and limited supplies of phosphate rock.
- Most of the world's farms do not have or do not receive adequate amounts of phosphorus. Feeding the world's increasing population will accelerate the rate of depletion of phosphate reserves. Future generations ultimately will face problems in obtaining enough to exist.
- Policy responses are necessary soon to prepare society for declining phosphorus supplies, to promote efficient phosphorus use, and to develop phosphorus recycling programs.

The Role of Phosphorus in Nature and Agriculture

Phosphorus (chemical symbol P) is an element necessary for all life. Phosphorus is one of the three major nutrients required for plant growth: nitrogen (N), phosphorus (P), and potassium (K). Phosphorus is often a limiting nutrient in natural ecosystems, in which the supply of available phosphorus limits the size of the population possible in a given ecosystem[117].

Phosphorus does not naturally occur as a free element, because it is highly reactive. Instead, phosphorus is bound up in phosphates, which typically occur in inorganic rocks. Most phosphorus is obtained from mining phosphate rock, but it is also obtained from deposits of guano[117].

The major use of phosphate is in fertilizers[117]. Growing crops remove phosphorus and other nutrients from the soil. Philip Abelson[168] warns,

"Most of the world's farms do not have or do not receive adequate amounts of phosphate. Feeding the world's increasing population will accelerate the rate of depletion of phosphate reserves...resources are limited, and phosphate is being dissipated. Future generations ultimately will face problems in obtaining enough to exist."

Further, the U.S. Geological Survey[167] states, "There are no substitutes for phosphorus in agriculture." Therefore, phosphorus production and distribution is a major limiting factor in food production.

Peak Phosphorus

Reserves of phosphate rock are found in several countries, but the largest commercially recoverable reserves are located in just three – China, the United States and Morocco/Western Sahara[119]. At current rates of extraction, the U.S. will deplete its reserves within 30 years, and global reserves will start to run out within 50 – 100 years[119,167]. Phosphorus cannot be manufactured from alternative sources, but it can be recovered and reused (i.e. recycled). Some can be recovered from human, animal and organic waste, but as yet there have been few initiatives to promote recycling[119].

Cordell et al.[119] predict that phosphorus production will peak in 2033 (see Figure 28). Although the authors argue that the observed peak in 1989 was not a true maximum production peak, their 2033 prediction is based on forcing the behavior of their model to accommodate the ultimate recoverable reserve (URR) estimates of the U.S. Geological Survey[119]. They suggest that the 1989 production peak was instead a consequence of political factors like the collapse of the Soviet Union (formerly a significant phosphate rock consumer) and decreased fertilizer demand from North America and Western Europe.

Projections based on applying the technique of Hubbert Linearization to the rock phosphate production historical data series from the U.S. Geological Survey[169] to predict peak phosphorus suggest that global phosphorus production peaked in 1989 [117,118] (see Figure 29). This same model was used to successfully predict the peak phosphorus production year for two major phosphorus exporters: the U.S. (1988) and the island state of Nauru (1973)[117]. The historical data, declining production rates, the depletion of high quality phosphate rocks, increasing demand, and increasing prices suggest that the 1989 prediction for peak phosphorus may be a more reliable prediction.

Although Ward's analysis suggests that the 1989 downturn is a final peak with no recovery, the author indicates that lower-quality phosphate rock that is less economically viable to extract may allow for a less steep decline in phosphorus production in the future, if unconventional low-grade phosphate supplies can be brought online to replace declining conventional supplies in the near future[118]. Even though Cordell et al.[119] disagree with the 1989 peak phosphorus estimates, the authors admit that the fertilizer industry widely acknowledges that the quality of remaining phosphate rock is decreasing and that the production costs are increasing. Besides the issues of declining phosphorus supplies and the environmental cost of mining low-grade phosphate, it may not be economically viable in the long-term to continue mining low-grade phosphate rock as energy costs and the price of fertilizer rises. Furthermore, once phosphorus supplies are exhausted, phosphorus will need to be recycled in order to avoid a massive global food security crisis.

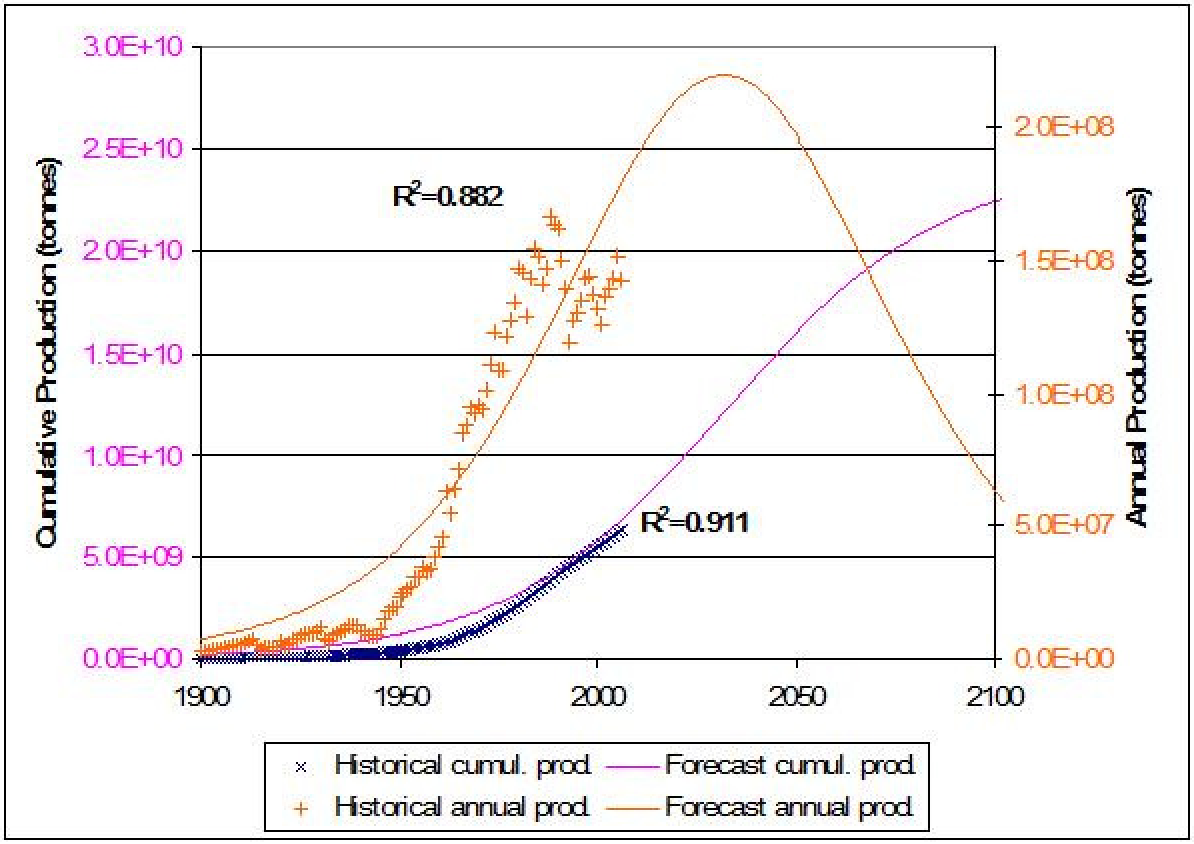


Figure 28: Annual and cumulative phosphorus production predicted by Cordell et al.[119]*, based on URR = 24.3 billion tonnes (URR from the USGS*[167] *). According to this graph global peak phosphorus occurs in 2033. Graph produced by Ward*[118]*.*

The availability of phosphate is reflected in the price of fertilizer and in the cost of food. In 2007 – 2008, the price of phosphate rock increased dramatically worldwide due to increased agricultural demand and limited supplies of phosphate rock. The average U.S. price in 2008 was more than double that of 2007, and was 4 times greater than that of 2004 [167]. Average spot prices from North Africa and other exporting regions increased more than 5 times the average price in 2007 [167]. Prices for nitrogen (dependent on energy prices), potash (a source of potassium), and sulfur (used to process phosphorus from phosphate rock) also increased, which caused the price of fertilizers to reach record highs[167]. This relationship between nitrogen, phosphorus and potassium prices is complicated since fertilizers are made up of nitrogen, phosphorus and potassium, and therefore, the price of one of these components can directly affect the prices of the other two[119]. The International Fertilizer Industry Association expects the fertilizer market to remain constrained for at least the next few years[119]. Consequently, the price of phosphate rock and related fertilizers will likely remain high in the near future, until new mining projects are commissioned[167].

The 4-fold increase in phosphate rock prices from 2004 to 2008 also coincides with the dramatic increase in oil prices from less than $0 per barrel in 2004 to over $80 dollars per barrel in 2008 (reaching a high of $147 per barrel in summer of 2008) (see Figure 22). Supplying phosphate rock requires a lot of oil and other energy resources to extract, process, distribute, and apply to cropland. Rising oil prices will likely increase future phosphate prices, which will likely further increase food prices and economic decline.

In 2007 – 2008, the price increase of phosphate fertilizer was also due in part to the increasing popularity of meat- and dairy-based diets, especially in growing economies like China and India, and to the expansion of the biofuel industry[119]. Increasing concern about oil scarcity and climate change resulted in the recent sharp increase in biofuel production. The biofuel industry competes with food production for grains, productive land, and phosphorus fertilizers. The year 2007 was the first year a clear rise in phosphate rock demand could be attributed to ethanol production[119]. Biofuel production pushed fertilizer into a pricing structure determined directly by the rising oil prices, which resulted in a sharp increase in food prices[119]. Therefore, the volatility of the phosphate market due to biofuel and oil production may also affect the prices of nitrogen and potassium, the two other components of fertilizer, and ultimately the price of food in general.

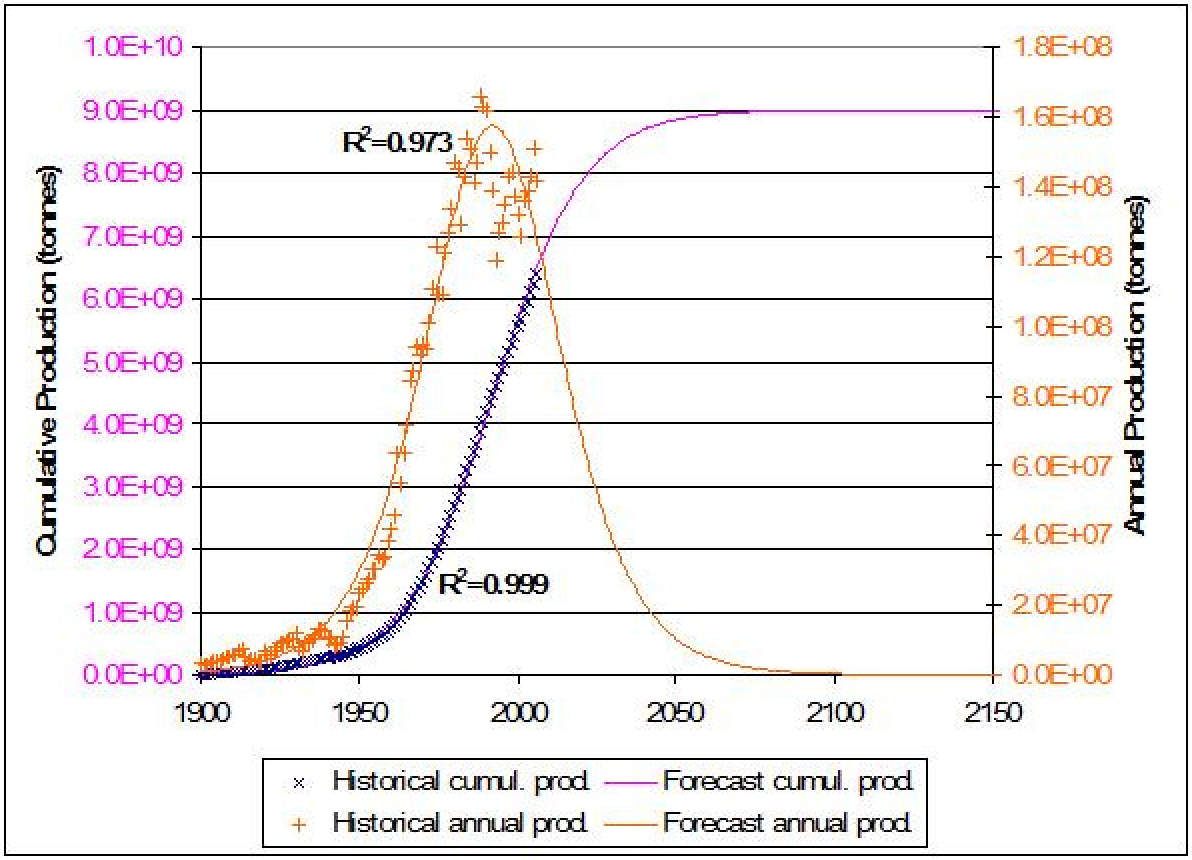


Figure 29: Annual and cumulative phosphorus production predicted by Ward[118]. Global peak phosphorus occurs in 1989.

Phosphate reserves are expected to be depleted in 50 – 100 years[119,167]. Regardless of whether peak global phosphorus production occurred in 1989, or will occur by 2033 or sometime in between these two years, it is clear that policy responses are necessary soon to prepare society for declining phosphorus supplies, to promote efficient phosphorus use, and to develop phosphorus recycling programs. Otherwise, the growing global population, the increasing demand for phosphorus, the decreasing phosphorus supply, and rising fertilizer prices will threaten a massive global food security crisis.

Responses to Peak Phosphorus

The challenge of peak phosphorus is more difficult than other peak energy resources issues, like peak oil, in some ways. For instance, energy sources other than oil are available, although they all have their own associated problems and limitations. However, unlike fossil fuels, phosphorus can be recycled.

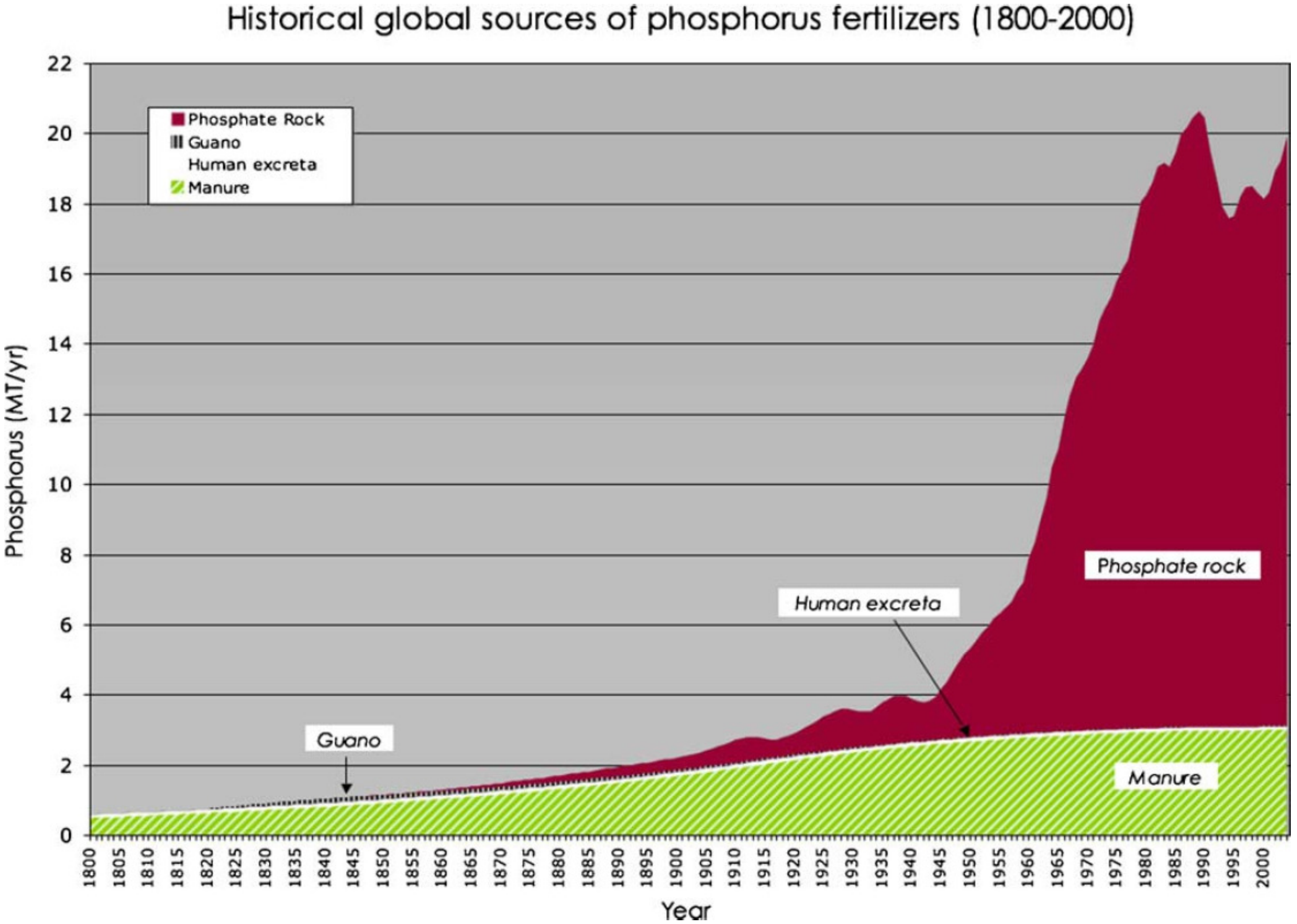


Figure 30: Historical sources of phosphorus for use as fertilizers, including manure, human excreta, guano and phosphate rock (1800 – 2000)[119]. *Reliability of data sources vary, therefore data points for human excreta, guano and manure should be interpreted as indicative rather than precise.*

If phosphorus is wasted, it cannot be replaced by any other source. Cordell et al.[119] estimate that the global human population physically consumes approximately 3 million tonnes (Mt) per year, based on the calculation that human bodies require roughly 1.2 g per person per day of phosphorus for healthy functions. However, the authors infer that significant losses (i.e., waste) occur throughout the system—from mine to field to fork. Globally, people are mining 5 times the amount of phosphorus that humans are actually consuming in food. Currently, 90% of global demand for phosphorus (i.e., around 148 million tonnes of phosphate rock per year) is for food production[119]. The limited supplies of concentrated phosphates are being depleted[117,118]. Phosphate fertilizer is often applied carelessly, which leads to waste and pollution. Food is consumed by people and animals, who excrete most of the phosphorus where it is lost to the environment as pollution, if it is not reclaimed and recycled. In developed societies, the excreted phosphorus goes into the sewage which drains into the sea, waterways, or is buried[117].

A critical response to peak phosphorus would be to recreate a cycle of nutrients. For example, human and animal manure can be returned to the soil to enabled agriculture to continue to be productive. Applying sewage sludge is another method currently used for returning nutrients to agriculture, although there are safety concerns about the process[117]. Other possible methods include: using composting toilets, composting organic waste, diverting urine, more efficient application of fertilizer, and developing technological innovations[117].

Since it is possible and will be necessary for phosphorus to be reclaimed and recycled, the degree to which phosphorus affects the human carry capacity in terms of food production will depend on human policy, behavior, and demand. If people successfully manage and recycle their phosphorus resources, then the remaining resources might be adequate to supply future global demand. However, as Figure 30 shows global production of phosphorus increased dramatically starting at the beginning of the Green Revolution, which coincided with a dramatic exponential increase in human population. Therefore, it is possible that a decline in the phosphorus supply may lead to a proportional decrease in the global human carry capacity. This report assumes optimistically that the global population will be able secure an adequate supply of phosphorus through recycling and from phosphate production. Nevertheless, peak phosphorus will limit the potential for biofuels production to replace petroleum (see *Biofuels* in *Mitigating Peak Oil*).

"FAO estimates that 1.02 billion people are undernourished worldwide in 2009."

– United Nations Food and Agriculture Organization (FAO), The State of Food Insecurity in the World[133], 2009

- It is beyond the scope of this analysis to estimate how much food waste can be reduced in the global food system, and how this reduction in waste might increase the potential global human carrying capacity in terms of food.

- Supplying future global food demand will need to include increasing the efficiencies of existing production areas and processes to reduce waste, reducing policies and incentives for businesses to generate unnecessary waste, and converting wasted food to animal feed and compost.

- However, it will be impossible to avoid generating some food waste along the supply chain from field to plate.

The UN[170] estimates that up to 30 – 40% of the food produced, processed, transported, sold and taken home by consumers in the UK and U.S. is wasted. However, the rate of food wasted in other OECD and developing countries will likely vary. Food can be wasted or otherwise lost at every stage of the supply chain, from field to plate and consumer storage. Supplying future global food demand will need to include increasing the efficiencies of existing production areas and processes to reduce waste, reducing policies and incentives for businesses to generate unnecessary waste, and converting wasted food to animal feed and compost. However, it will be impossible to avoid generating some food waste along the supply chain from field to plate. Therefore, the goal should be to minimize the waste and recycle (as animal feed) or compost food waste when it is generated.

Food production systems from field to plate are very complicated due to complex interactions between environmental, social, cultural, economic and political factors. Additionally, the global food requirements per capita used to estimate global human carrying capacity in this analysis are based on minimal or just adequate food requirements – and presumably everyone living in the world would want an adequate food surplus to store for food-scarce times. Therefore, potential food waste reductions are here assumed to be offset by above-minimum demand for food and store. For these reasons, it is beyond the scope of this analysis to estimate how much food waste can be reduced in the global food system, and how this reduction in waste might increase the potential global human carrying capacity in terms of food.

Human Health

Chapter 21

"Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity."

– World Health Organization (WHO), 1948

- Oil scarcity will impact health systems, including by affecting the availability of medical supplies and equipment, transportation, energy supplies, food, and incomes to afford health services.
- Many pharmaceuticals are produced from feedstocks based on oil derivatives.
- Many medical supplies are made with plastics, such as bandages, prosthetic devices, syringes, tubing, radiological dyes, prostheses, toothbrushes, dental care products, corrective lenses, glasses, eye care supplies, and hearing aids.
- Transportation will cost more, which will affect access to health care services.

Oil scarcity will impact health systems, including by affecting the availability of medical supplies and equipment, transportation, energy supplies, food, and incomes to afford health services. Many pharmaceuticals are produced from feedstocks based on oil derivatives. Although most of these drugs can be synthesized through alternate chemical pathways, these alternatives may increase production costs at least marginally, and they could require much time until drug regulating and supervisory agencies (e.g., U.S. Food and Drug Administration) approve of any changes in synthetic pathways[171]. Many medical supplies are made with plastics, such as bandages, prosthetic devices, syringes, tubing, radiological dyes, prostheses, toothbrushes, dental care products, corrective lenses, glasses, eye care supplies, and hearing aids[172]. Consequently, oil scarcity will increase the prices of medical supplies and equipment as a result of declining supplies, shortages, and abrupt supply interruptions. Ironically, lack of supplies and increased prices in contraceptives may increase overall fertility rates, especially for the poor. Increased fertility rates could drive population growth faster toward the human carrying capacity of the environment. Increased mortality rates from lack of health care services could partially or wholly offset fertility rates.

Health inspectors, nurses, and doctors travel within their communities. Automobiles and public transportation transport health workers to work and patients to clinics, medical offices, and other health care facilities. Moreover, health care facilities are supported by the transportation of goods, services, service personnel, administrators, and staff operate, supply, and maintain them. Increased transportation costs, which will be internalized in the costs of many health care products, will also contribute to rising health care costs[171].

Although oil accounts for only a small amount of electrical energy production, oil scarcity will affect the prices of coal and other energy fuel sources (see *Peak Energy Resources*). For example, increased costs for oil will increase the production and distribution costs for coal, which would increase the price of coal-generated electricity delivered to hospitals and other health care facilities. Disruptions in electricity generation could impact health care facilities and burden or jeopardize their backup energy generators.

An economic decline due to increased oil prices could increase the number of people who are uninsured and who cannot afford health care. Consequently, mortality rates may increase due to lack of access to health care.

As discussed in the previous section, oil scarcity will increase food prices and decrease food availability, which will threaten the health of the poor and others who lack secure access to food. Hunger, malnourishment, decreased fertility rates, and increased mortality rates will likely further reduce the human carrying capacity of areas affected by food scarcity.

Similarly, decreased access to clean water supplies due to lack of oil for water transportation and irrigation pump fuel will increase the number of people living in water-stressed environments. Lack of clean water for drinking, sanitation and food production, and increased incidences of water-borne diseases, could further reduce the human carrying capacity of areas affected by constrained water supplies.

The oil crises of the 1970's illustrate some what post-peak oil impacts on health care might be like. For instance, during the 1973 oil crisis in the U.S., a shortage of petroleum feedstocks for plastic syringe manufacturers increased their prices and delayed product delivery to consumers[171]. During the oil shocks of 1973 and 1979, short-term interruptions in fuel availability disrupted transportation in the U.S., which consequently disrupted health care delivery. In 1979, U.S. hospitals also experienced increases in heating oil costs[171].

However, unlike the oil shocks of the 1970's, oil scarcity after peak oil will be permanent under the very possible assumption that alternative fuels and material feedstocks for a wide variety of medical and health care medicine, supplies, and equipment are not developed. Even if such alternatives are eventually developed, they may take at least several decades to implement on a commercial scale. Therefore, not only could shortages of oil have serious effects on health care delivery, the effects could be chronic in the long-term, if not permanent in many areas, particularly in impoverished and least developed areas.

Since the effects of health care services and health practices on human carry capacity of the environment and the factors that contribute to them are very complex and sometimes challenging to quantify, it is beyond the scope of this analysis to estimate the affects of peak oil on health care services and the effects of access to health care services on the carrying capacity of the environment. Quality of life and longevity are among the factors that would affect population size and capacity. Fertility and mortality rates will also be major factors determining population size and resource requirements.

Mass Extinction and Biodiversity Loss

Chapter 22

"Nature favors those organisms which leave the environment in better shape for their progeny to survive."

– James Lovelock[173], scientist and environmentalist, 2000

"If all mankind were to disappear, the world would regenerate back to the rich state of equilibrium that existed ten thousand years ago. If insects were to vanish, the environment would collapse into chaos."

– Edaward O. Wilson, biologist and author

- The Earth is currently in the midst of a mass extinction event of species of life – the sixth mass extinction event in the past half-billion years.

- One of the most well-known of the previous five mass extinction events was the extinction of the dinosaurs 65 million years ago.

- Although extinction occurs at a natural background rate of about 1 – 5 species per year, species are currently being lost at approximately 100 – 1,000 times the background rate.

- By mid-century, this rate of extinction may increase to 10,000 times greater than the background rate while as many as 30 – 50% of all species may go extinct.

- Unlike past mass extinctions, which were caused by natural events like asteroid strikes, volcanic eruptions and natural climate shifts, the current extinction crisis is almost entirely caused by humans. Anthropogenic climate change is also accelerating the extinctions at an alarming rate.

- With continued growth of human biomass and anthropogenic climate change, only extraordinary and stepped-up conservation efforts will prevent mass extinctions in most genera and families of life on the planet.

- Since people depend on countless ecosystem services (e.g., water and food provision, pollination, pollution remediation, etc.) provided by healthy and diverse ecosystems, the impacts of a mass extinction event on the human population and societies will likely be devastating.

The human population is nearly 7 billion people. The sheer number of people and the energy harnessed for human activities has made the human species the equivalent of a global geophysical force. Now, the human species is a dominant factor affecting the terrestrial, hydrological, atmospheric, and climate systems and the biodiversity and species abundance across the world (see Figure 25). Approximately 40% of all land-based photosynthetic capacity has been appropriated by humans[174]. In 1995, human activities already appropriate an estimated 54% of the global surface water that is potentially available[162]. By 2025, humans may use 70% of the global surface water that is potentially available[163].

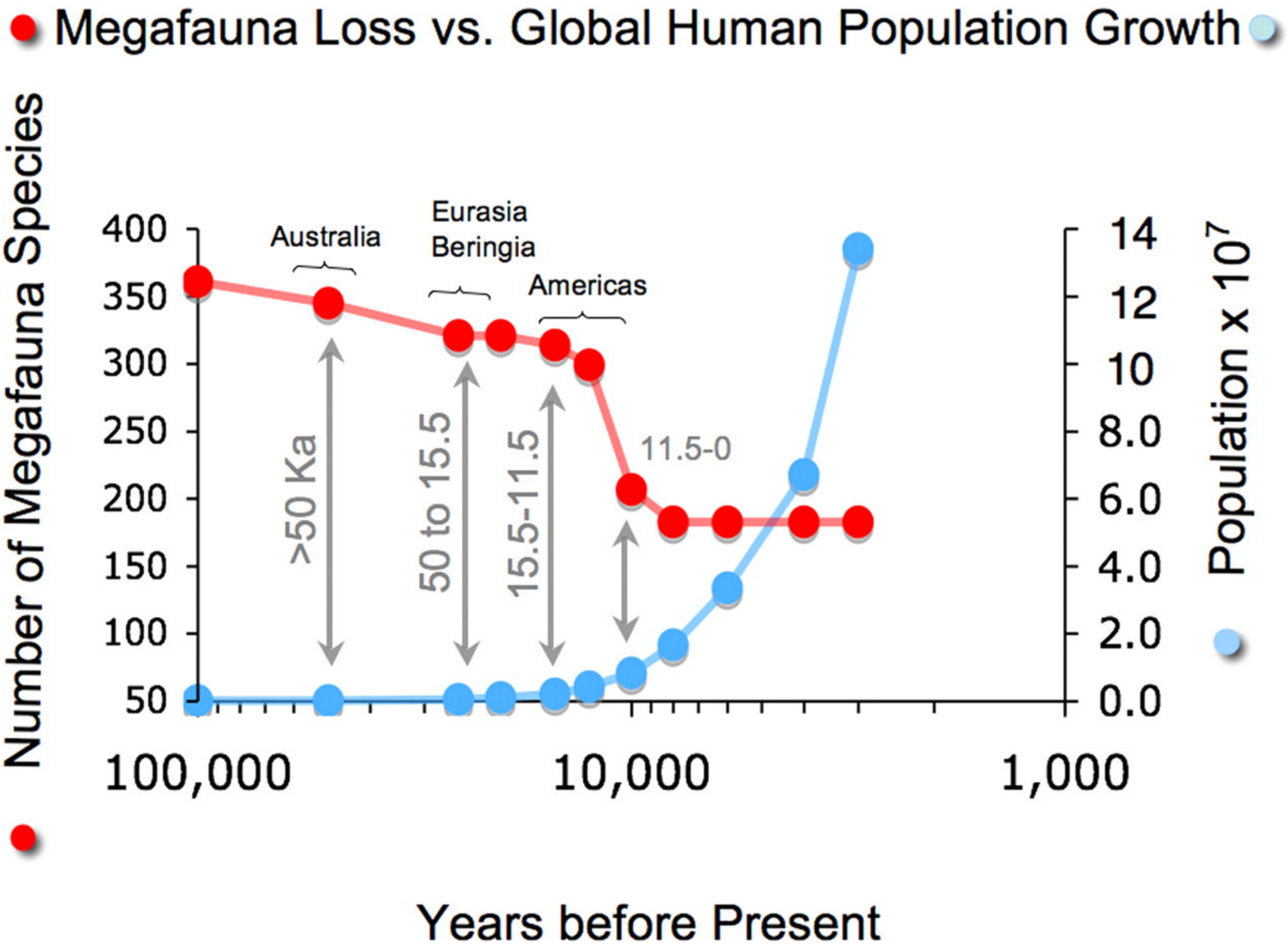


Figure 31: Number of non-human megafauna species that went extinct through time plotted against estimated population growth of humans[176].

The Earth is currently in the midst of a sixth mass extinction of plants and animals – the sixth wave of mass extinctions in the past half-billion years. One of the most well-known of the previous five mass extinction events was the extinction of the dinosaurs 65 million years ago. Although extinction occurs at a natural background rate of about 1 – 5 species per year, species are currently being lost at approximately 100 – 1,000 times the background rate[175]. Some 12% of birds, 25% of mammals, and at least 32% of amphibians are threatened with extinction over the next century[140]. This rate of extinction may increase to

10,000 times greater than the background rate while as many as 30 – 50% of all species may go extinct by mid-century[176,177]. Unlike past mass extinctions, which were caused by natural events like asteroid strikes, volcanic eruptions and natural climate shifts, the current extinction crisis is almost entirely caused by humans. In particular, 99% of currently threatened species are at risk primarily from human activities that drive habitat loss, introduce exotic species, and cause ocean acidification and climate change[178].

Earth's most recent mass extinction event, the Quaternary Megafauna Extinction, claimed two-thirds of mammal genera and one-half of species that weighed over 44 kg between 50,000 and 3,000 years ago (see Figure 31 and 32). Growth of human biomass largely coincided with the loss of non-human megafauna biomass (i.e., large animals) until around 12,000 years ago. Then, the total megafauna biomass crashed, and many non-human megafauna species disappeared in a short period of time while human biomass continued to increase[176]. Barnosky[176] states, "After the crash in megafauna, the global ecosystem gradually recovered into a new state where megafauna biomass was concentrated around one species, humans, instead of being distributed across many species." The pre-crash biomass levels were reached just before the beginning of the Industrial Revolution. Then, biomass levels increased very rapidly above the pre-crash baseline as humans augmented the energy available to the global ecosystem by exploiting fossil fuels. Barnosky[176] suggests that an increase in human biomass (with attendant hunting and other impacts) coincided with climate change to cause the Quaternary Megafauna Extinction and an ecological threshold event, after which humans became dominant in the global ecosystem. The author also suggests that with continued growth of human biomass and anthropogenic climate change, only extraordinary and stepped-up conservation efforts will prevent a mass extinctions in most genera and families of life on the planet.

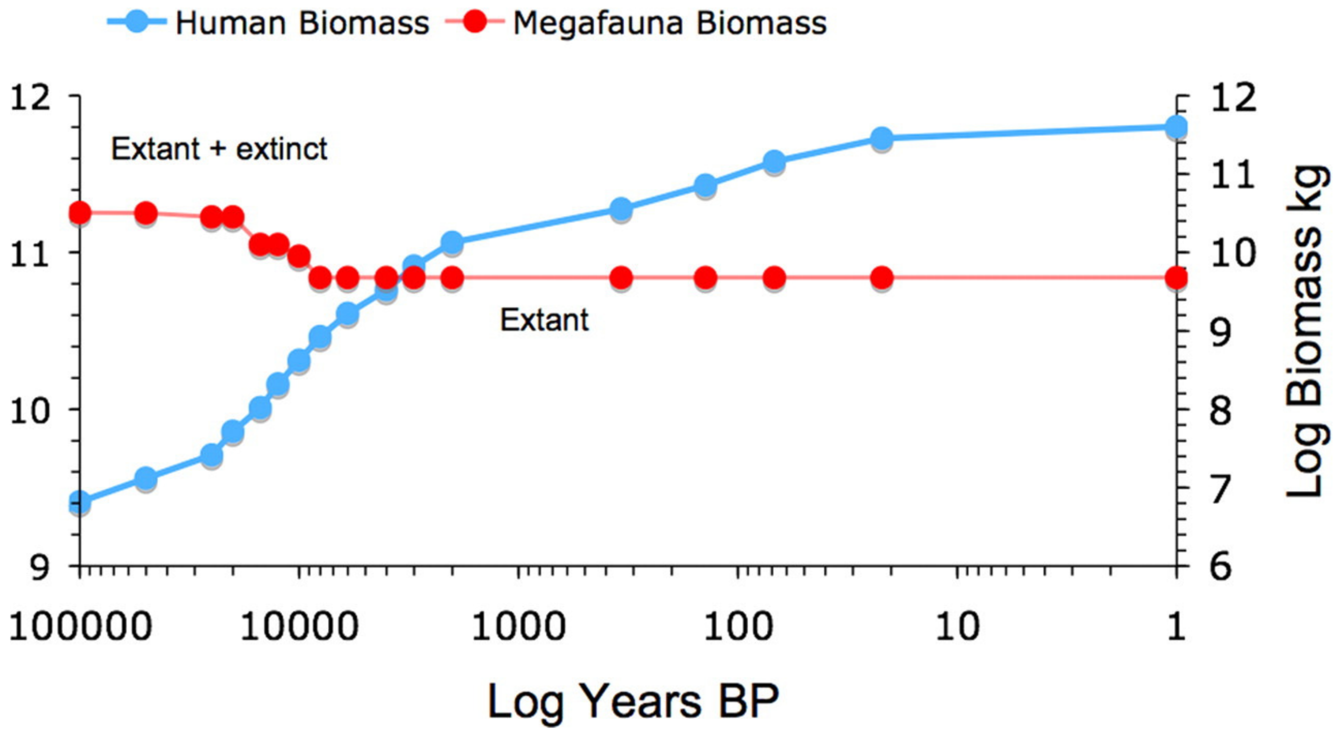


Figure 32: Estimated biomass of humans plotted against the estimated biomass of non-human megafauna[176].

A near-future biomass crash that will negatively and severely impact humans, their domesticates, and other species is unavoidable unless human activities are reduced and/or done more sustainably; the human population decreases; and dangerous ocean acidification and climate change are mitigated. Since the rate of decline in biodiversity and species abundance is accelerating, and because every species' extinction potentially leads to the extinction of other species dependent on that species in a complex ecological web, the numbers of extinctions throughout the world are likely to amplify and accelerate in the coming decades as ecosystems unravel from human activities, exploitation, degradation, destruction, and climate change. Since people depend on countless ecosystem services (e.g., water and food provision, pollution remediation, etc.) provided by healthy and diverse ecosystems, the impacts of a mass extinction event on the human population and societies will likely be devastating.

"If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, paleoclimate evidence and ongoing climate change suggest that CO2 will need to be reduced from its current 385 ppm to at most 350 ppm, but likely less than that."

– James Hansen et al.[179], head of the NASA Goddard Institute for Space Studies, 2008

- Humanity has already passed the threshold for dangerous anthropogenic interference with the natural climate system.
- By 2050, future climate change has the potential to substantially reduce the human carrying capacity of the Earth by 0.5 – 2 billion people, or more with abrupt climate changes.
- In 2010, the eight month mean (January 2010 – August 2010) global atmospheric concentration of CO_2 was approximately 391 parts per million (ppm).
- The average global atmospheric CO_2 concentration currently increases at a rate of approximately 2 ppm per year.
- Even if all anthropogenic GHG emissions cease in 2010 (an extremely unlikely scenario), thereby limiting atmospheric CO_2 concentration to 391 ppm, the climate system may have already passed the 2°C threshold for dangerous climate change.
- Cumulative GHG emissions may have already committed the planet to a warming of 2.4ºC (within a range of 1.4º – 4.3ºC) above the pre-industrial mean temperatures.
- As CO_2 concentrations approach 441 ppm a corresponding committed warming of 3.1ºC will occur by 2030 in the absence of strong countervailing mitigation.
- A CO_2 concentration of order 450 ppm or greater, if long maintained, would push the Earth toward an ice-free state and that such a CO_2 level likely would cause the passing of climate tipping points and initiate dynamic responses that could be out of humanity's control.
- Abrupt, non-linear changes are caused by small increases in global warming that result in large and irreversible environmental changes once climate tipping points are passed. Anthropogenic GHG emissions are driving the global climate system toward such tipping points earlier than previously predicted.
- The potential impacts of passing such climate tipping points could be catastrophic and global-scale, and include: the disappearance of Arctic summer sea ice; a major reduction of the area and

volume of Hindu-Kush-Himalaya-Tibetan Plateau (HKHT) glaciers (which provide the head-waters for most major river systems of Asia that supply almost 30% of the global population); ocean acidification; the deglaciation of Greenland Ice Sheet; the dieback of Amazonian and boreal forests; the shutdown of the Atlantic Thermohaline Circulation; and the collapse of West Antarctic Ice Sheet.

- The catastrophic impacts from these events could include many meters of sea level rise, massive displacement and loss of people and wildlife, severe loss of biodiversity, mass extinction of species and ecosystems, extreme climate events, megadroughts, catastrophic water shortages, and massive famines that could result in chronic economic depressions, political instability, social revolutions, resource wars, overwhelming humanitarian crises, and human rights challenges.

- Passing climate tipping points would likely cause other severe impacts, such as the release of CO_2 and methane from permafrost and ocean hydrates that would likely cause additional runaway climate feedbacks that could accelerate further climate change.

- A target atmospheric concentration of CO_2 of no greater than 350 ppm will likely be needed to prevent the world from passing climate tipping points.

- A target concentration of CO_2 of 300 ppm may be needed to ensure that the climate does not pass the 2ºC threshold. Substantial reductions in anthropogenic GHG emissions post-peak oil, combined with major efforts in carbon sequestration would likely be necessary to achieve this target.

- Temperature tipping points for abrupt and non-linear climate changes could be passed within this century, or even within the next decade or several years.

- Even if climate tipping points are not crossed, committed climate change that is already “in the pipeline” will likely have severe negative impacts on most water resources, food production systems, economies, and ecosystems worldwide.

