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Oil from a Critical Raw Material Perspective

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Oil from a Critical Raw Material Perspective

Abstract

Today approximately 90% of the supply chain of all industrially manufactured products depend on the availability of oil derived products, or oil derived services. As the source material for various types of fuels, oil is a basic prerequisite for the transportation of large quantities of goods over long distances. Oil, alongside information technology, container ships, trucks and aircraft form the backbone of globalization and our current industrial ecosystem.

Approximately 70% of our daily oil supply comes from oil fields discovered prior to 1970. Most of global oil supply still comes from 10 to 20 huge oil fields. In 2006, 10 oil fields accounted for 29.9% of the global proved reserves. Since 2006, comparatively very small oil fields have been discovered. 74% of the current global oil reserves is geographically concentrated in what is termed the Strategic Ellipse, which is the Middle East and Central Asia. Peak oil discovery was in 1962, since then rates of resource discovery has been declining persistently. New discoveries are limited: the exploration success rate in 2017 was a record low of 5%, and the average discovery size was 24mbbls. A projected range for average decline rate on post-peak production is 5-7%, equivalent to around 3-4.5mb/d of lost production every year.

Currently the market is oversupplied. When the market returns to demand taking up all global supply, effective spare capacity could only shrink by just 1% of global supply/demand of 96mb/d, leaving the market very susceptible to disruptions. Oil demand is still growing by ~1mbd every year, and no central scenarios that have been recently assessed see oil demand peaking before 2040.

Of existing world liquids production, 81% is already in decline (excluding possible future redevelopments). By 2040, this means the world could need to replace over 4 times the current crude oil output of Saudi Arabia (>40mb/d), just to keep output consistently flat.

In January 2005, Saudi Arabia increased its number of operating rig count by 144%, to increase oil production by only 6.5%. This suggests that the market swing producer (as Saudi Arabia was seen) was not able increase production enough to meet increasing demand.

Global conventional crude oil plateaued in January 2005. This would prove to be a decisive turning point for the industrial ecosystem. Since then, unconventional oil sources like tight oil (fracked oil shale) and oil sands have made up the demand shortfall, where U.S. shale (tight oil, fracking with horizontal drilling) contributed 71.4% of new global oil supply since 2005. Global conventional oil production broke out of its plateau in late 2013 and has been able to expand in capacity, where deep off shore plays become more important.

Since 2008, the Shale revolution (tight oil or fracked oil) has increased global oil supply which stabilized increased demand. This was achieved with the application of precision horizontal drilling applied to the existing hydraulic fracking industry. US tight oil produced in August 2019 was 7.73 million barrels per day, approximately 8.37% of global supply. The U.S. tight oil sector accounted for 98% of global oil production growth in 2018. Future global demand growth is now dependent on the U.S. tight oil sector.

Fracked well average production increased between 2010 and 2018 by 28%, but also water injection (and therefore chemical and proppant use) increased by 118%. This is an average across the whole U.S. Tight Oil Sector. Hydraulic fracked wells (used in Tight Oil) go through four basic stages in their life cycle. The three biggest tight oil producer basins of Permian, Eagle Ford and Bakken are all still growing but are in the mature stage of their life cycles. Mature is the third of four stages, where the fourth is decline.

The productivity (per rig as measured by EIA) of the U.S. Tight Oil sector in 2018 is less effective than in 2016. This suggests that the U.S. Tight Oil sector is approaching its peak production reasonably soon. Due to well depletion in fracking, 5 399 new wells are needed to be drilled to keep the U.S. tight oil production consistent in 2019. Each year a similar number of new wells are required.

The environmental impacts of fracking tight oil and oil sands is being largely ignored. Most of these are related to water way pollution and destruction of forestation habitat.

Most oil producers in the U.S. tight oil fracked sector have a negative cash flow and struggle to raise capital to develop upstream infrastructure. This is unfortunate as to maintain production levels, continual new drilling is required (which requires capital). As such Q1 2019 performance of fracking oil producers was far below projections, suggesting further difficulties in this sector.

If the BRIC economies (Brazil, Russia, India and China) was to become as developed as the German economy in context of oil consumption, the BRIC economy 2018 oil consumption would have to expand by 254%. If the whole World was to become as developed as the 2018 German economy in context of oil consumption in 2018, the global oil consumption of 99.84 million barrels per day would have to expand by 117% and an extra 116.68 million barrels per day of oil would need to be brought to market.

Starting in January 2005, all commodity prices that the World Bank track to monitor the industrial ecosystem (base metals, precious metals, oil, gas and coal) blew out in an unprecedented bubble. The second worst economic correction in history, The Global Financial Crisis (GFC) in 2008, was not enough to resolve the underlying fundamental issues. After the GFC, the volatility in commodity price continued. This report makes the case that the GFC was created as the entire industrial ecosystem was put under unprecedented stress, where the weakest link broke. That weakest link was in the financial markets. The strain that created this unprecedented stress, was triggered by the global oil production plateauing. This made the oil market in elastic in form. This is postulated to have happened because the Saudi Arabian oil production was unable to increase production in January 2005, in spite a significant increase of operating rig count. If further analysis supports this hypothesis, then the GFC was created by a chain reaction that had its origins in the oil market.

Due to our dependence on oil, it may be the primary, or master raw resource. Oil has a more significant CRM profile (immanent shortage in context of a vital resource) than almost any other raw material supplying industry. It is recommended that oil, gas, coal and uranium are all added to the European CRM list.

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Keywords oil, conventional crude, reserves, depletion, production, tight oil, fracking, oil sands, peak oil, resource discovery, ERoEI, refining, oil industry investment, oil shock, Global Financial Crisis, quantitative easing			
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REVIEW PROTOCOL

GTK has not traditionally researched oil as a commodity. It became clear it was necessary to do so in context estimating pressure that will be applied to the battery minerals in context of the electric vehicle revolution. This report was to understand the possible timing of the perceived transition away from fossil fuels.

This report was subject to not only an internal review but was subject to external review from a number of professionals from outside GTK. These reviewers were from a range of professions in the oil industry and related areas of capability. The external reviewers were:

- An oil industry professional who works with a wide technical platform in petroleum economics for Norwegian Continental Shelf (NCS), shale gas/oil dynamics and economics.

- A retired industrial financial actuary in the insurance industry that has been studying the energy sector on a global scale.