Impacts of Climate Change

The previous discussion on the human carrying capacity of the Earth's food resources ignores the impacts of climate change on food production systems. However, climate change will likely reduce the Earth's human carrying capacity overall. In 2010, the eight month mean (January 2010 – August 2010) global atmospheric concentration of CO_2 was approximately 391 parts per million (ppm)[180] (see Figure 33). Currently, average global atmospheric CO_2 concentration increases at a rate of approximately 2 ppm per year[180]. Given current CO_2 emissions trends, it is likely that the annual mean global atmospheric concentration of CO_2 for 2010 will be approximately 391 ppm, which is 4 ppm more than the annual mean in 2009 (387 ppm)[180]. By 2030 and 2050, atmospheric CO_2 concentrations will respectively be at least 431 ppm and 471 ppm or more assuming current BAU emissions trends. Reaching such

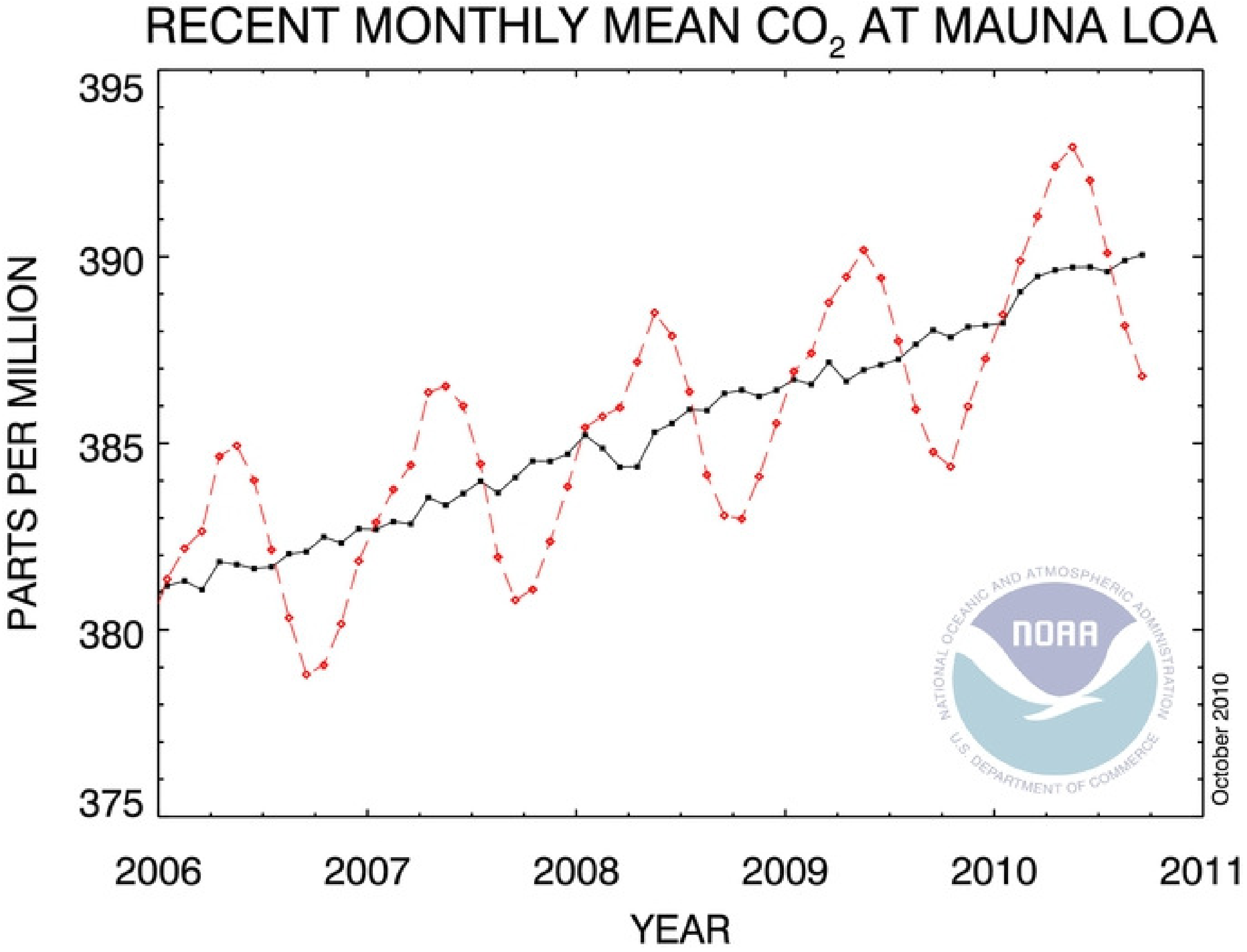


Figure 33: Recent monthly mean carbon dioxide measured at Mauna Loa Observatory, Hawaii. The last four complete years of the Mauna Loa CO_2 record plus the current year are shown. Data are reported as a dry air mole fraction defined as the number of molecules of carbon dioxide divided by the number of all molecules in air, including CO_2 itself, after water vapor has been removed. The mole fraction is expressed as parts per million (ppm). Example: 0.000400 is expressed as 400 ppm. In the above figure, the dashed red line with diamond symbols represents the monthly mean values, centered on the middle of each month. The black line with the square symbols represents the same, after correction for the average seasonal cycle. The latter is determined as a moving average of seven adjacent seasonal cycles centered on the month to be corrected, except for the first and last three and one-half years of the record, where the seasonal cycle has been averaged over the first and last seven years, respectively. The last year of data are still preliminary, pending recalibrations of reference gases and other quality control checks. The Mauna Loa data are being obtained at an altitude of 3400 m in the northern subtropics, and may not be the same as the globally averaged CO_2 concentration at the surface[180].

concentrations of CO_2 could lead to dangerous climate change. The IEA projects that the rise in emissions of greenhouse gases in their Reference Scenario (i.e., BAU) will cause a doubling of the concentration of those GHGs in the atmosphere by the end of this century, committing the world to an eventual global average temperature increase of up to 6°C[2]. However, peak oil will likely make BAU an improbable scenario. It is beyond the scope of this report to project GHG emissions trends after peak oil has occurred, in part because it may be impossible to generate emissions data sets from a collapsing global economy.

Nevertheless, even in the unlikely event that anthropogenic GHG emissions would cease altogether in 2010 due to peak oil, the climate system will still continue to change significantly over the coming decades due to "climate inertia" (i.e., the committed climate change that is already "in the pipeline").

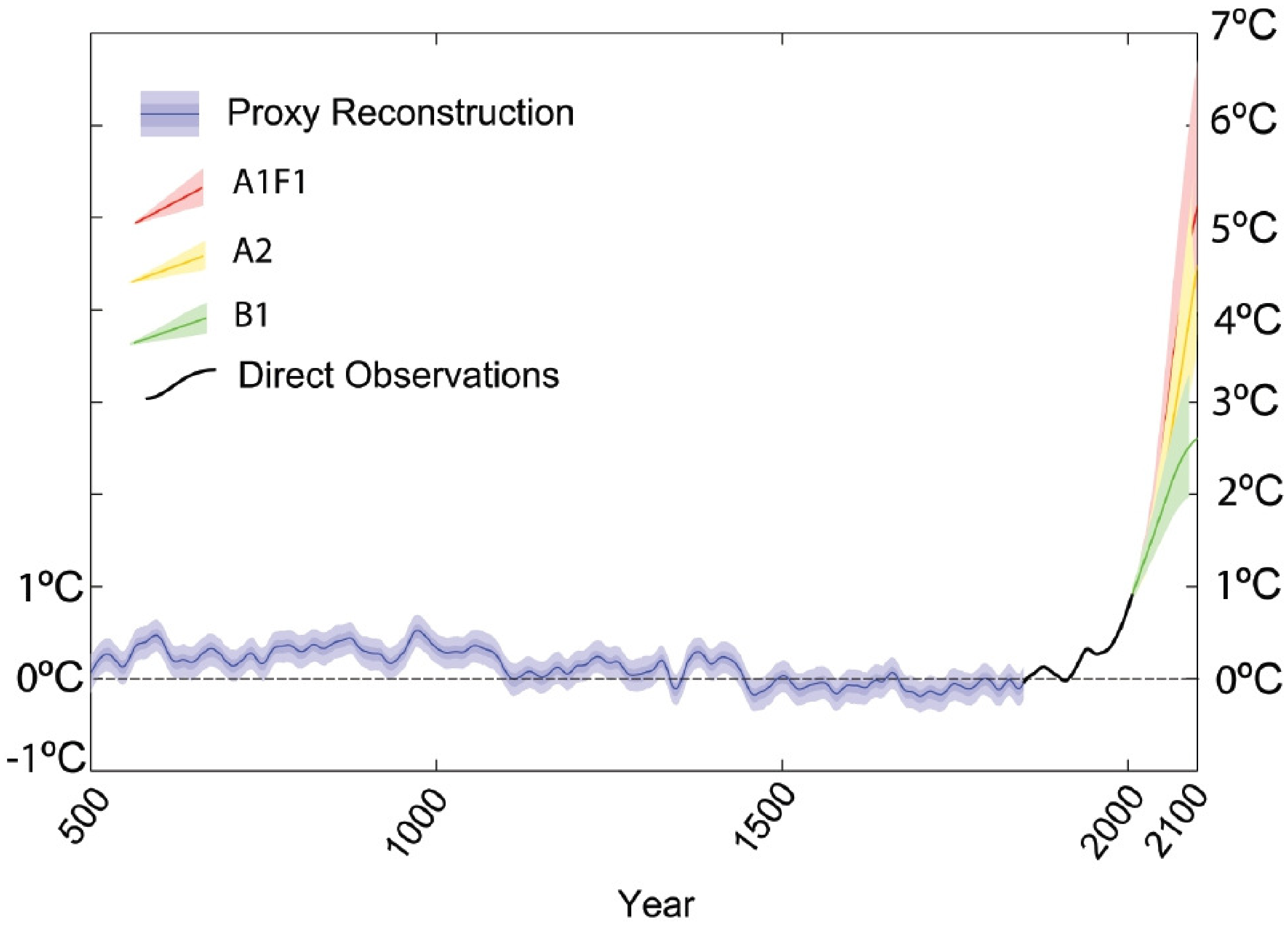


Figure 34: Reconstructed global average temperature relative to 1800 – 1900 (blue) and projected global-average temperature out to 2100 (the latter from IPCC AR4)[181]*. The envelopes B1, A2, A1F1 refer to the IPCC AR4 projections using those scenarios. The reconstruction record is taken from Mann et al.*[182]*.*

Regardless of any government policies, GHG emissions from fossil fuel burning, cement manufacture, land use and other GHG emitting activities are likely to experience a significant decline as production and the operational infrastructure decay due to lack of maintenance and use. Furthermore, exploiting most emissions-intensive sources of oil (e.g., tar sands, low grade oil) will likely become impractical as demand collapses, the purchasing power of consumers declines below the marginal cost of production, and energy infrastructure is lost to entropic decay (i.e., disuse, disrepair, and aging)[96]. Nevertheless, coal, natural gas, and other hydrocarbon fuel sources may continue to be exploited, albeit at an uncertain rate.

Land-use emissions may see various counteracting trends. A decline in global trade may result in a decline in GHG emissions from industry, industrial-scale agriculture, transportation and shipping, and from reduced pressures on forests and other ecosystems for material resources to support a global consumer economy. However, an increase in demand in agricultural land for food and biofuels may increase depending on the needs of local populations. Although global and even regional trade may collapse, localized industry, land use and deforestation may occur as people respond to immediate resource shortages.

There is a delay between the time GHGs are emitted and when the climate system responds with an observable physical change, such as a temperature increase or change in precipitation patterns. This is referred to as “climate inertia”. In other words, the GHGs people emit today will drive the climate to change in the future. This delay in the climate system will likely cause global temperatures to continue to rise, even with an abrupt collapse in emissions. Since we do not know how close we are to crossing climate tipping points and strong climate feedbacks (see below), the climate system could continue to cause further GHG emissions to occur from natural processes (e.g., permafrost thaw, wildfires) even though anthropogenic emissions may decline. Runaway GHG emissions from natural sources due to positive climate feedback cycles and the passing of climate tipping points could also drive and accelerate climate change. The sooner the GHG emissions decline, the less severe will future climate change impacts likely be.

Since it is impossible to generate emissions data sets from a collapsing global economy, it is challenging to project how climate change may evolve over time in a post-peak oil world. However, the following assessment of two possible GHG emission scenarios will provide illustrate how climate change might evolve in a post-peak oil world: (1) a business as usual scenario; and (2) a immediate stop in anthropogenic GHG emissions.

In the first case, business as usual is considered. In 2010, the average global atmospheric CO_2 concentration increases at a rate of approximately 2 ppm per year[180]. Given current CO_2 emissions trends, it is likely that the annual mean global atmospheric concentration of CO_2 will be approximately 391 ppm. Assuming BAU, the atmospheric CO_2 concentration would reach at least 431 ppm, if not more, by 2030.

The IPCC claims that a concentration of 450 ppm CO_2 equivalent (CO_2e) (i.e., 400 ppm CO_2) would only provide approximately a 50% chance (within a probability distribution of 26 – 78%) of remaining below a dangerous global average temperature rise of 2.1°C above pre-industrial global average temperature with a "likely in the range" of 1.4 – 3.1°C rise[183] (see Figure 34). However, caution should be used when interpreting the 2007 IPCC report findings since it ignores various critical climate forcing mechanisms (e.g. Arctic and Greenland ice sheet melt), assumes linear responses in the climate system, and inadequately considers abrupt, non-linear climate responses[183] (abrupt and non-linear climate change will be discussed further below). The 2007 IPCC estimates are thusly considered very conservative, in part, because they under-estimate climate sensitivity, climate forcing mechanisms and feedback cycles. In December 2008, the Copenhagen Climate Science Congress[184] concluded “the worst-case IPCC scenario trajectories (or even worse) are being realized”. The 2007 IPCC report also did not include the many new scientific findings published after its release. Therefore, these above concerns about the findings and recommendations of the 2007 IPCC report suggest that the recommended 450 ppm CO_2e stabilization target should be accepted as an upper limit – but not necessarily a safe limit – for atmospheric GHG concentrations. Indeed, Ramanathan and Feng[185] project that as CO_2 concentrations approach 441 ppm a corresponding committed warming of 3.1°C will occur by 2030 in the absence of strong countervailing mitigation.

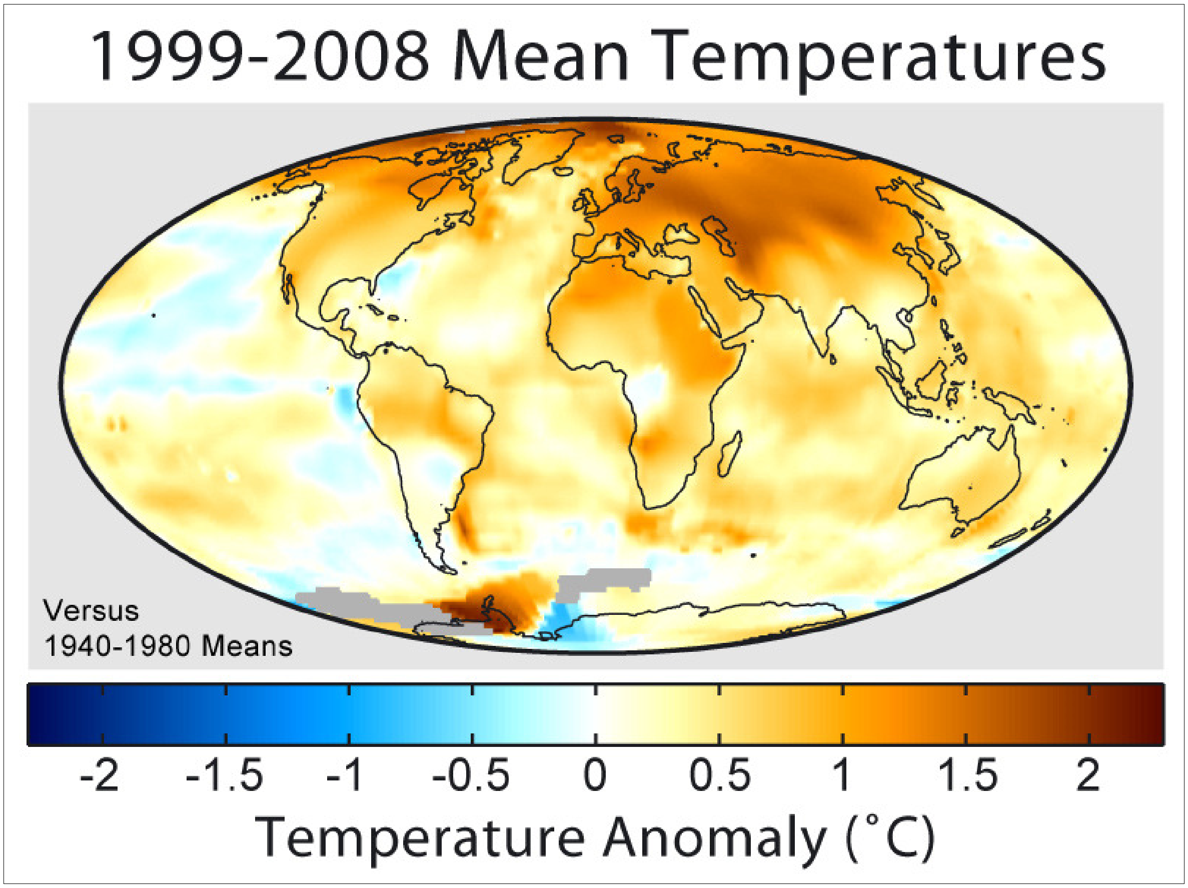


Figure 35: Mean global temperatures during 1999 – 2008. This figure shows the difference in instrumentally determined surface temperatures between the period January 1999 through December 2008 and "normal" temperatures at the same locations, defined to be the average over the interval January 1940 to December 1980. The average increase on this graph is 0.48 °C, and the widespread temperature increases are considered to be an aspect of global warming[186].

It is important to keep in mind that global temperature increases are the average of the temperatures for the entire world – local and regional temperature changes will vary by location based on a variety of environmental factors. For example, Figure 35 shows how the 1999 – 2008 mean temperatures varied across the planet. Similarly, Figure 36 shows one IPCC model's projections for average temperature increases across the world by the projection period of 2070 – 2100, as compared with the average for 1960 – 1990.

In the second case, it is assumed that all anthropogenic GHG emissions cease in 2010. Although this is an extreme and unlikely scenario, it is nonetheless illustrative as a best case scenario in terms of mitigating anthropogenic GHG emissions. By the end of 2010, the average atmospheric CO_2 concentration will likely be 391 ppm (441 ppm CO_2e). If all anthropogenic GHG emissions cease in 2010, then anthropogenic GHG emissions would likely peak. Consequently, the atmospheric concentration of CO_2 would peak at 391 ppm, assuming that natural GHG emissions do not increase due to runaway climate feedback.

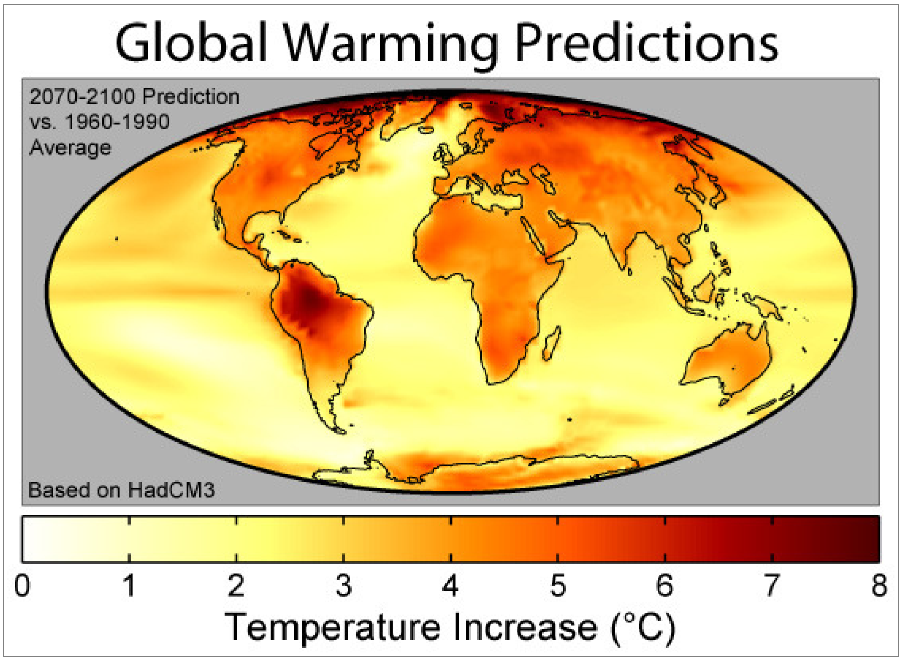


Figure 36: Global warming predictions showing a 2070 – 2100 prediction of average temperature versus 1960 – 1990 average temperature. This figure shows the predicted distribution of temperature change due to global warming from the Hadley Centre HadCM3 climate model. These temperature changes are based on the IS92a ("business as usual") projections of CO_2 *and other greenhouse gas emissions during the next century, and essentially assume normal levels of economic growth and no significant steps are taken to mitigate global greenhouse gas emissions. The plotted colors show predicted surface temperature changes expressed as the average prediction for 2070 – 2100 relative to the model's baseline temperatures in 1960 – 1990. The average change is 3.0°C, placing this model on the lower half of the IPCC's 1.4 – 5.8°C predicted climate change from 1990 – 2100. Due to their lower specific heat, continents are expected to warm more rapidly than oceans with an average of 4.2°C and 2.5°C in this model, respectively. The lowest predicted warming is 0.55°C south of South America and the highest is 9.2°C in the Arctic Ocean (points exceeding 8°C are plotted as black). This model is fairly homogeneous except for strong warming around the Arctic Ocean related to melting sea ice and strong warming in South America related predicted changes in the El Niño cycle and Brazilian rainforest. This pattern is not a universal feature of models, since other models can produce large variations in other regions (e.g. Africa and India) and less extreme changes in places like South America*[187].

Although this second case is a very conservative and rather unrealistic assumption, it demonstrates an important point. Despite limiting atmospheric CO_2 concentration to 391 ppm, the climate system may have already passed the 2°C threshold for dangerous climate change. Given that as of 2005, when the atmospheric CO_2 concentration was already about 380 ppm (422 ppm CO_2e), GHG emissions may have committed the planet to a warming of 2.4ºC (within a range of 1.4º – 4.3ºC) above the pre-industrial surface temperatures[185]. Based on an estimated history of CO_2 through the Cenozoic Era (the period from 65.5 million years ago to the present), Hansen et al.[179] suggest that a CO_2 concentration of order 450 ppm or greater, if long maintained, would push the Earth toward an ice-free state and that "such a CO_2 level likely would cause the passing of climate tipping points and initiate dynamic responses that could be out of humanity's control". Nevertheless, Hansen and other climate scientists believe that humanity has already passed the threshold for "dangerous anthropogenic interference" with the natural climate system[179].

Achieving a 2°C target with at least a likely chance (>66%) would require a long-term stabilization below 400ppm CO_2e (350 ppm CO_2)[188]. At 400 ppm CO_2e, the mean probability of exceeding 2°C is 28%[189]. A target of stabilizing greenhouse gas emissions at 350 ppm CO_2e (approximately 300 ppm CO_2) would reduce the mean probability of exceeding a 2°C temperature rise to 7%[189]. A target atmospheric concentration of GHGs of no greater than 400 ppm CO_2e will likely be needed to prevent the world from passing climate tipping points. However, a target concentration of 350 ppm CO_2e (300 ppm CO_2) may be needed to ensure that the climate does not pass the 2ºC threshold. Therefore, even if post-peak oil production enters a terminal decline or even collapses all together, climate change will likely significantly impact the planet and human population since the climate system may have already passed the 2°C threshold for dangerous climate change.

Although international climate policy considers climate change as a gradual and linear development; abrupt, non-linear changes on a global-scale can occur. Abrupt, non-linear changes are caused by small increases in global climate change that result in large and irreversible environmental changes once temperature and biogeochemical (e.g., Arctic sea ice loss, ocean acidification) tipping points are passed. Temperature tipping points for abrupt climate changes could be passed within this century, or even in the next decade or years[190]. Much of the following discussion on climate change impacts on the human carrying capacity assume steady, linear climate changes. Further below, the impacts of abrupt, non-linear climate changes will be discussed briefly.

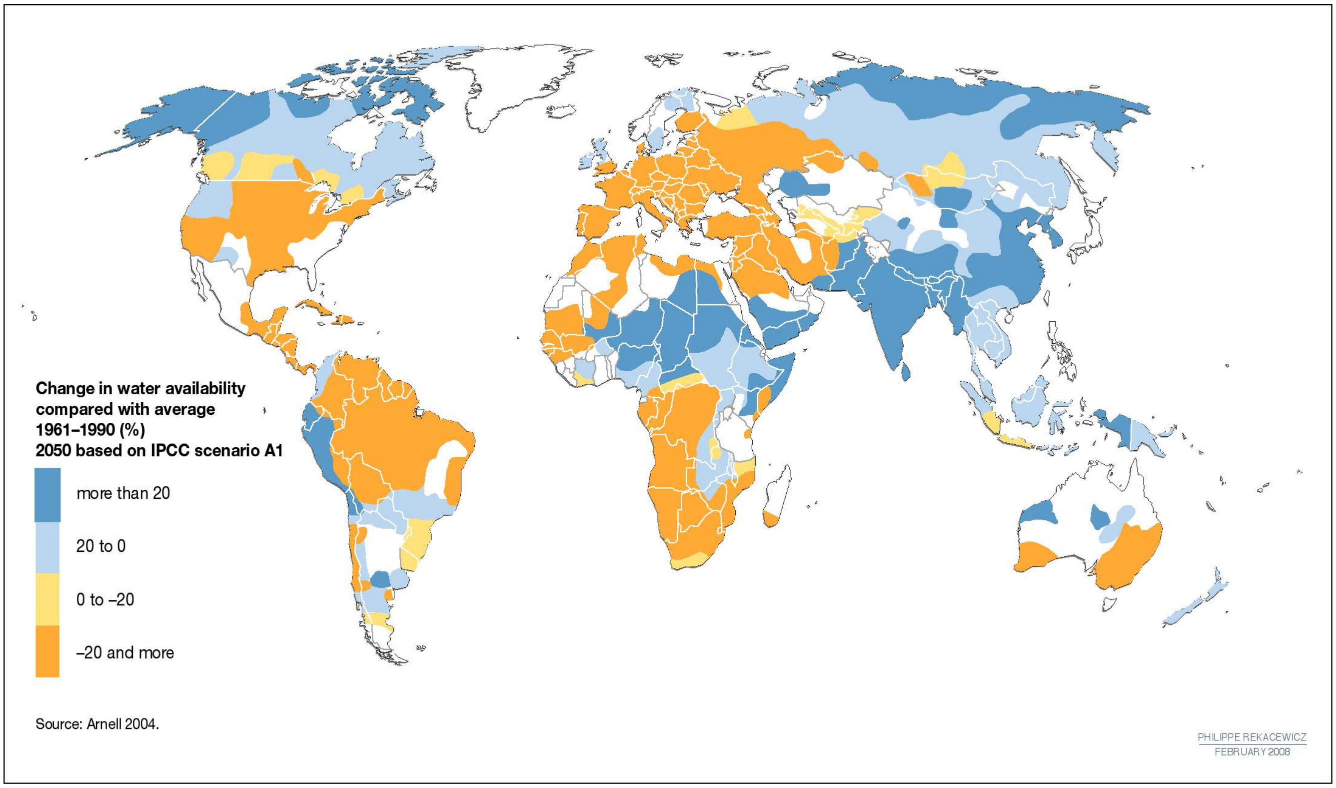
Worldwide

Climate change will significantly impact every part of the world. According to the IPCC[165], climate change will cause an increase in average global temperatures, fewer cold days and nights, and more frequent hot days and nights. As a consequence, a warming climate will likely increase crop yields in some colder environments, decrease crop yields in warmer environments, and increase crop damaging insect outbreaks. A warmer climate will also effect water resources that depend on snowmelt to maintain water runoff for ecosystems and agriculture during dry seasons. An increase in the frequency of heat spells and heat waves in most land areas will reduced crop yields in warmer regions due to heat stress. Additionally, wildfire risks will increase. Increased hot weather will cause an increase in water demand while also creating water quality problems (e.g. algal blooms). Increased periods of heat will also increase the risk of heat-related mortality

As global warming increases global water evaporation and the atmosphere's capacity to hold water vapor, more intense precipitation events will occur with increasing frequency in most areas. Although some areas may benefit from more precipitation, the heavy rain, snow, and ice that falls during intense precipitation events can overwhelm human systems and damage food production, infrastructure, and property. Crops and cropland can also be damaged by soil erosion, flooding, and soil waterlogging. Climate change will also increase intense tropical cyclone activity, which can damage crops, trees, land, coral reefs, coastal ecosystems, fisheries, and communities due to flooding, strong winds, and an increased risk of deaths, injuries, water- and food-borne diseases. Heavy precipitation events can adversely impact the quality of surface and groundwater, contaminate water supplies. Intense precipitation events can reduce the human carrying capacity of the environment by increasing the risk of deaths, injuries, and infectious diseases in both humans and livestock. Human carrying capacity can be further reduced by the disruption of settlements, commerce, transport and food distribution systems, and societies due to flooding and loss of property[159].

A future decrease of run-off water from changing patterns of rainfall due to climate change will likely put at risk large areas of cropland. Figure 37 indicates how serious this issue is – the map shows that some of the richest agricultural regions and much of Africa, Europe, South America, and the United States are threatened with a significant reduction of run-off water, which would result in a lack of water for rain-fed agriculture and irrigation[160]. Compare Figure 37 with the world population distribution and density in 2000 in Figure 38. There are many populations at increased risk of water scarcity. As global temperature rises, the global area affected by droughts will increase. Droughts degrade cropland, lower agricultural yields while increasing crop damage and failure, livestock deaths, wildfire risk, and more widespread water stress. Consequently, droughts will increase the risks of food and water shortages, malnutrition, and water and food-borne diseases[159].

Much of the world's coastal population and agricultural land is located in low elevation coastal zones, such as in the coastal fertile river basins of the Nile and Mekong River Deltas (see Figures 42 and 47). Sea level rise will inundate cropland in those areas. Sea level rise also threatens food and water security of coastal areas due to salinization of irrigation water, estuaries, and freshwater systems. Saltwater intrusion into coastal freshwater aquifers and freshwater systems will decrease freshwater availability for food production and other human and ecological uses.



Source: Arnell 2004.

Figure 37: Change in water availability compared with average 1961 – 1990 in percentage (%). Year 2050 based on IPCC scenario A1 [160].

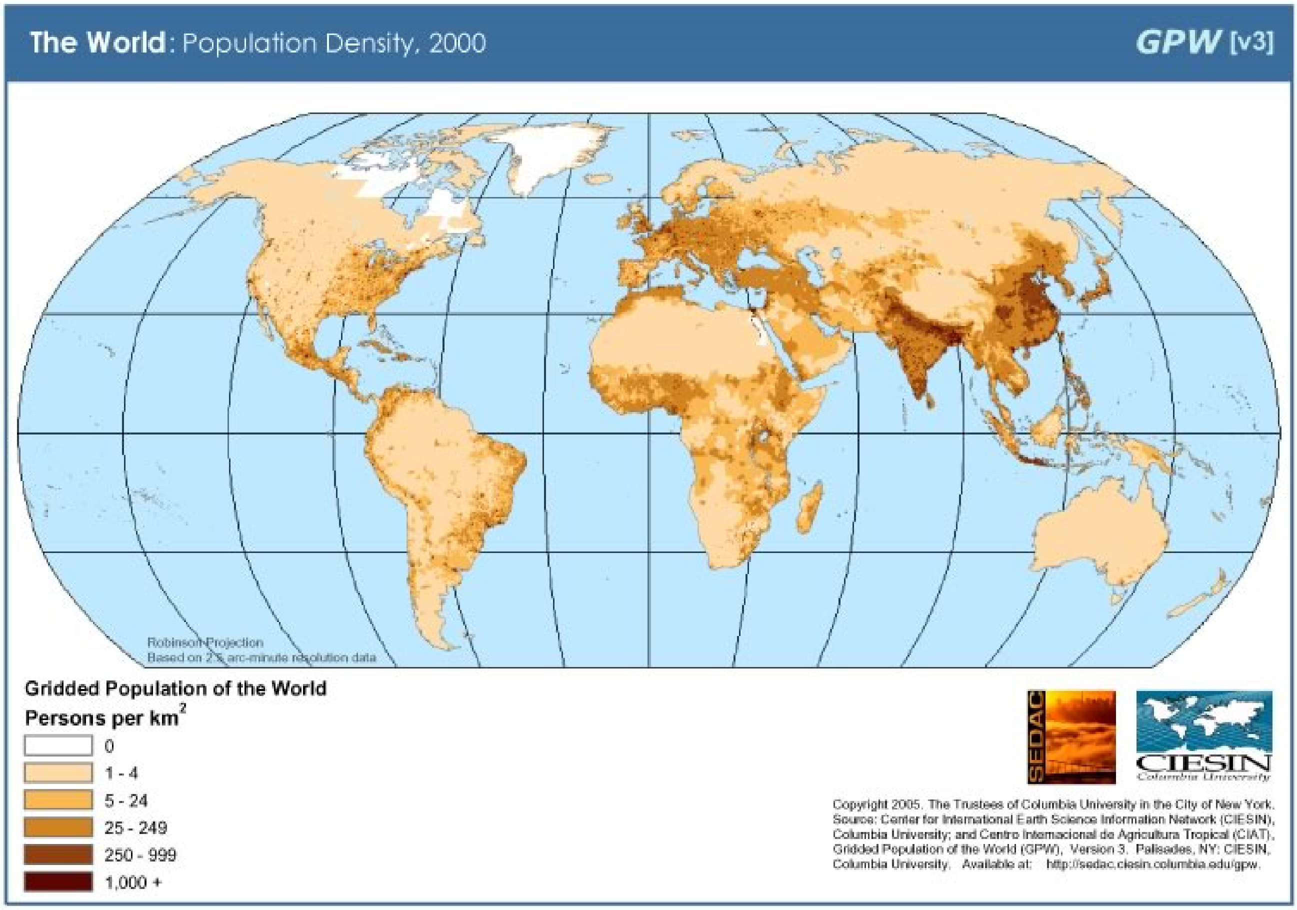


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Figure 38: The world population density, 2000 [191].

These above projected climate change impacts illustrate what will likely occur worldwide. The intensity and timing of these climate change impact will depend on how far humans push the climate system (e.g., from GHG emissions). Furthermore, each region will experience specific climate change impacts based on their particular geography and environment.

Africa

Africa is one of the most vulnerable continents to climate change and climate variability. Major economic sectors in Africa are vulnerable to climate change, which is aggravated by existing developmental challenges such as poverty; complex governance and institutional dimensions; limited access to capital, markets, infrastructure and technology; ecosystem degradation; and complex disasters and conflicts. These challenges contribute to weak adaptive capacity, which increases Africa's vulnerability to projected climate change[192].

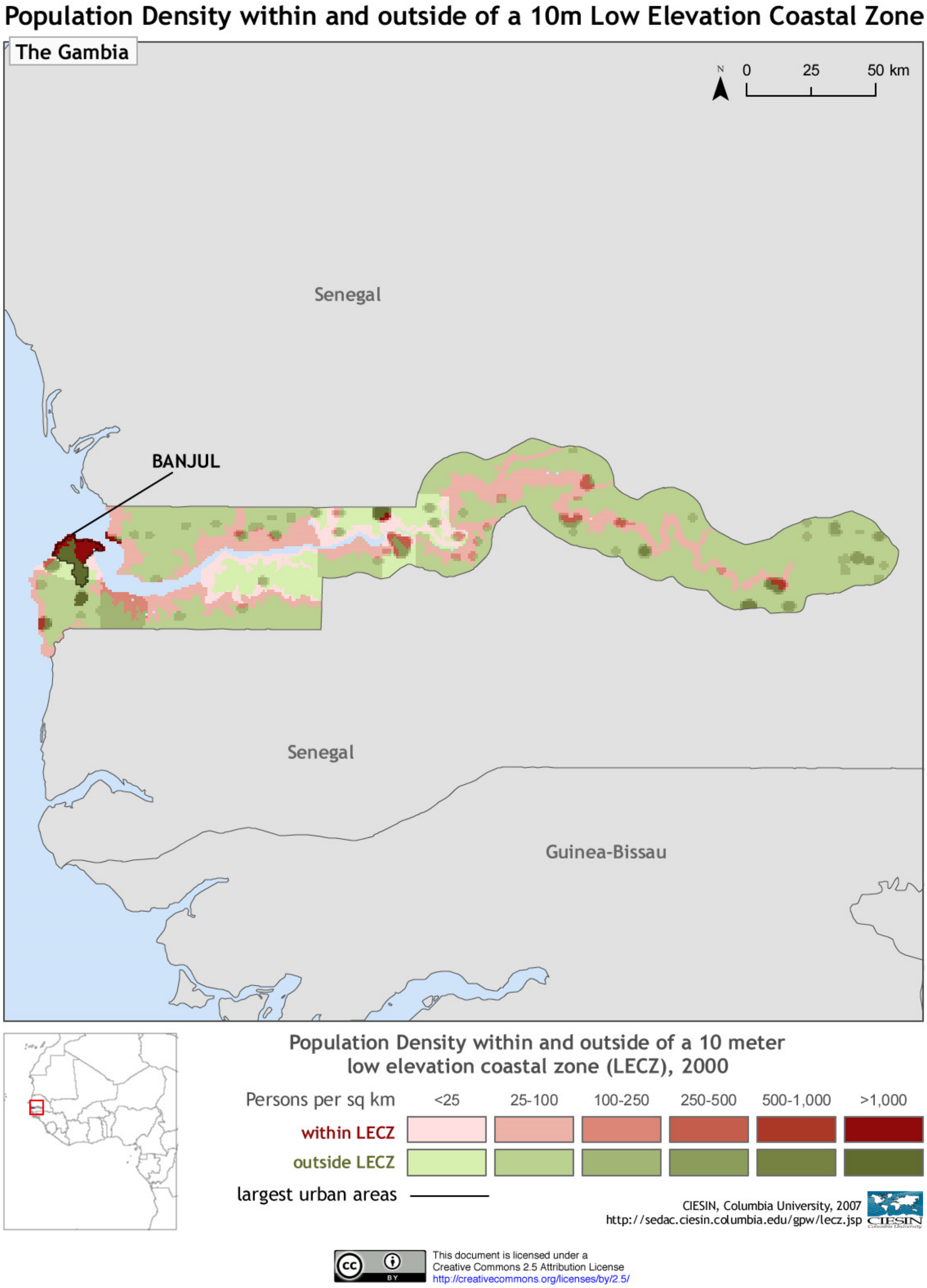


Figure 39: Population density within and outside of a 10 m low elevation coastal zone (LECZ) for The Gambia[193].

Climate change will increase the water stress currently experienced by some African countries; while some countries that currently do not experience water stress will become at risk of water stress. Even ignoring climate change, several African nations, particularly in northern Africa, will exceed the limits of their economically usable land-based water resources before 2025. About 25% of Africa's population (about 200 million people) currently experience high water stress. The population at risk of increased water stress in Africa is projected to be between 75 – 250 million and 350 – 600 million people by the 2020's and 2050's, respectively[192].

Agricultural production and food security (including access to food) in many African nations will likely be severely compromised by climate change and climate variability. Some African nations already experience semi-arid conditions that make agriculture difficult. Climate change will likely reduce the length of the growing season and drive large regions of marginal agriculture out of production. Crop yields may decline by as much as 50% by 2020 in some African countries. Crop net revenues could fall by as much as 90% by 2100. Sea level rise (see Figure 39) could degrade coastal agricultural and fishing areas. These factors would adversely affect food security in the continent[192].

Changes in a variety of ecosystems are already being detected, particularly in southern African ecosystems, at a faster rate than anticipated. Climate change, interacting with human drivers such as deforestation and forest fires are threatening African forest ecosystems, which provide food and water resources among other invaluable ecosystem services. Changes in grasslands and marine ecosystems, which support food production systems (e.g., livestock and fisheries) are also noticeable. By the 2080's, the proportion of arid and semi-arid lands in Africa is likely to increase by 5 – 8%[192].

Asia

Climate change has already affected many parts of Asia[192]. Crop yields in many Asian countries have declined, partly due to increasing temperatures and extreme weather events. Increasing temperatures have caused an unprecedented retreat of glaciers and permafrost in Asia in recent years. The frequency of occurrence of climate-induced diseases and heat stress in Central, East, South and South-East Asia has increased with rising temperatures and rainfall variability[192].

Future climate change is likely to impact agriculture in Asia, and increase the risk of hunger and water scarcity, as climate variability increases in intensity and as the rate of glacier melt accelerates. The IPCC[165] projects a 2.5 – 10% decrease in crop yields for parts of Asia by the 2020's and a 5 – 30% decrease by the 2050's compared with 1990 levels, ignoring CO_2 fertilization effects. Freshwater availability in Central, South, East and South-East Asia is likely to decrease due to climate change. Combined with climate change, population growth and a rising standard of living could adversely affect the food and water security of the Asian population. The IPCC[165] projects that between 120 – 1,200 million in Asia will likely experience increased water stress by the 2020's assuming BAU. By the 2050's, this number could range from 185 – 981 million people. An additional 49 million, 132 million and 266 million people in Asia could be at risk of hunger by 2020, 2050 and 2080, respectively.

In particular, there are two factors that combine to create a major environmental problem facing Asia: (1) the acceleration of the retreat of the Hindu Kush-Himalayan-Tibetan Plateau (HKHT) (see Figures 40 and 41) glaciers and snowpack since the 1970's; combined with (2) the decrease in the summer monsoon

Table 6: Nations and their estimated populations with national boundaries in the watersheds of the HKHT region, including those nations that are located in the river basins of the Amu Darya, Indus, Ganges, Brahmaputra, Irrawaddy, Salween, Mekong, Yangtze, Yellow River, and Tarim[195].

Nation	**Population in 2010**
China	1,354,146,000
Vietnam	89,029,000
Cambodia	15,053,000
Thailand	68,139,000
Laos	6,436,000
Myanmar	50,496,000
Bangladesh	164,425,000
Bhutan	708,000
Nepal	29,853,000
India	1,214,464,000
Pakistan	184,753,000
Afghanistan	29,117,000
Tajikistan	7,075,000
Turkmenistan	5,177,000
Uzbekistan	27,794,000
Kyrgyzstan	5,550,000
Kazakhstan	15,753,000
Total	3,267,968,000

rainfall in the Indo-Gangetic Plain region[194]. Climate change directly and indirectly threatens to adversely impact both the water and the food security of up to 3.3 billion people (47% of the global population) currently living in the HKHT watersheds that supply China, and South, South East, and Central Asia (including the Af-Pak region). The HKHT (especially the Greater Himalayas) holds the largest mass of ice outside the polar regions. The declining HKHT glaciers and snow packs are the source of the 10 largest river systems in Asia – the Amu Darya, Indus, Ganges, Brahmaputra, Irrawaddy, Salween, Mekong, Yangtze, Yellow River, and Tarim (see Figure 41). In effect, the water resources of the HKHT acts as the primary water reservoir for the surrounding region. Consequently, the HKHT is a major limiting factor in the human carrying capacity of the surrounding HKHT region.

Widespread and rapid reductions in the volumes and areas of HKHT glaciers are already occurring due to climate change. The cascading effects of rising temperatures and loss of ice and snow in the region are affecting water availability (amounts, seasonality), biodiversity (endemic species, predator-prey relations), ecosystem boundary shifts (tree-line movements, high elevation ecosystem changes), and global climate feedbacks (monsoonal shifts, loss of soil carbon)[192]. For instance, this deglaciation includes a 21% decline in the area of 466 glaciers that were studied in the Indian Himalayas[185]. If the current rate of ice retreat continues unabated, these glaciers and snow packs could shrink by up to 75% by the year 2050. Considering that much of the region's population already live in water-stressed environments, further reductions in water availability would greatly threaten the region's water and food security. For example, water availability in South and East Asia is approximately 2,000 – 3,000 m^3 per capita per year, which is much less than the global average of 8,549 m^3 per capita per year[159]. Additional water scarcity would increase the water insecurity experienced by the current water stressed population, while increasing the risk that additional people will become water-stressed in the future.

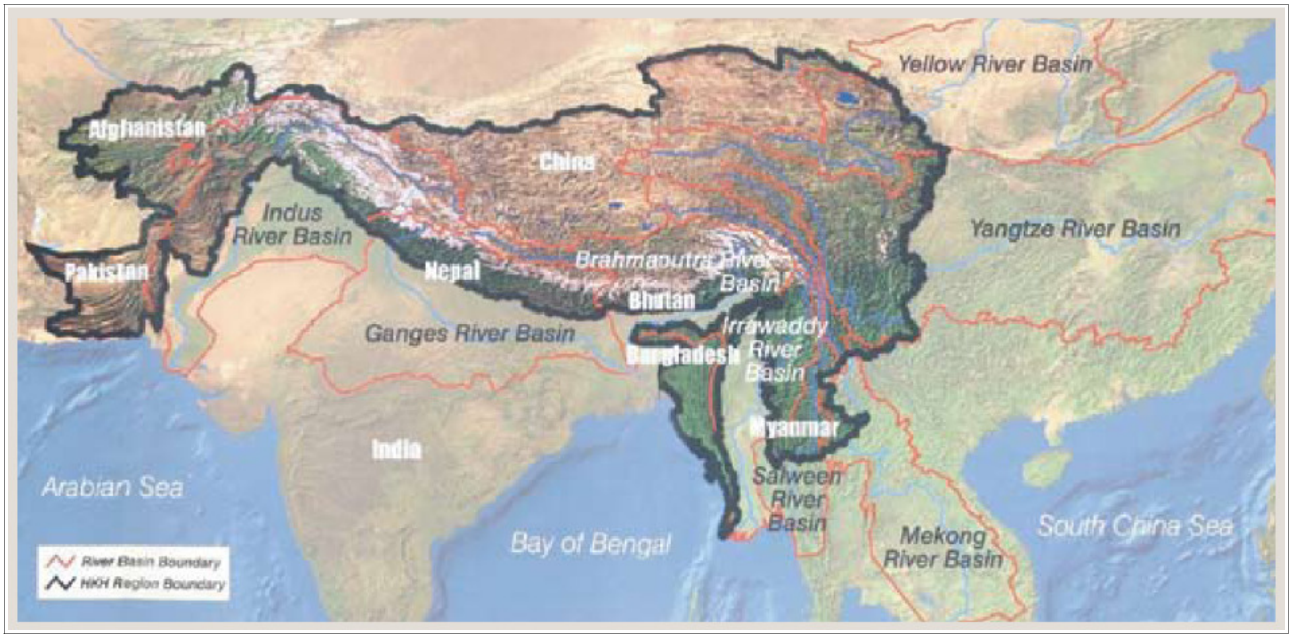


Figure 40: Map of the HKHT with major river basins[194]. The region in the center bounded by the black line denotes the the HKHT region. The regions bounded by the red lines denote the river basins downstream of the HKHT.

Although the HKHT ultimately affects the global climate system, the HKHT is also the "regulating area" for the regional climate of China, India, and much of Asia. Glaciers and snow cover play an important role in Earth's energy radiation budget. In summer, the vast highlands in Asia heat up more than the Indian Ocean, which results in a pressure gradient and a consequent flow of air and moisture from the ocean intensifying the Indian monsoon. This pressure gradient is changing due to the loss of glacial and snow cover in the Greater Himalayas, which is affecting the pattern of the monsoons[196]. Consequently, the dry season will become more arid, and the rainy season will experience increased precipitation levels within shorter time intervals. The increase in heavy rain will likely increase the frequency and intensity of floods in the region[196].

Table 6 [195] shows the countries and their estimated populations that have their national boundaries in the watersheds of the HKHT region, including those nations that are located in the river basins of the Amu Darya, Indus, Ganges, Brahmaputra, Irrawaddy, Salween, Mekong, Yangtze, Yellow River, and Tarim. In total, there are nearly 3.3 billion people (about 47% of the current global population) who inhabit these countries. Kazakhstan is included in this figure since the Amu Darya watershed supplies the shrinking Aral Sea area (part of Kazakhstan's territory) with water from HKHT. Since the population of Kazakhstan is about 15,753,000 the inclusion of its population does not substantially skew the 3.3 billion estimate of the region's population at this scale. Overall, climate impacts on the HKHT will likely exacerbate regional economic and political instability, and encourage more humanitarian crises. Water, food, economic, and environmental stresses may stimulate internal and transboundary conflicts in region. Regional conflict, particularly over water resources, could become particularly disastrous especially considering that China, India, Pakistan, Russia, and possibly Iran are nuclear states.

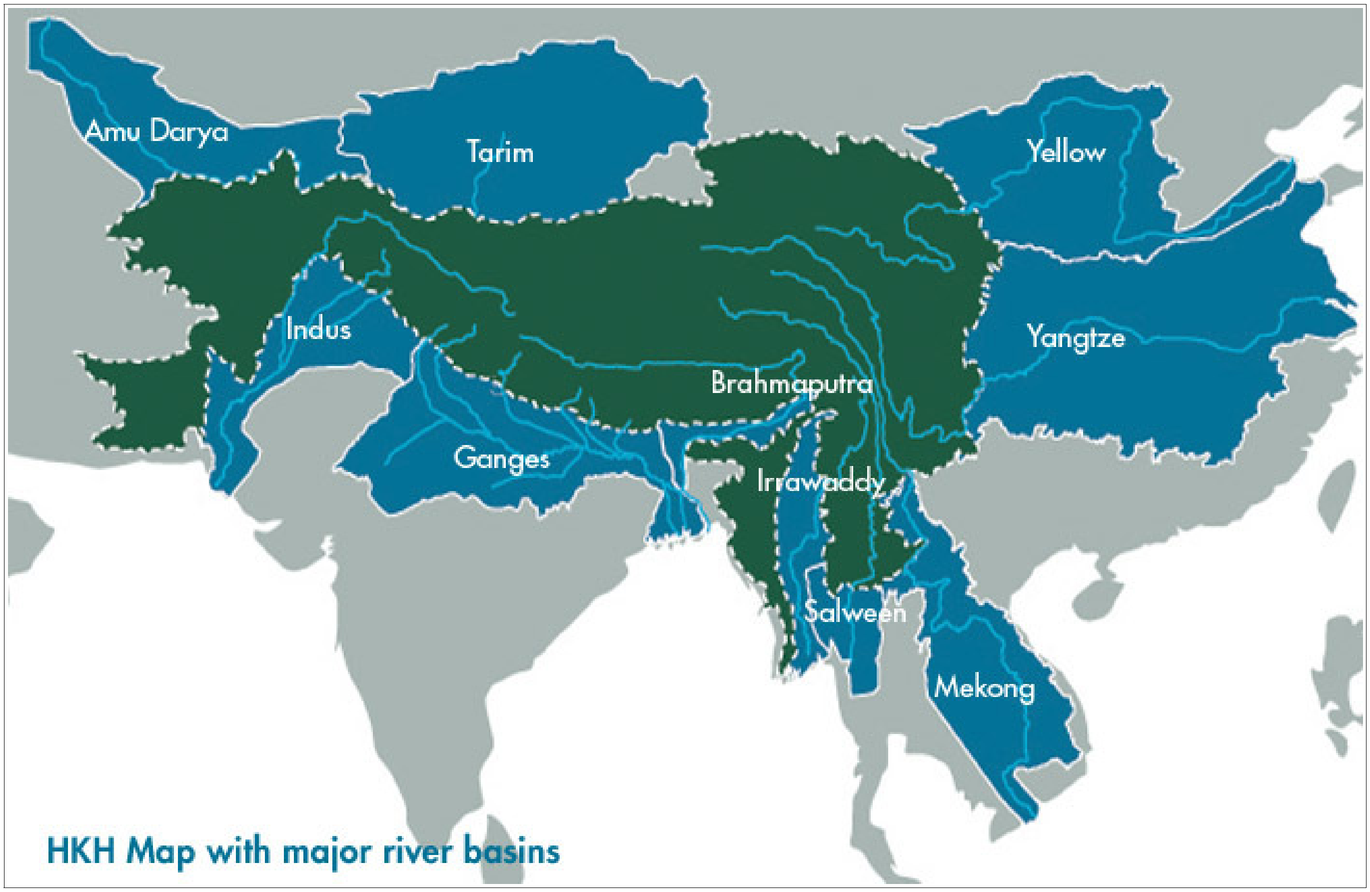


Figure 41: Map of the HKHT with major river basins. The dark green region in the center denotes the the HKHT region. The dark blue regions denote the river basins downstream of the HKHT[197].

In addition to the water and food security issues raised by the climate change impacts on the HKHT, marine and coastal ecosystems in Asia are likely to be affected by sea level rise (see Figures 42, 44, and 45) and temperature increases[192]. Projected sea level rise is very likely to cause significant losses of coastal ecosystems. Millions of people and their associated food production systems along the coasts of East, South, and South-East Asia also will likely be at risk from flooding due to sea level rise[192]. Seawater intrusion due to sea level rise and decreasing river runoff is likely to increase the habitat of brackish water fisheries. However, coastal inundation is likely to seriously impact the aquaculture industry and infrastructure, particularly in heavily-populated, heavily-cultivated megadeltas like the very large Mekong River Delta[192] (see Figure 42). The stability of wetlands, mangroves and coral reefs (all of which support fisheries) around Asia will likely decline at an accelerated rate. For example, 24% and 30% of the coral reefs in Asia are likely to be lost during the next 10 years and 30 years, respectively[192]. This loss could have unanticipated impacts on the viability of marine fisheries that supply food (see *Coastal Areas* below).

Between the HKHT water security, coastal, and general climate change threats, human carrying capacities of Asia will likely be severely impacted (i.e., reduced) in the coming decades. Nearly 50% of the global population lives in countries dependent on the watersheds of the HKHT. Countless millions live in the food productive river basins and coastal areas around Asia. Already, the carrying capacity in terms of food, water, and energy resources of Asia is strained. Undoubtedly, climate change impacts will be particularly severe for this region.

Australia and New Zealand

Regional climate change in Australia and New Zealand is already occurring. Since 1950, there has been an average 0.4 – 0.7°C warming in the region – with more heatwaves, fewer frosts, and more rain in north-west Australia and south-west New Zealand; less rain in southern and eastern Australia and north-eastern New Zealand; an increase in the intensity of Australian droughts; and an approximate 70 mm rise in sea level[192]. Australia and New Zealand are already experiencing substantial impacts from recent climate change, such as increasing stresses on water supply and agriculture, changed natural ecosystems, reduced seasonal snow cover, and glacier shrinkage. Some adaptation in the region has already occurred in response to observed climate change in sectors such as water resources, natural ecosystems, agriculture, and coastal management. However, ongoing vulnerability to extreme climate events is demonstrated by substantial economic losses caused by droughts, floods, fire, tropical cyclones and hail[192].

The climate of the 21st Century for Australia and New Zealand will almost certainly be much warmer[192]. Heatwaves and wildfires are virtually certain to increase in intensity and frequency. Floods, landslides, droughts, and storm surges are very likely to become more frequent and intense; while snow and frost are very likely to decrease in frequency. Large areas of mainland Australia and eastern New Zealand are likely to experience reduced soil moisture, although western New Zealand is likely to receive more rain.

Potential impacts of climate change are likely to be significant without further adaptation[192]. As a result of reduced precipitation and increased evaporation, water security problems will likely intensify by 2030 in southern and eastern Australia, and in Northland and some eastern regions in New Zealand. By 2050, ongoing coastal development and population growth are likely to increase risks from sea level rise, and from increases in the severity and frequency of storms and coastal flooding. A significant loss of biodiversity will likely occur by 2020 in some ecologically rich sites, which could negatively impact ecosystem services such as food and water services. Increased drought and wildfires will likely cause agricultural and forestry production to decline by 2030 in much of southern and eastern Australia, and over parts of eastern New Zealand. However, initial benefits to agriculture and forestry yields may occur in western and southern areas in New Zealand and close to major rivers due to a longer growing season, less frost, and increased rainfall.

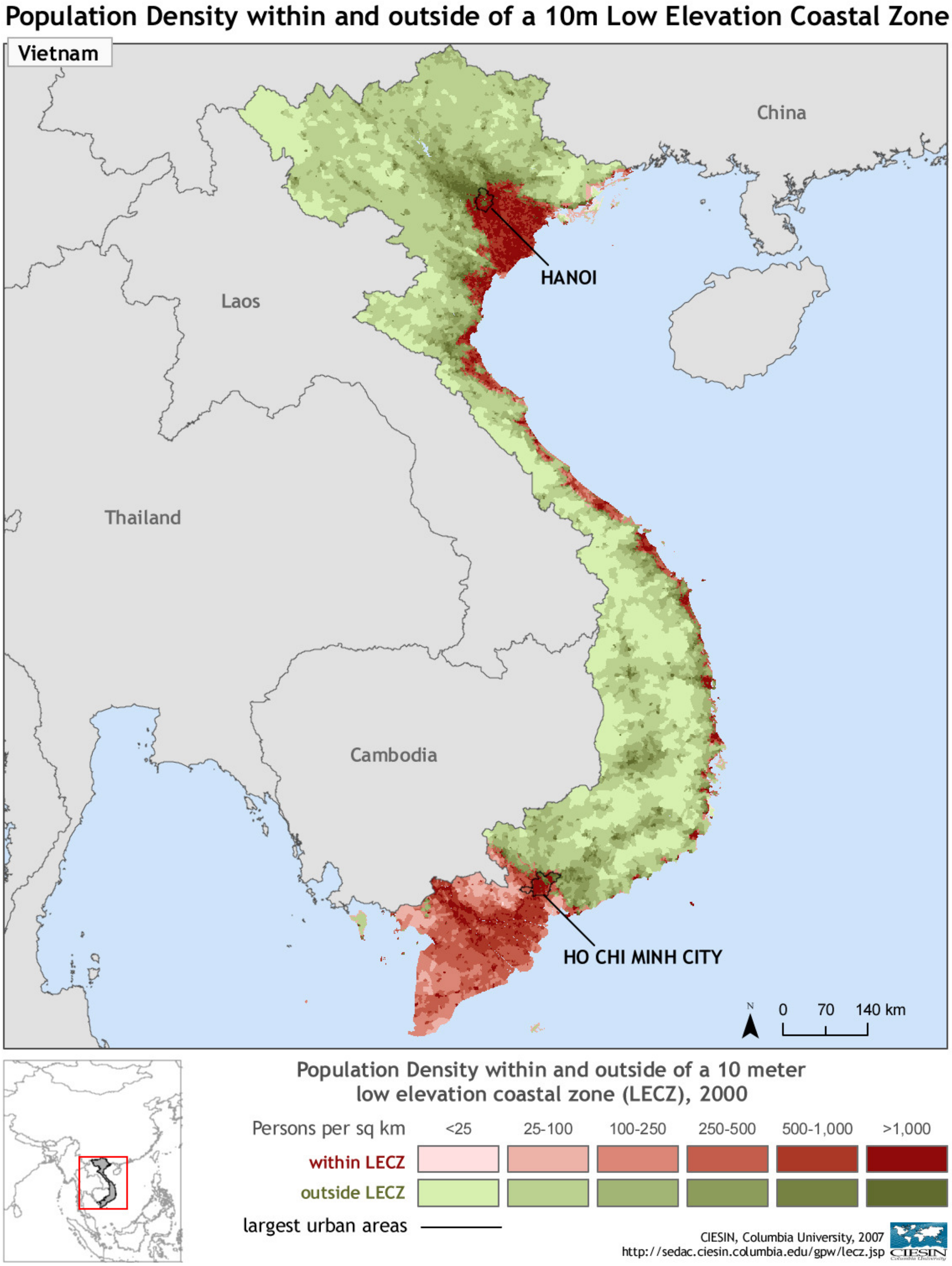


Figure 42: Population density within and outside of a 10 m low elevation coastal zone (LECZ) for Vietnam[193].

Coastal Areas

Coasts are experiencing adverse consequences of hazards related to climate change and sea level rise (see Figure 43). Coasts are highly vulnerable to extreme weather events (e.g., storms), which impose substantial costs on coastal societies. Annually, about 120 million people are exposed to tropical cyclone hazards, which killed approximately 250,000 people from 1980 – 2000 [192]. Through the 20th Century, global rise of sea level contributed to increased coastal inundation, erosion and ecosystem losses with considerable local and regional variation due to other factors[192]. The cumulative effects of rising temperature on marine systems in the past century include the loss of sea ice, thawing of permafrost and concomitant coastal land retreat, and more frequent coral bleaching and mortality.

Coastal areas will be exposed to increasing risks (e.g., coastal erosion, flooding) in the next few decades due to climate change and sea level rise. Anticipated climate-related changes include[192]: an accelerated rise in sea level of up to 0.6 m or more by 2100; a further rise in sea surface temperatures by up to 3°C; an intensification of tropical and extra-tropical cyclones; larger extreme waves and storm surges; altered precipitation/run-off patterns; and ocean acidification. These phenomena will vary considerably at regional and local scales, but the impacts are virtually certain to be overwhelmingly negative, including in terms of food and water security[192]. Degradation of coastal ecosystems, especially wetlands and coral reefs, has serious implications for the well-being of societies dependent on coastal ecosystems for goods (e.g., food) and services (e.g., provision of clean freshwater). As a result of sea level rise, increased storm surges, coastal erosion and ecosystem loss, increased flooding and the degradation of freshwater supplies, fisheries, soil, and other natural resources could negatively impact hundreds of millions of people.

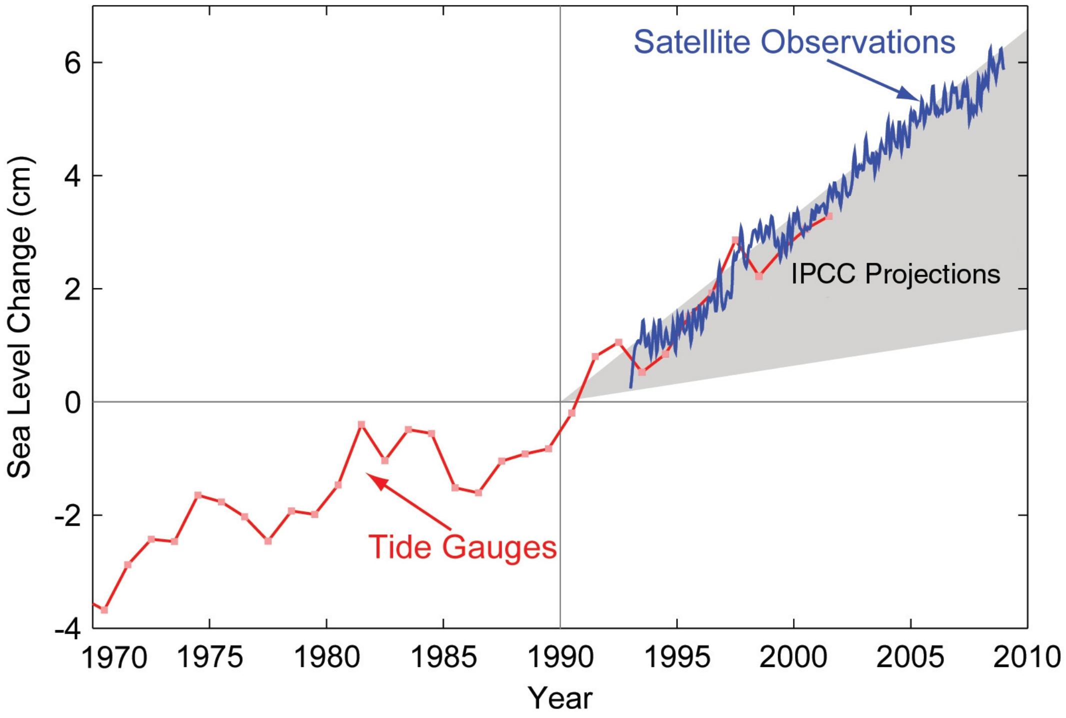


Figure 43: Sea level change during 1970 – 2010 [181]. The tide gauge data are indicated in red[198] and satellite data in blue[199]. The grey band shows the projections of the IPCC Third Assessment report for comparison.

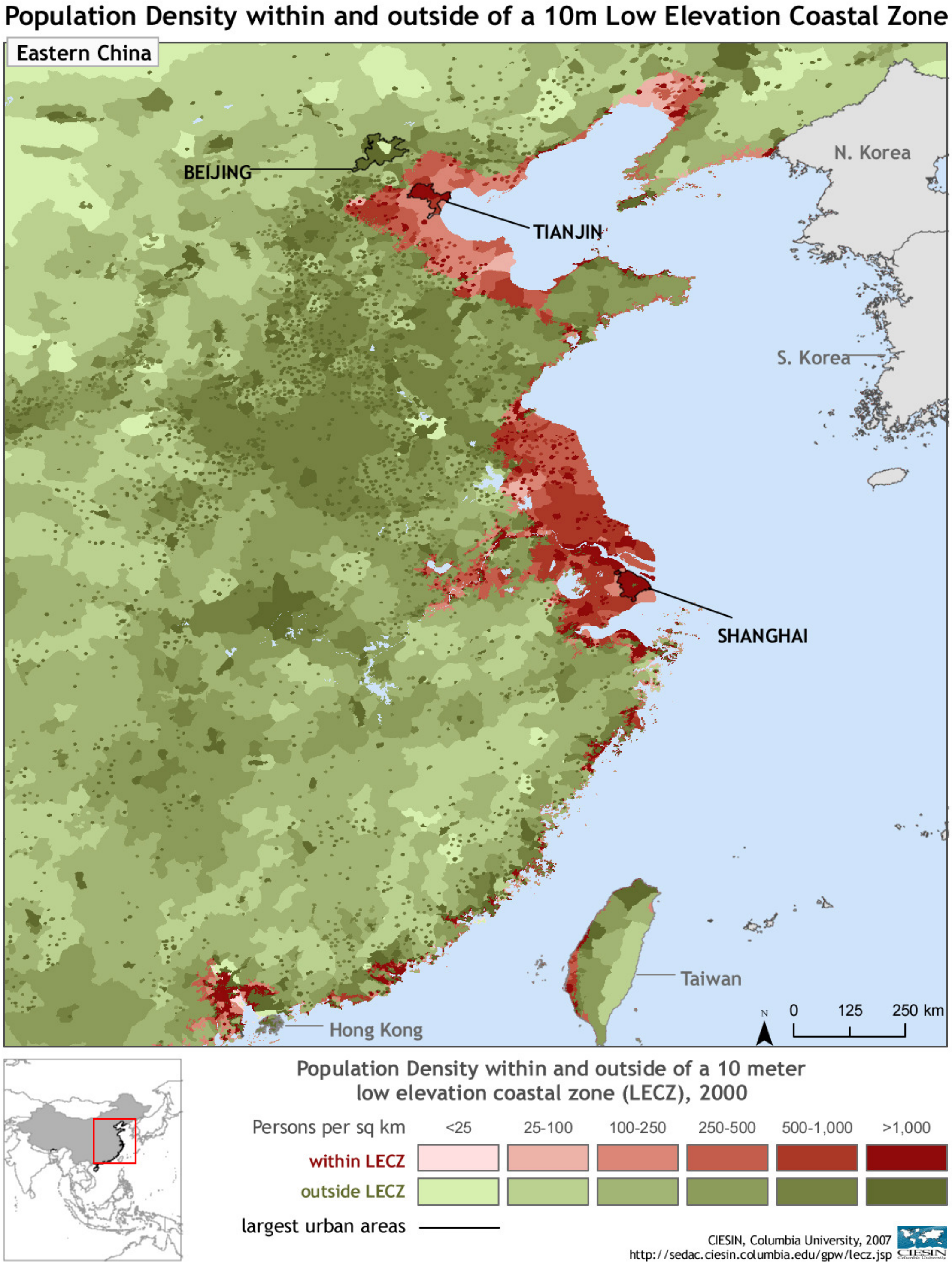


Figure 44: Population density within and outside of a 10 m low elevation coastal zone (LECZ) for eastern China[193].

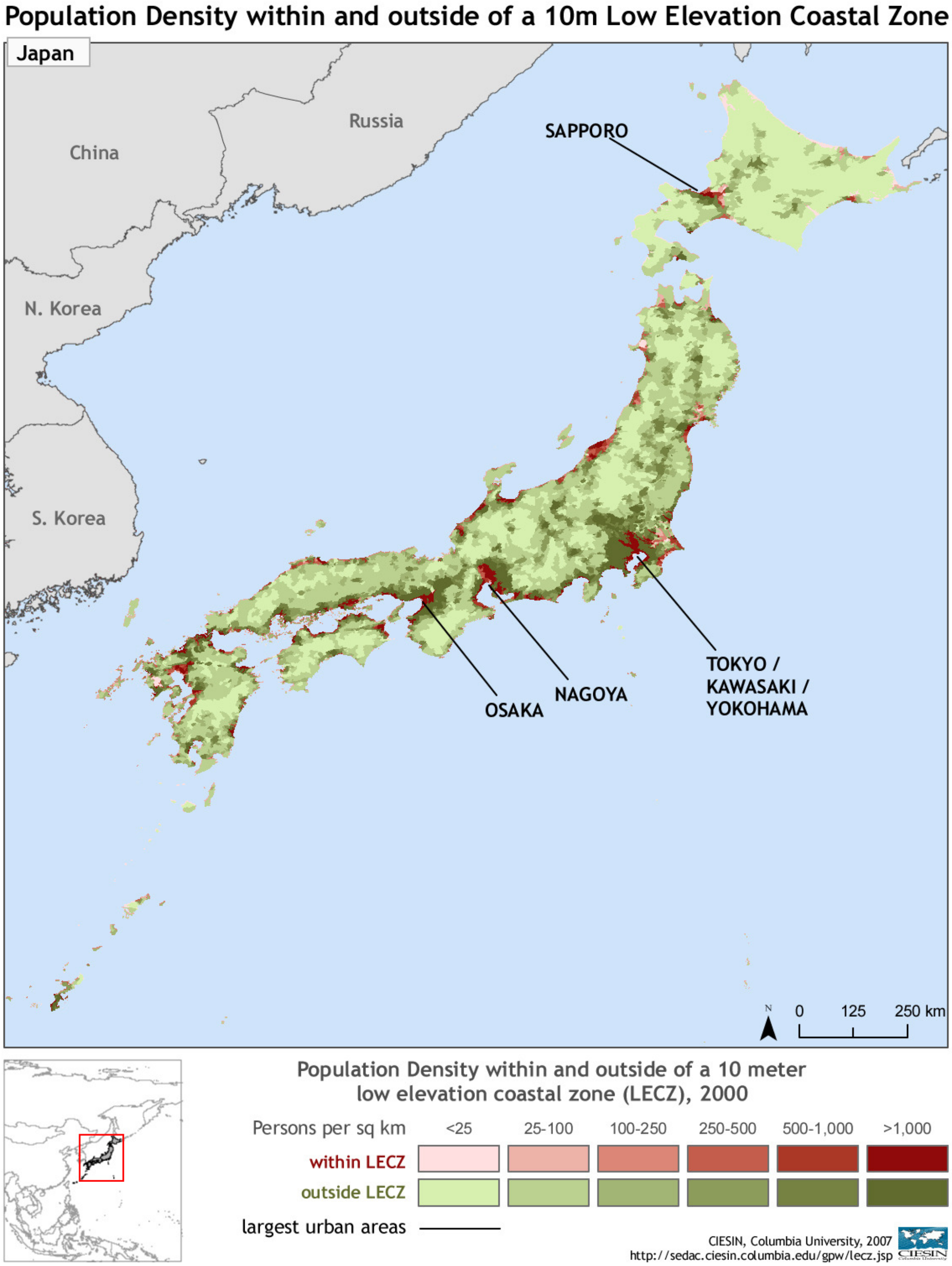


Figure 45: Population density within and outside of a 10 m low elevation coastal zone (LECZ) for Japan[193].

The impacts of climate change on coastal areas are aggravated by increasing human-induced pressures. Utilization of the coast increased dramatically during the 20th Century and this trend is virtually certain to continue through the 21st Century. Low elevation coastal zones (LECZs) are the continuous area along coastlines that is less than 10 m above sea level. LECZs account for 2% of the world's land area but have 10% of the global population and 13% of global urban population[200,201]. Many countries that have a large proportion of their population in LECZs are small island countries, but most of the countries with large populations in LECZs are large countries with heavily populated delta regions[201] (see Figures 39, 42, 44 – 49). Cities located near the sea, along river banks, or in a river delta are usually the largest cities in all regions of the world[200]. Of the world's 19 largest cities, 14 are port cities that are located on a coastline or in a river delta[200]. Of the world's 20 megacities, 13 are located along coastlines[200]. In total, there are 3,351 cities located in low elevation coastal zones around the world[200]. The IPCC[192] projects that global coastal population will grow from 1.2 billion people (in 1990) to 1.8 – 5.2 billion people by the 2080's, depending on assumptions about migration. Populated river deltas (especially Asian megadeltas) and low elevation coastal urban areas and islands are very vulnerable since the stresses on natural systems often coincide with low human adaptive capacity and high risk exposure. Regionally, South, South-East and East Asia, Africa, and small islands are most vulnerable.

Europe

A wide range of climate change impacts have already been observed in Europe[192]. A warming trend and spatially variable changes in precipitation have affected the composition and functioning of both the cryosphere (e.g., retreat of glaciers, melting of permafrost), and natural and managed ecosystems (lengthening of growing season, shift of species). The observed changes are consistent with projections of impacts due to climate change[192].

Climate-related hazards will mostly increase in Europe, although the changes will vary geographically[192]. Winter floods are likely to increase in maritime regions, while flash floods are likely to increase throughout Europe. Coastal flooding related to increasing storm activity and sea level rise will likely threaten up to 1.6 million additional people annually (see Figure 46). Warmer, drier conditions will lead to more frequent and prolonged droughts, in addition to a longer wildfire season and increased fire risk, particularly in the Mediterranean region. During dry years, catastrophic wildfires will likely occur on the drained peatlands in central Europe. The frequency of rock falls will increase due to destabilization of mountain walls by rising temperatures and melting of permafrost. Without adaptive measures, health risks will likely increase due to more frequent heatwaves (particularly in central and southern Europe), flooding, and greater exposure to vector- and food-borne diseases. Although some climate change impacts may be positive (e.g., reduced risk of extreme cold events due to increasing winter temperatures), overall health risks are very likely to increase.

Climate change is likely to magnify regional differences of Europe's natural resources[192]. Climate change will likely significantly increase average temperatures in Europe – resulting in warmer winters in the northern Europe, and warmer summers in southern and central Europe. Mean annual precipitation will likely increase in the north and decrease in the south. The suitability to grow certain types of crops in particular regions is likely to change throughout Europe. Crop productivity (all other factors remaining unchanged) is likely to increase in northern Europe, and decrease along the Mediterranean and in south-eastern Europe. Forests will likely expand in the northern Europe and retreat in the south. Forest

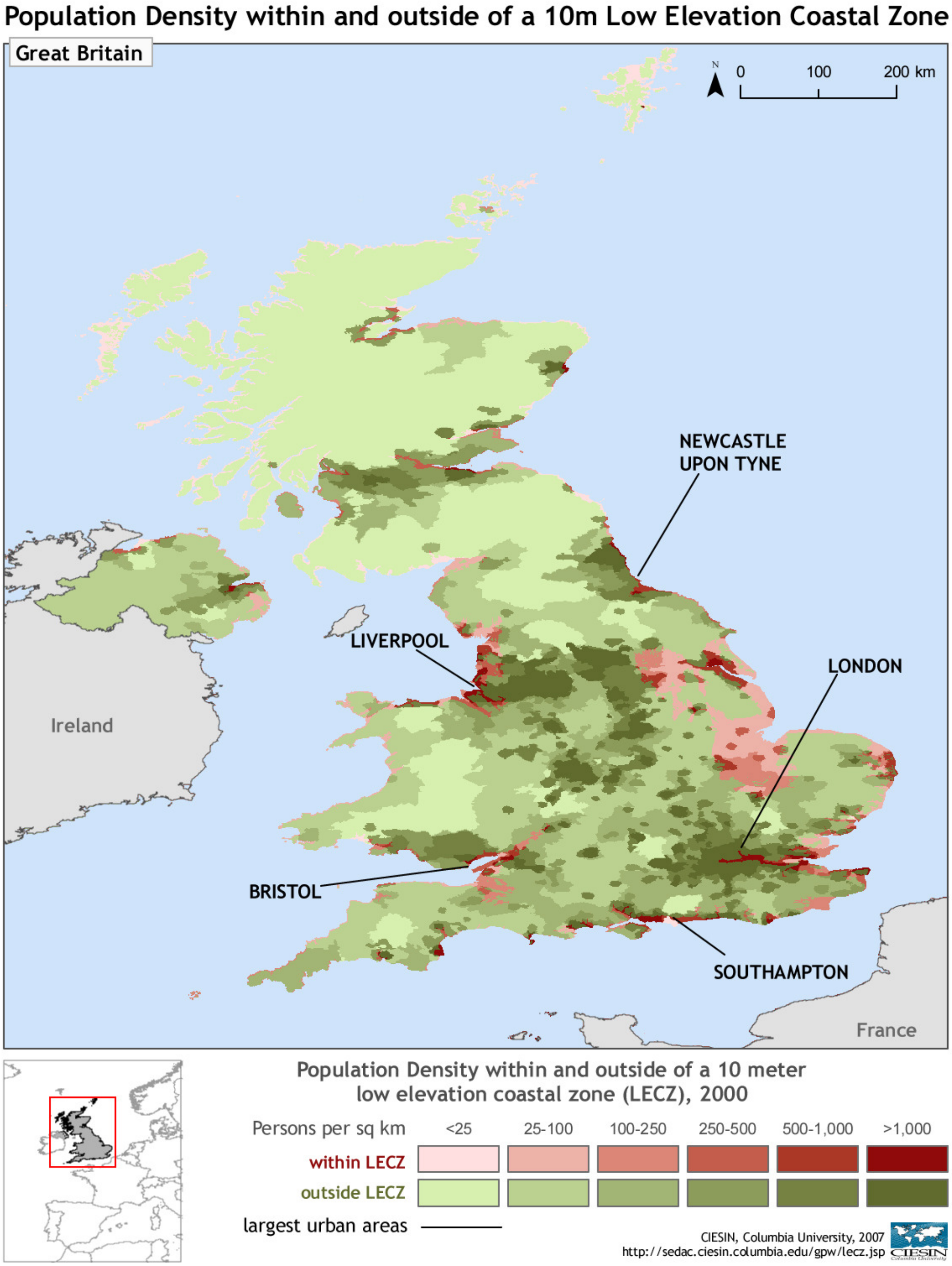
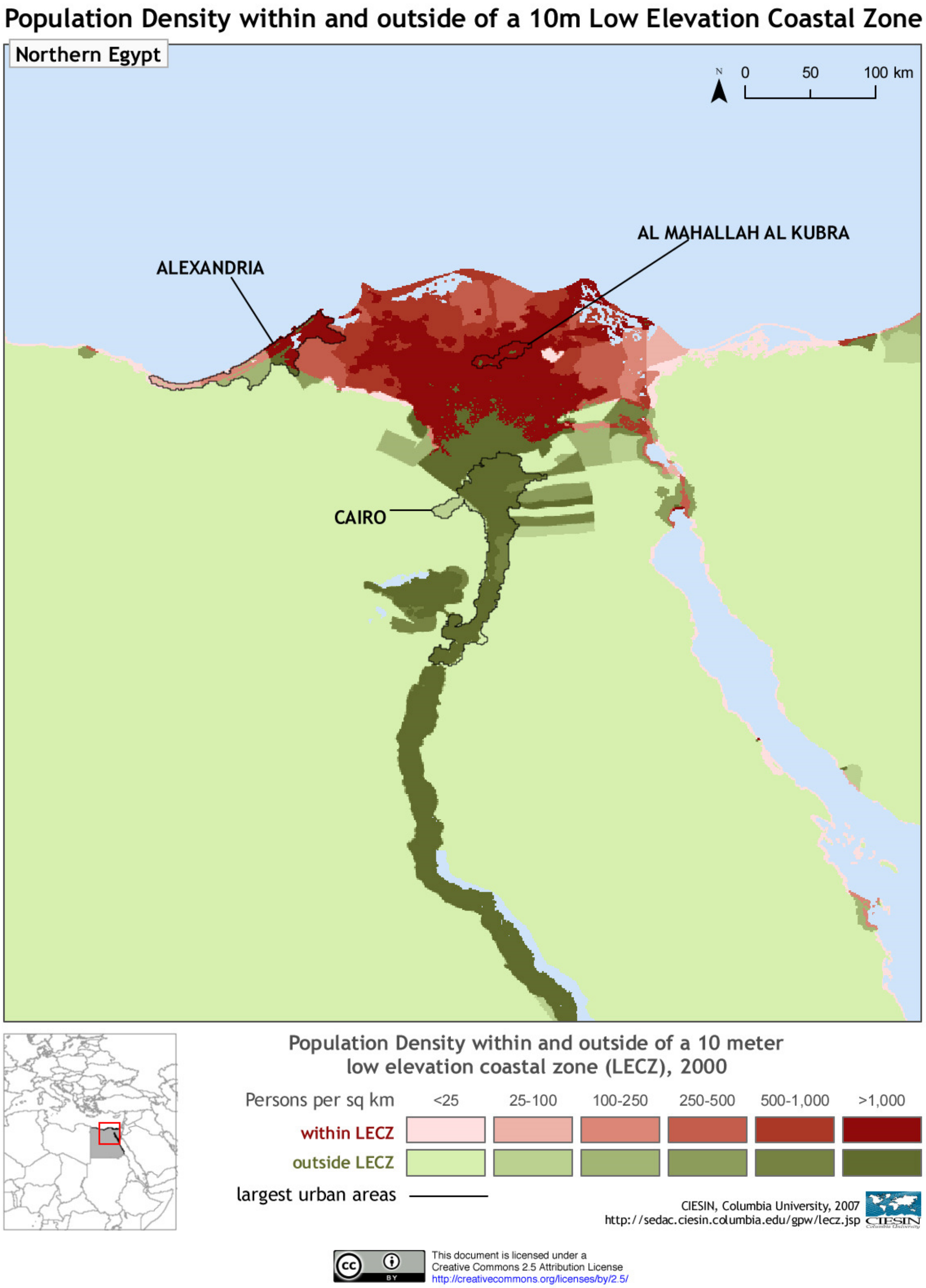


Figure 46: Population density within and outside of a 10 m low elevation coastal zone (LECZ) for Great Britian[193].



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http://sedac.ciesin.columbia.edu/gpw/lecz.jsp

Figure 47: Population density within and outside of a 10 m low elevation coastal zone (LECZ) for northern Egypt[193].

productivity and total biomass is likely to increase in the north and decrease in central Europe, while tree mortality is likely to accelerate in the south. Differences in water availability between regions will likely become more dramatic with annual average runoff increases in northern and north-western Europe, and decreases in south and south-eastern Europe.

The number of people that will live in river basins under high water stress will likely increase in Europe, especially in central and southern Europe[192]. The percentage area under high water stress is likely to increase from 19% in 2007 to 35% by the 2070's, with between 16 – 44 million additional people affected by water stress by the 2070's. The most affected regions will be southern Europe and some parts of central and eastern Europe, where summer flows may be reduced by up to 80%.

Middle East

Climate change may present a very serious threat to human security in the Middle East. The Middle East is already challenged with scarce water, food insecurity, poverty, and social and political instability, each of which will likely be exacerbated by climate change[192]. Climate change will most likely create a hotter, drier and less predictable climate for the region. Higher temperatures and decreased precipitation will reduce water supplies, slow the recharge rate of aquifers, raise sea levels (see Figure 47), and make the entire region more arid. These changes will seriously impact water, food, and environmental security[192]. For instance, under moderate temperature increases, the flow of the Euphrates River could decrease by 30% and the Jordan River by 80% by the end of the 21st Century. Climate change and water scarcity could decrease agricultural productivity and make global food prices increasingly volatile as populations and food demand grow. It is likely that these climate-induced pressures will stimulate further social and political volatility and conflict over resources in the Middle East in the future.

North America

Climate-related changes are already observed in the North America, including increases in heavy rainfall, increases in temperature, sea level rise, rapidly retreating glaciers, thawing permafrost, lengthening growing seasons, lengthening ice-free seasons on the ocean and on lakes and rivers, earlier snowmelt, and changes in river flows[202]. U.S. average temperature has increased by more than 1ºC over the past 50 years. The global average temperature since 1900 has increased by approximately 0.76ºC. By 2100, the U.S. average temperature will likely increase more than the global average (1 – 6ºC) by 2100 [202].