- A biophysical systems analyst working with energy networks in society. Currently a director of an independent, nonprofit trans disciplinary research-solutions network analyzing violent conflict in context of global ecological, economic and energy crises

- An industrial systems analyst with a multidisciplinary background and an international speaker on energy, international finance and geopolitics, previously a research fellow of the energy industry in a research institution.

- An industrial professional with varied Norwegian and international experience strategic & economic analysis, modeling, taxation, fiscal mechanisms, fiscal regulatory frameworks, accounting, law and auditing/internal controls within extractive industries (oil & gas, and mining) and general industry.

This report is dedicated to Prof. Marion King Hubbert (October 5, 1903 – October 11, 1989), who more than half a century before most industrial analysts, understood what oil really meant for the industrial ecosystem. Hubbert then had the integrity to communicate to the rest of us what he saw, in professionally challenging circumstances.

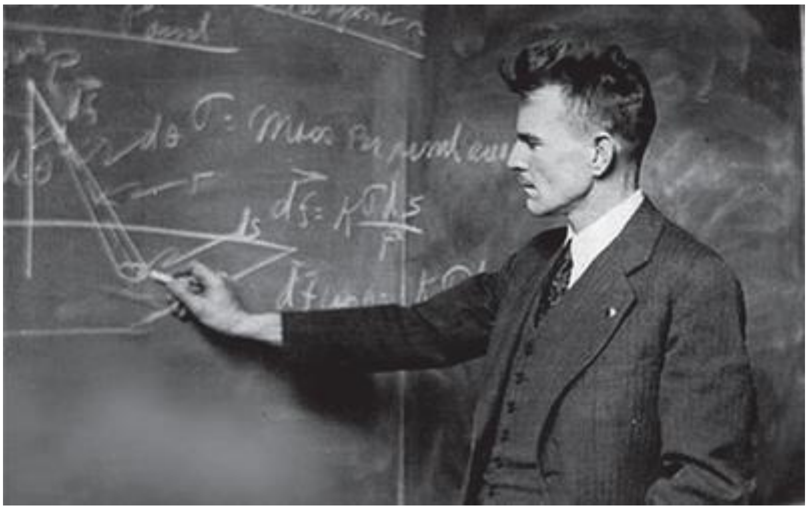

Figure 0. M. K. Hubbert
(Image: Post Carbon Institute)

“We should leave oil before it leaves us.”

Dr Fatih Birol, chief economist of the IEA, 2008

1 INTRODUCTION

Today approximately 90% of the supply chain of all industrially manufactured products depend on the availability of oil derived products, or oil derived services. Oil is not only the source material for producing fuels and lubricants but is also used as hydrocarbon for most organic polymers (plastic materials). Currently substitution materials for plastics like hemp is not accepted by the current plastics industry and considered not economically viable. It is therefore one of the most important raw materials in the production of many different products such as pharmaceuticals, dyes and textiles.

As the source material for various types of fuels, oil is a basic prerequisite for the transportation of large quantities of goods over long distances. Oil, alongside information technology, container ships, trucks and aircraft form the backbone of globalization and our current industrial ecosystem.

International division of labor, to which many countries owe their wealth, would not be possible without today's volume of cost-efficient goods transport. Oil-based mobility also significantly influences our lifestyle, both regionally and locally. For example, living in suburbs several kilometers away from their workplace would be impossible for many people without a car. To a certain extent, the classical suburb thus also owes its existence to oil.

A considerable increase in the oil price would pose a systemic risk because the availability of relatively affordable oil is crucial for the functioning of large parts of the economic and social systems. For some subsystems, such as worldwide goods shipping or individual transportation, the importance of oil is obvious.

The systemic relevance and strategic significance that is ascribed to oil in particular and to secure energy supplies in general is also reflected in various strategic documents of states and international organizations. The international community as well as every single country therefore have a vital interest in secure oil supplies.

A global lack of oil could represent a systemic risk because its versatility as a source of energy and as a chemical raw material would mean that virtually every social subsystem would be affected by a shortage.

> *The purpose of this report is to address the current dependency of oil, the industrial implications of a possible supply short fall and an assessment of how far away a supply to demand gap could be. This is done in a global context as energy is an international industrial ecosystem. This study also will consider the implications for Europe and will advocate the addition of oil to be added to the CRM list.*

In 2019, there is a widely supported push to transform the industrial system into a non-fossil fuel (preferably renewable) supported system (European Commission 2019). To do this oil, and petroleum based technology is to be phased out. This is often referred to the Electric Vehicle Revolution (IEA 2019). In studying this task, the mineral requirements for industrial supply to construct and manage the new power system is of strategic interest to GTK. What is also useful to understand is in what time frame the new system is required to be commissioned.

One of the strategic restraints for the time frame is the understanding of the existing system of fossil fuels, in this case, oil. How reliable is the current oil supply system? How long will it remain to be so?

Figure 1 shows what part of the transition to a non-fossil fuel energy system that this report attempts to examine.