Many types of extreme weather events (e.g., heat waves and droughts) have increased in frequency and intensity during the past 40 – 50 years[202]. Precipitation has increased an average of about 5% over the past 50 years. Future precipitation will likely increase in northern latitudes, while southern regions, particularly in the West, will become drier. The amount of precipitation in the heaviest rain events has increased approximately 20% on average in the past century. More intense rainfall is very likely to continue, with the largest increases in the wettest regions. Cold-season storm tracks are shifting northward. The frequency and intensity of these storms is likely to increase with projected climate change. Atlantic hurricanes have become more intense (i.e., more powerful) in recent decades. The intensity of these storms is likely to increase in this century. Since the 1980's, the strongest hurricanes in

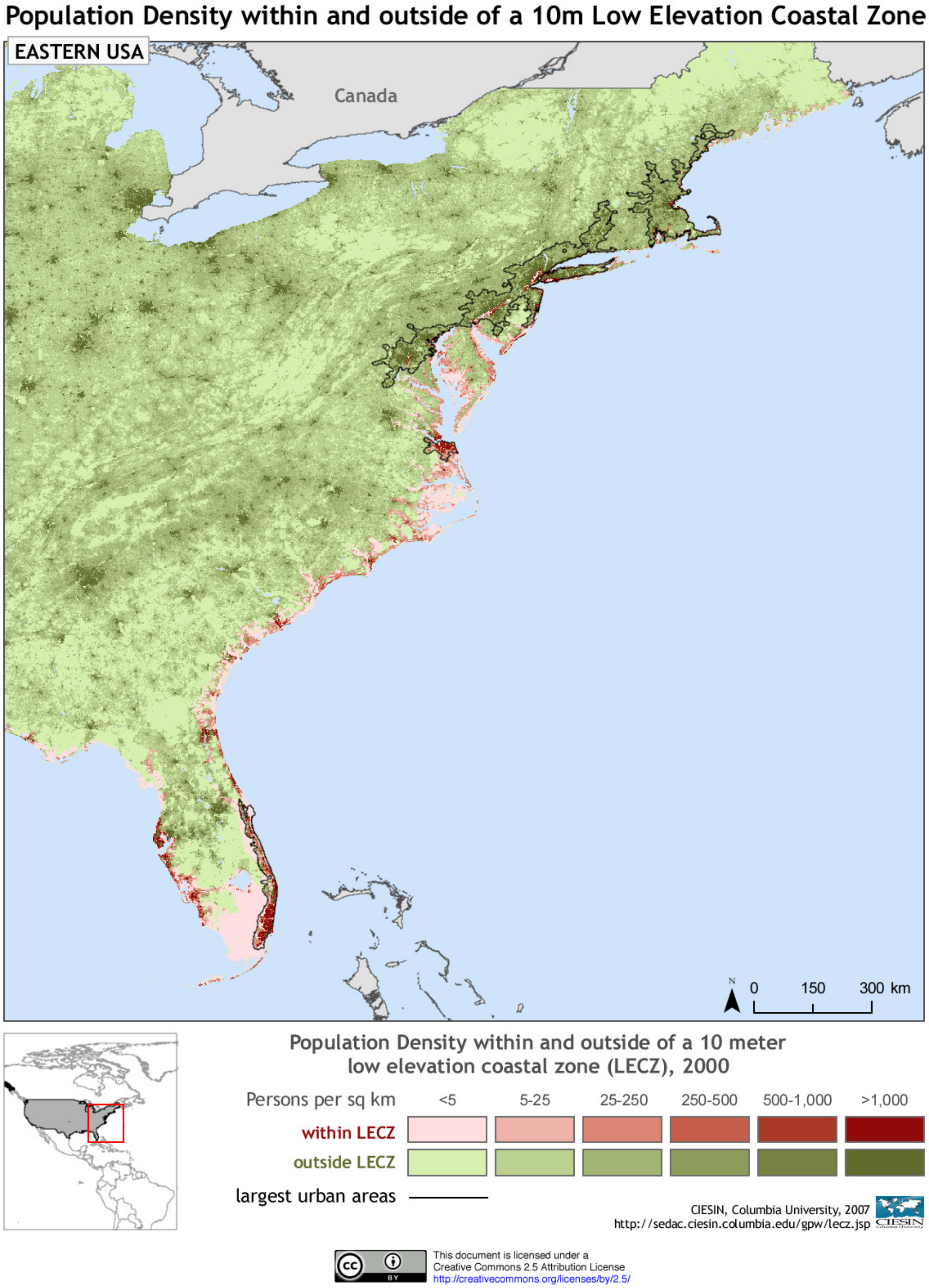


Figure 48: Population density within and outside of a 10 m low elevation coastal zone (LECZ) for the eastern United States of America[193]*.*

the eastern Pacific have become more powerful, while the total number of storms has decreased. Sea level rise (see Figure 48) and potential storm surges expose many U.S. coastal areas at increasing risk of erosion and flooding, especially along the Atlantic and Gulf Coasts, Pacific Islands, and parts of Alaska.

Climate change has already altered the hydrological cycle throughout North America[202]. As regional and seasonal precipitation patterns change, and as precipitation occurs in more concentrated heavy rainfall events – with longer, hotter dry periods in between – floods and droughts will likely become more common and more intense. Precipitation and runoff will likely increase in the Northeast and Midwest and in Canada during winter and spring; and decrease in the West, especially the Southwest, in spring and summer. In areas where snowpack supplies most of the water runoff, runoff will continue to shift to earlier in the spring, while runoff flows will decrease in late summer. In addition, surface water and groundwater quality and quantity will be impacted by climate change, which will increase water scarcity in already stressed water systems.

Many crops show positive responses to elevated CO_2 and low levels of temperature increase, but higher levels of warming often negatively affect crop yields[202]. Extreme events, such as heavy precipitation and droughts, will likely reduce crop yields, because excesses or deficits of water can damage crops, livestock, and cropland. Crops may become more vulnerable to weeds, diseases and insect pests, which can benefit from increased temperatures and other climate-related factors. Furthermore, increased heat, disease, and weather extremes will likely reduce livestock productivity.

Risks to human health will increase in North America, including health impacts related to increasing heat stress, waterborne diseases, poor air quality, extreme weather events, and diseases transmitted by insects and rodents[202]. However, reduced cold stress may reduce some of the occurrences of cold-related mortality and disease.

Small Island States

Small island states (SIS), whether located in the tropics or higher latitudes, have characteristics which make them especially vulnerable to the effects of climate change, sea level rise, and extreme weather events[192]. Characteristics such as limited size, proneness to natural hazards, and other external shocks (e.g., loss of food imports) enhance the vulnerability of islands to climate change. In most cases, SIS have low adaptive capacity, and adaptation costs are high relative to gross domestic product (GDP). Sea level rise will exacerbate inundation, storm surge, erosion and other coastal hazards, which will threaten vital infrastructure, settlements and facilities that support the livelihoods of island communities. Furthermore, sea level rise could significantly decrease the size of many islands (i.e., reduce the surface area).

Water resources on small islands will likely be seriously compromised[192]. Most small islands have a limited freshwater supply. Water resources on SIS are especially vulnerable to future changes in the amount of and distribution in precipitation. For example, many islands in the Caribbean are likely to experience increased water stress as a result of reduced rainfall in summer, so that it is unlikely that water demand would be met during low rainfall periods. Increased rainfall in winter is unlikely to compensate, due to high runoff and a lack of storage during storms. Many small islands have begun to invest in the implementation of adaptation strategies, including desalination, to offset current and projected water shortages.

Climate change is likely to heavily impact coral reefs, fisheries and other marine-based resources[192]. Changes in the occurrence and intensity of El Niño-Southern Oscillation (ENSO) events are likely to have severe impacts on commercial and artisanal fisheries. Increasing sea surface temperatures; sea level; water turbidity; nutrient loading; chemical pollution; damage from tropical cyclones; and decreases in coral and fish growth rates due to the effects of higher CO_2 concentrations on ocean chemistry; are all very likely to affect the health of coral reefs and other marine ecosystems which sustain island fisheries.

Forests provide valuable ecosystem services, including the provision of food and water resources. Forests can require long periods of time to regenerate. In the short term, increases in extreme weather events are virtually certain to affect the adaptation responses of forests on tropical islands[192]. Forests on many islands can easily be decimated by violent cyclones or storms. However, it is possible that forest cover will increase on some high-latitude islands[192].

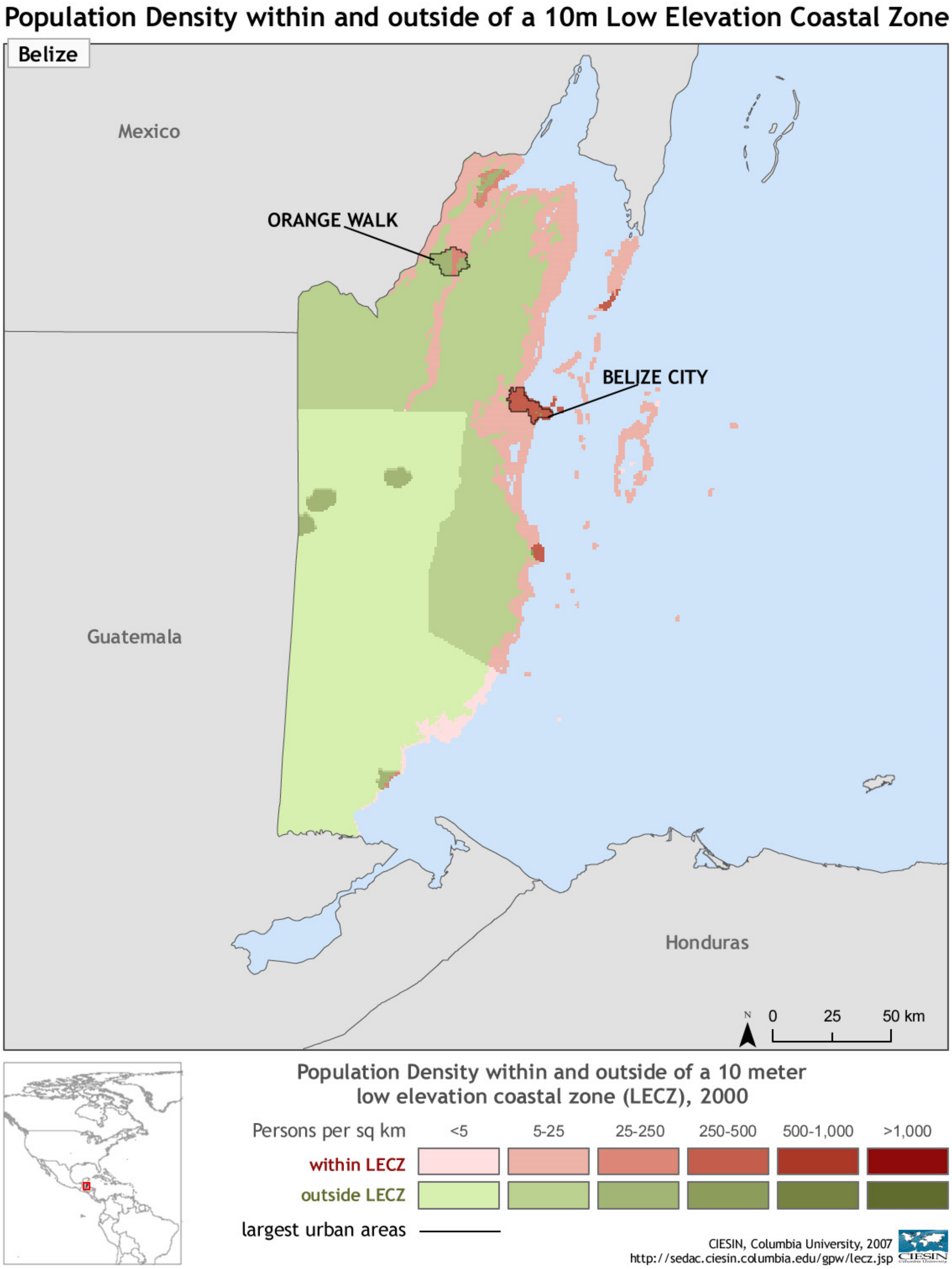
It is very likely that subsistence and commercial agriculture on small islands will be adversely affected by climate change[192]. Sea level rise, inundation, seawater intrusion into freshwater aquifers, soil salinization, and declines in water supply will very likely adversely impact coastal agriculture. Away from the coast, increases in extreme climate events (e.g., flooding and drought) are likely to have a negative effect on island food production. Appropriate adaptation measures may help to reduce these impacts. In some high-latitude islands, new opportunities may arise for increased agricultural production.

South America

Climatic variability and extreme weather events have severely affected regions of South America in recent years[192]. Highly unusual extreme weather events have occurred in the past decade. Significant changes in precipitation and increases in temperature have occurred during the last few decades. Increases in rainfall and increased flood frequency and intensity have had impacts on land use and crop yields in south-east Brazil, Paraguay, Uruguay, the Argentinean Pampas and some parts of Bolivia. Conversely, precipitation has declined in southern Chile, south-west Argentina, southern Peru and western Central America.

Glacier retreat is accelerating as a consequence of temperature increases[192]. This issue is critical in Bolivia, Peru, Colombia and Ecuador, where water availability has already been compromised either for consumption or for hydropower generation. These problems with water supply will likely increase in the future; and will likely become chronic, if no appropriate adaptation measures are implemented[192]. Over the next few decades, tropical glaciers in the Andes Mountains region will very likely disappear, which will affect the availability of water resources and hydropower generation. By the 2020's, the increase in the number of people experiencing water stress in South America due to climate change will likely be between 7 – 77 million. During the second half of the 21st Century, potential water availability reduction and an increasing demand from a growing regional population could increase the number of people experiencing water stress to between 60 – 150 million.

Land-use changes have intensified the use of natural resources and increased land degradation. Almost 75% of South American drylands are moderately or severely affected by land degradation processes. The combined effects of human activities and climate change are causing a continuous decline in natural land cover at very high rates, including an increase in the deforestation of tropical forests[192]. Land-use and climate change acting synergistically will increase wildfire risk significantly.



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http://sedac.ciesin.columbia.edu/gpw/lecz.jsp

Figure 49: Population density within and outside of a 10 m low elevation coastal zone (LECZ) for Belize[193].

Average temperatures in South America will likely increase by 1 – 6°C by 2100 assuming BAU[192]. Sea level rise will impact coastal areas (see Figure 49). There is a risk of substantial species extinctions in many areas of tropical South America. Replacement of tropical forest by savannas will likely occur in eastern Amazonia and the tropical forests of central and southern Mexico. Replacement of semi-arid vegetation by arid vegetation will likely occur in parts of north-east Brazil and most of central and northern Mexico due to the combined effects of both land-use and climate change. By the 2050's, 50% of agricultural lands will very likely be subjected to desertification and salinization in some areas[192]. Increasing temperatures will likely decrease cattle and dairy productivity. Reductions in rice yields, as well as increases in soybean yields, are possible by the 2020's when CO_2 effects (e.g., CO_2 fertilization) are considered. Projected responses to climate change for other crops (e.g., wheat, maize) are more uncertain. If CO_2 effects on crops are ignored, the number of additional people at risk of hunger under the IPCC A2 scenario is likely to reach 5 million, 26 million and 85 million in 2020, 2050 and 2080, respectively[192].

Abrupt Non-Linear Climate Change and Tipping Points

The above discussion of climate change assumes that climate change will be a steady and linear development. This assumption can be misunderstood to mean that climate change will be a smooth and steady transition over the coming decades. However, the paleoclimate records show that past climate changes included both steady, linear changes and abrupt, non-linear changes. The abrupt, non-linear changes were caused by small increases in global climate change that resulted in large and irreversible environmental changes once temperature and biogeochemical (e.g., ocean acidification, ice sheet loss) tipping points were passed. Anthropogenic GHG emissions are driving the global climate system toward such temperature and biogeochemical tipping points earlier than previously predicted. The potential impacts of passing such climate tipping points would be catastrophic, and include[190]:

- the disappearance of Arctic summer sea ice (see Figures 50 and 51);
- a major reduction of the area and volume of Hindu-Kush-Himalaya-Tibetan Plateau (HKHT) glaciers, which provide the head-waters for most major river systems of Asia including the Indus, Ganges, Irrawaddy, Mekong, Red, Yangtze, and Yellow rivers (almost 30% of the world’s population lives in the watersheds of these rivers) (see Figures 40 and 41);
- ocean acidification (see Figures 52 – 55);
- the deglaciation of Greenland Ice Sheet (see Figure 56);
- the dieback of Amazonian and boreal forests (see Figure 57);
- the shutdown of the Atlantic Thermohaline Circulation (see Figure 58);
- the collapse of West Antarctic Ice Sheet (see Figure 59); and
- a mass extinction event (see Figures 25, 31, and 32).

The catastrophic impacts from these events could include many meters of sea level rise, massive displacement of people and wildlife, severe loss of biodiversity, megadroughts, catastrophic water shortages, and massive famine that could result in political instability, resource wars, overwhelming humanitarian crises, and human rights challenges[190]. Furthermore, passing climate tipping points would likely cause other severe impacts, such as the release of methane and other GHGs from permafrost and ocean hydrates that would likely cause additional runaway climate feedbacks. Temperature tipping points for abrupt climate changes could be passed within this century, or even in the next decade[190]. Under a BAU scenario, where atmospheric CO_2 concentrations are increasing approximately 2 ppm per year, the question is not whether abrupt climate change will occur, but rather how soon[179].

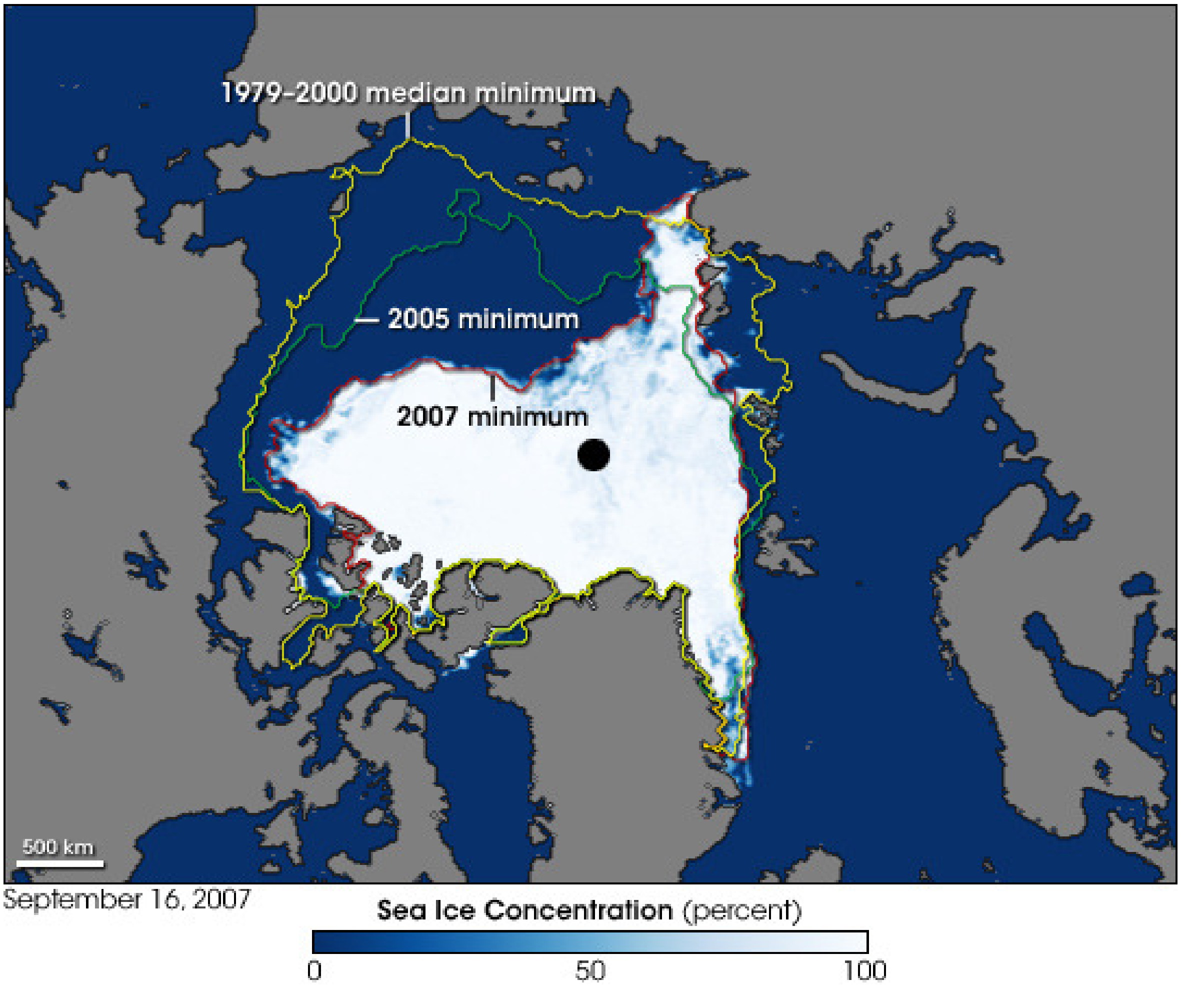


Figure 50: Arctic sea ice reached a record low in September 2007, below the previous record set in 2005 and substantially below the long-term average sea ice minima during 1979 – 2000. This image[206] shows the Arctic as observed by the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) aboard NASA's Aqua satellite on September 16, 2007. In this image, blue indicates open water, white indicates high sea ice concentration, and turquoise indicates loosely packed sea ice. The black circle at the North Pole results from an absence of data as the satellite does not make observations that far north. Since open ocean is much darker than sea ice, ocean will absorb more heat than a similarly sized region of sea ice, hence the retreating sea ice accelerates warming in the Arctic. This is known as the ice-albedo feedback, and causes the Arctic to warm 2 or more times faster than the global average.

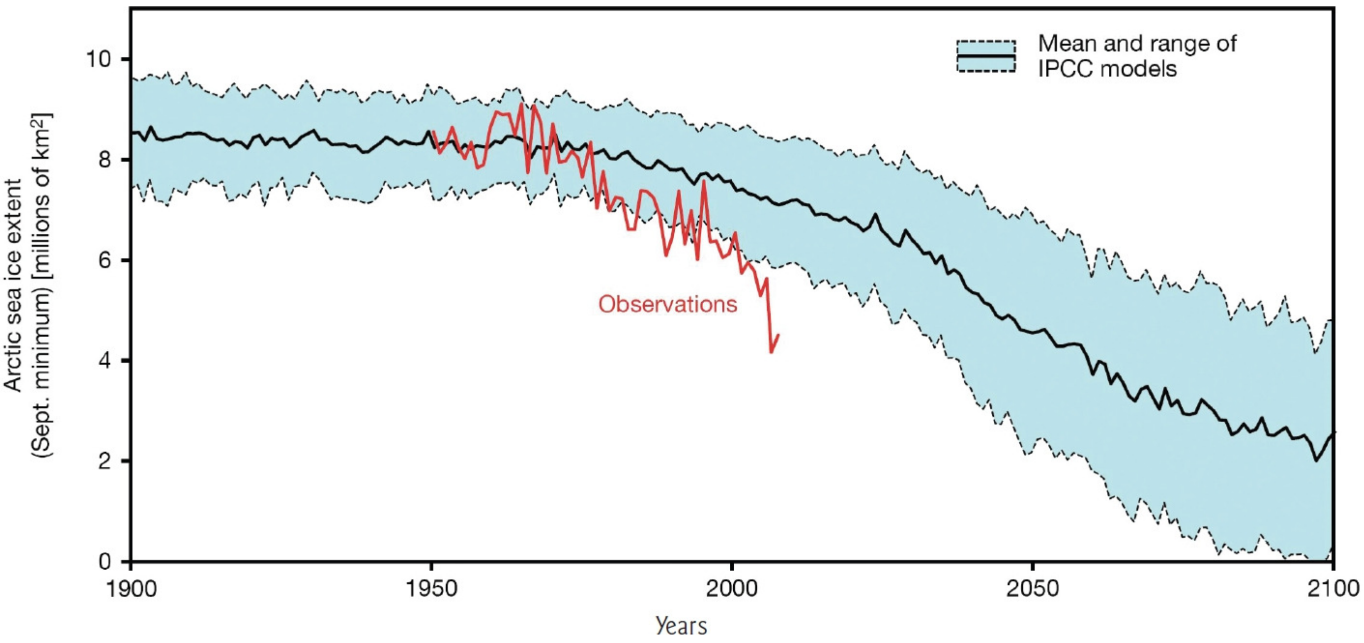


Figure 51: Observed (red line) and modeled September Arctic sea ice extent in millions of square kilometers[181]. The solid black line gives the ensemble mean of the thirteen IPCC AR4 models while the dashed black lines represent their range. From Stroeve et al.[207] updated to include data for 2008. The 2009 minimum has recently been calculated at 5.10 million km^2, the third lowest year on record, and still well below the IPCC worst case scenario.

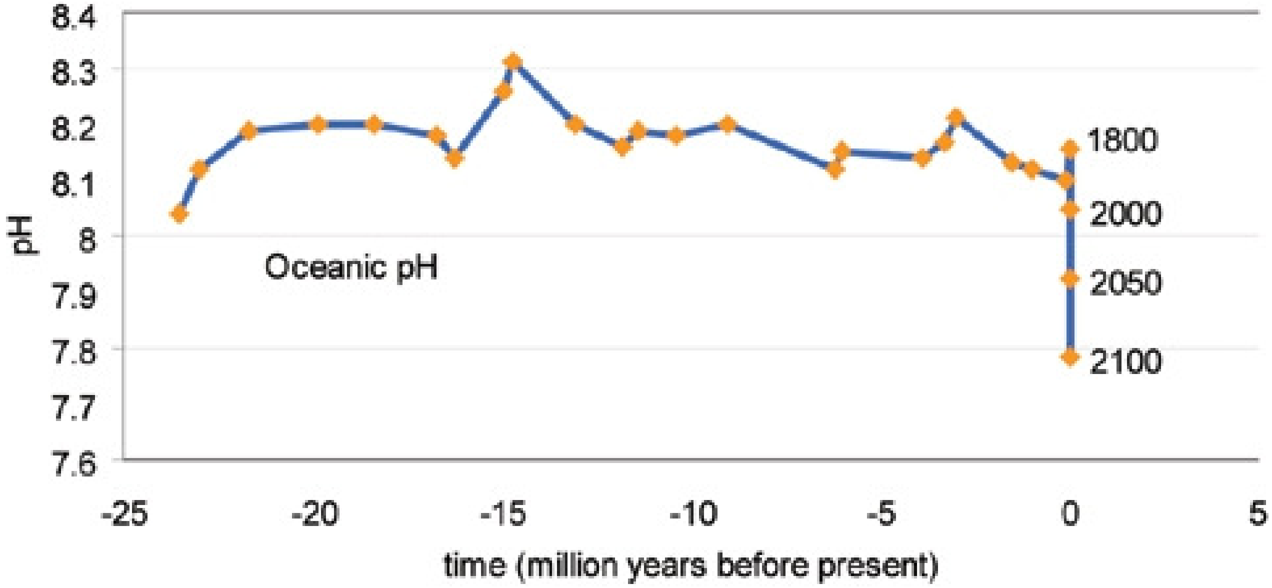
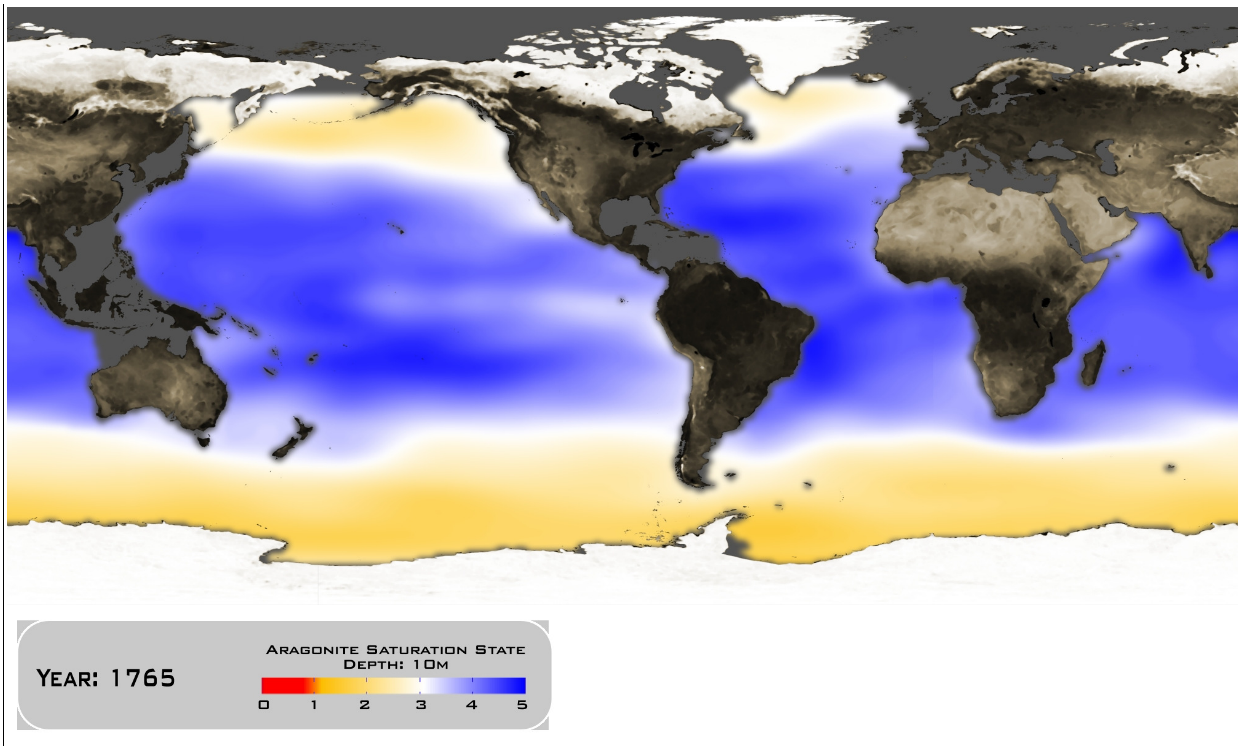


Figure 52: Past and present variability of marine pH. Future predictions for years shown on the right-hand side in the figure are model-derived values based on IPCC mean scenarios. From Pearson and Palmer[208], adapted by Turley et al.[209] and from the Eur-Oceans Fact Sheet[210].



Figre 53: Model output showing the impact of ocean acidification on the ocean's carbonate (aragonite) saturation state at a depth of 10 m in the year 1765 [211].

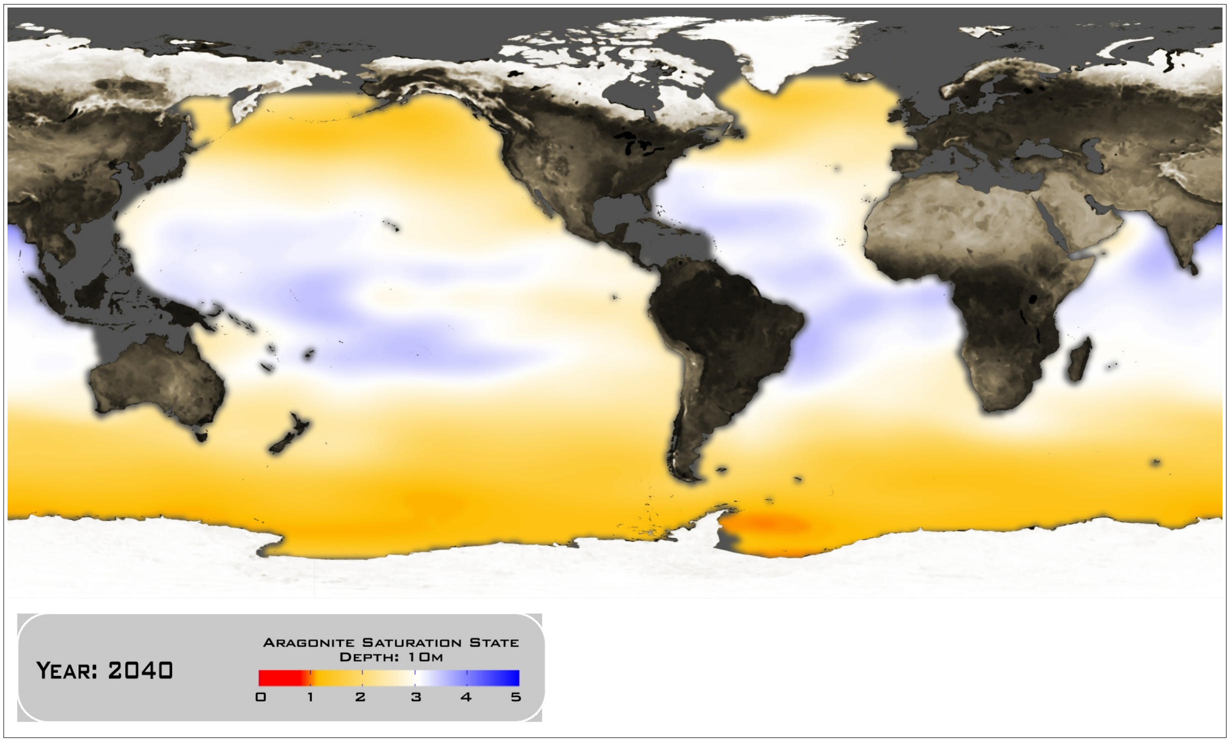


Figure 54: Model output showing the impact of ocean acidification on the ocean's carbonate (aragonite) saturation state at a depth of 10 m in the year 2040 [212].

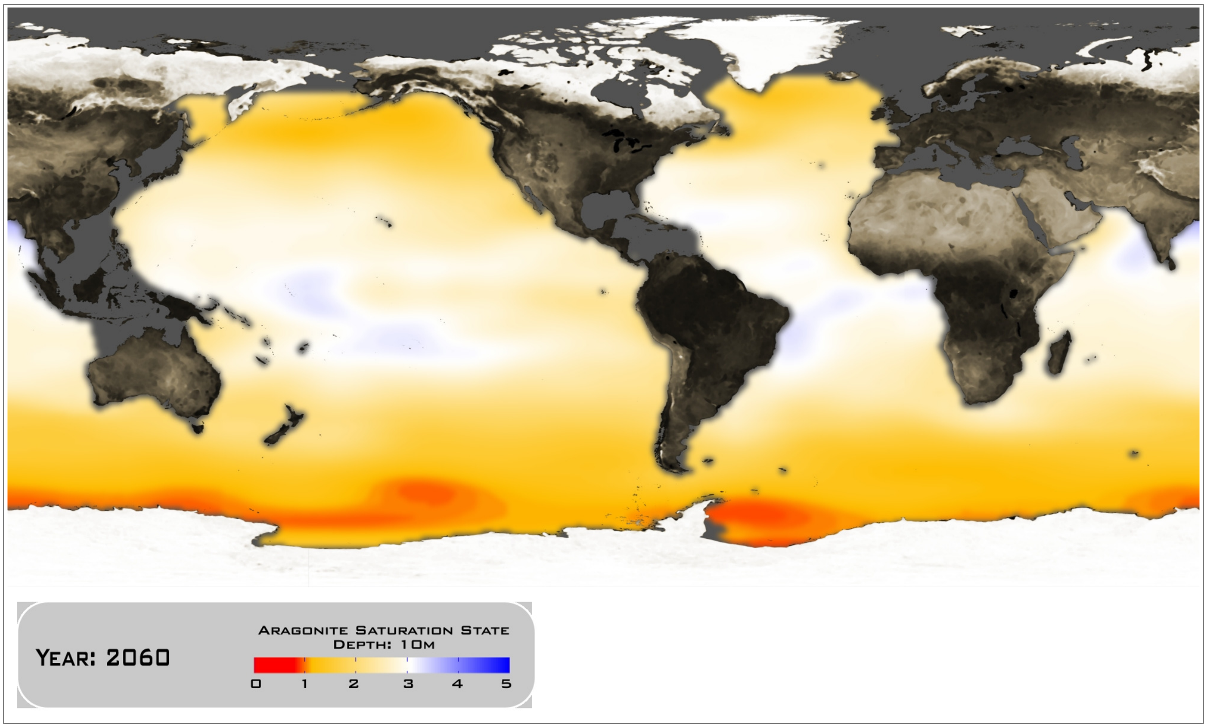


Figure 55: Model output showing the impact of ocean acidification on the ocean's carbonate (aragonite) saturation state at a depth of 10 m in the year 2060 [213].

The gravity of the threat of passing climate tipping points cannot be understated. Areas at high latitudes and altitudes are already experiencing major rapid changes. For example, the disappearance of Arctic summer sea ice, which is the first predicted tipping point, is already occurring at a rate more rapid than any of the IPCC models projected (see Figures 50 and 51). The Arctic could be virtually ice-free in September of 2037, or even as early as September of 2028 [203]. Furthermore, temperatures are rising faster than the global average at high latitudes and altitudes. The Arctic, Greenland, and the Tibetan Plateau (part of the HKHT) are at particular risk[190]. Arctic temperatures increased at least 2 times as rapidly as global averages during the period between 1965 – 2005 [204]. The temperature of the Greenland Ice Sheet is increasing 2.2 times faster than global averages[204]. The temperature of the Tibetan Plateau increased by about 3 times the global average for the past half-century[204]. which has contributed to substantial glacial retreat[205].

The melting of the Arctic, Greenland, and HKHT would also cause additional runaway climate feedbacks. For instance, melting of ice sheets produces positive feedbacks by reducing surface albedo (i.e. surface reflectivity), which results in more absorption of solar heat by the exposed underlying surface (i.e., the ground or water), which then accelerates the melting of the remaining ice. For example, melting Arctic sea ice reduces albedo which leads to more absorption of solar heat by the exposed dark Arctic waters[190]. This reduction of albedo is further accelerated by the additional darkening of polar surfaces caused when atmospheric anthropogenic black carbon or black soot (i.e. impure carbon particles resulting from the incomplete combustion of organic matter, such as wood or fossil fuels) deposits on snow and ice[205]. Black carbon is also a heat-absorbing component of *atmospheric brown clouds* (see below). The deposition of black carbon is also a significant driver of glacial retreat in the HKHT region[185].

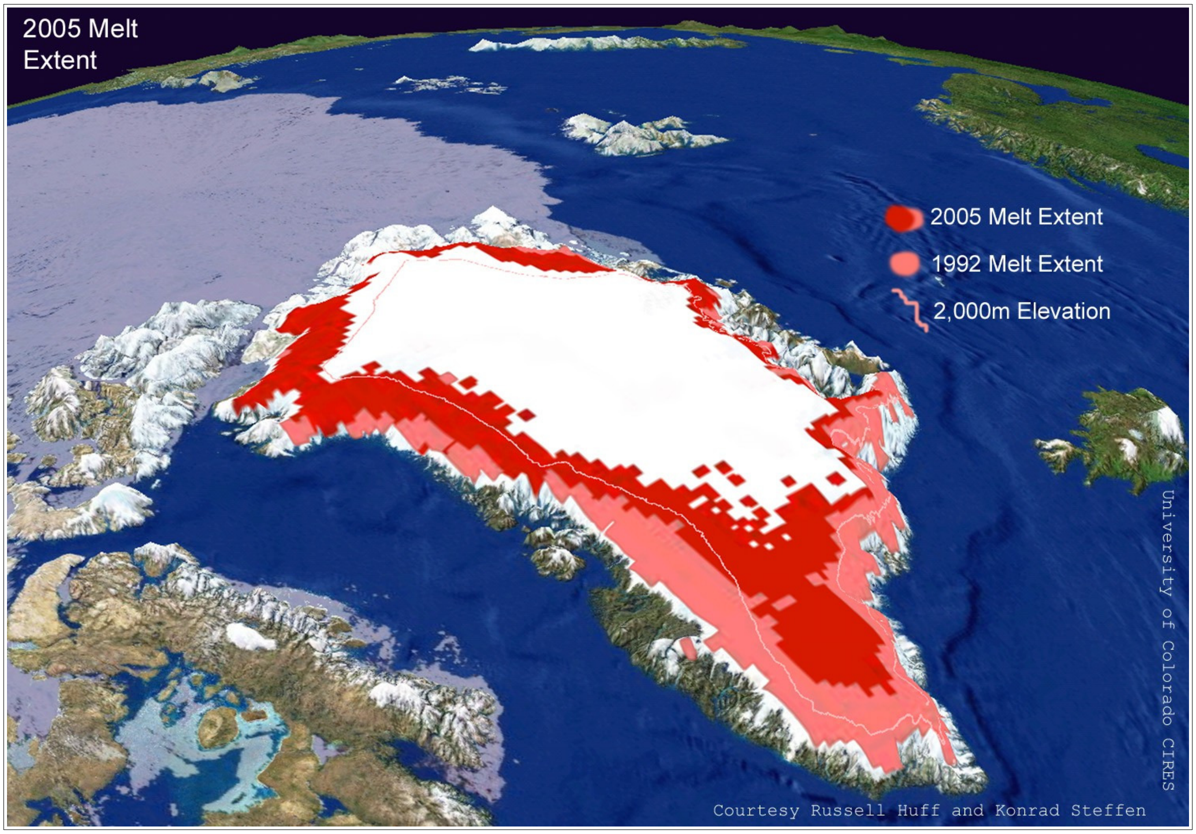
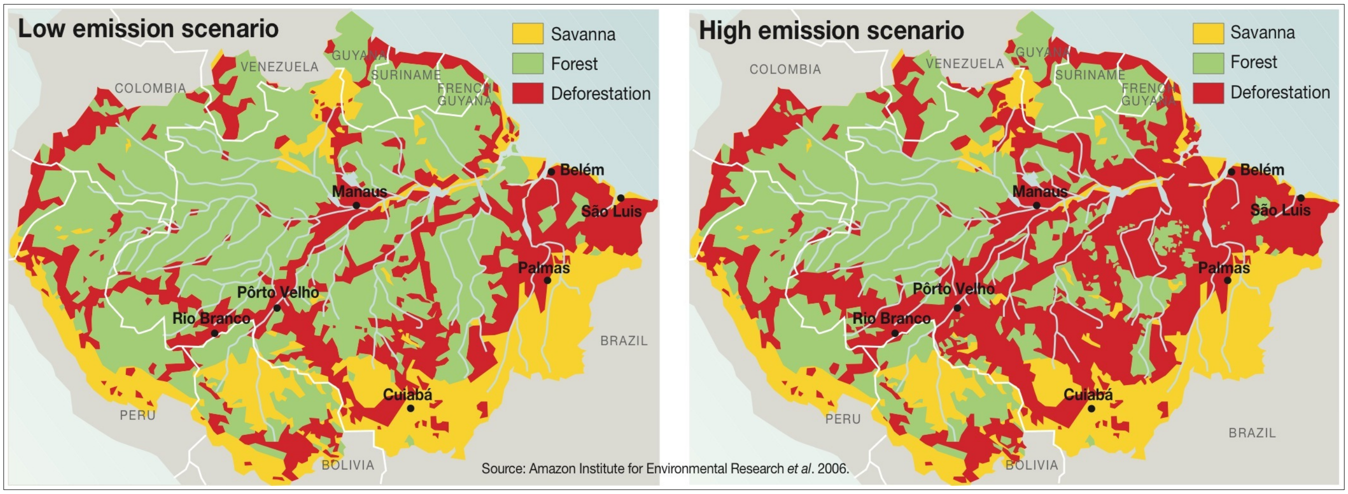


Figure 56: Passive microwave satellite data are used to map snowmelt extent and duration on the Greenland ice sheet[214] *. The total melt extent of the ice sheet, experiencing at least 1 melt day between April 1 – September 25 shows a record extent in 2005 for the 27-year long time passive microwave data set. The 2005 melt extent exceeds the previous record of 2002.*



Source: Amazon Institute for Environmental Research *et al*. 2006.