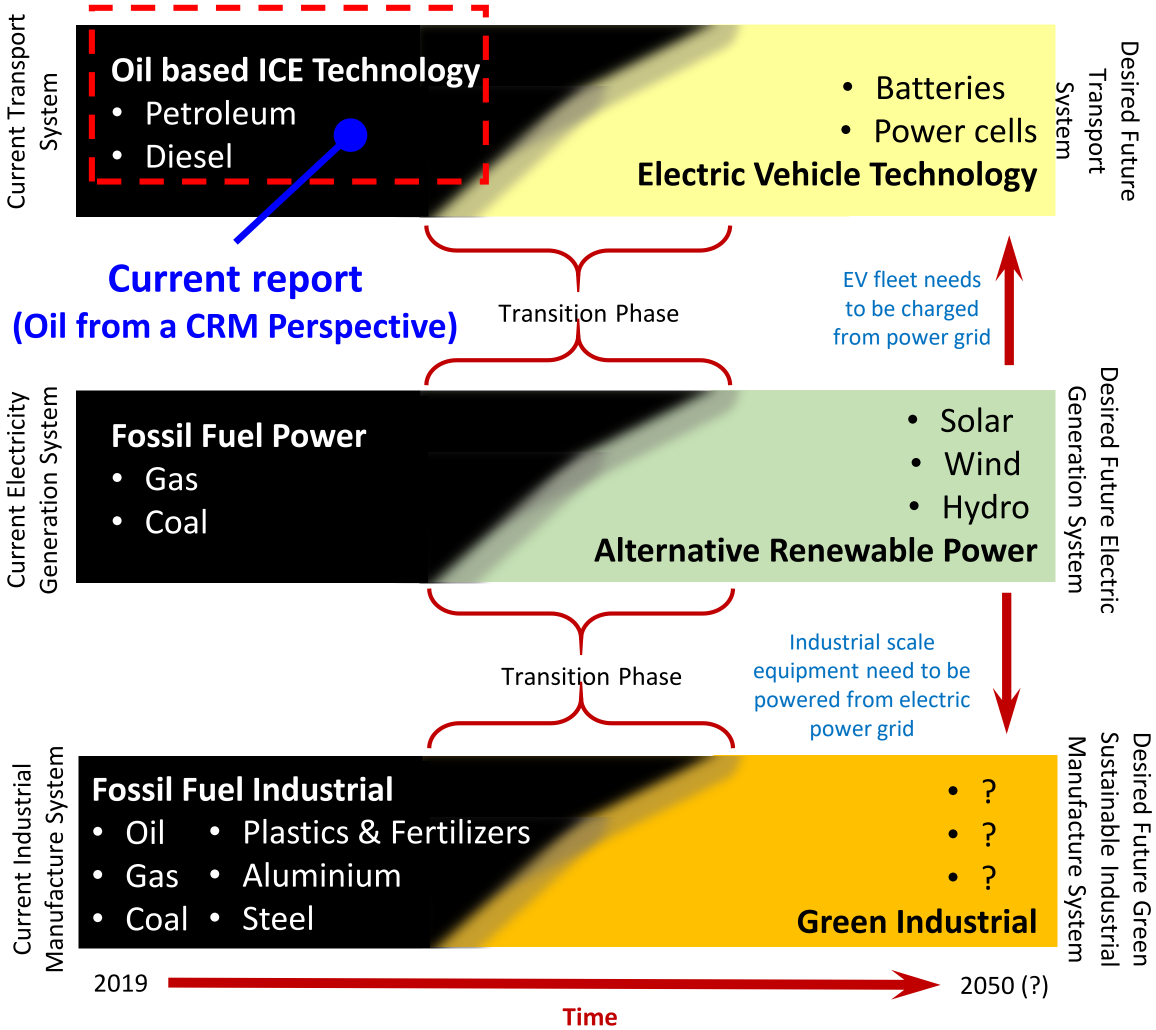

Figure 1. Transition from a fossil fuel based industrial system to a renewable power industrial system

1.1 Energy is the master resource

Energy is the master resource. It allows and facilitates all physical work done, the development of technology and allows human population to live in such high density settlements like modern cities.

Currently the majority of society's energy comes from fossil fuel sources. The renewable energy sources like solar, wind and hydro have been shown to be stable from an engineering context and are being implemented at an increasing rate. Whether these renewable systems will be available to all sections of society in the same quantities as the existing system remains to be seen.

Energy consumption correlates directly with the real economy (Bradley and Fulmer 2008). The real economy is the part of the economy that is concerned with actually producing goods and services, as opposed to the part of the economy that is concerned with buying and selling on the financial markets (conceptually mapped in Figure 2).

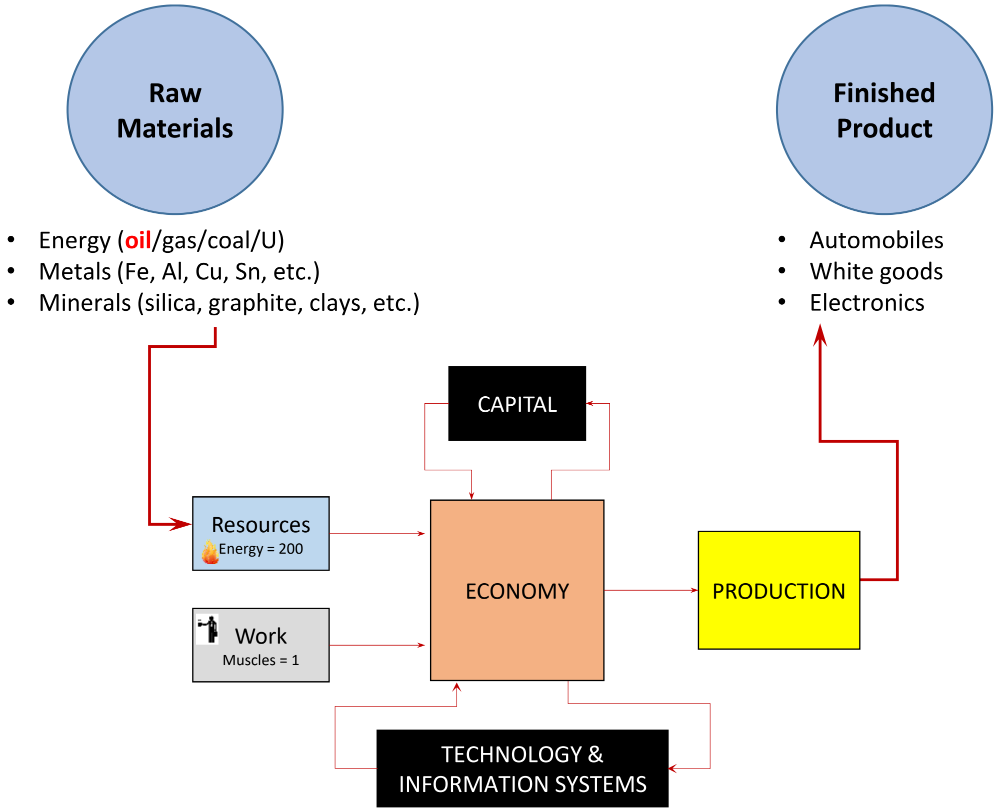

Figure 2. A simplified flow physical flows that sustain our productive system (Source: developed from Jancovici 2011)

Future projections of global energy demand are usually developed on past behavior, with no understanding of finite limits or depleting resources. Generally, reserves have been projected on by past production and demand has been defined by population growth and economic GDP.

The modern world is heavily interdependent. Many of the structures and institutions we now depend upon function in a global context. Energy as a fundamental resource underpins the global industrial system (Fizaine & Court 2016, Meadow *et al*. 1972, Hall *et al*. 2009, Heinberg 2011, Martenson 2011, Morse 2001, Ruppert 2004 and Tverberg 2014).

Figure 3 and 4 show that global crude oil production is related to global GDP and global human population, but they are not direct correlations. The relationships are event and era based, where events over time create different conditions of influence. This report will discuss what each of the turning point dates shown might mean.

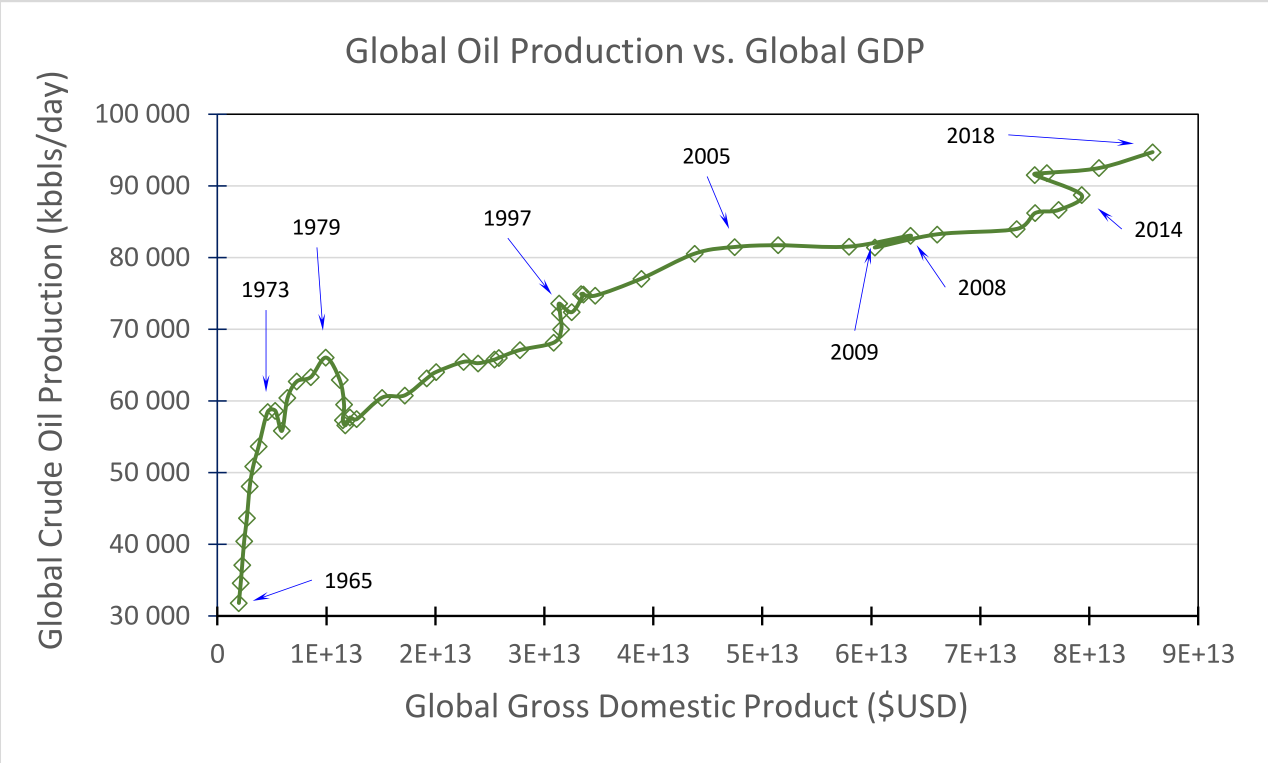

Figure 3. World GDP in $USD dollars (as measured in 1st Jun 2019) vs. global human population, 1965 to 2018. (Source: BP Statistical Review 2019, BP Statistical Review 2011, and World Bank 2015 (GDP))

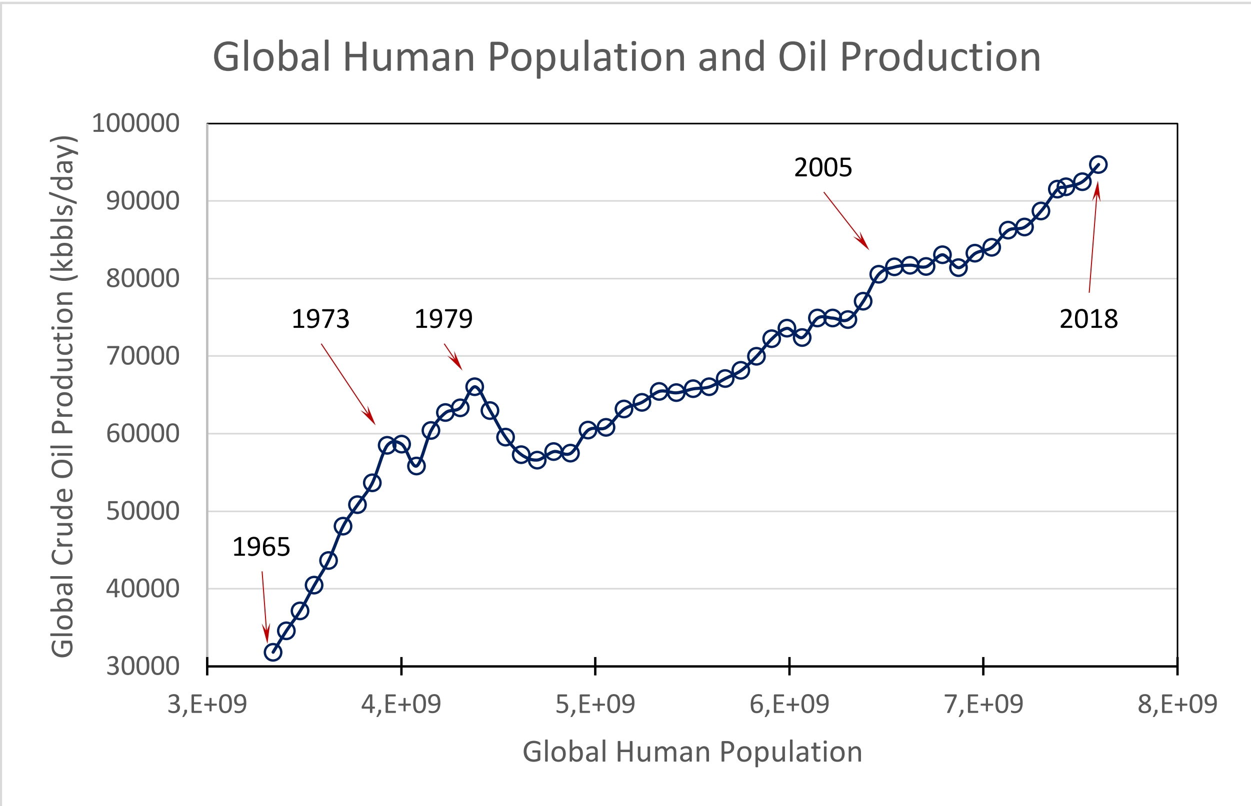

Figure 4. Global human population correlation with global crude oil production (Source: World Bank Group Population data, BP Statistical Review 2019, BP Statistical Review 2011)

Figure 5 shows how Europe compares to other societies around the world in context of energy consumption and Gross Domestic Product (GDP) per capita population. This highlights the challenge of maintaining long term economic security in context that not all nations have the same requirement.