Figure 57: Worst case scenario for the Amazon Forest by 2050 [215]*. Global climate change has already contributed to rising temperatures in the Amazon which, when combined with deforestation, have led to a cycle of lower precipitation and a greater frequency of droughts. In 50 – 60 years, the Amazon could reach a tipping point at which deforestation and climate change combine to trigger self-sustaining desertification.*

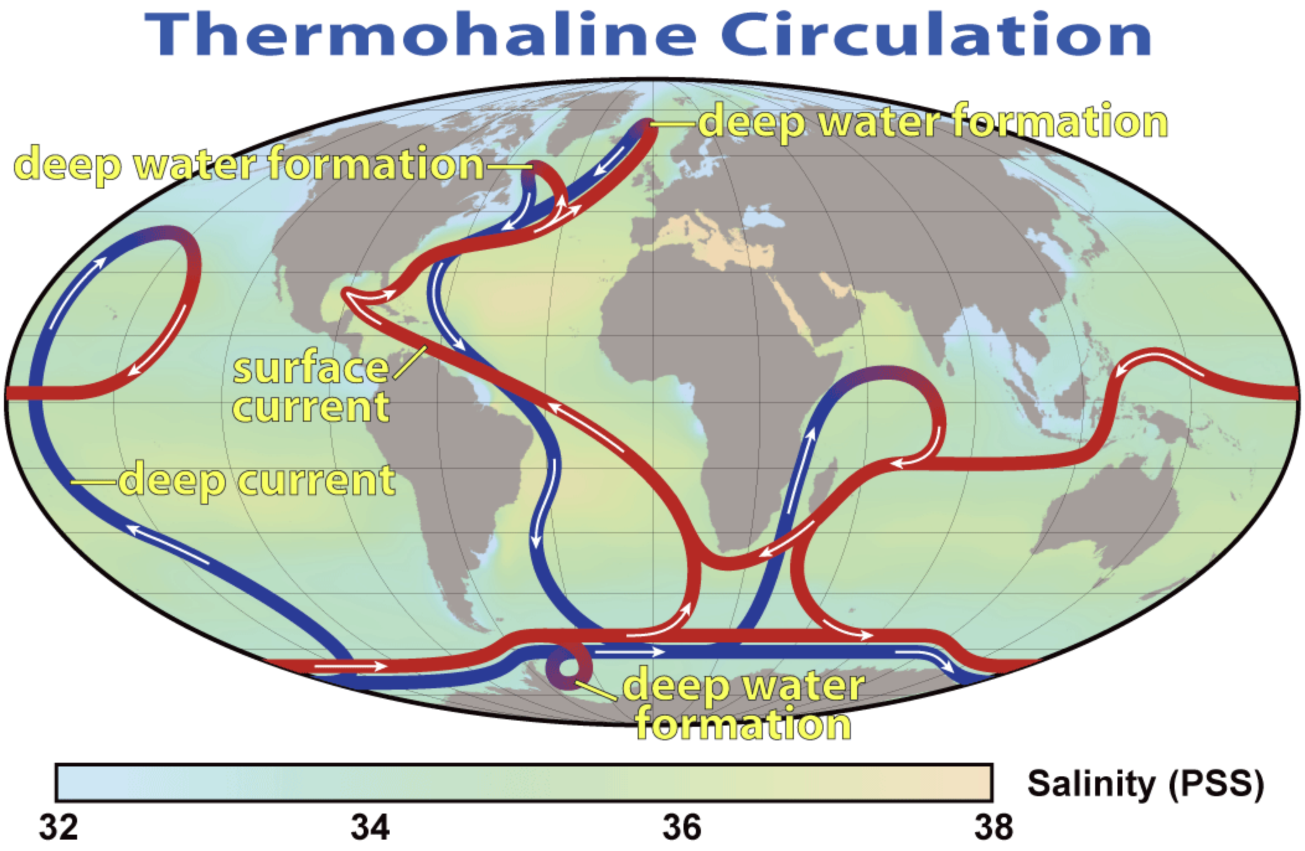


Figure 58: The pattern of thermohaline circulation[216]*. This collection of currents is responsible for the large-scale exchange of water masses in the ocean, including providing oxygen to the deep ocean. The entire circulation pattern takes approximately 2,000 years. The thermohaline circulation is driven by differences in seawater density, caused by temperature and salinity. Like a great conveyor belt, the circulation pattern moves warm surface water from the southern hemisphere toward the North Pole. Between Greenland and Norway, the water cools, sinks into the deep ocean, and begins flowing back to the south. These sinking currents flow into and across the deep ocean basins and circulate across the global ocean system before eventually returning to the surface, mostly in the Pacific and Indian Ocean basins. This movement carries a tremendous amount of heat northward, and plays a vital role in maintaining the current climate. Shutting the thermohaline circulation down due to global warming could cause a substantial regional and global shift in climate.*

James Hansen, Director of NASA's Goddard Institute for Space Studies, and other climate scientists believe that humanity has already passed the threshold for "dangerous anthropogenic interference" with the natural climate system[179]. Ramanathan and Feng[185] project that as CO_2 concentrations approach 441 ppm a corresponding committed warming of 3.1ºC will occur by 2030 in the absence of strong countervailing mitigation.

As of 2005, when atmospheric CO_2 concentrations were already about 380 ppm (422 ppm CO_2e), GHG emissions may have committed the planet to a warming of 2.4ºC (within a range of 1.4º – 4.3ºC) above the pre-industrial surface temperatures[185], which is within the range of predicted tipping points (see Figure 60). If the total committed warming is at least 2.4ºC, the present observed temperature increase of 0.76ºC[185] is misleading. Warming of at least another 1ºC is currently masked by *atmospheric brown clouds* that contain cooling particulates released with GHG emissions and other pollution[185]. As societies continue to reduce the pollution that create these clouds, temperature increases of 1ºC or greater temperature that are already committed from current emissions will be unmasked[185]. A sharp drop in polluting emissions due to a rapid collapse of global human activity due to peak oil may also "unmask" this 1ºC or greater temperature increase. A further 0.6ºC warming is temporarily delayed by ocean thermal inertia. More than 50% of this total committed warming of 2.4ºC is expected to occur within decades[185].

If the total committed global warming is at least 2.4ºC, as of 2005 when atmospheric CO_2 concentrations were already about 380 ppm, then clearly an atmospheric CO_2 concentration of 450 ppm would very likely commit the Earth to a deleterious, if not catastrophic, increase in global temperature. Indeed, a CO_2 concentration of 380 ppm would very likely be dangerous, as well. In the absence of atmospheric brown clouds, the amount of which could be reduced by pollution controls, global temperatures could have increased by 0.76º – 1.76ºC as of 2005.

Limiting the atmospheric CO_2 concentration to no greater than 350 ppm might prevent committed global warming to no more than 2.4ºC in the long-term, after the temporary delay by climate and ocean thermal inertia reach their peak potential climate forcing (i.e. peak warming potential). Stabilization at or below 350 ppm CO_2e provides a 93% probability of staying below 2°C above pre-industrial values[165,189]. Therefore, a CO_2 target as low as 300 ppm may be necessary to prevent a dangerous warming of 2ºC. Global average temperatures may stabilize within a likely range of 0.6 – 1.4°C above pre-industrial values at or below 350 ppm CO_2e (300 ppm CO_2)[165,189].

In addition to the climate changes discussed above (e.g., temperature increases, changes in precipitation, etc.), ocean acidification poses another major climate tipping point. The ocean is one of the planet's largest natural reservoirs of carbon. The ocean absorbs approximately 26 – 29% of anthropogenic carbon emissions each year[217]. The rate of change of ocean chemistry due to anthropogenic carbon emissions is rapid and unprecedented[217] (see Figures 52 – 55). Ocean acidification is a direct consequence of increasing atmospheric CO_2 concentrations[217]. CO_2 dissolves in seawater to form carbonic acid. The IPCC[165] defines *ocean acidification* as "a decrease in the pH of sea water due to the uptake of anthropogenic carbon dioxide". Additionally, freshwater will also experience a decrease in the pH of sea water due to the uptake of anthropogenic carbon dioxide, which also makes freshwater bodies, such as lakes and rivers, and the organisms living in them susceptible to anthropogenic acidification.

Ocean acidity affects marine carbonate chemistry. Ocean acidification will likely have major negative impacts on corals, shellfish, plankton, and other marine organisms that build calcium carbonate ($CaCO_3$) skeletons and shells, and whose success is significantly controlled by marine carbonate chemistry. Increasing ocean acidification reduces the availability of carbonate minerals (aragonite and calcite) in seawater, which are important building blocks for marine plants and animals. Oceanic carbonate ion concentrations are currently lower than at any other time during the last 800,000 years[217]. Many calcifying species occupy the bottom or middle of global ocean food webs. Consequently, the loss of these calcifying organisms to ocean acidification will alter predator–prey relationships, the structure of food webs and ecosystems[217]. Ocean acidification will also negatively affect other organisms besides calcifying organisms. Some fish species are sensitive to anomalous environmental pH levels, which can be toxic and cause stress and reproductive problems[217]. Fisheries will likely be affected as affected fish species migrate to more suitable habitat.

A loss or change in biodiversity as a result of ocean acidification will likely have significant ecological consequences, which could cause extinction of species and ecosystems, and lead very possibly to a global mass extinction event while also contributing to the current mass extinction event[217]. During the past 300 million years, global mean ocean pH values have probably never been more than 0.6 pH units below current values[217]. Therefore, ocean ecosystems have evolved over this time in a pH environment of relative stability. It is unknown if they can adapt to such large and rapid changes. Since the end of the Ordovician period (434 million years ago), five mass extinction events have significantly influenced the paths of evolution of life on Earth. Perturbations of the carbon cycle in general, and changes in ocean chemistry in particular, with clear association to atmospheric CO_2 levels, have been the primary causes of each extinction event[219]. By 2050, ocean pH is predicted to be lower than it has been for around 20 million years[220] (see Figure 52). The records from the Earth's past are a disquieting cause for concern that ocean acidification could trigger a sixth mass extinction event, independently of the anthropogenic and climate change-driven extinctions that are currently happening[219].

In order to safely avoid passing a dangerous threshold for ocean acidification, the maximum concentration of atmospheric CO_2 should be limited to no greater than 450 ppm. However, additional stressors (e.g. increased temperatures from climate change, pollution) will also seriously impact fish and other marine organisms, especially the world's corals and their associated species whose resilience will be compromised by ocean acidification. A scientific consensus is that atmospheric CO_2 concentrations need to be "significantly below 350 ppm" for the long-term viability of coral reefs[221].

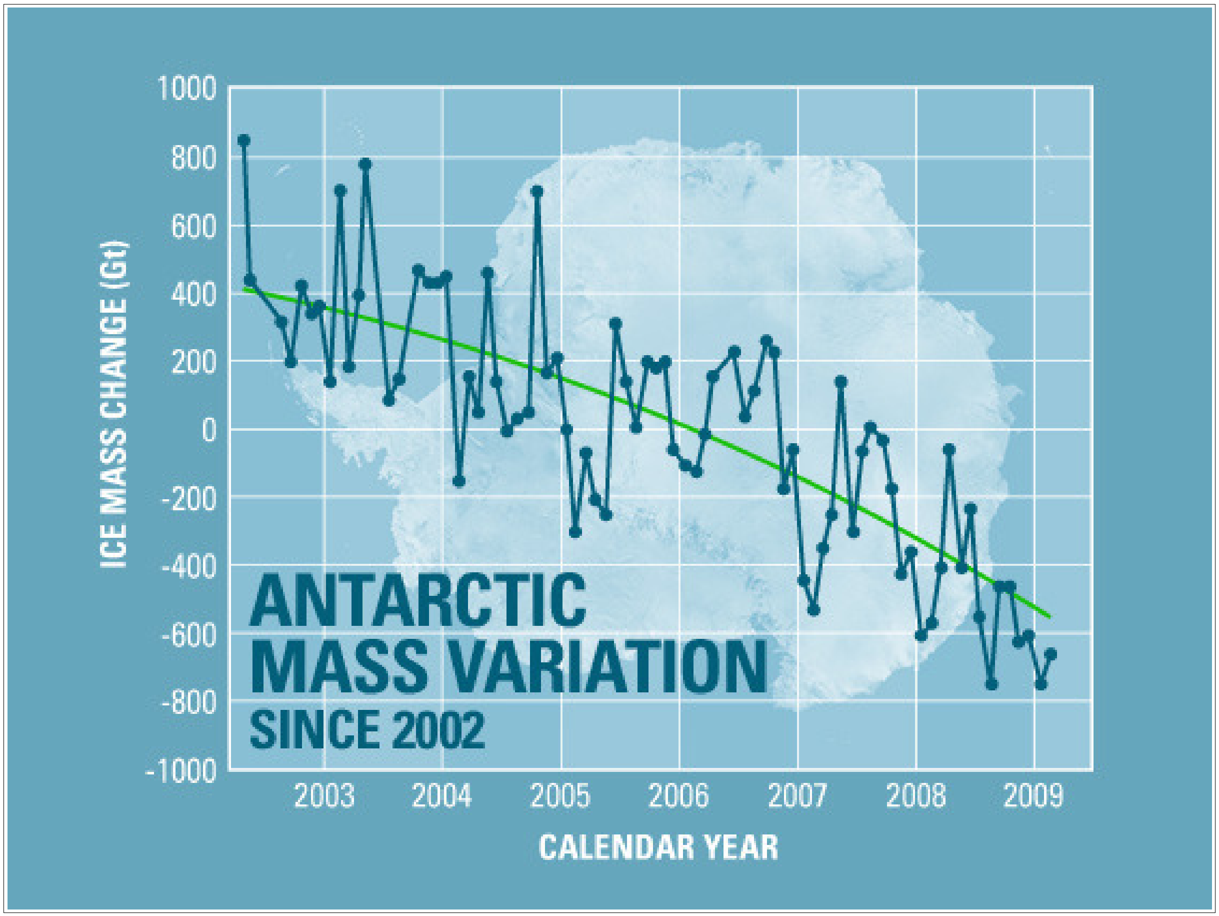


Figure 59: Antarctic ice mass variation since 2002. The continent of Antarctica has been losing more than 100 cubic kilometers (km^3) of ice per year since 2002 [218].

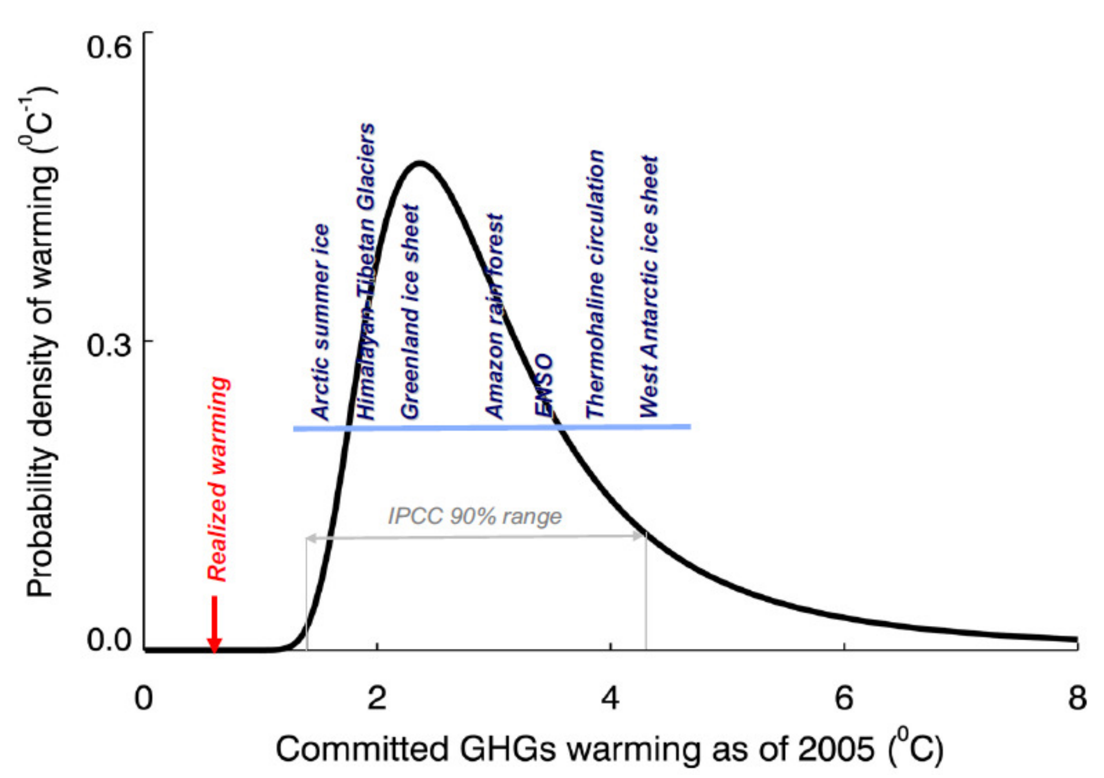


Figure 60: Probability distribution for the committed warming by GHGs between 1750 – 2005. Shown are the climate-tipping elements and the temperature threshold range that initiates the tipping point[185].

Despite the certainty that climate changes have occurred abruptly in the past, and that abrupt climate changes could be triggered again in the near future, current climate policy does not account for abrupt climate change[204]. Remarkably, abrupt climate change is not considered in the projections of the IPCC, which is still regarded by policy-makers and the public as one of the most authoritative sources of information on climate change.

Although policy must continue to address mid- and long-term mitigation strategies to reduce CO_2 emissions, societies also must begin fast-track mitigation strategies that can produce immediate climate mitigation and delay the onset of tipping points in order to avoid catastrophic climate changes. As the climate passes the first tipping point, the disappearance of Arctic summer sea ice, it is apparent that a CO_2 concentration of 450 ppm could be disastrous. A target atmospheric concentration of CO_2 of no greater than 350 ppm will likely be needed to prevent the world from passing climate tipping points. However, a target concentration of CO_2 of 300 ppm may be needed to ensure that the climate does not pass the 2ºC threshold. Obviously, major efforts in carbon sequestration combined with a substantial reduction of GHG emissions would be necessary to achieve this improbable target.

Currently, many nations are dealing with climate change impacts that are resulting from shifts in the onset of seasons; irregular, unpredictable rainfall patterns; uncommonly heavy rainfall; increased incidence of storms; major flood events; and prolonged droughts[222]. Further, changes in temperatures and weather patterns have driven the emergence of diseases and pests that affect crops, trees, and animals. All these climate impacts already have a direct impact on the quality and quantity of crop yields, and the availability and price of food, animal feed, and fiber[222]. Agriculturalists and rural communities are challenged by increasing risks, such as increasing and recurrent crop failure, loss of livestock, and reduced availability of fisheries and forest products. More frequent and more intense extreme weather events (e.g., storms, floods, droughts) will impact substantially agricultural and livelihood assets in both rural and urban areas throughout the world. Sea level rise will flood low elevation coastal zones (LECZs) and contaminate coastal aquifers with salt water, particularly in fertile river deltas that produce much of the world's food[192,222]. Preparing for future long-term climate change impacts is challenging since they can emerge gradually or occur abruptly when certain climate system thresholds are exceeded.

Climate change already threatens human security and negatively affects global development efforts by undermining development achievements and slowing progress toward achieving the Millennium Development Goals (MDGs), especially those goals regarding hunger and poverty reduction and ensuring environmental sustainability[222]. Climate change also negatively impacts food security – food availability, food accessibility, the stability of the food supply, and the ability of consumers to utilize food including food safety and nutritional value[223]. Although every person and ecosystem is vulnerable to climate variability and change, the impacts are location specific. They depend on the how the climate changes and varies, the rate of the change, sensitivity of the area, and the adaptive capacity of the people and ecosystems in that area.

Increasing changes in temperature, precipitation, evaporation, and other climate patterns will likely amplify the food and water shortages. For instance, agricultural productivity in many of the tropical areas such as India, Africa, and Mexico may suffer 20% – 40% reductions by 2080 [136]. Although Cline[224 as cited in 136] conservatively projects that global reductions due to climate change will average 3.2%, the author suggests that it will likely be 10 – 25%. Using simple ratios, Schade and Pimentel[136] suggest that food production reductions due to climate change could reduce the global carrying capacity by another 0.5 – 2 billion people. This reduces the the maximum potential human carrying capacity of the planet to 3.5 – 7.5 billion (about 5.4 billion people average) by 2050 assuming BAU . By 2100, the maximum potential human carrying capacity of the planet may be further reduced to 3 – 6 billion people (4.5 billion people average).

“We gotta get off oil, American has got to change its habits...It should be obvious to all, demand has outstripped supply, which makes prices go up.”

– George W. Bush[225], 2008

“What people need to hear loud and clear is that we're running out of energy in America.”

– George W. Bush[226], 2001

- A small gasoline engine can convert one gallon of gasoline to do roughly equivalent of nearly 12 days of work for one human being working 8 hours per day, or about 97 hours of work total.
- The input of fossil fuels supports high-yielding modern industrial agriculture, especially oil as transport fuel and material feedstock (e.g., for pesticides, plastics).
- The Green Revolution increased the energy consumption of industrial agriculture by an average of 50 times or more the energy input of traditional agriculture.
- Between 1950 – 1984, global grain production increased enormously by 250%.
- Modern industrial agriculture has allowed the human population to increase at a very high exponential rate since around 1950 when it was about 2.5 billion.
- By 2000, the global human population had increased to around 6 billion people. In 2010, the human population is nearly 7 billion (i.e., 6.8 billion).
- By 2030, the global population is projected to increase to about 8 billion people assuming BAU.
- To a great extent, the difference between 2.5 billion people in 1950 and 7 billion people in 2010 is oil.

The above section on the carrying capacity of the Earth assumes that BAU trends in population growth, changing diets, and land and water use are possible. However, given the decline in global oil production, modern globalized industrial agriculture may not be sustainable in the near future. The Green Revolution led to the rapid and global expansion of industrialized agriculture. Although the development and use of high-yielding varieties of cereal grains and the distribution of hybridized seeds contributed to increased crop yields, the input of fossil fuels supports high-yielding modern industrial agriculture, especially oil as transport fuel and material feedstock (e.g., for pesticides, plastics). Modern industrial agriculture has allowed the human population to increase at a very high exponential rate since around 1950. By 2000, the global human population had increased to around 6 billion people. In 2010, the human population is nearly 7 billion (i.e., 6.8 billion). By 2030, the global population is projected to increase to about 8 billion people assuming BAU[135]. To a great extent, the difference between 2.5 billion people in 1950 and 7 billion people in 2010 is oil (see Figure 61). Although other fossil fuel energy resources are important for increasing and supporting the global human population, oil is vital since it supports modern industrial agriculture in so many ways (e.g., feedstock for pesticides, transport fuel).

Until the Industrial Revolution, and especially since the last century, nearly all of the food energy available on the Earth came from the sun through the photosynthesis of plants. A minority of microscopic organisms generally found in extreme environments derive their energy from chemical and geothermal processes. Therefore, energy acquired from food ultimately comes from the sun, whether the food source is a plant or an animal or other organism that consumes plant material (e.g., fungi).

Although solar energy is a renewable resource, the amount that irradiates the Earth at any time is limited by the output of the Sun. Therefore, the process of photosynthesis set a limit on the amount of food that could be produced at a given time. Consequently, this limited population growth. The area of land under cultivation needed to increase in order to increase food production given the constraints on solar energy. The human population increased by expanding the area of land used to grow food crops. Currently, approximately 40% of all land-based photosynthetic capacity has been appropriated by humans[174]. In the U.S., more than 50% of the solar energy captured by photosynthesis is appropriated[227].

Fossil fuels are formed by the decomposition of the remains of organisms (including plankton and plants) under particular geologic conditions over millions of years. Whereas solar energy is a renewable resource limited by its rate of flow from the sun to the Earth, fossil fuels are a nonrenewable (on a human timescale) stock resource that can be exploited at a nearly unlimited rate, constrained primarily by production rates. Fossil fuels are a deposit of solar energy – much like a battery – from which the stored energy may be drawn at any rate depending on fuel supplies and production capacity. The Green Revolution consumed much of this stored fossil fuel energy to increase agricultural production and the distribution of food. In particular, oil has been used on a global industrial scale to:

- produce pesticides and other agrochemicals (herbicides, fungicides, some synthetic fertilizers);
- produce pharmaceuticals and medical supplies for livestock;
- fuel tractors, sprayers and crop dusters, farm equipment, and vehicles to produce food;
- pump and transport water for irrigation;
- make plastic materials for irrigation and other infrastructure;
- transport materials to farms;
- transport food from field to processors, storage, distributors, and consumers; and to
- make plastic materials in which to contain, store, and package food.

Between 1950 – 1984, global grain production increased enormously by 250%[155]. However, the additional energy to produce and distribute the increased food yields came from an increase in the use of fossil fuels in the form of fertilizers (natural gas), pesticides (oil), and fossil-fueled irrigation (e.g., diesel, electricity). The Green Revolution increased the energy consumption of industrial agriculture by an average of 50 times the energy input of traditional agriculture[228]. Nevertheless, in some cases energy inputs to agriculture have increased more than 100 times[228]. One study estimates that the total energy consumption in industrial agriculture consists of[229]:

- 31% for the manufacture of inorganic fertilizer
- 19% for the operation of field machinery
- 16% for transportation
- 13% for irrigation
- 8% for raising livestock (not including livestock feed)
- 5% for crop drying
- 5% for pesticide production
- 8% miscellaneous

The energy costs for packaging, refrigeration, transportation to retail outlets, and household cooking are not considered in the above estimate of energy consumption.

For instance, in the manufacture of inorganic fertilizer the energy equivalent of 1.4 – 1.8 L of diesel fuel is required for the production of 1 kg of nitrogen for synthetic fertilizer, ignoring the input of the natural gas feedstock[229]. Between 2001 – 2002, the U.S. applied 12,009,300 tons or about 10.9 billion kg of nitrogen fertilizer, which is the equivalent of about 96 – 123 million barrels of diesel fuel[228]. Since the start of the Green Revolution, total fossil fuel consumption in the U.S. increased 20 times. People in the U.S. consume 20 – 30 times more fossil fuel energy per capita than people in developing nations[228]. In the U.S., agriculture accounts for 17% of the energy consumed[228]. In 1990, the U.S. used approximately 6.41 barrels (1,000 L) of oil to produce food on one hectare of land[228].

Despite the vast inputs of fossil fuel energy into global food production, the energy return on investment (EROI) has been declining substantially. Between 1945 – 1994, the energy input to agriculture increased 4 times, which increased crop yields 3 times. However, energy input has continued to increase since then, but without a corresponding increase in crop yield[228].

Pimentel and Giampietro[228] define two forms of energy input called *endosomatic energy* and *exosomatic energy. Endosomatic*, or *metabolic energy*, is produced through the metabolic transformation of food energy into muscle energy in the body (*endosomatic* means *inside the human body*). *Exosomatic energy* is generated by converting external energy sources into useful energy outside of the body (e.g., burning gasoline in an engine, harnessing wind through a sail or turbine) (*exosomatic* means *outside the human body*). In particular, exosomatic energy can refer to energy that is converted into power via mechanic devices such engines and machines (also referred to as commercial energy). For instance, a small gasoline internal combustion engine can convert roughly 20% of the energy input of one gallon of fuel into useful work[230]. Therefore, a small gasoline engine can convert one gallon of gasoline (which contains about 31,310 kcal of energy, or 36 kWh) into 7.2 kilowatt hours (kWh) of energy to do exosomatic work, which is equivalent to nearly 2 weeks (i.e., 12 days) of work for one human being (endosomatic energy) working 8 hours per day (about 97 hours of work total) at 0.074 kW (approximate human work output in agriculture).

Although it is not physically possible, if the engine was 100% fuel efficient (i.e., the engine could convert 100% of the fuel into useful energy), then the entire 36 kWh of fuel energy would be equivalent to nearly 2 months (i.e., 61 days) of work for one human being (endosomatic energy) working 8 hours per day, or about 487 hours of work at 0.074 kW.

Before the Industrial Revolution, almost 100% of both endosomatic and exosomatic energy was supplied by the sun. For instance, much exosomatic energy came from renewable firewood resources and domesticated animals (which consume plants or other animals). Fossil fuels now make up 90% of the exosomatic energy used in the U.S. and other developed countries[228]. The exosomatic to endosomatic ratio of pre-industrial societies is approximately 4:1. This ratio has increased to 40:1 in developed countries. In the U.S., this ratio is greater than 90:1 [228].

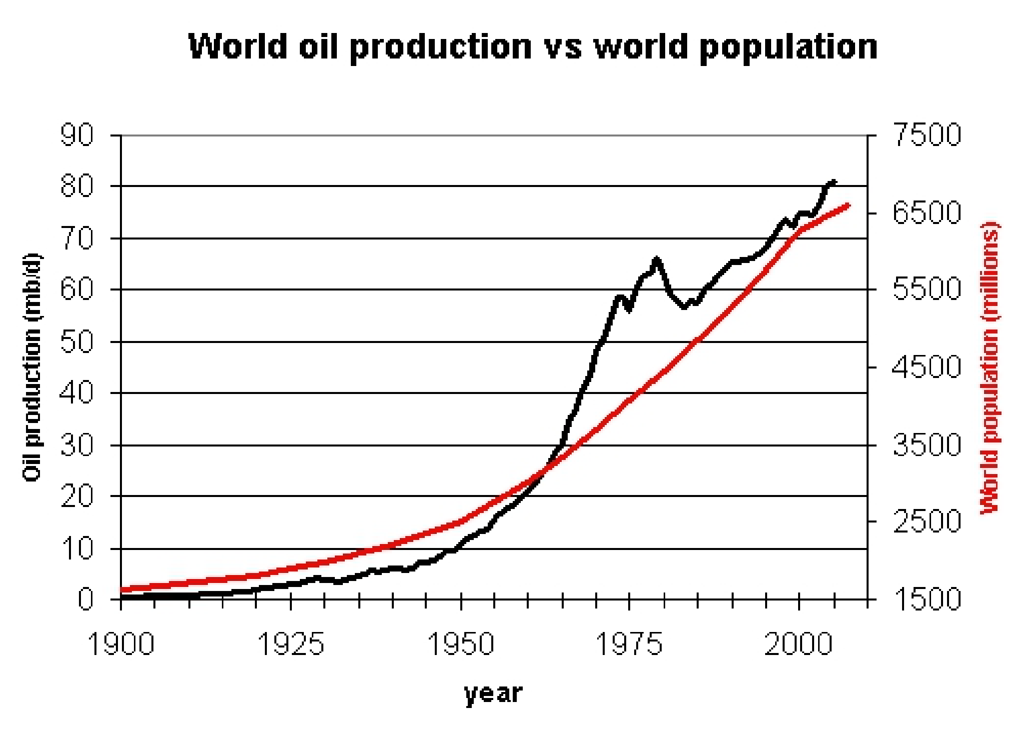


Figure 61: World oil production versus world population[117].

Much of the endosomatic energy is no longer used to power direct economic processes. Instead, a majority of endosomatic energy is used to support the flow of information that directs the flow of exosomatic energy to power machines. For example, in the U.S. where the exosomatic to endosomatic ratio is 90:1, every 1 kcal of endosomatic energy used supports the circulation of 90 kcal of exosomatic energy. The authors estimate that 10 kcal of exosomatic energy are used to produce 1 kcal of food in the U.S. food system, including packaging and all delivery expenses, but excludes household cooking[228]. This exosomatic energy comes from the use of nonrenewable fossil fuel resources. In effect, people living in food systems like that of the U.S. are essentially eating oil.

The type of food production system affects the crop yield per area land. Wolf et al.[142] define two different general food production systems for calculating global food production. In the High External Input (HEI) system, crop production is assumed to be optimally managed and crop yields maximized by using all possible external inputs (e.g., mechanized operations, chemical fertilizers, pesticides and other biocides). This HEI system is analogous to modern fossil fuel dependent industrial agriculture using “best technical means” based on the common agronomic practices in current Dutch agriculture. Crop production in the HEI system is only limited by the availability of water, if no irrigation water can be applied. Yield losses (mainly by pests) are assumed to be 0%.

In the Low External Input (LEI) system, crop production is assumed to be optimally managed applying “best technical and ecological means”, in which environmental risks are minimized; no chemical fertilizers, pesticides and other biocides are applied; and nitrogen inputs to the system are achieved mainly by the biological fixation of nitrogen. In the LEI system, crop production is limited by both nitrogen (i.e., no external nitrogen inputs from synthetic fertilizers) and water availability. This system is based on the currently applied techniques and cultivation practices in integrated ecological and biological production systems in the Netherlands. Yield losses (mainly by pests) are assumed to be 10%.

Based on the estimates in Wolf et al.[142], the HEI food production system overall can yield approximately 2.3 times the amount of food than the LEI system, taking into consideration that some portion of the HEI and LEI food production systems each are irrigated. While this estimate represents overall global food production, estimated grain yields show how much crop yields can vary between the two food production systems. For instance, the authors estimate that irrigated grain production per growth period ranged from 2,000 – 12,000 kg (dry matter) per ha in the HEI system; and from 1,500 – 3,000 kg per ha in the LEI system per growing period. However, irrigated agriculture can support multiple growing periods, unlike non-irrigated agriculture, which is generally limited by the duration and frequency of precipitation during a single rain season per year. Globally, water-limited grain yields vary significantly more strongly than irrigated yields. Combined with up to three growing periods per year, annual grain production ranged from 4,000 to over 25,000 kg ha for the HEI system; and from 2,000 to about 7,000 kg ha for the LEI system. Therefore, per growing period the HEI production system yields 1.3 – 4 times more grain than the LEI system. Combined with up to three growing periods per year, annual grain production in the HEI system was 2 – 3.5 times more productive than the LEI system.

Although the difference between HEI and LEI food production systems is very significant, it is beyond the scope of this investigation to determine how much of the agricultural system is HEI and LEI, in order to estimate how much of the current global population is supported by HEI versus LEI agriculture. Projecting the proportion of future HEI and LEI food production systems is similarly beyond the scope of this investigation, especially in the context of climate change and declining energy resources. However, it is useful to include this comparison of food productivity in order to illustrate how peak oil may reduce food production capacity, which would impact the carrying capacity of the planet as the energy resources to produce food decline. Without oil, food yields will likely be less without applying permaculture and other highly productive agricultural systems methods and/or some technological breakthrough that would increase yields.

"The fact that hunger was increasing even before the food and economic crises suggests that present solutions are insufficient and that a right-to-food approach has an important role to play in eradicating food insecurity."

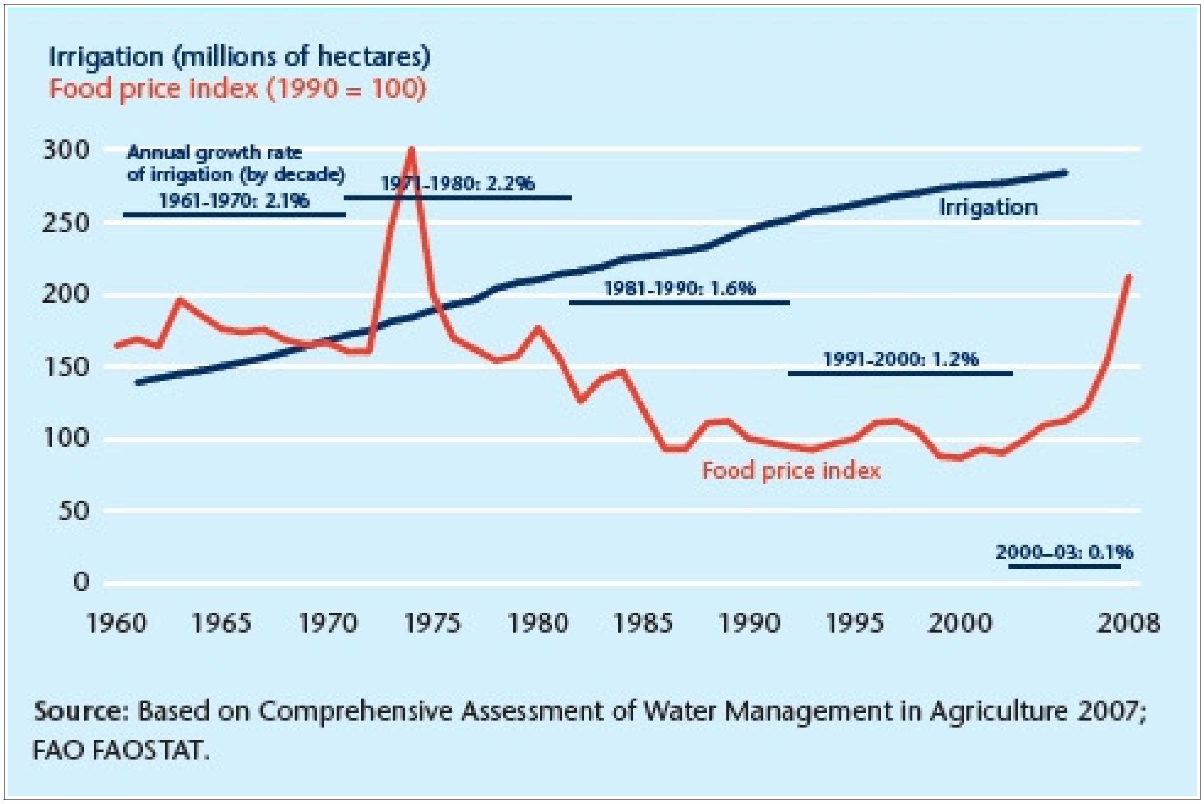
– United Nations Food and Agriculture Organization (FAO), The State of Food Insecurity in the World[133], 2009

- Until very recently, the success in agricultural production brought by the Green Revolution resulted in a 30-year decline in food prices in most countries.
- Until the early 2000's, food prices in real terms declined to their lowest levels in history. Beginning around 2005, agricultural commodities prices increased and became more volatility.
- Increased oil prices had a substantial impact on food prices.
- Increased oil prices have also stimulated demand for biofuels, which competes with food crops for resources and increases food prices.

Until very recently, the success in agricultural production brought by the Green Revolution resulted in a 30-year decline in food prices in most countries. Until the early 2000's, food prices in real terms declined to their lowest levels in history[150] (see Figure 62). Recent price increases of main agricultural commodities (e.g., wheat, rice, soybeans) has increased the number of people suffering from hunger from 850 million to 963 million[150]. Beginning around 2005, agricultural commodities prices increased and became more volatility (see Figure 63). Food prices increased by 83% between 2005 – 2008. During this time, maize prices nearly tripled, wheat prices increased by 127%, and rice prices increased by 170% between January 2005 – June 2008 [231]. Between September 2007 – March 2008, the price of wheat, corn, rice and other cereals increased an average of 41% on the international market (see Figure 63).

Although the increase in food commodity prices began in 2000, previous global food price increases have not been this rapid. The rising demand for high value food commodities has also caused a sharp increase in prices for meat and dairy products, which depend on grain and other vegetable-based production inputs. From the beginning of 2000 to the mid-2008, butter and milk prices tripled, and poultry prices nearly doubled[150].

The rapid increase in food and feed commodities prices in 2007 – 2008 resulted from a combination of causes, including sharp increases in oil prices (see Figure 63), long-term increases in demand for meat and



Source: Based on Comprehensive Assessment of Water Management in Agriculture 2007; FAO FAOSTAT.

Figure 62: Food prices and irrigation area. As irrigation area expanded, food prices fell for 30 years before starting to rise again. Based on Comprehensive Assessment of Water Management in Agriculture 2007; FAO FAOSTAT[150].

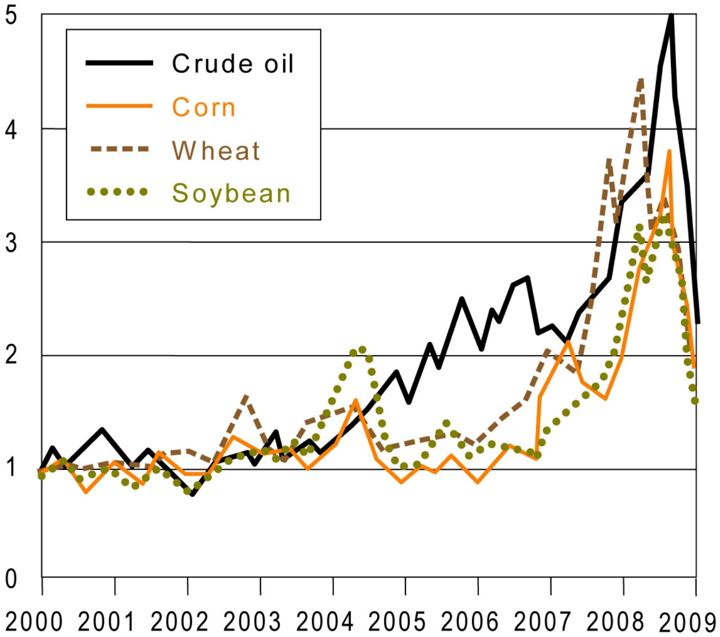


Figure 63: Relative price of crude oil, corn, wheat, and soybean on world markets, 2000 – 2008 (2000 price = 1)[232].

dairy products in emerging market economies, a progressive reduction in the stocks of the main commodities, and adverse climate conditions in some of the largest exporting nations[150]. Although these causes in combination contributed to rising food prices, increased oil prices had a substantial impact in particular. Moreover, increased oil prices have stimulated demand for biofuels. Therefore, the impacts of these factors have likely been amplified by incentives for bioenergy production in OECD nations and by food trade speculation[223].

Since mid-2008, food prices have fallen due in part to reductions in the price of oil and the overall slowdown of the global economy[150]. However, domestic prices of food in developing nations did not follow the downward trend of the international market, and the prices of major staple commodities remain high in many places. The effects of price increases on consumption vary by country and consumer group. Since food expenditures can represent 50 – 75% of the income of low-income consumers, consumers in low-income nations are much more vulnerable to food price changes than are consumers in high-income nations[150]. Therefore, increases in food prices thus negatively impact the poorest populations the most.

"If oil has peaked, do we face a future of growing energy shortages, rising prices and international conflict for supplies? No one should underestimate the energy challenge..."

– Jeroen Van der Veer[233], CEO Royal Dutch Shell, 2006

- Global peak energy is the point at which the total amount of useable energy available to the global human population from currently known primary energy sources reaches its maximum.
- Global peak coal production will likely occur between 2011 – 2025.
- Global natural gas production will likely peak sometime between 2019 – 2030.
- Global peak uranium will likely occur by 2015 to sometime in the 2020's.
- Global peak energy production thusly may occur by 2020 – 2030.
- Since oil is used to produce, distribute, and build and maintain the infrastructure for coal, gas, unconventional oil, nuclear and renewable energy resources, the decline in oil production could very simply bring about declines in the production rates of the other energy resources sooner than the above dates indicate.
- Peak oil thusly may cause peak energy resources to occur sooner.
- Global peak energy will be delayed only if:
    - one or more major new primary energy sources are discovered or developed that are comparable in quantity, quality, and versatility to fossil fuels (especially oil and liquid fuels);
    - significant breakthroughs occur in the quantity, quality, and/or versatility associated with one or more existing primary energy sources; and/or
    - a substantial and sustained decrease in the level of human energy consumption occurs.
- If either or both of the first two caveats do not occur, then the third caveat must come true, either through a reduction of per capita energy consumption and/or by a decrease in human population.

Global peak energy is the point at which the total amount of useable energy available to the global human population from currently known primary energy sources (i.e., fossil fuels, biomass, renewable energy sources, nuclear) reaches its maximum. Although the human carrying capacity of the Earth is largely determined by a variety of environmental biophysical constraints – such as the availability of water, cropland and food – it is also limited by the amount of energy available for human use, especially energy required for water and food production and distribution, the construction of shelter, health care, and other basic needs. Until this point, this paper has discussed the biophysical constraints of human carrying capacity based primarily on the carrying capacity of cropland and water resources, and to a lesser access to extent health care. The impacts of declining oil supplies on these carrying capacity factors have also been addressed. However, all energy resources are a critical limiting factor in human carrying capacity, and not only oil.

In addition to the peaking of global oil production, global peak production of coal, natural gas, and uranium will likely occur within the next 20 years assuming that BAU (and the cheap abundant oil to support it) continues. Global peak coal production will likely occur between 2011 – 2025. Global natural gas production will likely peak sometime between 2019 – 2030. Global peak uranium will likely occur by 2015 to sometime in the 2020's. Consequently, the human carrying capacity of the Earth may also peak between the years 2020 – 2030 (if it has not already done so) and then terminally decline thereafter, assuming a continuation of the historical relation between the total energy consumed by the human population and corresponding population levels and material living standards. As global oil production and economies decline, it is likely that the production of other energy resources will peak sooner. Therefore, peak oil may also result in peak coal, gas, and uranium occurring nearly simultaneously.

Peak Coal

- Global peak coal production will likely occur between 2011 – 2025.

Coal accounts for about 27% of global primary energy supply, which makes coal the second most important fuel after oil[8] (see Figure 64). By 2030, the IEA[35] projects that coal will grow to account for 29% of the global fuel mix by 2030 assuming BAU. In 2008, coal was used to generate 41.0% of global electricity[8]. Of global coal consumption in 2008, about 78.5% was consumed in producing industrial energy; 0.4% for transportation; 16.6% for energy in other sectors (includes agriculture, commercial & public services, residential and non-specified other sectors); and 4.5% was for non-energy uses[8].

The IEA[35] also projects that coal demand will increase more rapidly than all other energy sources (except for modern non-hydro renewables) at an average rate of 1.9% per year. At this rate, demand will increase from 4,548 million tonnes of coal equivalent (Mtce) in 2007 to 6,980 Mtce by 2030 [35]. The share of OECD global coal use declined from 54% in 1980 to 36% in 2007; and the IEA[35] projects that the share will decline to 23% by 2030. Most of the projected increase in global coal demand will likely occur in non-OECD countries, primarily in Asia, which accounts for 97% of incremental demand. For instance, China and India consumed about 20% of global coal in 1980, but now demand nearly 50% of global supplies[35]. Their share of global demand is projected to increase to nearly 66% by 2030 [35]. By 2030,

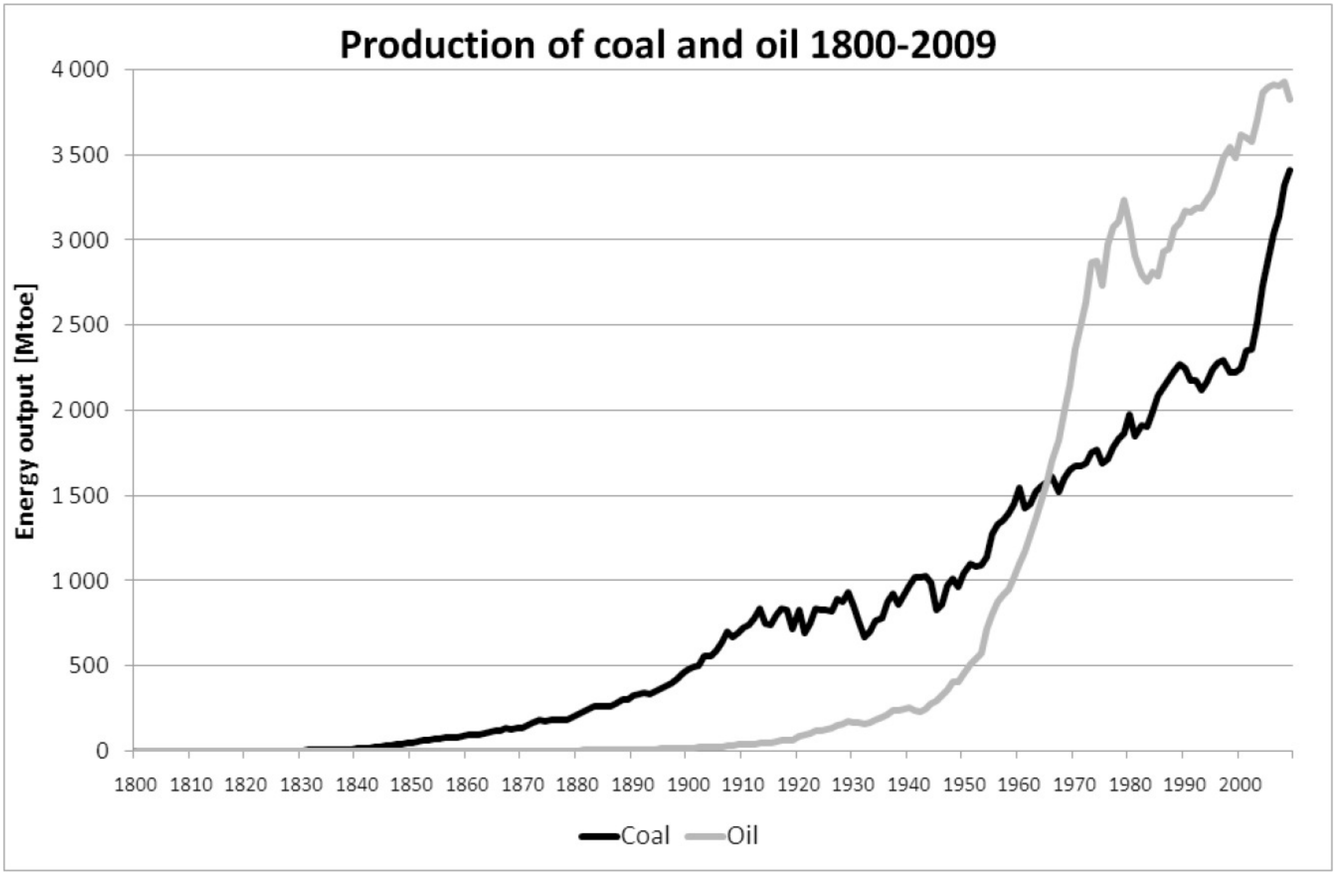


Figure 64: Historical production of energy from coal and oil since 1800 to present[82]. Data taken from Uppsala Global Energy Databases.

China's and India's coal demand each will nearly double[35] assuming BAU. By 2030, India will likely exceed the U.S., and become the world's second-largest coal consumer after China[35].

As with its projections for future oil supply, the IEA projects that global production of oil will be just enough to supply projected demand. By 2030, global coal production will increase by 52% (or by 2,400 Mtce), which is almost equal to the current combined production from China, India, and Indonesia[35]. However, in a similar way that the IEA's data and claims have been shown to be inflated and spurious regarding oil resources, so are the agency's claims for future coal capacity.

As with oil resources, the data for coal reserves and resources are of poor and questionable quality. A study published by the Energy Watch Group[234] (EWG) claims that there is no objective way to determine how reliable the available coal data are. Based on historical analyses of coal reserves, resources and production rates, the authors suggest that coal statistics overestimate the quantity and quality of global coal reserves and resources. This claim is supported by downward revisions of global reserves and resources estimates over the past two decades[234], in some cases drastically. The quantity of coal produced during this period cannot account for these decreases in reserve and resource estimates.

The best explanation may be that nations now have better data from more thorough surveys. If so, then future downward revisions are likely from nations that still rely on old reserves estimates. For instance,

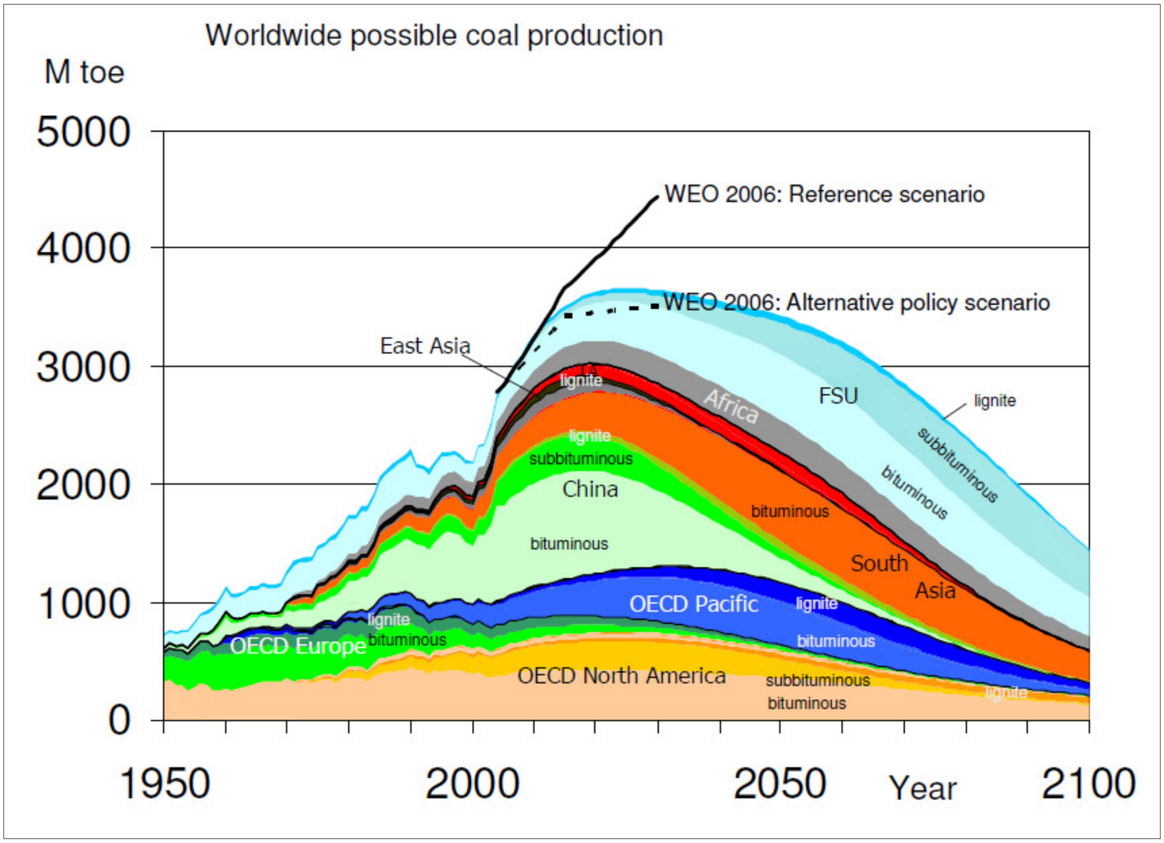


Figure 65: Worldwide possible coal production[234].

many countries have not updated their proven reserves for up to 40 years (e.g., Vietnam)[234]. Coal data for China were last updated in 1992, even though approximately 20% the 1992 stated reserves have since been produced, and an additional 1 – 2% has been consumed in uncontrolled coal fires (e.g., coal mine fires)[234].

The most drastic instance is the unexplained decrease in the German proven hard coal reserves by 99% in 2004 – from 23 billion tons to 0.183 billion tons[234]. The large reserves formerly classified as proven were reclassified as speculative. The German administration responsible for this change in estimates and reclassification of resources did not publish any explanation[234].

Since the available coal statistics are likely inflated, projections based on these data may provide an upper boundary for potential coal production. So far, global reserves of coal have decreased from 10 trillion tons of hard coal equivalent to 4.2 trillion tons in 2005, which is 60% downward revision in a span of 25 years[234].

As with oil, the coal industry and science have their own terminology to classify coal. However, only reserve data are of practical relevance, and not resource data[234]. Reserves are defined as being proved and recoverable. Resources include additional discovered and undiscovered quantities that are inferred, assumed, and/or speculative. Resources are defined in situ as quantities of which up to 50% can eventually be recovered. Future production and exploration activities would allow for the reclassification of some resources into reserves. However, the EWG[234] notes that such a reclassification of coal resources

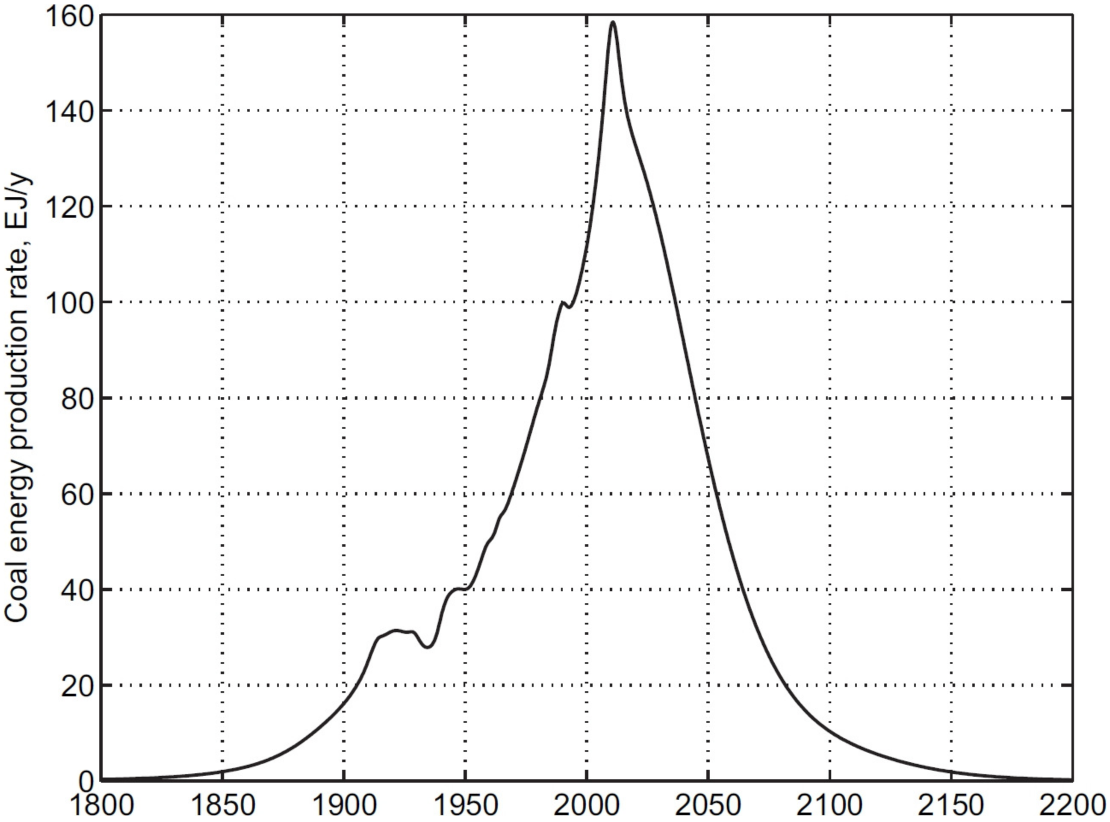


Figure 66: The best multi-Hubbert cycle match of the historical rate of production of energy in coal of all ranks worldwide. The year of peak production is 2011, and peak coal energy production (higher heating value) is 160 exajoules (EJ) per year[235]*.*

has occurred only twice in the past two decades – once in India and in Australia. In effect, coal resources have not been reclassified into reserves over the past two decades despite increasing coal demand and prices.

Approximately 85% of global coal reserves are located in six countries. Listed in descending order of reserves, the countries are the U.S., Russia (about half of U.S. reserves), India (half of U.S. reserves), China (half of U.S. reserves), Australia, South Africa. Over 80% of global coal production occurs in China, U.S. (half of Chinese production), Australia (less than half of U.S. production), India (less than half of U.S. production), South Africa, and Russia (also listed in descending order).

The U.S. has about 30% of global coal reserves, and it is the second largest producer. Conversely, China has only the equivalent of half the reserves of the U.S., but it is the largest coal producer[234]. Therefore, the U.S. and China strongly influence global coal production. Since coal consumption occurs mainly in the country of origin, only 15% of coal production is exported, whereas 85% of it is consumed domestically[234]. Therefore, China, the U.S., Australia, India, South Africa, and Russia will likely continue to dominate the global coal market into the future, in terms of both supply and demand.

China is experiencing the most rapid reserves depletion globally, at a decline rate of 1.9% of reserves produced annually[234]. The U.S. passed peak production of high quality coal in 1990. The production of sub-bituminous coal in Wyoming may have compensated for this decline in terms of volume, but not in terms of quality. Due to the lower energy content of sub-bituminous coal, U.S. coal production in terms of energy (i.e., EROI) already peaked in 1998 at 598 Mtoe compared to 576 Mtoe in 2005 [234]. This production decline may be terminal[234].

The EWG[234] projects that global coal production will likely peak around 2025 at 30% above present production, in a best case scenario (see Figure 65). Thereafter, coal production will reach a plateau and then eventually decline. The authors emphasize that their projections are a best estimate of an upper limit of future coal production, since they did not consider climate policy and other restrictions on coal production.

Höök et al.[236] project that a global peak in coal production will likely occur between 2020 – 2050, depending on estimates of recoverable volumes. Based on the actual reported reserves, increased coal production is sustainable for another decade or two until peak production is reached in 2020 – 2030. Since the coal reserve and resource estimates are likely to be inflated, peak coal production could occur sooner, as suggested by Patzek and Croft[235] (see below). However, Höök et al.[236] note that even if the global recoverable coal volumes are 2 times more than reported, peak production would only be postponed until 2030 – 2050.

Although the above two estimates for when peak coal production will occur are only one or two decades in the future, global coal production could reach a maximum level much sooner. Patzek and Croft[235] developed estimates for global coal production based on the physical multi-cycle Hubbert analysis of historical production data. The authors predict that global peak of coal production from existing coalfields will likely occur “close to the year 2011” (see Figure 66). They expect that the peak coal production rate will be 160 exajoules (EJ) per year (an exajoule is equal to 1 billion billion joules of energy). After 2011, the coal production rates are likely to reach 1990 levels by the year 2037, and then reach 50% of the peak value in the year 2047. The authors suggest that it is unlikely that future coal mines will reverse the projected decline in their BAU scenario.

All of the above estimates for when peak production of coal will occur all assume BAU. In particular, they assume that global oil supplies will be available to drive demand or and production of global coal resources. As the price of oil increases as it becomes more scarce, the production, processing, and distribution costs for coal will also likely increase. As global oil production and economies decline, it is likely that the production of coal will peak sooner. Therefore, peak oil may also result in peak coal occurring nearly simultaneously.

Peak Gas

- Global natural gas production will likely peak sometime between 2019 – 2030.

In 2008, natural gas accounted for about 21.1% of the total global primary energy supply[8]. Of total global final consumption of gas in 2008, 5.9% was consumed for transportation, 35.1% for industry, 10.8% for non-energy use, and 48.2% for other sectors (including agriculture, commercial & public services, residential and non-specified other sectors)[8]. About 21.3% of global electricity is produced from gas[8]. Gas is also used as a feedstock primarily in the petrochemical and ammonia industries. Natural gas accounts for nearly 80% of the world's output of both methanol and ammonia[35]. Ammonia is used as to make synthetic fertilizer. Natural gas feedstock accounts for 70 – 90% of the total cost of making ammonia[35].

Discoveries of natural gas resources peaked in the mid-1970's at nearly 60 billion barrels oil equivalent (see Figure 67). Since the early 1980's, natural gas discoveries have plummeted dramatically.

The IEA[35] projects that natural gas demand will increase on average by 1.5% per year assuming BAU; from 3 trillion cubic meters (tcm) per year in 2007 to nearly 3.4 tcm per year in 2015; and to 4.3 tcm per year in 2030. In comparison, 1 tcm is equal to 1,000 km^3 or 1,000 billion cubic meters (bcm). As with oil supplies, the IEA also estimates that global gas resources will be "more than sufficient to meet projected demand to 2030", even though they have doubts about whether sufficient investment for exploration and development can be mobilized in all regions.

The share of gas in the global primary energy mix is expected to increase slightly from 20.9% in 2007 to 21.2% in 2030. The IEA[35] projects that primary gas demand will continue to increase in all regions through until 2030, except in the U.S. (where demand will be flat). Demand is projected to increase most in non-OECD regions, which accounts for 80% of the global increase to 2030. The largest increase in demand is expected to occur in the Middle East. Demand in non-OECD Asia and Africa may also rise strongly. Gas demand is expected to increase by more than 5% per year in both China and India by 2030. North America and Europe are expected to experience low rates of demand growth through to 2030. However, they are expected to be the largest gas consumers in 2030.

Although the IEA's projections for global gas supplies are very optimistic, they should be accepted with skepticism for much the same reasons as their oil analysis is suspect – the data are of poor quality and the IEA may be inflating its estimates and figures as it has done with its oil figures. Like its estimates for oil production until 2030, the IEA[35] also has important caveats to its predictions. Despite the IEA's optimistic outlook on global gas supplies for the next two decades, the agency admits[35]

"...just because the gas is there does not mean that it will be produced. Investment needs are set to rise in the coming years, both to meet rising demand and to make up for the loss of capacity through the decline of existing fields (equivalent to about half current global production or more than twice current Russian production by 2030). Upstream and downstream gas companies...may not have the opportunity or the incentive to invest. This depends very much on host government policies...Moreover, logistical, practical and technical factors may constrain the ability of gas companies to launch major new projects in a timely way".

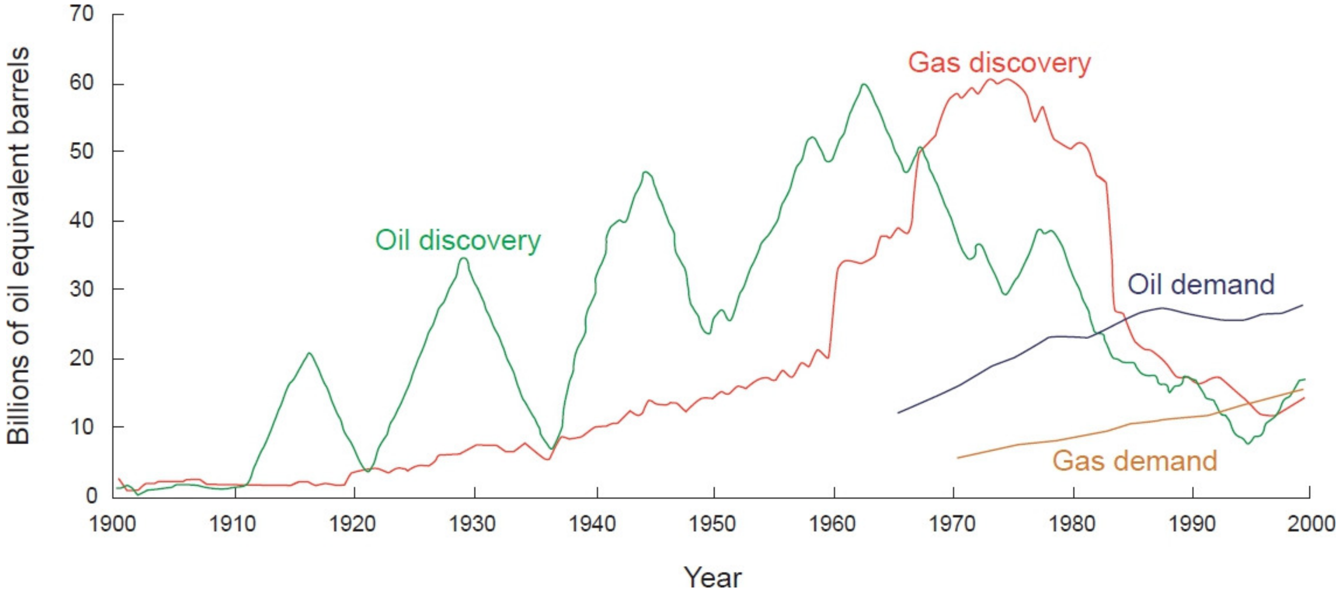


Figure 67: 100-year oil and gas discovery history and recent demand[240 as cited in 237].

The IEA makes two very important points in the above quote. By 2030, not only will about half current global production need to be replaced (roughly 1.5 tcm per year), but over 1 tcm of additional capacity would have to be put into production by 2030. In other words, roughly 2.5 tcm per year of additional capacity must be put into production by 2030 assuming BAU. Since global natural gas demand was about 3 tcm per year in 2007, adding 2.5 tcm per year of additional capacity would be almost like replacing current capacity. The second point that the IEA makes is that the investment required to develop future gas production may not be sufficient to supply future demand. These points raise serious doubts about the IEA's projections of future natural gas production.

Independent research suggests that the peak production of natural gas may be much sooner than the IEA indicates. Using multicyclic Hubbert models, several research groups have estimated when a global peak in gas production may occur. Whereas the IEA claims that peak oil will not occur before 2030, these other authors have more dire projections. Jian et al.[237] estimate that global gas production will peak "around 2030". Bentley[238] expects global gas production to peak by around 2020. Using a multicyclic Hubbert model, Imam et al.[239] project that global natural gas production will likely peak at 2.5 trillion cubic meter (tcm) per year in 2019 (see Figure 68).

After natural gas production peaks, the rate of production decline will likely be at least as dramatic as the post-peak oil decline rate. The IEA[35] estimates that the global, production-weighted, gas production decline rate is 7.5% for all fields beyond their peak. The report also projects that output from existing fields will likely fall by nearly half between 2007 – 2030. The report also projects that production from all existing fields (in production in 2008) will drop by more than 1,400 bcm between 2007 – 2030, which is equivalent to more than twice the annual production of Russia, the world's largest producer.

Although the global supply of gas is significant to support the global economy, the direct effects of peak gas production are relatively localized since it is difficult to transport gas large distances to consumers in other regions due to the tremendous economic and energetic expense of liquefying and transporting natural gas as a compressed liquid. In addition to their estimate of global peak gas production, Imam et al.[239] also provide regional estimates of peak gas production. In 2002, the Western Hemisphere was the largest gas-producing region in the world, producing 37.1% of the global total. However, the authors[239] indicate that gas production likely peaked in this region in 2000. Further, the authors estimate that that the Western Hemisphere has only 9% of the world's estimated future recovery. The Western Hemisphere has already produced about 56% of its ultimate recoverable reserves. For instance, gas production in the U.S. peaked in 1973, and the cumulative gas production of the U.S. to 2004 was more than 85% of its estimated total recovery.

In 2002, the amount of gas produced in Western Europe was approximately 12% of the global total. However, Western Europe has less than 3.5% of the world's future recoverable gas. Peak gas production in Western Europe occurred in 2000, reaching a production plateau during 1999 – 2002 [239]. Approximately 49% of the ultimate recovery has already been produced. Over 50% of the major gas producers in this region are either past their production peak or are about to peak.

Eastern Europe and the former Soviet Union (FSU) is the second largest gas-producing region in the world. Together, they account for 36% of the world's estimated future recovery, which represents the greatest potential future gas recovery. Russia is the country with the greatest estimated reserves and annual production in the world. However, the authors mention that there is a general skepticism about Russia's reserves reporting, since some of Russia's reported reserves are understood to be proved plus some probable reserves, while most nations report only proved reserves that are economically recoverable with the present technology. The authors estimate that gas production in Russia will peak by 2029. However, Imam et al.[239] did not provide estimates of when peak gas would occur in Eastern Europe, except for Romania (peaked in 1981).

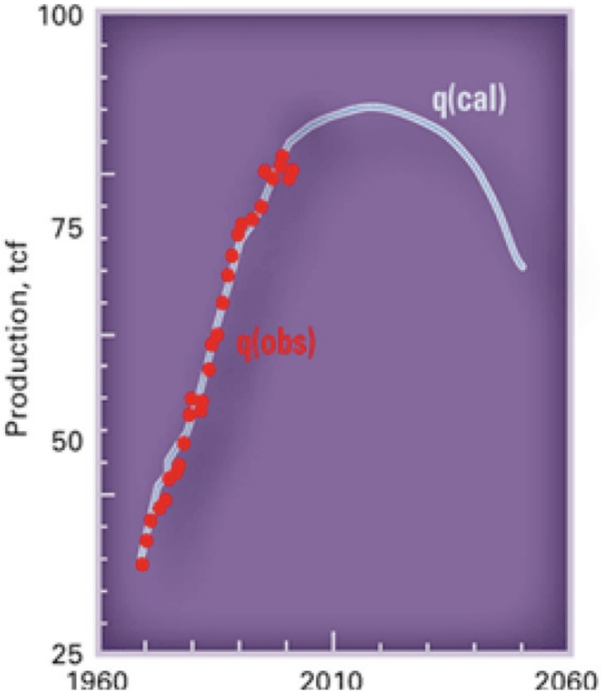


Figure 68: World gas production model in trillion cubic feet (tcf) per year. Peak gas production occurs in 2019 [239].

Natural gas production in Africa will likely peak by 2015 [239]. However, ultimate gas recovery is expected to be the lowest of all regions. Nonetheless, future remaining recoverable gas is at 85% of the region's ultimate total.

The Middle East has the world's second highest estimated future gas recovery. Gas production in Middle East is expected to peak in 2039 [239]. The region's cumulative gas production is only about 4% of its ultimate recovery. Iran, Qatar, Saudi Arabia, and the UAE are the major producers in the region, with nearly 90% of the projected future recovery and nearly 84% of the total gas produced in the region.

Imam et al.[239] estimate that gas production will peak in the Asia-Pacific region in 2010. Future recovery in the Asia-Pacific region is about 8% of the global total, and only about 19% of its total recovery produced has been so far produced.

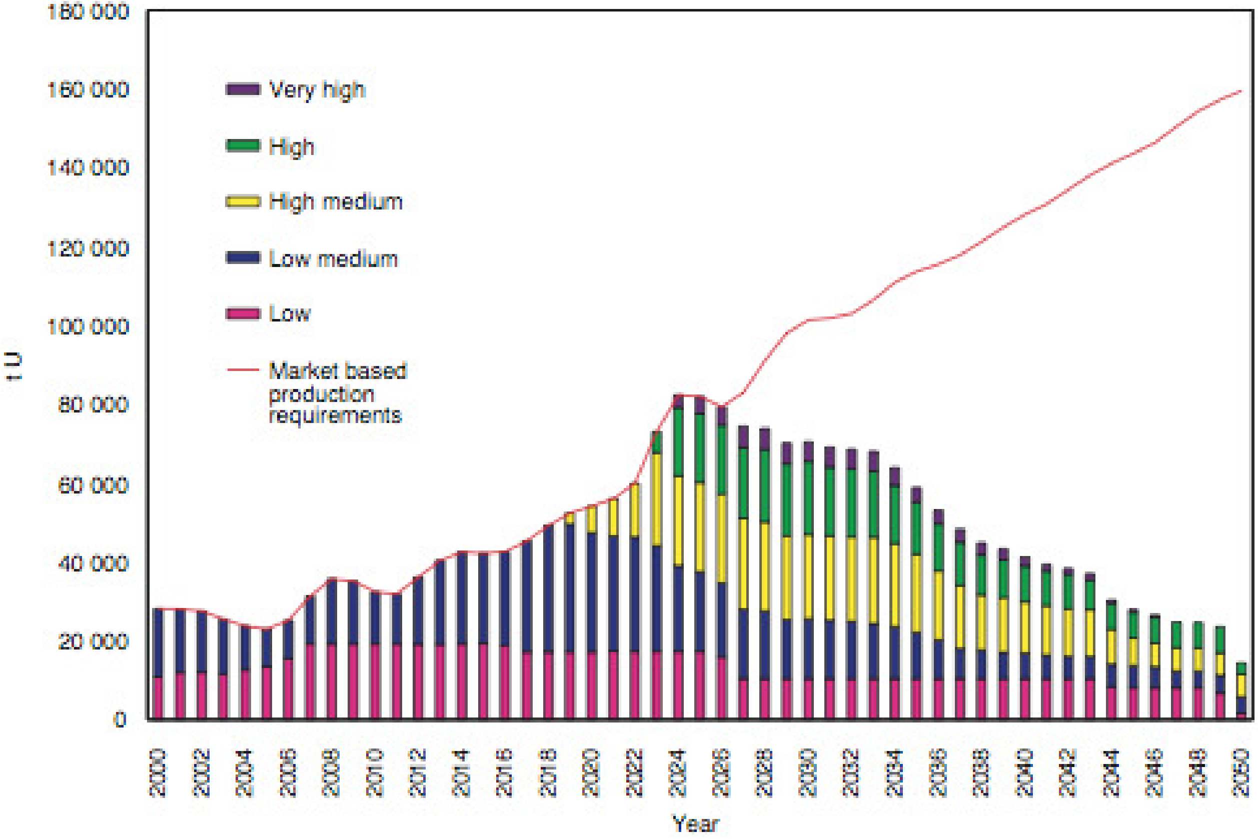


Figure 69. IAEA projection of market-based production from reasonably assured resources by cost category - middle demand case[242].

Regional and global peaking of gas production will likely have serious economic and geopolitical impacts throughout the world. The European Union is expected to require the largest increase in gas import volumes through to 2030, because of declining regional production (especially in the Netherlands and the United Kingdom) and a modest increase in demand. By 2030, the EU will likely need to import 83% of its gas supply, compared with 59% at present[35]. Emerging Asian nations will also become much more dependent on gas imports. China and India have modest proven gas reserves and only a limited potential for increasing production rates. Without any large new discoveries, China and India will become increasingly dependent on imports, where gas imports reach 48% of total gas consumption in China and 39% in India by 2030. Assuming BAU, the most of the increase in natural gas exports will come from Russia, Iran and Qatar, with lesser quantities supplied by other Middle Eastern producers, Africa, and the Caspian and Central Asian region. Consequently, increasing dependence on natural gas imports from a limited number of exporting nations will increase the market dominance of producers and increase vulnerability to supply disruptions at major choke points[35].

All of the above estimates for when peak production of gas will occur all assume BAU. In particular, they assume that global oil supplies will be available to drive demand or and production of global gas resources. As the price of oil increases as it becomes more scarce, the production, processing, and distribution costs for gas will also likely increase. As global oil production and economies decline, it is likely that the production of gas will peak sooner. Therefore, peak oil may also result in peak gas occurring nearly simultaneously.

Peak Uranium

- Global peak uranium will likely occur by 2015 to sometime in the 2020's.

Although it is not a fossil fuel, uranium is also an important and finite energy resource. In 2008, nuclear energy accounted for 5.8% of the global primary energy supply[8]. About 13.5% of global electricity was produced using nuclear fuel in 2008 [8]. Nuclear energy does not contribute significantly to transportation energy, nor is it used as a feedstock for materials like plastics, fertilizers, or pesticides. However, the following discussion about peak uranium production is nonetheless relevant, because a peak in uranium production would limit the potential for nuclear energy to replace or substitute for dwindling oil and fossil fuel supplies.

The IEA[35] projects that electricity generation from nuclear power plants will increase from 2,719 trillion watt hours (tera watt hours or TWh) in 2007 to 3,670 TWh in 2030 assuming BAU[35]. The agency also projects that nuclear power generation capacity will increase from 371 billion watts (giga watts or GW) in 2007 to 410 GW by 2015 and to 475 GW by 2030 [35].

Nevertheless, the IEA's projections assume that uranium resources will be able to supply future demand. New nuclear power plants have enormous upfront capital costs (e.g., the cost of a typical new 1600 MW plant is likely to exceed $5 billion) and long lead times (i.e., 8 – 10 years) for design, approval, and construction (e.g., construction alone can require at least 5 years)[35,241]. Many nations have developed a renewed interest over the past few years in building nuclear power plants, due to concerns over energy security and GHG emissions. However, few governments have begun to promote the construction of new reactors. Furthermore, the global economic crisis that started in 2008 could cause delays and possibly cancellations of new nuclear power plants, and also discourage new construction programs[35].

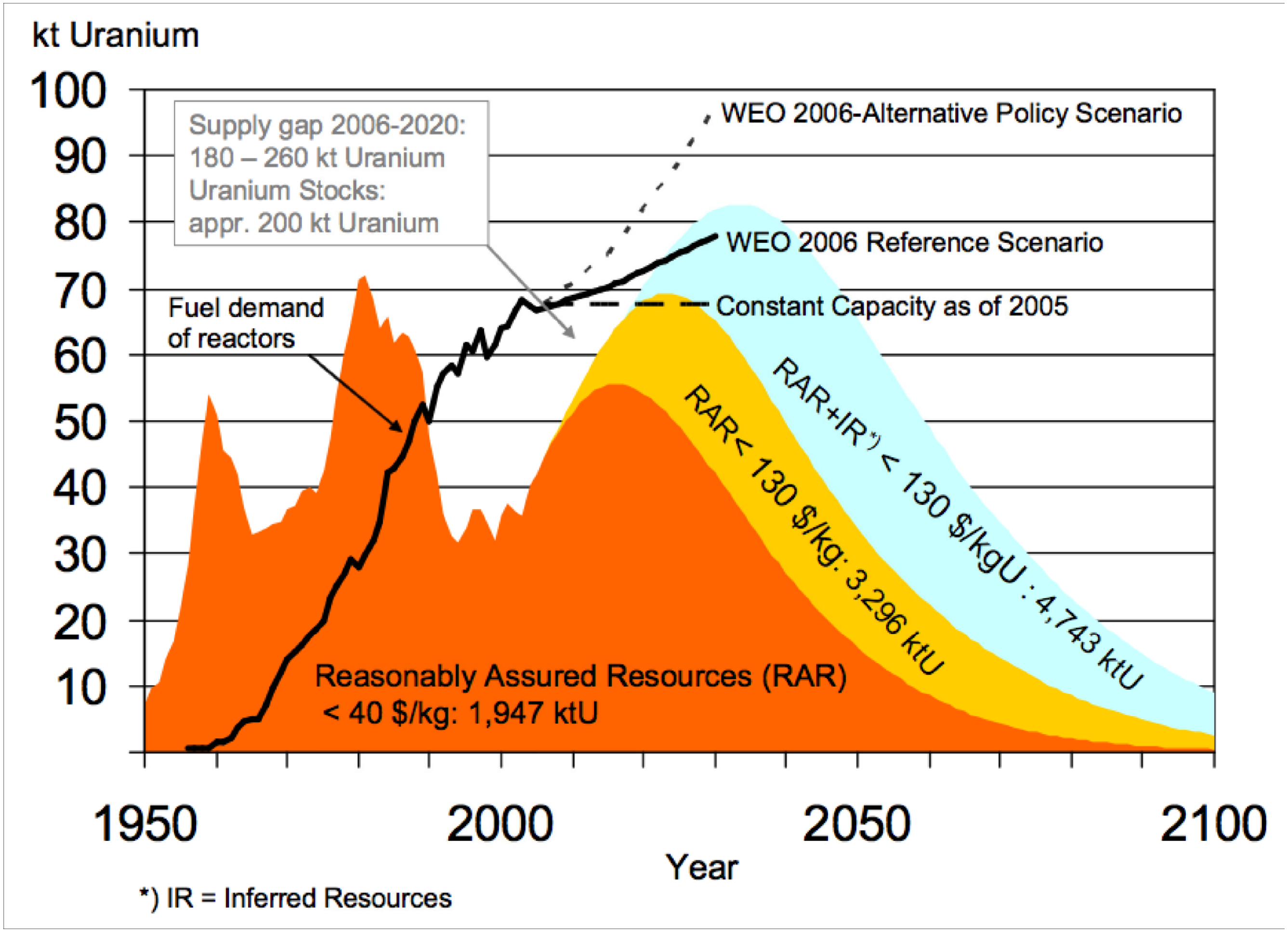


Figure 70: Demand scenarios with forecast of uranium production using three different reserve estimates [241].

A few analyses of uranium resources suggest that uranium production will likely peak during the 2020's. In 2001, the International Atomic Energy Agency (IAEA) projected peak production of uranium would occur in 2024 (see Figure 69), assuming all resources (including the highest cost resources) can be extracted. If only lower cost uranium resources can be extracted, then the peak will be sooner[242] (see Figure 69).

The World Nuclear Association[243] (WNA) projects that uranium production will peak by 2015. Thereafter, the WNA projects that uranium production will fall to 90% its peak 2015 level in 2030 [243].

In a joint report by the OECD Nuclear Energy Agency (NEA) and the International Atomic Energy Agency[244] (IAEA), global primary uranium production capabilities including existing, committed, planned and prospective production could supply projected high case world uranium demand until 2028, and projected low case demand until 2035. After 2028 – 2035, the authors anticipate that additional uranium resources will need to be identified and developed in order for global production to be able to provide uranium for all reactors for their entire operational lifetimes. Secondary sources (e.g., recycled uranium) will also be required. However, supplies of secondary sources are projected to decline after 2013.

The Energy Watch Group (EWG) also offers an in-depth analysis of uranium supplies. In 2006, the EWG[241] suggested that proved uranium reserves will be "exhausted within the next 30 years at current annual demand", but that "after about 2020 severe uranium supply shortages will become likely". The net nuclear energy capacity will likely decline by about 70% until 2030, if present trends continue[241].

Eleven countries have already exhausted their uranium reserves. In total, about 2.3 million tons (mega tons or Mt) of uranium have already been produced globally. Between 1.9 – 3.3 Mt of reasonably assured resources are available. Based on lower data quality, there are between 0.8 – 1.4 Mt of additional resources[241].

Presently, only Canada has uranium deposits that contain uranium with an ore grade of more than 1%. Most of the remaining reserves in other nations have ore grades below 0.1%; and, two-thirds of remaining reserves have ore grades below 0.06%[241]. This is a significant EROI issue since the energy requirement for uranium mining is at best indirectly proportional to the ore concentration. The energy required for uranium processing over the whole fuel cycle increases significantly for ore concentrations below 0.01 – 0.02%[241]. According to the EWG[241], the proven reserves (i.e., reasonably assured below $40 per kg uranium extraction cost) and stocks will likely be exhausted within the next 30 years at current annual demand. And, possible resources (i.e., all estimated discovered resources with extraction costs of up to $130 per kg) will likely be exhausted within 70 years. The EWG concludes, "In the long term beyond 2030 uranium shortages will limit the expansion of nuclear power plants."