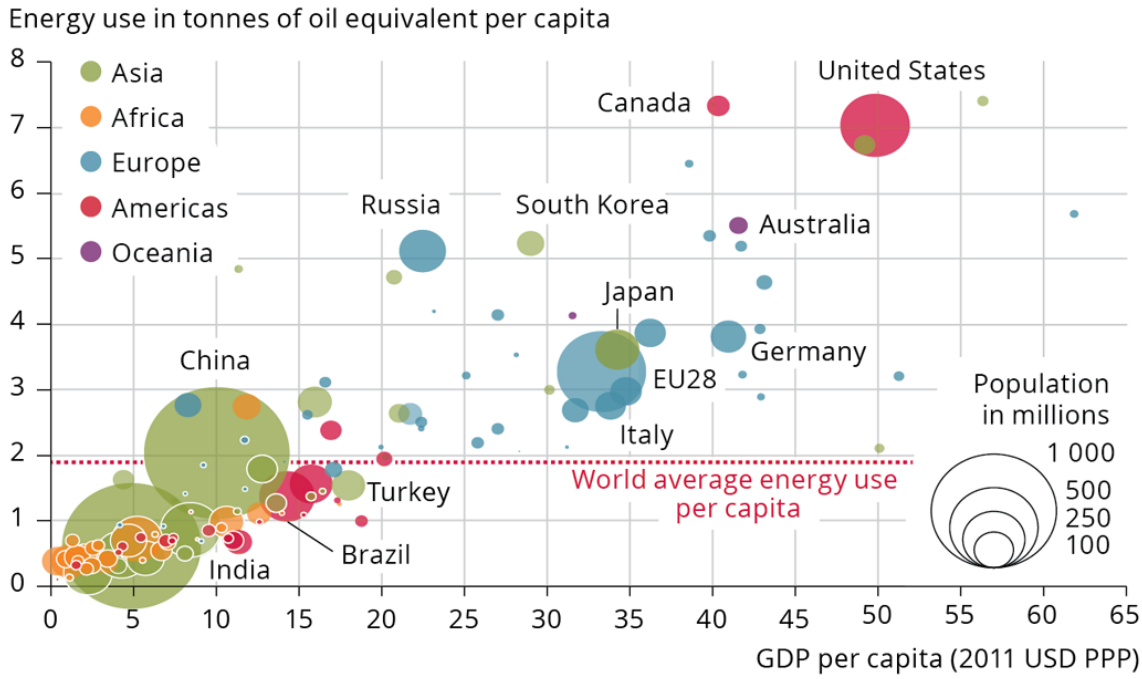

Figure 5. Per capita energy consumption (tonnes of oil equivalent) vs. per capita GDP, PPP (2016 $USD). The size of the bubbles denotes total population per country. All values refer to the year 2011.
(Source: European Environment Agency)
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American society consumes petroleum products at a rate of three-and-a-half gallons of oil and more than 250 cubic feet of natural gas per day each, but as shown in this report, petroleum is not just used for fuel.

Ever since the Industrial Revolution started in the 18th century, vast quantities of fossil fuels have been used to power the economy and deliver unprecedented affluence to large numbers of people (consumers). Energy for the modern industrial world is generated from many sources. The usage of fossil fuels has been increasing in step with economic growth. Fossil fuels were prerequisites for the birth of a new industrial civilization that transformed our world.

Technology is made possible with the quality and quantity of available energy. Energy has been the fundamental facilitator in the application of technology, seen as industrial revolutions. The First Industrial Revolution (IR1), was the transition to new manufacturing processes in Europe and the United States, in the period from about 1760 to sometime between 1820 and 1840.

The Second Industrial Revolution (IR2) is characterized with new technological advancements initiated the emergence of a new source of energy: electricity, gas and oil. An approximate date for the start of IR2 is the mid to late 19th century, or approximately the year 1870. As a result, the development of the internal combustion engine (ICE) made it possible to use these new resources to their full potential. Furthermore, the steel industry began to develop and grow alongside the exponential demands for steel. Chemical synthesis also developed to bring us synthetic fabric, dyes and fertilizer (the petrochemical industry). IR2 was made possible with the use of fossil fuels.

In approximately 1969, a Third Industrial Revolution (IR3) appeared with the emergence of a new type of energy whose potential surpassed its predecessors: nuclear energy. This revolution witnessed the rise of electronics—with the transistor and microprocessor—but also the rise of telecommunications and computers.