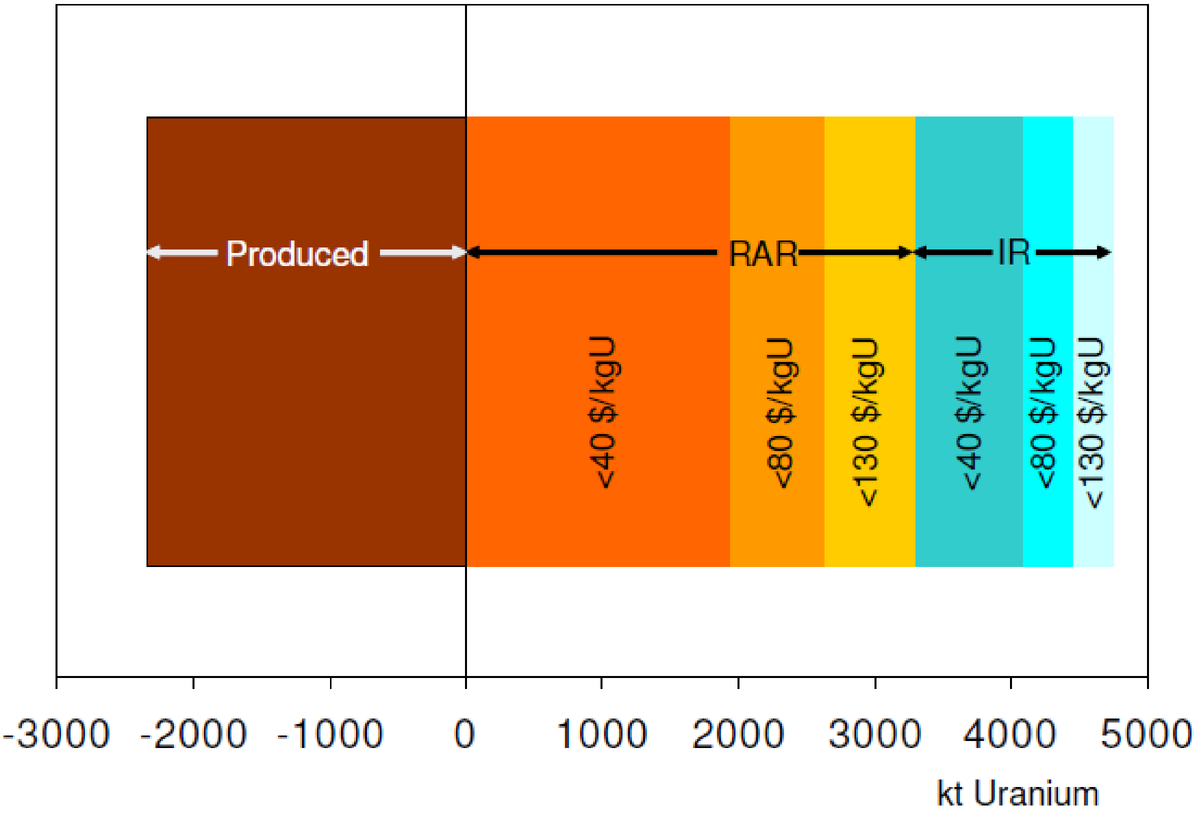


Figure 71: Reasonably assured (RAR), inferred (IR) and resources of uranium already produced [241,244].

In Figure 70, the EWG[241] analyzes three types of uranium reserves and projects their likely production rates. The dark orange section represents “reasonably assured resources” that can be economically extracted for $40 per kg or less. The yellow section represents "reasonably assured resources" that may be mined for $130 per kg or less. During the summer of 2010, spot prices for uranium ranged between $40 – 50 per pound (about $88 – 110 per kg), which means that current prices are between the $40 – 130 price levels.

The light blue section represents "inferred resources", which is analogous to “undiscovered oil” (i.e., no one has actually found and assessed the quantity and quality of the resources. Even with these undiscovered and unknown resources, shortages of uranium are likely to occur within the next few decades, if not sooner.

Recent uranium demand has been around 67 thousand tons (kilo tons or kt) per year. Of this total, only 42 kt per year (63% of the total) are supplied by new uranium production. The remaining 25 kt per year (37%) are recycled from stockpiles that were accumulated before 1980 [241] (see Figure 71). These accumulated stocks will be exhausted within the next 10 years. Therefore, uranium production capacity will need to increase by at least 50% in order to supply the future demand of current capacity[241]. If only 42 kt per year of proved uranium reserves that are less than $40 per kg can be produced, then supply shortages are likely before 2020. If all of the estimated known resources up to $130 per kg extraction cost can be produced, then a supply shortage can at best be delayed until about 2050 [241].

Although the supply of uranium is important in assessing peak nuclear energy production, nuclear capacity (i.e., nuclear power plants and distribution infrastructure) is also a constraining factor since nuclear power plants have long life cycles and high capital costs. Developing nuclear capacity requires several years of designing and planning, and then a period of construction of at least 5 years. An average nuclear power plant can operate for about 40 years once it is made operational[241]. Globally, approximately 45% of nuclear reactors are over 25 years old; and about 90% are older than 15 years old[241]. Therefore, once these current nuclear reactors reach the end of their lifetime by 2030, they will need to be replaced by new reactors in addition to any new power plants necessary to supply increased demand.

Although only 3 – 4 new nuclear reactors per year are completed, 15 – 20 new reactors per year will need to be completed in order to maintain the present reactor capacity[241]. The EWG[241] concludes that until about 2015, the long lead times of new reactors and the decommissioning of aging reactors will prevent the rapid extension of nuclear energy supplies; and after about 2020, substantial uranium supply shortages will likely occur which will further constrain the expansion of nuclear energy.

All of the above estimates for when peak production of uranium will occur all assume BAU. In particular, they assume that global oil supplies will be available to drive demand or and production of global uranium resources. As the price of oil increases as it becomes more scarce, the production, processing, and distribution costs for uranium will also likely increase. As global oil production and economies decline, it is likely that the production of uranium will peak sooner. Therefore, peak oil may also result in peak uranium occurring nearly simultaneously.

Peak Energy and Carrying Capacity

Chapter 27

"The power of population is so superior to the power of the earth to produce subsistence for man, that premature death must in some shape or other visit the human race. The vices of mankind are active and able ministers of depopulation. They are the precursors in the great army of destruction, and often finish the dreadful work themselves. But should they fail in this war of extermination, sickly seasons, epidemics, pestilence, and plague advance in terrific array, and sweep off their thousands and tens of thousands. Should success be still incomplete, gigantic inevitable famine stalks in the rear, and with one mighty blow levels the population with the food of the world."

– Thomas Robert Malthus[132]. *An Essay on the Principle of Population*, 1798

"Peak oil threatens to be a historic discontinuity as the economic growth of the past Century, which was driven by an abundant supply of cheap oil-based energy, gives way to decline. The population of the world, which grew six-fold in parallel with oil, faces decline, probably accompanied by rising migration pressures. Radical new political structures may be needed in a world facing ever deeper resource and environmental constraints."

– Colin J. Campbell[245], petroleum geologist, consultant, founder of the
Association for the Study of Peak Oil and Gas (APSO), 2002

- In terms of energy resources, the human carrying capacity of the Earth may be even lower based on historical relationships between global population and energy resource use, since the availability of all energy resources may limit the size of the global human population.

- The consumption of abundant fossil fuel energy has allowed the human population to increase greatly from approximately 0.5 billion before the year 1700 to about 7 billion today.

    - Until around 1500, the global human population had never exceeded 0.5 billion people.

    - By 1800, approximately 1 billion people lived on the Earth at the beginning of the the Industrial Revolution when fossil fuel energy was beginning to be exploited on a large-scale.

    - Since the advent of modern industrialized agriculture around 1950, the global population has increased from 2.5 billion to nearly 7 billion in 2010.

- Decreasing energy resources may decrease the global human population that depends on them.

- Without enormous amounts of energy that oil and other fossil fuel energy resources have supplied for the past two centuries, the human carrying capacity of the Earth may be as low as 0.5 – 2.5

billion people.

- Therefore, the total estimated human carrying capacity of the planet is 0.5 – 7.5 billion by 2050, and 0.5 – 6 billion by 2100, assuming that no abrupt and non-linear climate changes, a rapid mass extinction event, a global conflict (e.g., nuclear war) or any other massive environmental catastrophe occurs that might change the carrying capacity.
- This analysis only considers minimally adequate per capita food and energy supplies. The more resource-intense are the economies and lifestyles of the global population, the lower will be the potential carrying capacity.
- The human response to peak oil and environmental management practices will be a key factor affecting the potential human carrying capacity of the Earth.

Never before have people harnessed and consumed more energy; and it is possible that people never will again (see Figures 72 and 73). Global peak energy is the point at which the total amount of useable energy available to the global human population from currently known primary energy sources (i.e., fossil fuels, biomass, renewable energy sources, nuclear) reaches its maximum. Global peak energy will be delayed only if: (1) one or more major new primary energy sources are discovered or developed that are comparable in quantity, quality, and versatility to fossil fuels (especially oil); (2) significant breakthroughs occur in the quantity, quality, and/or versatility associated with one or more existing primary energy sources; and/or (3) a substantial and sustained decrease in the level of human energy consumption occurs[246]. If either or both of the first two caveats do not occur, then the third caveat must come true, either through a reduction of per capita energy consumption and/or by a decrease in human population.

As suggested in Figure 72, the availability of all energy resources may limit the size of the global human population. Until the Industrial Revolution, the primary supplies of energy were from human labor (including slave labor), firewood and other biomass, and animal labor. Additionally, wind (driven by solar energy flowing through the atmospheric system) also powered mills and boats to some extent.

Campbell[245] briefly puts into historical context the increase in energy production and consumption over time. Until around 1500, the global human population had never reached 0.5 billion people. By 1800, approximately 1 billion people lived on the Earth at the beginning of the the Industrial Revolution (see Table 7 and Figure 72). New machinery was driven by abundant supplies of inexpensive energy sources – beginning with coal, and then oil, natural gas, and other resources see Figure 72. Although the Industrial Revolution began in England, the expansion of the British Empire was followed by the industrialized empires of France and other European nations, Russia, and eventually the United States.

These empires where supported by inexpensive energy sources. And the growth of emerging economies, such as China and India, are also driven in part by access to inexpensive energy resources. The global economic hegemony of the U.S. and its Western allies is maintained by its military and economic power driven by cheap fossil fuel energy. And, as the war in Iraq demonstrates, this hegemony depends on securing large supplies of inexpensive fossil fuels at relatively high acquisition costs. Since it started about three centuries ago, this age of globalized industry and empires was built using cheap fossil fuels, which drove the machinery and the new transportation systems associated with railroad, trucking, shipping, and eventually air- and space-craft. Coal, then oil, gas, and electricity replaced wind, water, biomass, and human and animal labor as the driving force for the machinery and the new transportation systems. Now, at nearly 7 billion people, the global population is confronted with the limits of the planet's capacity to support it.

In Figure 72, Campbell estimates how the consumption of abundant fossil fuel energy has allowed the human population to increase greatly from approximately 0.5 billion before the year 1700 to about 7 billion today. Campbell also projects how decreasing energy resources may decrease the global human population that depends on them. According to Figure 72, the Earth's carrying capacity in terms of energy resources is about 0.5 billion, relying only on firewood (and other biomass) and human and animal labor; but without the use of significant quantities of fossil fuels (i.e., coal, oil, etc.). According to Campbell, coal use currently supports an additional 2 billion people – raising the total carrying capacity to approximately 2.5 billion, the equivalent of the estimated global population at the start of the Green Revolution in 1950. The introduction of large-scale oil use in the early 20th Century, and especially since the start of the Green Revolution, currently supports another 2.5 billion – raising carrying capacity to about 5 billion people. The use of natural gas roughly supports another 1.5 billion people – which brings the carrying capacity up to about 6.5 billion people. Unconventional oil, nuclear, and renewable energy resources support an additional 0.5 billion.

Campbell’s estimates may somewhat oversimplify the complexity of how the each the production of each energy resource affects the production of the others (e.g., oil is used as a transportation fuel and to power production machinery); and how the consumption of energy resources affects the potential human population. Nevertheless, they are a very useful model for understanding the possible correlation between energy resource use and population carrying capacity.

Furthermore, Campbell makes some assumptions about when the production of each of these energy and feedstock resources will peak. In particular, Campbell assumes that the production of oil, coal and natural gas – and thusly, the peak of all energy resources in aggregate – will peak around the year 2020. As discussed in the previous sections about peak production of energy resources, other energy resources may all peak by around 2020 – 2030 assuming BAU (except for oil which will likely occur sooner). Global peak coal production will likely occur between 2011 – 2025. Global natural gas production will likely peak sometime between 2019 – 2030. Global peak uranium will likely occur by 2015 to sometime in the 2020's. Consequently, the human carrying capacity of the Earth may also peak (if it has not already done so) between the years 2020 – 2030 and then terminally decline thereafter, assuming a continuation of the historical relation between the total energy consumed by the human population and corresponding population levels and material living standards.

It is worth noting that Campbell may also be making decline curve assumptions about the decline in oil and in the subsequent production rates of the other energy resources in the graph. That is to say, in addition to making assumptions about the decline curve of oil production post-peak oil, the author may also be making assumptions about the future productivity of the remaining resources. Since oil is used to produce, distribute, and build and maintain the infrastructure for coal, gas, unconventional oil, nuclear and renewable energy resources, the decline in oil production could very simply bring about increased declines in the production rates of the other energy resources. A decline in any of the other energy resources has the potential to decrease the overall human population proportionately. Since peak oil and energy has never occurred before now, it is of course reasonable to have to make such decline curve assumptions.

The human carrying capacity of the planet is also determined by the standard of living of the population. For example, OECD nations consume more energy per capita than do the developing nations per capita[2]. Since energy resources are limited, there is a tradeoff between quantity of life and quality of life. For each person that lives a highly energy- and resource-intensive life, the less people can be supported by environmental resources. Additionally, more people compete for limited resources in a large population, which lowers the per capita share of resources.

The matter of human carrying capacity can be summarized by the question, *"How many people can the planet support?"* This question implies another essential one, *"What is desired?"*. So far in this paper, the maximum human carrying capacity of the Earth has assumed a minimal but adequate quality of life (e.g., the minimum daily requirement of food and water to avoid malnourishment is considered). Food surpluses as insurance against low crop yields are not specifically addressed. If people wish to live a more energy- and resource-intensive lifestyle (e.g., defined by high consumerism, consumption of meat and affluent diets, global industrialized trade), then the maximum sustainable population will likely be less in proportion to the amount of energy and material resources that are available and consumed per capita.

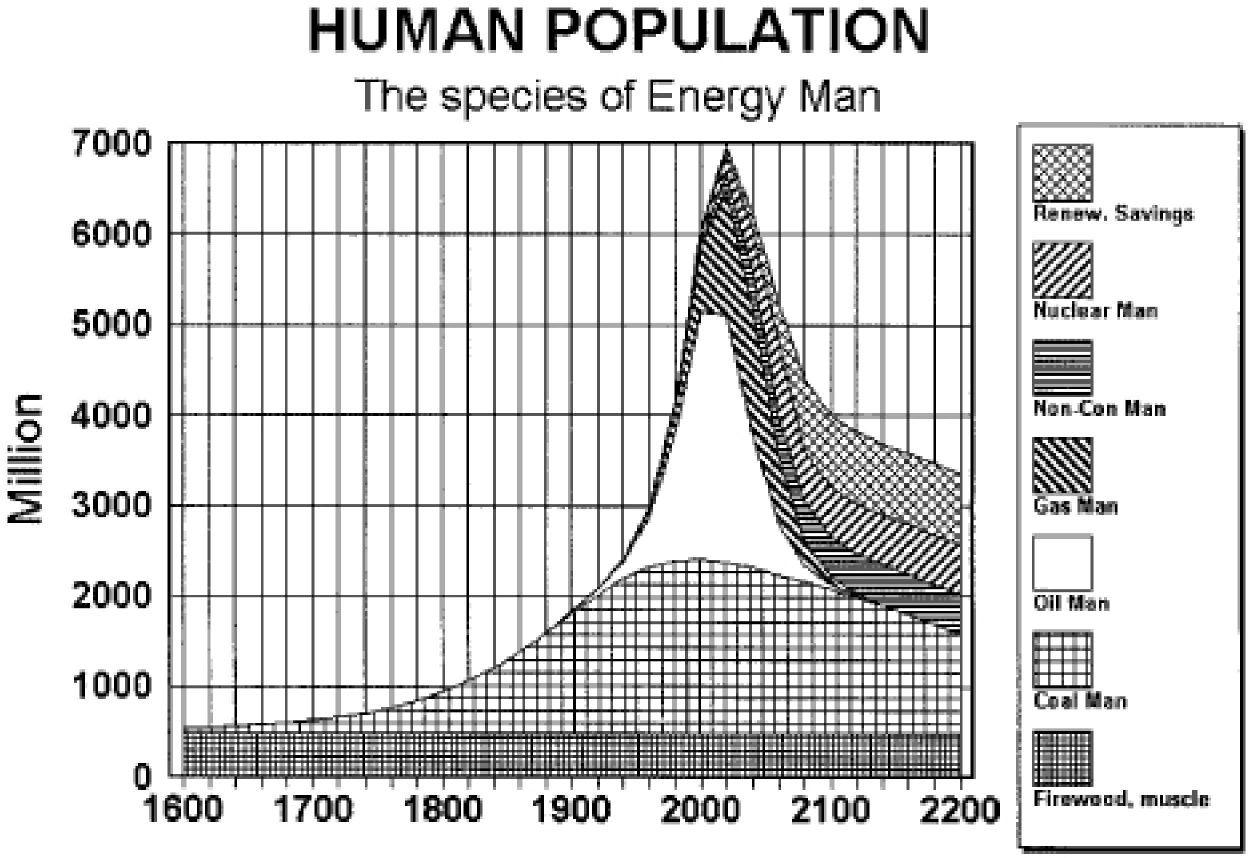


Figure 72: Global population as a function of energy consumption. Each source of energy supports a corresponding population. The impact on population of oil and gas has been dramatic, but it is short lived[245].

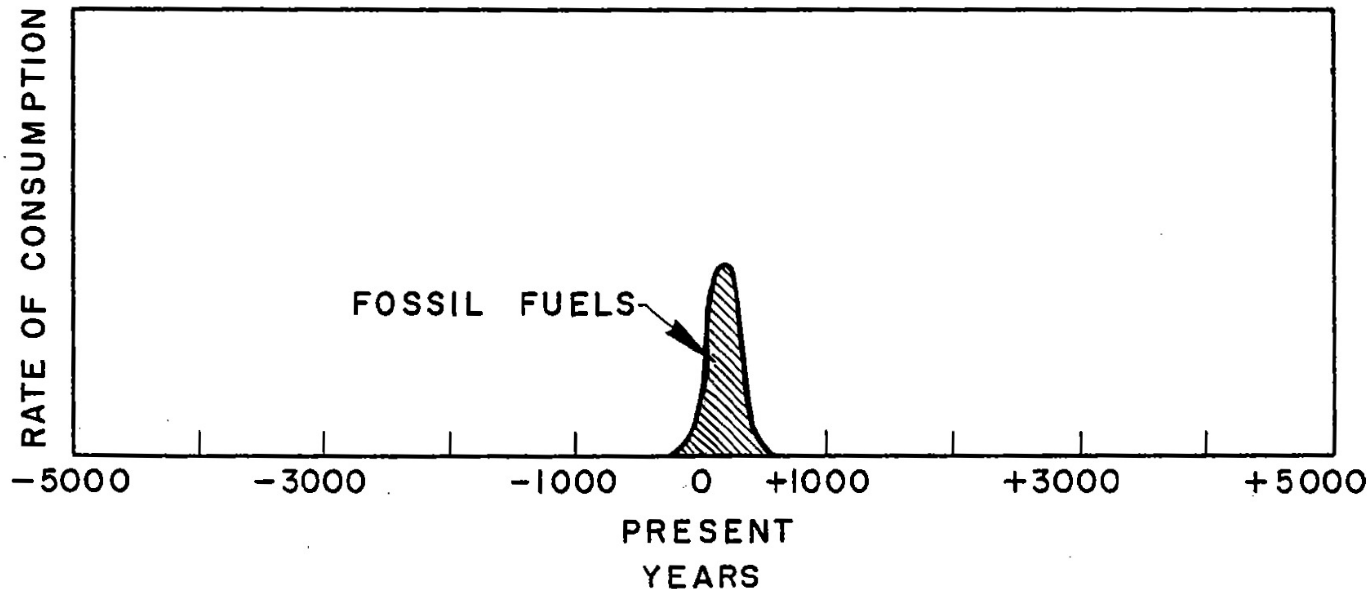


Figure 73: Relative magnitude of possible (fossil fuel) energy consumption in time perspective of minus to plus 5,000 years adapted from 4.

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If peak energy resources occurs within the next decade or sooner, then the human carrying capacity of the planet in terms of energy may be around 7.5 billion people. This is equal to the rough upper limit of carrying capacity in terms of food discussed in the previous sections. The human carrying capacity in terms of food is between 3.2 – 7.5 billion people. As energy supplies decline over time, the carrying capacity in terms of energy may reduce the overall global human carrying capacity, unless low-energy input food systems will be able to support a higher population.

The global population is projected to be about 9.2 billion by 2050[135]. According to Schade and Pimenetel[136], in terms of food production and assuming BAU trends, the planet will only be able to sustain 0.5 – 3 billion fewer of those 9.2 billion people by 2050 due to both the limits of cropland availability and land degradation. Further, the planet will only be able to support 1.2 – 4 billion fewer of those people due to limited irrigation capacity, constrains on water resources, and the degradation of irrigated land. Climate change may further reduce this number by 0.5 – 2 billion people. All together, the human carrying capacity of the Earth may be 3.2 – 7.5 billion people by 2050. Assuming BAU, the human carrying capacity of the planet may be 3 – 6 billion by 2100. According to the author's analysis, the global population may have nearly reached or already exceeded the planet's carrying capacity in terms of food production.

In terms of energy resources, the human carrying capacity of the Earth may be even lower based on historical relationships between global population and energy resource use. While not proof of correlation, the historical relationship nonetheless offers another rough model of human carrying capacity. Based on Campbell's[245] projections (see Figure 72), the Earth's carrying capacity in terms of energy resources is about 0.5 billion, relying only on firewood, other biomass, and human and animal labor; but without the use of substantial quantities of fossil fuels (i.e., coal, oil, etc.). Add to this the impacts of future climate change, and it is possible that these lower limits to human carrying capacity may indeed be more accurate.

In other words, *the human carrying capacity of the planet may be between 0.5 – 7.5 billion people by 2050, in terms of both food and energy resources.* As the global environment degrades and declines due to climate change, pollution, over exploitation and other human activities, the carrying capacity may decrease further. *Assuming BAU, the carrying capacity may limit the global population to 0.5 – 6 billion by 2100.*

For most of its existence, the global human population has never exceeded 0.5 billion people. Not until 1800 had the population been 1 billion people. In 2010, the global population is about 7 billion people. In the 200 years since 1800, the human population has increased by 7-fold. Two centuries is only a fleeting moment in geological time or human history. During these past two centuries, humans have come to dominate the biophysical systems of the planet, and consumed and scattered most of its vital and precious resources. This has all been driven by an unprecedented and epic-scale use of energy – both from food and fossil fuels. Once that energy is depleted, the global human population may peak and then possibly enter a terminal decline to a new equilibrium population size, even with the successful implementation of adaptive strategies.

How rapid the decline, or how long the population can be sustained, will be determined by individual and social responses to a world post-peak energy, as well as by the limitations of environmental factors. Increased mortality – from reduced healthcare, disease, conflict, and wars – will also contribute to population decline. However, increased fertility rates from a potential decline in the availability of contraception and reproductive health services and education may contribute to population increases. The question of whether and when fertility can offset population declines is uncertain. However, environmental constraints (e.g., food and energy scarcity) may require a decrease in population to reach a state of dynamic equilibrium with the carrying capacity of the Earth's planetary systems.

However, one caveat must be made clear: This analysis only considered minimal but adequate per capita food and energy supplies. The more resource-intense are the economies and lifestyles of the global population, the lower will be the potential carrying capacity.

Another vital caveat must also be made clear: The affects of abrupt and non-linear climate change, a rapid mass extinction event, a global conflict (e.g., nuclear war), and other massive environmental catastrophes have not been considered in this analysis. For instance, the climate system may pass planetary tipping points, such as the loss of Arctic sea ice, the collapse of the ice sheets and water cycle of the HKHT, or the dieoff of the Amazon Forest. If any these of these abrupt and non-linear events occurs, the human carrying capacity of the Earth may decline significantly more. Even if future planetary conditions or technological innovations increase the planet's carrying capacity, the near- and long-term transition period to a new planetary equilibrium may be challenging, if not volatile. The human response to peak oil and environmental management practices will be a key factor affecting the potential human carrying capacity of the Earth.

Table 7: Estimates of world population[11,247]

Year	**Population with estimated range in parentheses (in millions of people); average of range of population (rounded to nearest 25 million)**
8000 BC	5
1000 BC	50
500 BC	100
1 AD	300 (170 – 400)
1000 AD	275 (254 – 300)
1500 AD	500 (425 – 540)
1800 AD	1,000 (813 – 1,125)
1900 AD	1,500 (1,550 – 1,762)
1930 AD	2,070
1950 AD	2,556
1960 AD	3,042
1975 AD	4,090
1990 AD	5,289
2000 AD	6,089
2010 AD	6,853
2012 AD	7,005 (assuming BAU)
2020 AD	7,600 (assuming BAU)
2030 AD	8,275 (assuming BAU)
2050 AD	9,300 (assuming BAU)

Given the analysis thus far, the best estimate of the human carrying capacity can only be a rough estimation, limited in accuracy by assumptions, data quality, approximations, and uncertainty. For successful global governance and management, and for humanitarian and quality of life concerns, it seems it would be a most prudent endeavor to estimate accurately the human carrying capacity of the planet and the environments and regions thereon and therein. However, other criteria for estimating the carrying capacity of the world may also be relevant. For instance, perhaps the human species cannot live harmoniously in the long-term when it populates the planet to the limits of its capacity. Other quality of life issues may also be relevant. Bear in mind that one of the questions to answer is, *“What is desired?”*.

PART III

CONCLUSIONS

“We are in a crisis in the evolution of human society. It's unique to both human and geologic history. It has never happened before and it can't possibly happen again. You can only use oil once. You can only use metals once. Soon all the oil is going to be burned and all the metals mined and scattered.”

– M. King Hubbert[1], geophysicist and energy advisor Shell Oil Company and USGS, 1983

"We can't solve problems by using the same kind of thinking we used when we created them."

– Albert Einstein, physicist

"When written in Chinese the word crisis is composed of two characters. One represents danger, and the other represents opportunity."

– John F. Kennedy, President of the United States, 1959

- Adaptation is ultimately the only solution and strategy to peak oil.
- Mitigation and adaptation are the only solutions for climate change.
- Peak oil crises will soon confront societies with the opportunity to recreate themselves based on their respective needs, culture, resources, and governance responses.
- The impacts of peak oil and post-peak decline will not be the same equally for everyone everywhere at any given time.
- There are probably no solutions that do not involve at the very least some major changes in lifestyles.
- Local and societal responses and adaptation strategies to peak oil and climate change will vary and be influenced based on many factors including: geography, environment, access to resources, economics, markets, geopolitics, culture, religion, and politics.
- The sooner people and societies prepare for peak oil and a post-peak oil life, the more they will be able to influence the direction of their opportunities.
- The peak oil crisis may become an opportunity to recreate and harmonize local, regional, and international relationships and cooperation.
- The localization of economies will likely occur on a massive scale, particularly the localization of the production of food, goods, and services.
- In the 1990's, Cuba and North Korea both experienced their own "peak oil crises" after the fall of the Soviet Union disrupted their supplies of imported oil and petroleum products (including agrochemicals):
  - Cuba provides a case study of successful adaptive strategies to energy and food scarcities and

economic collapse.

  - North Korea offers case study of an adaptive strategy that have let hundreds of thousands of people starve to death and countless more go hungry and suffer to this day.

- One of the most important modern technologies to preserve post-peak oil may be the Internet, which can potentially help the world stay connected in terms of communications, information, and Internet technology services even after global transportation services decline.

- Peak oil and energy resources may offer the only viable solution and opportunity for humanity to mitigate anthropogenic climate change on a global scale – by essentially pulling the plug on the engine of the global economy that has driven the climate system to a very dangerous state.

- The climate system may have already passed the 2°C threshold for dangerous climate change. Committed global warming may be at least 2.4°C. Therefore, post-peak oil life will be further challenged by future climate changes, even with drastic decreases in fossil fuel emissions after peak-oil.

- Ultimately, the question of what should be done about peak oil and climate change is arbitrary, and can be only be answered with the question: *"What do you want?"*

  - What kind of world do you want to live in?
  - What kind of world do you want others to live in?
  - Where do you want to live in this world?
  - With whom do you want to live?

Crisis and Opportunity

Although it is not true that the Chinese word for *crisis* (*wēijī*) also means *opportunity* (the Chinese have other words for *opportunity*), the rhetoric of the claim nonetheless is appropriate, compelling, and points to a profoundly simple logic – crisis is an opportunity for reform, change, and revolution. Although crisis can have negative consequences, it is also an opportunity to create a new order and life from the old. Depending on the response to crisis, opportunities can make changes for the better or worse. In the past century, modern civilization has created lifestyles, communities, economies, and systems for food, water, transportation, and health that depend on cheap and abundant fossil fuels and a relatively mild and stable climate system. Modern societies and their expectations of prosperity have been shaped by these lifestyles and systems. However, these lifestyles and systems are no longer stable or sustainable, nor were they ever in the long-term.

Ultimately, there is only one solution or strategy to peak oil and living in a post-peak oil world beset by climate change: adapt. Mitigation and adaptation are the only solutions for climate change. Peak oil crises will soon confront societies with the opportunity to recreate themselves based on their respective needs, culture, resources, and governance responses. The sooner people prepare for peak oil and a post-peak oil life, the more they will be able to influence the direction of their opportunities. Nevertheless, there are probably no solutions that do not involve at the very least some major changes in lifestyles, especially for wealthy and developed societies. Consequently, peak oil will probably result in some catastrophic upheavals. Peak oil will also present some opportunities to address many underlying societal, economic, and environmental problems. Furthermore, peak oil will present opportunities for societies to return to simpler, healthier and more community-oriented lifestyles. Peak oil is also a major but unavoidable opportunity to mitigate GHG emissions and the human activities that drive anthropogenic climate change.

It is beyond the scope of this analysis to thoroughly discuss solutions and strategies for peak oil and living in a post-peak oil world. Nevertheless, some discussion on strategies for preparing for peak oil and a post-peak oil world is appropriate. In general, the following discussion on responses and solutions for living in post-peak oil world are equally applicable at all scales of society and economy – i.e., applicable to individuals, families, communities, governments, businesses, societies, and the international community.

Transitions

As discussed in the section *The Consequences of Peak Oil*, climate change and energy scarcity will have wide ranging and complex consequences that will affect all aspects of peoples' lives. Nevertheless, some people and populations will be affected more than others – for better and for worse. The impacts of peak oil and energy resources and climate change will not be homogenous – rather they will be heterogeneous. That is to say, the impacts will not be the same equally for everyone everywhere at any given time. Each region, nation, community, family and individual will experience decline and collapse differently; and therefore will respond to it in different ways. While the poor and low-income will likely suffer significantly from scarcity and socioeconomic changes, the rich and affluent will also be impacted as entire societies cope with a radically changing world order, social contract, and economic paradigm. Furthermore, many of the materially wealthy and rich will likely find themselves newly poor as the global market and economic system collapses and new ones emerge. Conversely, some of the poor may find themselves relatively wealthy as new opportunities become available in the transition to a new order.

Without oil and cheap energy resources, much of the world (both developed and undeveloped) will likely decline into the equivalent of pre-Industrial Revolution economies, albeit probably with a mix of industry and high-technology in some areas and societies. Even as the wealth and prosperity of developed countries declines, some developed societies may remain “developed” in places while the rest of their territories decline into less developed and/or poorer conditions.

Ruppert[7] appropriately states, “The end of the Age of Oil will also be the end of globalization, long-distance commutes, and long-distance transportation of goods and services – period.”. While it seems likely that long-distance transportation of people, goods and services will be possible on some scales in some areas, economies will become localized as transportation costs become prohibitively high to support a globalized economy. In particular, food production will necessarily become localized; and energy production and the production of goods and services will likely become regionalized and localized.

Long-distance transportation existed before the Industrial Revolution. Nonetheless, the use of fossil fuels and machinery made possible transportation capable of moving greater quantities of people and goods farther and faster than before. Much of the world may revert to or remain at a pre-Industrial Revolution state after peak oil. Therefore, long-distance travel will likely be limited to pre-Industrial Revolution and early industrial modes of transportation in most places. Trains may be used where infrastructure and energy supplies are available. Shipping will be possible using wind energy, human labor, remaining fossil fuel resources, and possibly nuclear for some applications. Flight may become more rare as large quantities of liquid transportation fuels are required for aviation. Domestic animals (e.g., horses, mules, oxen) will likely be used for transportation, agriculture, and other labor-intensive activities. Human-powered vehicles (e.g., pedal driven cycles) will likely also be used where material resource are available.

Automobiles, aircraft, and other transportation and energy-intensive machinery will likely be reserved for wealthy individuals and organizations, governments, industry, and basic services (e.g., health care, public transportation, infrastructure). Much of the remaining fossil fuel and energy resources will likely be appropriated by militaries in the name of ensuring security and for securing resources and political economic agendas. The public will likely experience energy and food rationing in many areas where resources are still available, but are scarce and expensive.

Without abundant and inexpensive transportation fuel and other energy resources, globalization will decline. The localization of economies will occur on a massive scale, especially localization of the production of food, goods, and services. Local currencies and barter will likely replace national currencies as they devalue. Moreover, as currencies, stocks, pensions and other financial instruments devalue, commodities and other physical assets will likely increase markedly in valuable – e.g., food, water, land, a well-built home, tools (e.g., garden and farm tools), energy resources, precious metals. Global and regional trade will likely continue, but at a much smaller scale than at present. Goods and services (especially imports), will likely be more costly and limited due to higher transportation and production costs. Many industries, including those currently outsourced to foreign and remote locations, will need to be established locally in order to supply demand for goods and services. For example, clothes will likely have to be manufactured in local or regional production facilities instead of overseas. More importantly, food production will have to be localized.

With energy scarcity and a decline in economies and societies, many people will have to find new employment to support themselves and their families since many jobs (especially for bureaucrats, technocrats, and people in trades for elastic, luxury, and non-essential goods and services) will be lost. Many people will need to learn new skills and be retrained to work in such sectors as food production,, local industries, and in local markets and trades.

Mass migrations and population shifts will likely occur as people relocate to where they can find social and material resources, such as food, water, health care, education, employment, community, security, and basic services. Some populations may experience a dieoff due to food and water scarcity, a decrease in the environment's carrying capacity, increased mortality from lack of health care services, and conflicts. However, other populations will struggle to survive. Other societies may prosper during the transition time ahead. At the same time, other populations may not notice much change in their lives as the presence of globalization declines around them, such as those who already live at a subsistence level, in remote self-sustaining environments, or in other more primitive lifeways. For example, traditional hunter-gatherers and people living in self-sustaining communities off of the power and communications grid may not notice much change in their own lives.

Civil unrest, social revolutions, and massive public and private debt defaults will undoubtedly occur throughout the world, which will likely result in a further destabilization of international politics and economies. While some may prosper and some may suffer post-peak oil, it is likely that many people will both prosper and suffer losses. The transition to a new stable world order could take decades or longer. The world will be a dynamic and uncertain place during that time. For many people and societies, the peak oil crisis may become an opportunity to recreate and harmonize local, regional, and international relationships. For example, neighbors, communities, and nations could choose to cooperate, share resources, and create efficient and sustainable economic and social systems to ensure mutual security and prosperity. For many societies and cultures, the measures and standards for quality of life may change as the paradigm of mass consumerism, unlimited growth, and the promise of an affluent life for all based on cheap and abundant resources declines.

Adaptation

Local and societal responses and adaptation strategies to peak oil and climate change will vary and be influenced based on many factors including: geography, environment, access to resources, economics, markets, geopolitics, culture, religion, and politics. Cultures of mass consumerism will decline as societies adjust to living within their means and with scarce limited resources. New governance and economic regimes will evolve as societies abandon or reform the old paradigm in many places, while old regimes struggle to maintain control and avoid social unrest. Resilient and cooperative communities and social networks will likely fare well against the challenges of the future.

A fundamental issue that societies will try to resolve is how the remaining wealth and power relationships will be distributed, and by what governance and economic systems will that wealth and power be maintained. Some areas may undergo a relatively smooth and peaceful transition while others will likely experience revolutionary changes. Anything might be possible after peak oil. Furthermore, how people choose to manage the environment will affect their economic and social systems.

One of the most important adaptation strategies is for people, societies, businesses, and institutions to make the transition as soon as possible to non-petroleum based economies and lifeways. As suggested by Ruppert[7], in order to proactively address peak oil and climate change policy-makers, industry, corporations, news and other media should stop promoting unconventional oil resources, in part because their promotion interferes with developing energy policies that do not rely on fossil fuels, and gives the public the wrong impression that unconventional oil is a long-term or even viable solution to increasing energy security. Rather, the author suggests that governments would do better to incentivize the development of alternative safe and clean energy resources, and on energy conservation. Remaining fossil energy supplies should be saved for the most important uses. Ultimately, one of the most important responses and solutions to declining energy supplies to to educate everyone – the public, their governments, and businesses – about these energy resource issues and the consequences of declining energy production. Similarly, climate change and basic environmental science (including the causes and consequences of climate change) should also be taught to the public in order to facilitate mitigation and adaptation efforts.

Without adequate preparation, early responses to the challenges of energy scarcity and climate change will likely be motivated simply by increasing and volatile energy prices. They will also likely be characterized by trial and error, incorrect decisions, and highly politicized debate. Fortunately, societies, organizations, and individuals can plan ahead to provide themselves with the essential capacity and resources necessary to be resilient and adaptable in an increasingly uncertain future. Adaptation to energy scarcity and climate change will likely influence and be challenged by[248]:

- dependability and affordability of basic needs (e.g., food, water)
- environmental management
- water management
- food production systems
- urban planning and design
- reliable energy systems
- reliable transportation systems
- community economic vitality
- employment rate
- health and health care services
- social and political economic stability
- social and political economic equity/inequity
- neighborliness/cooperation/social harmony and integration
- discrimination
- crime
- political/military conflict
- population dislocation/mass migration
- freedom of/restrictions on movement
- confidence/worry about the future
- disaster preparedness (how communities respond to droughts, floods, and heat waves)

Ruppert[7] also proposes some policy recommendations in *An Emergency 25-Point Plan for Action*. Although it was written with U.S. national and state policy in mind, most of the recommendations are applicable to societies worldwide. In general, some of the author's policy suggestions are to: increase the Strategic Petroleum Reserves of refined oil products for state and local governments (see *Strategic Petroleum Reserves*); establish a new and uniform crude oil reserve accounting systems; stop all highway and airport expansion; expand railway systems; curb oil market speculation; expand feed-in tariffs for electricity generation and food production; discourage biofuel production; encourage and expand community and home farming and gardening; invest in grid and energy infrastructure; improve building codes to optimize energy and resource efficiency; educate the public in energy use and conservation; expand training in the energy technology industries; and address population growth in a global dialogue.

Ruppert[7] also proposes an *Oil Depletion Protocol* similar to *The Uppsala Protocol* proposed by Campbell and Aleklett[249]. The *Uppsala Protocol* outlines a global agreement on how to share and use the remaining oil and energy resources among the international community in a way such that the a post-peak oil decline would be as managed and equitable as possible during the transition to lower energy economies. In short, the objectives are to have the world reduce its oil consumption by at least the rate of global depletion. Specifically, the objectives are to avoid profiteering from oil shortages; regulate oil prices to prevent excessive and volatile prices; ensure poor nations can afford their imports; encourage consumers to avoid waste; and to encourage the development of alternative energy resources[7,249]. The complete *Uppsala Protocol* is reprinted in *Appendix 2*.

In addition to creating new economies and infrastructure, there is much of the past that is worth preserving. Humanity has created a tremendous legacy of great advances in knowledge and technology in the past couple of centuries. With energy and resource scarcities, and a possible collapse in industrial-scale manufacturing for many products, people may no longer have access to many goods and services that many in the developed world have taken for granted. It is likely that energy and material resources will no longer be able to support societies based on disposable technology and goods. Much will have to be reused and recycled. In other cases, it would be prudent to keep some resources aside in order to maintain the important existing infrastructure and services. For example, bridges along major traffic routes may need to be maintained and repaired in order to keep them functioning. While highways and paved roads may not need to be preserved in many places, railroad infrastructure will be important to maintain, if trains are kept operating. Right now, societies should not be investing in expanding roads, highways, and airport infrastructure. They should be investing in public transportation, trains, domesticated animals (e.g., horses, labor animals), and alternative-energy shipping.

One of the most important modern technologies to preserve after peak oil may be the Internet. The Internet can potentially help the world stay connected in terms of communications, information, and Internet technology services. News from around the world, oftentimes uncensored by governments and private media interests, can help people keep aware of events and developments worldwide. Social movements and civil society can network, share information, and mobilize. Governments can communicate with their citizens, and vice versa. Some post-peak oil trade and commerce can be facilitated through the Internet. Telecommuting and video conferencing can replace long-distance travel for meetings and other business in many instances. Moreover, the Internet can be a powerful tool for teaching primary, secondary and higher education, and for teaching new skills and technology. For example, many people may need to learn how to grow their own food post-peak oil. The Internet can host information on agricultural techniques, almanacs, and other relevant agricultural information; while social network services can allow people to share information, seek advice and training, and to organize community food production and other activities. Internet can be used for health care, such as for remote exams, diagnosis, and health care instruction. Of course, there will likely be other countless uses for the Internet post-peak oil.

The Internet may be one of the most important technologies to preserve and to expand in post-peak oil, lest all of global society reverts to more isolated and distant societies as they were until less than a century ago. Even if people become limited on physical travel due to energy scarcity, at least they will be able to communicate and share knowledge. However, sustained efforts to prevent the Internet from becoming censored and controlled by governments and private interests for purposes of social control and other agendas will likely need to implemented in order to prevent the Internet from being used to for oppressive ends. Cyber-security from cyber-attacks, conflicts, viruses, hacking, and other risks will also need to be maintained somehow.