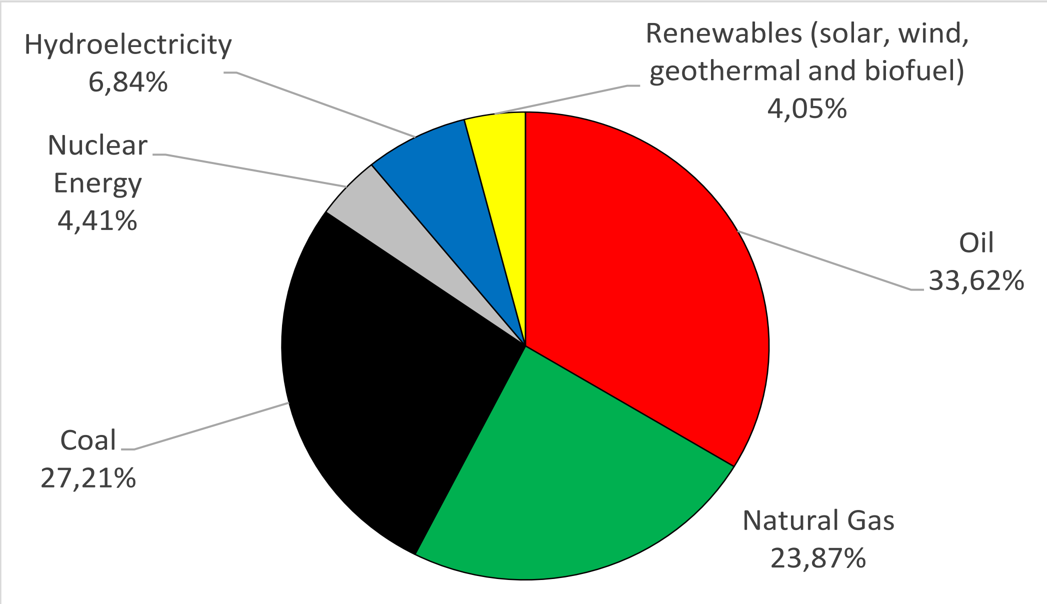

Figure 6. Global primary energy consumption by source in 2018
(Source: BP Statistical Review of the World Energy 2019)

In 2018, the global system was still 84.7% dependent on fossil fuels, where renewables (including solar, wind, geothermal and biofuels) accounted for 4.05% of global energy generation (Figure 6). Figure 7 shows the global energy consumption by source between 1820 and 2018.

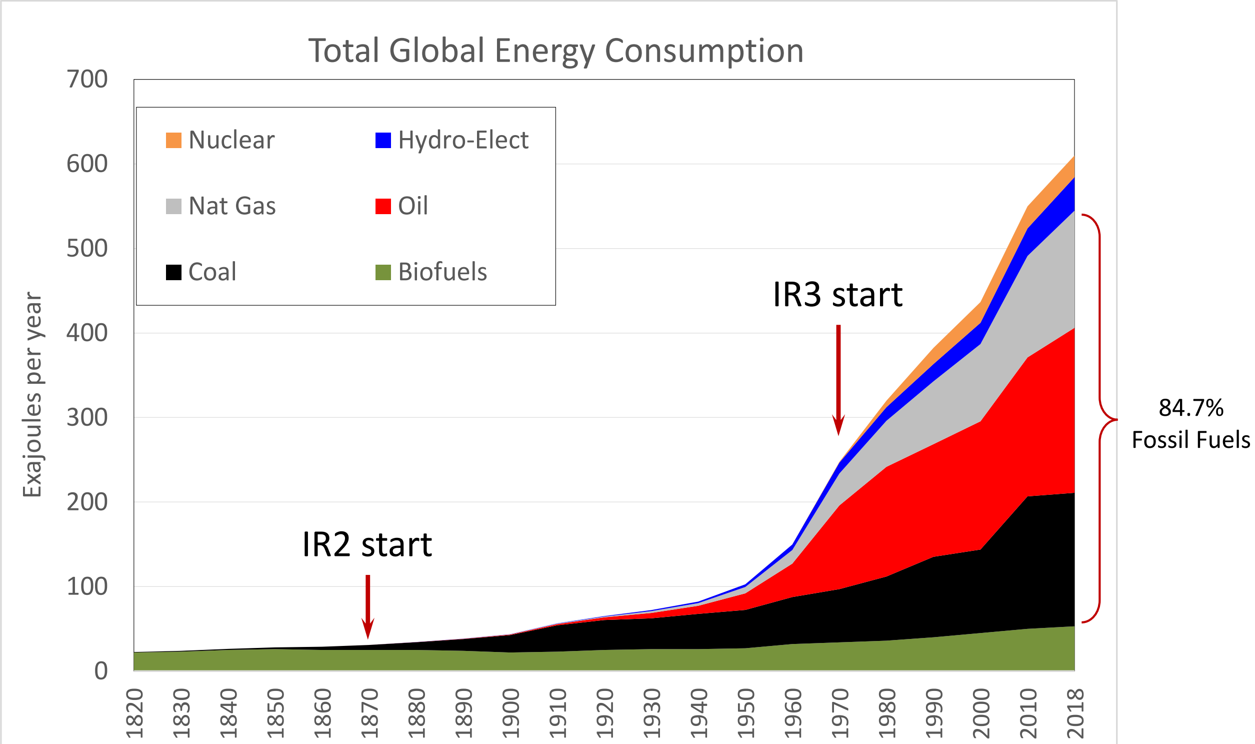

Figure 7. Global energy consumption by source 1820 to 2018 (excluding solar and wind)
(Source: Data from Tverberg, G. https://ourfiniteworld.com/, and BP Statistical Review of the World Energy 2019, US Census Bureau)

Figure 8 shows the energy flows for the global industrial ecosystem. Figure 9 and 10 shows the energy flows for the European Union (EU-28). Note the ubiquitous presence of fossil fuels. Note the comparative volume of the contribution of oil (petroleum products). Appendix A shows the energy flows through the ecosystems through multiple countries in the global ecosystem.

But the different sources of energy are not equal in calorific content. Nor are they used in the same applications. What the different energy sources are and how they are used is discussed in Section 2. Transfer of energy source to power technology from one resource to another is often not possible. With the exception of oil and to a lesser extent gas, once these energy resources are used to generate power, those power stations have to run at a consistent supply to grid level or suffer degradation in their infrastructure. Oil and gas are flexible in use, coal and nuclear are not. Figure 5 shows the energy inputs into the industrial ecosystem in a global context. Appendix A - ENERGY FLOWS THROUGH INDUSTRIAL ECONOMIES shows a Sankey diagram of energy flows of many of the nation state economies discussed in this report.