However, maintaining the Internet with post-peak oil energy scarcity and economic decline may be very challenging. The telecommunications infrastructure and energy generation plants are costly to develop, maintain, and expand. Telecommunications cables, satellites, and other broadcasting infrastructure are costly, require significant quantities of energy, and are spread across vast distances. Therefore, it is very possible that much of the Internet may cease to operate as infrastructure, websites, Internet connections, and Internet services decline over time due to age, disuse, lack of demand, lack of energy resources, natural disasters, disrepair and possible cyber-conflicts (e.g., transmission of computer viruses, cyber-attacks and warfare).

Examples of Governance Responses

Although social and governance responses to peak oil will vary due to local and regional circumstances, many governance responses to peak oil and economic decline are possible. For instance, while some societies and communities may develop populist or democratic regimes, others may become suppressed by extreme and radical social movements and totalitarian regimes. Many other governance systems could develop. In the section *Governance Responses* in *The Consequences of Peak Oil*, three possible governance responses are briefly discussed: *predatory militarism*, *totalitarian retrenchment*, and *socioeconomic adaptation*[128]. Societies inclined to use military, police, and other coercive solutions may follow a strategy of predatory militarism to secure resources and economic stability. Many resources wars (e.g., for oil, water) will likely be driven by predatory militaristic regimes.

When North Korean access to oil and other resources was disrupted after the fall of the Soviet Union disrupted deliveries of oil in 1990, elite privileges to resources were preserved at the expense of starving to death hundreds of thousands of North Korean citizens. Nations with a strong authoritarian tradition may follow a path of *totalitarian retrenchment* in which the ruling political and economic elites of a nation preserve their status and access to resources by suppressing and controlling their populations through authoritarian means[128].

All societies, including democratic societies, can destabilize and fall under tyrannical regimes, as demonstrated by the history of the 20th Century. Also, any combination of governance regimes can be established to govern a society. While some people and societies may find militaristic and totalitarian governance systems acceptable, if not desirable, many others would prefer more democratic and egalitarian governance whether libertarian, socialist, some other types and combinations of systems. Regardless of the choice of governance system (e.g., democratic, authoritarian, etc.), the strategies of socioeconomic adaptation will be necessary to some extent to preserve equitably the highest quantity and quality human life possible.

As discussed in *Governance Responses* in *Consequences of Peak Oil*, Cuba makes for a relevant example of a relatively successful *socioeconomic adaptive* response to an abrupt and long-term peak oil crisis. Cuba adapted to its own “peak oil” crisis after the fall of the Soviet Union disrupted deliveries of oil in 1990. Cuba experienced a 98% reduction of its petroleum supplies, which resulted in a great socioeconomic, energy, and food crisis for during the 1990's[250]. The lack of fuel, machinery, and spare parts prevented large-scale agricultural production and the subsequent transport of food product from rural areas to supply demand. The capacity to store food also declined since energy production was also reduced by a shortage of fuels. At the time, 57% of the Cuban population’s total calories came from imported food items[250]. As a result of large declines in domestic food production and food imports, Cuba experienced severe food shortages. Cuba had to become as self-sufficient as possible in a very short space of time.

As this energy and food crisis impacted the country, Fidel Castro declared *The Special Period in the Time of Peace*[250]. The *Special Period* was influenced primarily by severe shortages of oil resources (e.g., gasoline, diesel, pesticides). As a form of socioeconomic adaptation Cuba implemented an unprecedented set of reforms in land and agriculture that included breaking up most large state farms into production cooperatives, while opening farmers markets where farmers could sell surplus output (i.e., crop production beyond quotas farmers had to sell to the state) at free market prices[128,250]. Organic agriculture and methods of permaculture began to be implemented throughout Cuba (see *Glossary* for a definition of

Figure 74: Urban farms in Havana[251].

permaculture). The government supported these reforms through the provision of parcels of land to anyone willing to cultivate them, and by the provision of university experts to educate Cubans about agriculture.

Widespread adoption of urban agriculture resulted in thousands of small plots in cities being converted into urban market gardens[128,250]. Crop yields within Cuba's cities steadily increased over time. Currently, there are now more vegetables available to Cubans than there were before the crisis[250]. In Cuba's capital city of Havana, more than 90% of the fruit and vegetables consumed in the city are produced in and around the city[250] (see Figures 74 and 75). By 2008, around 8% of the land in Havana was used for urban farming[250].

The entire Cuban population regardless of occupation was required to produce food. Farmers became one of the highest paid occupations in Cuba. While farmers were given large economic incentives to produce food, the rest of the population began to produce food in community gardens, home gardens, patio and window boxes, on rooftops, and in vacant lots. Home gardens have become a source of pride and social status for many Cubans[128,250].

These policy changes resulted in gradual recovery in the agriculture sector[128]. Despite the radical changes and social mobilization that occurred during the *Special Period*, the caloric intake of Cubans decreased significantly, and at times food was rationed. This period radically transformed Cuban society and the economy, as it required the successful nationwide introduction of sustainable organic agriculture, decreased use of motor vehicles and machinery, and changes in industry, health, and diet. People were forced to live without many goods to which they had become accustomed[128,250].

Figure 75: Organopónico in Alamar, Havana[252].

Despite the food shortages, substantially leaner diets and austerity, there was no mass starvation event comparable to the one experienced in North Korea after the collapse of the Soviet Union[128]. Rather, the central government of Cuba implemented policy in which Cubans were supported by the decentralization of food production and economic activities, by social networks, and by non-industrial methods of production to adapt to energy, agrochemical, and food scarcity. Currently, the average calorie consumption in Cuba is just slightly less than that of a typical person in the UK. However, the Cuban diet is more healthful since the typical western diet contains 3 times as much meat and dairy product[250]. Nevertheless, with over 11 million people to support on an island nation, Cuba has become increasingly dependent on food imports to feed its population. Cuba's total food and agricultural imports nearly doubled between 2000 – 2006 [129]. Currently, Cuba imports about 80% of the food it rations to the public[130]. Therefore, once global peak oil occurs, Cuba may experience another severe food crisis and possible decrease in its population as imports and international trade decline.

Although the Cuban government is of an authoritarian disposition, its response to its domestic oil and food crisis was significantly different than that of North Korea's totalitarian retrenchment. Nonetheless, as Cuba demonstrates, the different reactive strategies of societies are not exclusive. Nations that adopt a strategy of socioeconomic adaption, such as Cuba did, might potentially be an optimal and more equitable path to follow than predatory militarism and totalitarian retrenchment. People may be able to effectively mitigate and adapt to the effects of peak oil by developing localized, community-based economies that do not require the high energy inputs that are required for industrialized societies. Socioeconomic adaptation would be easier to implement for people in societies in which individualism, industrialism, and mass consumerism are not part of the cultural norm, especially where subsistence lifestyles have been practiced for generations. Socioeconomic adaptation would be more challenging to implement for people in developed and industrialized societies in which individualism, industrialism, and mass consumerism have been part of the cultural norm and way of life for generations[128].

Looking Forward

Regardless of how societies respond and adapt to peak oil and economic collapse, they will all be affected by current and future climate changes – for better and for worse. As discussed in *Climate Change* and other sections of this analysis, humanity has already passed the threshold for dangerous anthropogenic interference with the natural climate system. Indeed, even if most or all anthropogenic GHG emissions cease after peak oil (an unlikely event), GHG emissions may have committed the planet to a warming of at least 2.4ºC (within a range of 1.4º – 4.3ºC) above the pre-industrial surface temperatures as of the year 2005 [185]. In addition to the present observed temperature increase of 0.76ºC, warming of at least another 1ºC is currently masked by 'atmospheric brown clouds' that contain cooling particulates released with GHG emissions and other air pollution. As societies continue to reduce their air pollution (e.g., from automobiles, factories, burning of land and forests) that create these clouds, temperature increases of 1ºC or greater temperature that are already committed from current emissions will be unmasked[185]. A sharp drop in polluting emissions due to a rapid collapse of global human activity due to peak oil may also "unmask" this 1ºC or greater temperature increase. Furthermore, another 0.6ºC of warming is temporarily delayed by ocean thermal inertia. More than 50% of this total committed warming of 2.4ºC is expected to occur within decades[185].

Since the climate system may have already passed the 2°C threshold for dangerous climate change, it is possible that the world may pass climate tipping points and experience abrupt and non-linear climate changes, such as the melting of the Arctic sea ice, the melting of the Hindu-Kush-Himalayan-Tibetan Plataea (HKHT), ocean acidification, and the dieoff of the Amazon forest (see *Abrupt Non-Linear Climate Change and Tipping Points* for more examples and further discussion). Passing these climate tipping points could result in catastrophic climate changes and could possibly create a volatile and less stable climate system for future generations. Current and future societies and generations should prepare for drastic and abrupt climate changes that may occur in the future.

Ironically, peak oil and energy resources may offer the only viable solution and opportunity for humanity to mitigate anthropogenic climate change on a global scale – essentially by pulling the plug on the engine of the global economy that has driven the climate system this a very dangerous state. Perhaps, the saving grace for humanity is that peak oil is occurring now rather than later lest the climate system be driven certainly to a catastrophic state.

Whether living at a survival level or in affluence, the most fundamental strategy for living in a post-peak oil world undergoing radical climate changes will be adaptation. It will be important to be aware of what is happening in one's economic, social, and physical environment. Thinking critically will be paramount as confusion and uncertainty challenge individuals and societies to cope and adapt. In order to adapt successfully to peak oil and climate change, people and societies will need to prioritize their needs against their desires (especially for non-essential goods and services). The limits of population size will be challenged by quality of life choices. The greater the population, the less resources are available per capita. Ultimately, the challenges of making quality of life choices is a human right and security issue that will have to be addressed by each community and society.

Since adaptation solutions will vary based on local circumstances and needs, is it is not possible to detail every possible strategy in this analysis. The discussion above offers only some basic concepts and issues to consider for adapting to a post-peak oil world. In *Appendix 3*, some information resources on peak oil and climate change are listed. Although it is not an exhaustive list, it does offer a starting point for those seeking more information and discussion on the matter. Ultimately, the question of what should be done is arbitrary, and can be only be answered with the question: *"What do you want?"* In other words: What kind of world do you want to live in? What kind of world do you want others to live in? Where do you want to live in this world? With whom do you want to live?

"All that needs to be done is to completely overhaul modern culture and find an alternative to money."

"We are not starting from zero. We have an enormous amount of existing technical knowledge. It's just a matter of putting it all together. We still have great flexibility but our maneuverability will diminish with time."

"Things have to get worse before they can get better. The most important thing is to get a clear picture of the situation we're in, and the outlook for the future"

– M. King Hubbert[1], geophysicist and energy advisor Shell Oil Company and USGS, 1983

- Peak oil is happening now.
- The era of cheap and abundant oil is over.
- Global oil production likely peaked during 2005 – 2008 or will peak by 2011.
- Huge investments are required to explore for and develop more reserves, mainly to offset decline at existing fields.
- An additional 64 mbpd of gross capacity – the equivalent of six times that of Saudi Arabia today – needs to be brought on stream between 2007 – 2030 to supply projected business as usual demand.
- Since mid-2004, the global oil production plateau has remained within a 4% fluctuation band, which indicates that new production has only been able to offset the decline in existing production.
- The global oil production rate will likely decline by 4 – 10.5% or more per year.
- Substantial shortfalls in the global oil supply will likely occur sometime between 2010 – 2015.
- Furthermore, the peak global production of coal, natural gas, and uranium resources may occur by 2020 – 2030, if not sooner.
- Oil shortages will lead to a collapse of the global economy, and the decline of globalized industrial civilization.
- Economies worldwide are already unraveling and becoming insolvent as the global economic system can no longer support itself without cheap and abundant energy resources.

- This current transition of rapid economic decline was triggered by the oil price shock starting in 2007 and culminating in the summer of 2008. This transition of decline will likely accelerate and become more volatile once oil prices exceed $80 – $90 per barrel for an extended time. Demand destruction for oil may be somewhere above $80 per barrel and below $141 per barrel.

- Another oil shock and/or permanent increase in oil prices would likely push many nations and the global economy over the cliff edge into economic collapse.

- Economic recovery (i.e., business as usual) will likely exacerbate the global recession by driving up oil prices.

- A managed "de-growth" is impossible, because effective mitigation of peak oil will be dependent on the implementation of mega-projects and mega-changes at the maximum possible rate with at least 20 years lead time and trillions of dollars in investments.

- Peak oil and the events associated with it will be an unprecedented discontinuity in human and geologic history.

- Adaptation is the only strategy in response to peak oil.

- Mitigation and adaptation are the only solutions for climate change.

- Existential crises will soon confront societies with the opportunity to recreate themselves based on their respective needs, culture, resources, and governance responses.

- If the international community does not make a transcendent effort to cooperate to manage the transition to a non-oil based economy, it may risk a volatile, chaotic, and dangerous collapse of the global economy and world population.

- Ironically, peak oil and energy resources may offer the only viable solution for humanity to mitigate anthropogenic climate change on a global scale – by essentially pulling the plug on the engine of the global economy that has driven the climate system to a very dangerous state.

- Nevertheless, this potential mitigation of climate change will not stop the committed climate changes that are expected to occur in the future, nor will it stop all anthropogenic sources of greenhouse gas emissions altogether.

- It is possible that climate negotiations may be abandoned or at least marginalized for a long time (if not permanently) as the crisis of peak oil and economic shock and awe overwhelms the stability and security of every nation.

- It will likely require a concerted and transcendent effort on the part of any remaining international climate negotiators, their governments, and the public to pursue a meaningful international climate policy – much less a binding international climate treaty.

Peak oil is happening now. The era of cheap and abundant oil is over. Global conventional oil production likely peaked in 2005 – 2008 or will peak by 2011. Thereafter the global conventional oil production rate will likely decline by 4 – 10.5% or more per year. Since mid-2004, the global oil production plateau has remained within a 4% fluctuation band, which indicates that new production has only been able to offset the decline in existing production (see Figures 20a and 20b). Sometime between 2010 – 2015, substantial shortfalls in the global oil supply will likely occur (see Figures 8a, 8b, 9a, 9b, 20a, and 20b).

Furthermore, the peak global production of all known energy resources may occur by 2020 – 2030, if not sooner (see Figure 72). Global peak coal production will likely occur between 2011 – 2025 (see Figures 65 and 66). Global natural gas production will likely peak sometime between 2019 – 2030 (see Figure 68). Global peak uranium will likely occur by 2015 to sometime in the 2020's (see Figures 69 and 70). Oil is used to produce, distribute, and build and maintain the infrastructure for coal, gas, unconventional oil, nuclear and renewable energy resources. Consequently, a decline in oil production could very simply bring about declines in the production rates of the other energy resources sooner than the above dates indicate. In other words, global peak oil may mean global peak energy resources.

Oil shortages will lead to a collapse of the global economy, and the decline of globalized industrial civilization. Oil is by far the primary transportation fuels currently available, and it will be for some time. It will take at least 20 years to change modern civilization over to a non-oil-based economy and infrastructure; and would cost trillions of dollars and would still result in a massive global economic depression. A managed “de-growth” is impossible, because effective mitigation of peak oil will be dependent on the implementation of mega-projects and mega-changes at the maximum possible rate.

Economic recovery would stimulate oil demand and thereby increase oil prices. Therefore, economic recovery (i.e., BAU) will likely exacerbate the global recession by driving up oil prices. Given that many nations and their citizens are insolvent and on the brink of debt default, another oil shock and/or permanent increase in oil prices would likely push many nations and the global economy over the cliff edge into economic collapse.

Global oil reserve discoveries peaked in the 1960's (see Figure 10). New oil discoveries have been declining since then, and the new discoveries have been smaller and in harder to access areas (e.g., smaller deepwater reserves). Business as usual oil production projections require huge investments to explore for and develop more reserves, mainly to offset decline at existing fields. *An additional 64 mbpd of gross capacity – the equivalent of six times that of Saudi Arabia today – needs to be brought on stream between 2007 – 2030.* Yet, non-OPEC oil production is in decline and OPEC is entering decline. As demonstrated and discussed throughout this analysis, the above claims are supported by publications and statements made by several national governments, the George W. Bush and Obama administrations (see Figures 8a and 8b), the U.S. Department of Energy (see Figures 8a and 8b), the U.S. and German militaries, leading energy information reporting agencies, the oil industry (see Figures 9a and 9b), the private sector, science, and academia.

There are not enough recoverable unconventional oil resources (oil sands, heavy oil, oil shale, gas-to-liquids, and coal-to-liquids) to offset declining conventional oil supplies and to supply future demand. Furthermore, unconventional oil resources require enormous amounts of water and natural gas (supplies of which are peaking worldwide). Production of unconventional oils also causes substantial long-term environmental damage and human health risks.

Natural gas, coal, nuclear, and renewable energy sources (e.g., wind, solar, tidal, geothermal) in any combination or aggregate cannot replace oil as a transportation fuel on a global-scale in the near- and medium-term. There is not enough time, money, or uranium resources left to build enough nuclear power plants to offset energy production decline or to supply future BAU energy demand. Furthermore, nuclear elements like uranium are some of the most dangerous materials known to humankind, and its storage and disposal are potentially very risky. The dangers of nuclear proliferation are also major security issues.

As Ruppert[7] suggests, renewable energy resources cannot support the edifice of civilization built by fossil fuels. Nevertheless, renewable energy resources should be developed on a massive scale. It will be important to assess which geographical areas can benefit and which cannot benefit from renewable energy resources. For example, producing and using tidal energy requires access to coastal and marine environments.

Biofuels, including fuels produced from algae and microorganisms, cannot replace current oil demand on a global-scale. Many biofuel crops yield little or less energy than the energy required to produce them. Growing any biofuel crop (including algae and microbes) will compete substantially for land, water, and nutrients for food crop production, and can cause substantial environmental damage (e.g., from appropriating vast areas of natural habitats, runoff of agrochemical residues, and invading non-native habitats). Genetically-modified biofuel crops pose an additional hazard of genetic contamination of the environment.

The tradeoff between the environment and producing and using energy is evident with peak oil – without energy resources society will break down; but without a well maintained and preserved environment society will also breakdown. Producing and consuming energy resources can greatly impact the environment. For instance, anthropogenic climate change is being driven primarily by GHG emitting activities associated with energy production and use. Humanity should not take so many resources as to undermine the integrity of the environment on which it depends. Population growth and quality of life should always be examined with the connection between the energy and environment in mind.

Even if any of the above energy resources alone or in combination could replace oil and supply global energy demand, there is not enough time left before peak oil to build the production facilities, infrastructure, and markets to produce and distribute any of these potential energy resources, nor time or money to manufacture, upgrade, or retrofit the global stock of vehicles, machinery, and infrastructure that are powered and supported by petroleum.

Furthermore, pesticides, herbicides and other agrochemicals will become scarce, which may decrease future crop yields. Scarcities in pharmaceuticals and plastic medical supplies will increase medical costs, decrease access to health care, and may increase mortality rates. New plastic materials produced from biomass rather than petroleum will need to be developed and mass-produced in order to replace oil-based materials. Biomass crops grown for materials (e.g., plastics, fiber) competes with food production and natural habitats for ecosystems.

Clearly, the consequences of peak oil will be systemic and utterly disruptive for global industrialized society. The severity of the collapse will be largely determined by individual, social and governance responses to the resulting multiple systemic crises. Peak oil and collapse will likely have much of humanity question the institutions and global paradigm that has existed for the past few centuries. *Peak oil and the events associated with it will be an unprecedented discontinuity in human and geologic* *history.* A discontinuity in human history occurs when the world is no longer perceived, described, expressed, characterized, classified, and known in the same way from one era to the next. This refers to extreme and unprecedented changes in history. For instance, the three discontinuities in the past century of global history are World War II; the dropping of the nuclear bombs on Japan; and September 11, 2001. Another discontinuity in history could occur when the world experiences the passing of a major climate tipping point. This would also be a discontinuity in geologic history (i.e., discontinuities that occur on geologic time-scales rather than human ones). Mass extinction events are also discontinuities in geologic history, like the one that extinguished the dinosaurs; and like the current Holocene mass extinction event that is progressing at an accelerated rate.

At this point, it is worthwhile to quote Marion King Hubbert at length regarding his analysis of peak oil and its consequences. As Hubbert stated in an interview published in 1983 [1]:

"I was in New York in the 30s. I had a box seat at the depression...I can assure you it was a very educational experience. We shut the country down because of monetary reasons. We had manpower and abundant raw materials. Yet we shut the country down. We're doing the same kind of thing now but with a different material outlook. We are not in the position we were in 1929-30 with regard to the future. Then the physical system was ready to roll. This time it's not. We are in a crisis in the evolution of human society. It's unique to both human and geologic history. It has never happened before and it can't possibly happen again. You can only use oil once. You can only use metals once. Soon all the oil is going to be burned and all the metals mined and scattered."

Peak oil is not the end of the world, it is simply the end of the world as we have known it for only a few generations. As Hubbert[1] stated, people have the necessary technology – "all that needs to be done is to completely overhaul modern culture and find an alternative to money". Peak oil will require a change of economic and social systems, and will result in a new world order. Peak oil does not mean that everyone has to suffer unduly and perish. However, the future of the world will be determined in large part by the human response to peak oil. As Hubbert[1] stated,

"We are not starting from zero. We have an enormous amount of existing technical knowledge. It's just a matter of putting it all together. We still have great flexibility but our maneuverability will diminish with time."

Undoubtedly, there will likely be a decrease in the human population from conflict, hunger, and other natural and man-made events and disasters without a transcendent effort made by local, national and international level communities and organizations. Hubbert[1] summed this conclusion well by stating that unless society is made stable, a non-catastrophic solution is impossible:

"This means abandoning two axioms of our culture...the work ethic and the idea that growth is the normal state of life...our window of opportunity is slowly closing...at the same time, it probably requires a spiral of adversity. In other words, things have to get worse before they can get better. The most important thing is to get a clear picture of the situation we're in, and the outlook for the future – exhaustion of oil and gas, that kind of thing...and an appraisal of where we are and what the time scale is. And the time scale is not centuries, it's decades."

However, when Hubbert made this interview, it was nearly three decades ago. Now, the "time scale" is not in decades, it is in months and years.

Ultimately, the carrying capacity of the environment and quality of life and human rights issues should be considered when considering peak oil and adaptive strategies to energy scarcity and climate change. As Hubbert[1] observed nearly three decades ago, the planet's carrying capacity is being pushed and that modern population growth

"...is an aberration. For most of human history, the population doubled only once every 32,000 years. Now it's down to 35 years. That's dangerous. No biological population can double more than a few times without getting seriously out of bounds. I think the world is seriously overpopulated right now. There can be no possible solutions to the world's problems that do not involve stabilization of the world's population."

The global human population is currently about 7 billion. The global population is projected to be around 9.2 billion people by 2050 assuming BAU[156]. As discussed in this paper, the Earth's human carrying capacity might be between 0.5 – 7.5 billion people by 2050 due to environmental constraints on land, water, and energy resources for food production, and because of projected climate change impacts on food and water production systems. However, without abundant energy resources, the human carrying capacity of the planet might only be around 0.5 – 2.5 based on historical population and energy consumption trends.

Although it is possible that the actual carrying capacity of the planet may be significantly more than 7.5 billion, the estimates presented in this analysis are based on the "best case" range of data, projections, and assumptions. The planet might be able to support up to 7.5 billion or more people, but the quality of life might not be very high for most of them. Even if the planet can carrying 7.5 billion or more, it is clear that the global human population may be close to passing a threshold for the global carrying capacity. Indeed, it may be possible that the global population has already passed this threshold. If the human population has truly exceeded the global carrying capacity, then peak oil and subsequent economic decline may cause a rapid population crash within several years or decades time. A more detailed analysis of the human carrying capacity of the global environment would be very prudent in order to better manage environmental resources and the human population.

Ultimately, adaptation is the only strategy in response to peak oil. Mitigation and adaptation are the only solutions for climate change. Existential crises will soon confront societies with the opportunity to recreate themselves based on their respective needs, culture, resources, and governance responses. The impacts of peak oil and climate change will not be the same equally for everyone everywhere at any given time. There are probably no solutions that do not involve at the very least some major changes in lifestyles. Local and societal responses and adaptation strategies to peak oil and climate change will vary and be influenced based on many factors including: geography, environment, access to resources, economics, markets, geopolitics, culture, religion, and politics.

Cheap and abundant energy resources, especially oil, allowed humanity to develop society, culture, and technology to unprecedented levels of advancement. They have also allowed the human population to expand exponentially in size and power to come to dominate the global ecological, environmental and climate systems while pushing the limits of the planet's carrying capacity. Energy scarcity and future climate change may decrease the Earth's human carrying capacity and reduce the global human population in the near- to long-term. People not only have to adapt to a world of declining resources and dramatic climate changes, they will have to learn to live within their means lest they amplify and perpetuate the hardships and disasters that they create by living beyond the capacity of the planet.

Ironically, peak oil and energy resources may offer the only viable solution for humanity to mitigate anthropogenic climate change on a global scale – by essentially pulling the plug on the engine of the global economy that has driven the climate system to a very dangerous state. Nevertheless, this potential mitigation of climate change will not stop the dangerous climate changes that are expected in the future.

While reduced GHG emissions may help to mitigate climate change, peak oil may interfere with global efforts to further mitigate and adapt to climate change. It is possible that climate negotiations may be abandoned or at least marginalized for a long time (if not permanently) as the crisis of peak oil and economic shock and awe overwhelms the stability and security of every nation. It will likely require a concerted and transcendent effort on the part of any remaining international climate negotiators, their governments, and the public to pursue a meaningful international climate policy – much less a binding international climate treaty. Two main arguments against pursuing an international climate policy will likely be made: (1) the peak oil shock and the associated collapse of societies and the global economy will be a more pressing issue; and (2) climate change will no longer be a concern since most oil demand will have been destroyed which will cause GHG emissions to decline sharply. The international community and climate negotiators urgently need to review and reconsider the science and data regarding climate change and energy supplies. If this reassessment and discourse does not occur, not only will the international climate negotiations be ineffective, if it is not entirely destined to failure, human security and the stability of all societies may be gravely threatened by future climate changes.

Peak energy resources, peak phosphorus, dwindling mineral and natural resources, the passing of thresholds for dangerous climate change, a human-driven global mass extinction event, peak economy, possible peak food production, and peak globalization – this convergence of events all at the same time will surely create multiple systemic crises throughout the world, which will undoubtedly lead to a collapse of the current paradigm and the emergence of a new world order. The best and the worse of humanity will express itself in these coming times after peak oil. While civil unrest, revolutions, coups, conflicts and wars will likely occur as an indirect result of peak oil, the overall global outcome could either be relatively peaceful and benevolent or catastrophic. The international and local communities can come together and cooperate to create a benevolent and sustainable new world order, or they can drive the world to further humanitarian and environmental catastrophe.

Currently, economies worldwide are unraveling as the global economic system can no longer support itself without cheap and abundant energy resources. The world is beginning a rapid and volatile transition: currency and trade wars; deteriorating wars in the Middle East and elsewhere; countless regional and intranational conflicts and coups; rapidly shifting and volatile geopolitics; the mobilization of extremist movements; the decline of the West and East; exponential population and economic growth; soaring food prices; increasing natural resource scarcity; energy shortages; accelerating rates of extinction; and accelerating environmental degradation and climate change. At this point, even a global nuclear war might be possible, if either or both state and non-state actors escalate multiple crises into bitter conflict.

This current transition of economic decline that was triggered by the oil price shock starting in 2007 and culminating in the summer of 2008 will likely accelerate and become more volatile once oil prices exceed \$80 – \$90 per barrel for an extended time. Assuming BAU, oil prices are projected to reach \$100 – \$108 per barrel by 2020 and \$115 – \$133 per barrel by 2030 (in real 2008 dollars). Demand destruction for oil may be somewhere above \$80 per barrel and below \$141 per barrel. So, it is likely that very few will be able to pay afford to produce or purchase oil in the near future. This will likely occur once global production enters terminal decline and major supply shortfalls occur in the near-term. At this point, the global economy and world order will pass the edge of the cliff into collapse without a transcendent effort by the international community to cooperate and manage the collapse as harmoniously and securely as possible.

With global civilization approaching the proverbial cliff's edge, there is little time left to prepare for peak oil and the collapse of global civilization. The new world order that will emerge will be largely determined by local and international governance responses. Peak oil will surely destabilize the world as confusion and collapse ensue. Climate change will further challenge societies' abilities to adapt and prosper. Nevertheless, the human species has the unprecedented opportunity from this unprecedented crisis to radically change the world for the betterment of all humanity. The world also has the opportunity and capacity to turn this opportunity into a catastrophe of apocalyptic proportions. One way or another, the ending of the Age of Oil is the beginning of very uncertain times.

Appendix 1: Defining Reserve Estimates

Oil reserves are quantities of petroleum claimed to be commercially recoverable by the application of development projects to known oil accumulations under defined conditions. There is uncertainty in all reserve estimates that depends on the available amount and quality of geologic and engineering data and the interpretation of those data.

Two principle classifications are used to describe reserves: *proved* and *unproved*. *Unproved reserves* are further divided into two subcategories: *probable* and *possible* to indicate the relative degree of uncertainty about their existence.

Proved reserves are reserves claimed to have a reasonable certainty (i.e., at least 90% confidence) of being recoverable under existing economic and political conditions, and with existing technology. Proved reserves are also known as 1P[253]. Proved reserves are the only type of reserves the U.S. Securities and Exchange Commission permits oil companies to report to investors. Although companies listed on U.S. stock exchanges must substantiate their claims, many governments and national oil companies do not disclose verifying data to support their claims, nor are they audited.

Although *unproved reserves* are based on geological and/or engineering data similar to that used to estimate proved reserves, technical, contractual, or regulatory uncertainties prevent such reserves being classified as proved[253]. Unproved reserves may be used internally by oil companies and government agencies for future planning purposes, but are not routinely compiled. Unproved reserves are sub-classified as probable and possible reserves.

Probable reserves are assigned to known oil accumulations with at least a 50% confidence level of recovery. Probable reserves are also referred to in the industry as 2P (proved plus probable)[253].

Possible reserves are assigned to known accumulations that have a less likely chance of being recovered than probable reserves (i.e., at least a 10% certainty of being produced)[253]. Possible reserves are classified as such due to varying interpretations of geology, reserves not producible at commercial rates, uncertainty due to reserve infill (seepage from adjacent areas), and projected reserves based on future recovery methods. Possible reserves are referred to in the industry as 3P (proved plus probable plus possible)[253].

Unproved reserves may be estimated by assuming future economic conditions that are different from those prevailing at the time of the estimate. The effect of possible future improvements in economic conditions and technological developments on unproved reserves can be expressed by allocating appropriate quantities of reserves to the probable and possible classifications[253].

THE UPPSALA PROTOCOL[249]

WHEREAS the passage of history has recorded an increasing pace of change, such that the demand for energy has grown rapidly over the past 200 years since the Industrial Revolution;

WHEREAS the required energy supply has come mainly from coal and petroleum formed but rarely in the geological past, such resources being inevitably subject to depletion;

WHEREAS oil provides 90 percent of transport fuel, essential to trade, and plays a critical role in agriculture, needed to feed an expanding population;

WHEREAS oil is unevenly distributed on the Planet for well-understood geological reasons, with much being concentrated in five countries bordering the Persian Gulf;

WHEREAS all the major productive provinces had been identified with the help of advanced technology and growing geological knowledge, it being now evident that discovery reached a peak in the 1960's;

WHEREAS the past peak of discovery inevitably leads to a corresponding peak in production during the first decade of the 21st Century, assuming the extrapolation of past production trends and no radical decline in demand;

WHEREAS the onset of the decline of this critical resource affects all aspects of modern life, such having political and geopolitical implications;

WHEREAS it is expedient to plan an orderly transition to the new environment, making early provisions to reduce the waste of energy, stimulate the entry of substitute energies, and extend the life of the remaining oil;

WHEREAS it is desirable to meet the challenges so arising in a co-operative manner, such to address related climate change concerns, economic and financial stability and the threats of conflicts for access to critical resources.

NOW IT IS PROPOSED THAT

1. A convention of nations shall be called to consider the issue with a view to agreeing an Accord with the following objectives:
   a. to avoid profiteering from shortage, such that oil prices may remain in reasonable relationship with production cost;
   b. to allow poor countries to afford their imports;
   c. to avoid destabilising financial flows arising from excessive oil prices;
   d. to encourage consumers to avoid waste;
   e. to stimulate the development of alternative energies.

2. Such an Accord shall having the following outline provisions:
   a. No country shall produce oil at above its current Depletion Rate, such being defined as annual production as a percentage of the estimated amount left to produce;
   b. Each importing country shall reduce its imports to match the current World Depletion Rate.

3. Detailed provisions shall be agreed with respect to the definition of categories of oil, exemptions and qualifications, and scientific procedures for the estimation of future discovery and production.

4. The signatory countries shall cooperate in providing information on their reserves, allowing full technical audit, such that the Depletion Rate shall be accurately determined.

5. Countries shall have the right to appeal their assessed Depletion Rate in the event of changed circumstances.

Appendix 3: Resources

The following list of resources may be useful for finding a variety of information and resources on peak oil and energy resources, and on climate change and biodiversity. Most of them offer their own list of resources and links. Some of these resources refer and/or link to other resources on food, water, environmental, and social issues related to energy and the peaking of energy production. This list of resources is not exhaustive since there are many organizations, publications, and resources available. As such, there might be other useful resources not listed here. The reader is encouraged to use the resources below as a starting point in order search for additional information as desired.

The author and publisher of this analysis shall not be responsible for the contents of any linked or referenced site or resource, any link contained in a linked site, any products offered by any linked site or resource, or any changes or updates to such sites. Neither is the author nor the publisher of this analysis responsible for webcasting or any other form of transmission received from any linked site. These resources and their links are provided only as a convenience, and the inclusion of any link does not imply endorsement of any of these resources by the author or publisher of this paper.

PUBLICATIONS

Joint Operating Environment 2010

U.S. Joint Forces Command, 2010

http://www.jfcom.mil/newslink/storyarchive/2010/JOE_2010_o.pdf

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New Zealand parliament report: The next oil shock?
New Zealand Parliament, 2010

http://www.peakoil.net/headline-news/new-zealand-parliament-report-the-next-oil-shock

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Peaking of World Oil Production: Impacts, Mitigation, & Risk Management
(a.k.a., The Hirsch Report)
Robert L. Hirsch, Roger Bezdek, Robert Wendling, 2005
U.S. Department of Energy

http://www.netl.doe.gov/publications/others/pdf/Oil_Peaking_NETL.pdf

The Oil Crunch - a wake-up call for the UK economy

UK Industry Task Force on Peak Oil and Energy Security, 2010

http://peakoiltaskforce.net/download-the-report/2010-peak-oil-report/

Tipping Point: Near-Term Systemic Implications of a Peak in Global Oil Production

David Korowicz, 2010
Feasta and The Risk/Resilience Network

http://www.feasta.org/documents/risk_resilience/Tipping_Point.pdf

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Preparing for Peak Oil: Local Authorities and the Energy Crisis

The Oil Depletion Analysis Centre (ODAC) and Post Carbon Institute, 2008

ODAC's own report provides an introduction to peak oil with a focus on the impacts for Local Government. The report sets out steps for Local Authorities to begin to address the issues.

http://www.odac-info.org/sites/default/files/Preparing_for_Peak_Oil_0.pdf

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Global Climate Change Impacts in the United States

U.S. Global Change Research Program, 2009

The U.S. Global Change Research Program (USGCRP) coordinates and integrates federal research on changes in the global environment and their implications for society. The USGCRP began as a presidential initiative in 1989 and was mandated by Congress in the Global Change Research Act of 1990 (P.L. 101-606), which called for "a comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change."

http://www.globalchange.gov/publications/reports/scientific-assessments/us-impacts/download-the-report

direct link:
http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf

FILMS

There are a variety of films available on the subject of peak oil, declining energy resources, and their potential impacts on society. The following two films are particularly relevant for the discussion in this analysis.

Collapse

Collapse, directed by Chris Smith, is an American documentary film exploring the peak oil theories, writings and life story of author Michael Ruppert. An excellent and concise overview and summary of peak oil and its consequences presented in simple and non-technical English with poignant and informative imagery. This is a good and short introduction and overview to peak oil.

Run Time: 80 minutes

http://www.collapsemovie.com/

The Power of Community: How Cuba Survived Peak Oil

The Power of Community: How Cuba Survived Peak Oil is a project of the Arthur Morgan Institute for Community Solutions, a non-profit organization that designs and teaches low-energy solutions to the current unsustainable, fossil fuel based, industrialized, and centralized way of living. The film is a graphic presentation of how Cubans have adapted to limited energy resources and the continued U.S. embargo. Very useful for helping the audience visualize and understand the Peak Oil problem, which is may help to motivate people from an otherwise seemingly overwhelming issue.

Run Time: 53 minutes

http://www.powerofcommunity.org/cm/index.php

ORGANIZATIONS

PEAK OIL

Association for the Study of Peak Oil and Gas (ASPO)

APSO International

ASPO is a network of scientists, affiliated with institutions and universities, having an interest in determining the date and impact of the peak and decline of the world's production of oil and gas, due to resource constraints.

http://www.peakoil.net/

National ASPO Groups
in various languages

http://www.peakoil.net/aspo-organizations

APSO has a vast and comprehensive listing of various peak oil-related publications, reports, books.

http://www.peakoil.net/publications

Energy Bulletin

EnergyBulletin.net is a clearinghouse for information, news, research and analysis regarding the peak in global energy supply. Energy Bulletin was adopted as a core program by the Post Carbon Institute. Except for the Post Carbon Institute, Energy Bulletin is unaffiliated with any private, government, or institutional body. EnergyBulletin.net is a tremendous resource for people looking to gain deeper insight into our energy dilemma and related sustainability issues. A great forum for new voices and new ideas, EnergyBulletin.net explores energy-related impacts on food, population, culture, and more through original articles and multimedia.

http://www.energybulletin.net/

Start Here...
http://www.energybulletin.net/start

The Oil Depletion Analysis Centre (ODAC)

ODAC is an independent, UK-registered educational charity working to raise international public awareness and promote better understanding of the world's oil-depletion problem.

http://www.odac-info.org/welcome

ODAC Peak Oil Primer

http://www.odac-info.org/peak-oil-primer

Post Carbon Institute

Post Carbon Institute (PCI) provides individuals, communities, businesses, and governments with the resources needed to understand and respond to the interrelated economic, energy, and environmental crises that define the 21st century. PCI envisions a world of resilient communities and re-localized economies that thrive within ecological bounds. PCI has developed a number of programs and initiatives that further its mission. PCI also publishes a variety of reports and papers.

http://www.postcarbon.org/

BIODIVERSITY AND MASS EXTINCTION

Convention on Biological Diversity (CBD)

Signed by 150 government leaders at the 1992 Rio Earth Summit, the Convention on Biological Diversity is dedicated to promoting sustainable development. Conceived as a practical tool for translating the principles of Agenda 21 into reality, the Convention recognizes that biological diversity is about more than plants, animals and micro organisms and their ecosystems – it is about people and our need for food security, medicines, fresh air and water, shelter, and a clean and healthy environment in which to live.

http://www.cbd.int/

International Union for Conservation of Nature (IUCN)

IUCN, International Union for Conservation of Nature, helps the world find pragmatic solutions to our most pressing environment and development challenges. It supports scientific research, manages field projects all over the world and brings governments, non-government organizations, United Nations agencies, companies and local communities together to develop and implement policy, laws and best practice. IUCN is the world's oldest and largest global environmental network - a democratic membership union with more than 1,000 government and NGO member organizations, and almost 11,000 volunteer scientists in more than 160 countries. IUCN's work is supported by more than 1,000 professional staff in 60 offices and hundreds of partners in public, NGO and private sectors around the world. The Union's headquarters are located in Gland, near Geneva, Switzerland.

http://cms.iucn.org/

The IUCN Red List of Threatened Species

The IUCN Species Programme working with the IUCN Species Survival Commission (SSC) has for more than four decades been assessing the conservation status of species, subspecies, varieties, and even selected subpopulations on a global scale in order to highlight taxa threatened with extinction, and therefore promote their conservation. Although today they are operating in a very different political, economic, social and ecological world from that when the first IUCN Red Data Book was produced, the IUCN Species Programme, working with the Species Survival Commission and many partners, remains firmly committed to providing the world with the most objective, scientifically-based information on the current status of globally threatened biodiversity. The plants and animals assessed for the IUCN Red List are the bearers of genetic diversity and the building blocks of ecosystems, and information on their conservation status and distribution provides the foundation for making informed decisions about conserving biodiversity from local to global levels.

http://www.iucnredlist.org/

CLIMATE CHANGE

United Nations Framework Convention on Climate Change

Over a decade ago, most countries joined an international treaty -- the United Nations Framework Convention on Climate Change (UNFCCC) -- to begin to consider what can be done to reduce global warming and to cope with whatever temperature increases are inevitable. More recently, a number of nations approved an addition to the treaty: the Kyoto Protocol, which has more powerful (and legally binding) measures. The UNFCCC secretariat supports all institutions involved in the climate change process, particularly the COP, the subsidiary bodies and their Bureau.

http://unfccc.int/

International Panel on Climate Change (IPCC)

The Intergovernmental Panel on Climate Change is the leading body for the assessment of climate change, established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) to provide the world with a clear scientific view on the current state of climate change and its potential environmental and socio-economic consequences. The IPCC is a scientific body. It reviews and assesses the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change. It does not conduct any research nor does it monitor climate related data or parameters. Thousands of scientists from all over the world contribute to the work of the IPCC on a voluntary basis. Review is an essential part of the IPCC process, to ensure an objective and complete assessment of current information. Differing viewpoints existing within the scientific community are reflected in the IPCC reports. The IPCC is an intergovernmental body, and it is open to all member countries of UN and WMO. Governments are involved in the IPCC work as they can participate in the review process and in the IPCC plenary sessions, where main decisions about the IPCC work program are taken and reports are accepted, adopted and approved. The IPCC Bureau and Chairperson are also elected in the plenary sessions. Because of its scientific and intergovernmental nature, the IPCC embodies a unique opportunity to provide rigorous and balanced scientific information to decision makers. By endorsing the IPCC reports, governments acknowledge the authority of their scientific content. The work of the organization is therefore policy-relevant and yet policy-neutral, never policy-prescriptive.

http://www.ipcc.ch/

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