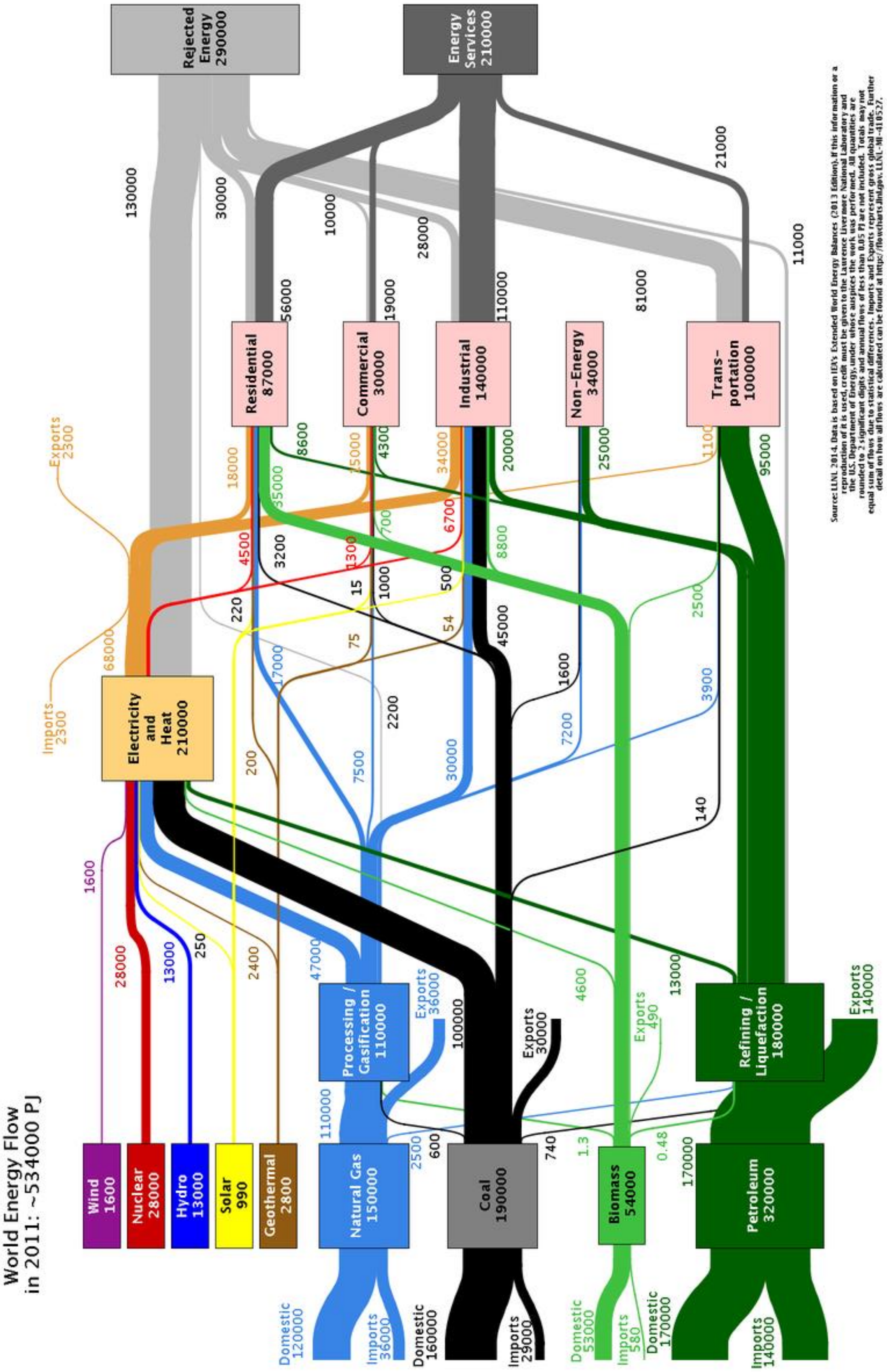

Figure 8. Global energy flow between energy source and application
(Source: Lawrence Livermore National Laboratory Energy Flow Charts)
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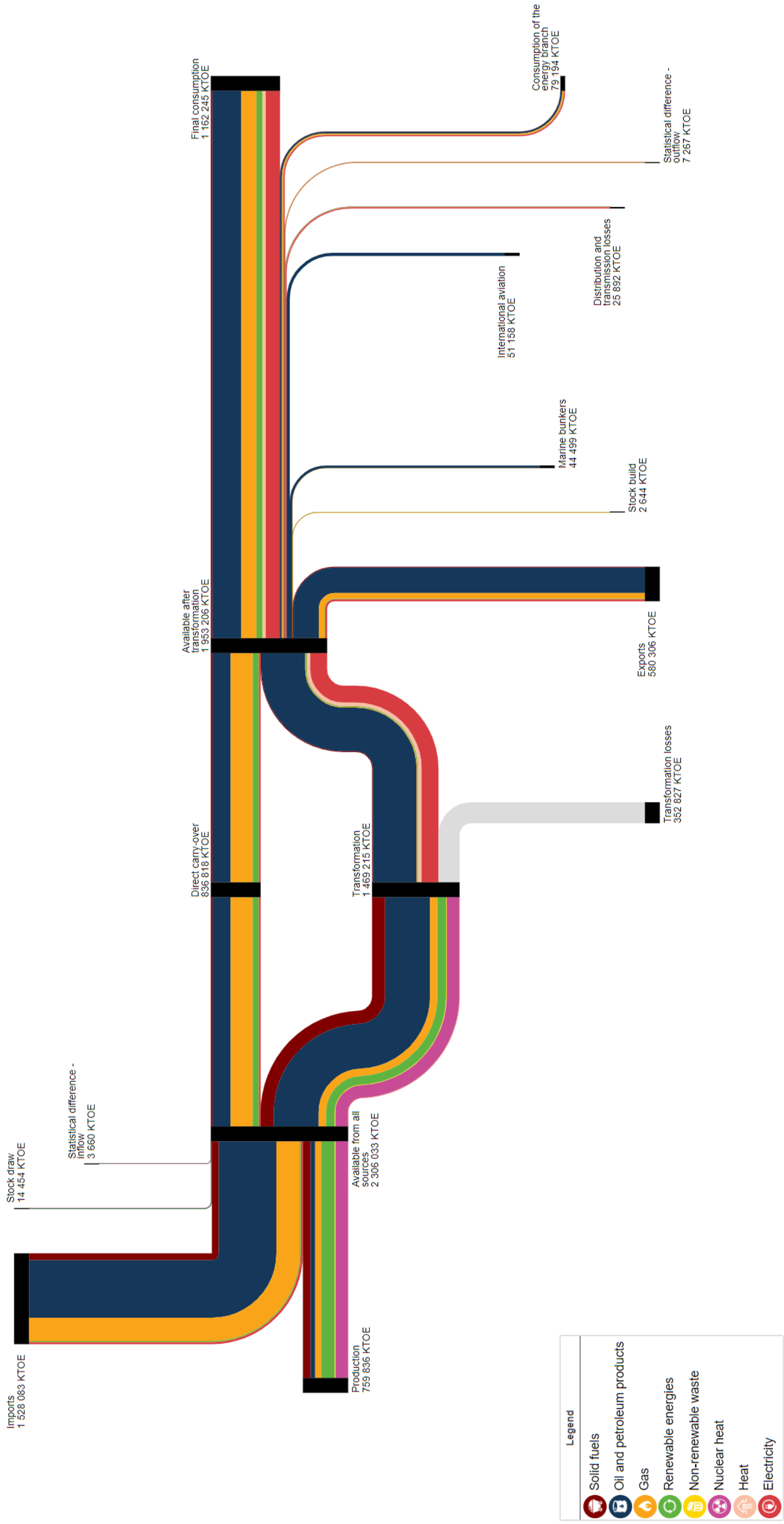

Figure 9. Energy balance flow for European Union EU-28 in 2017
(Source: European Commission Eurostat)
(https://ec.europa.eu/eurostat/web/products-eurostat-news/-/WDN-20190329-1)

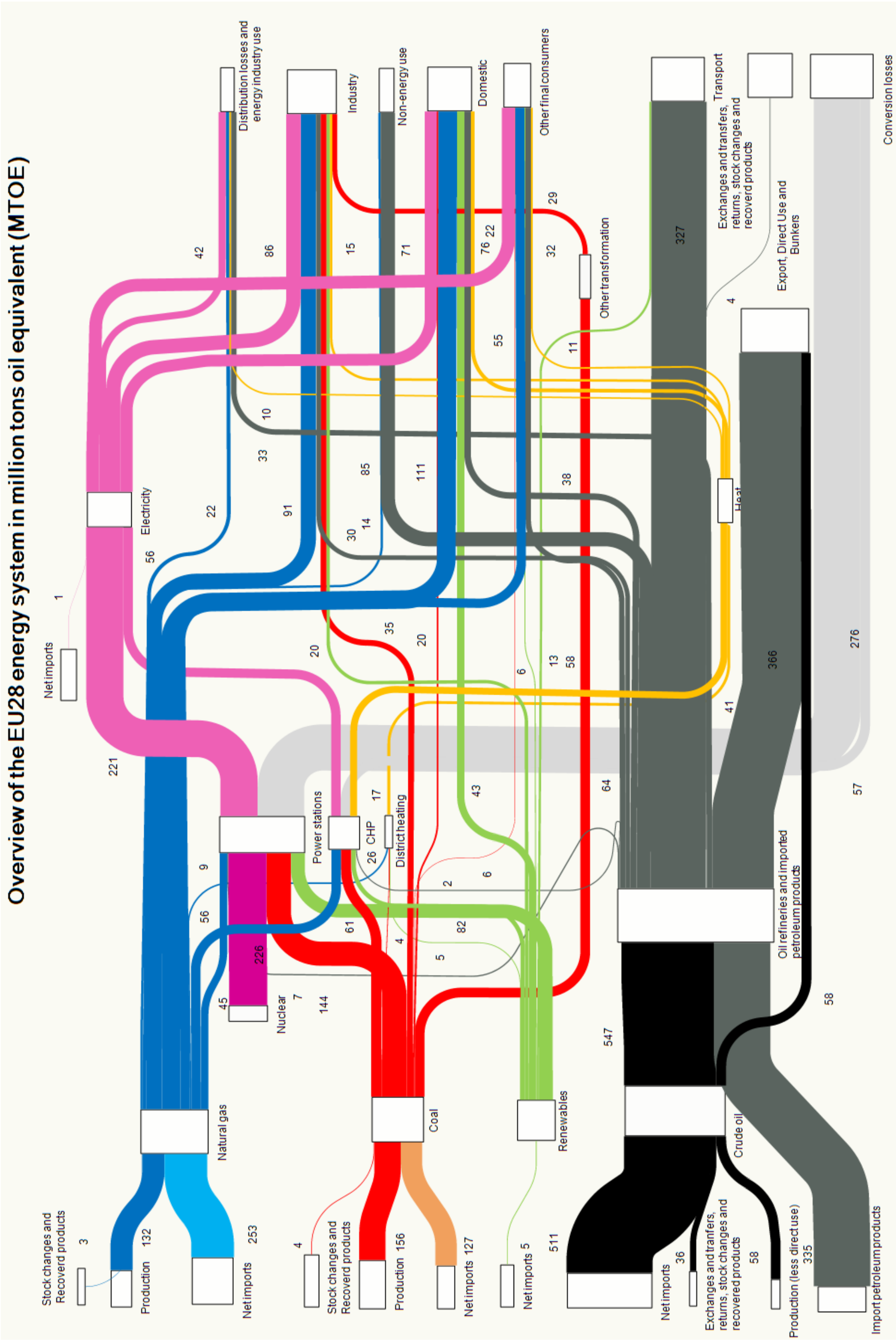

Figure 10. Composition of the primary energy entering the energy system of the EU-28 in 2013
(Source: European Environmental Agency, https://www.eea.europa.eu/)
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Current industrialization has a foundation in the continuous supply of natural resources. The methods and processes associated with this foundation has significant momentum. This will not be undone easily. Currently, our industrial systems are absolutely dependent on non-renewable natural resources for energy sources. Oil, gas and coal. It is probable that this will continue to do so for some time. A group of economists (Covert 2016) explored whether market forces alone would cause a reduction in fossil fuel supply or demand. By studying the history of fossil fuel exploration and technological progress for both clean and dirty technologies, they concluded that it is unlikely that the world will stop primarily relying on fossil fuels anytime soon.

1.2 Energy, oil price and the economy

Prominent ecological economists such as Herman Daly, Robert Goodland and Joan Martinez-Alier suggest a direct causal link from peak oil to high oil prices to low growth and economic crisis.

One of the core theses of ecological economics is that "increased energy use is the main or only cause of economic growth" (Stern, 2011) and that abundant and cheap energy has been historically a major driver of economic growth (Ayres and Warr, 2009; Cleveland *et al* 1984). The inexpensive and abundant energy that has facilitated much of the industrial golden era of the 1950's and 1960's was oil. What is recognized is the industrial eco-system has to be modelled in a global context. Sourcing of industrial raw materials and manufacture of goods has now become a global system with regions.

This paradigm is distinctly different to neoclassical resource or environmental economics. The three styles of economics discussed are briefly described below.

> **Ecological economics** is both a trans-disciplinary and an interdisciplinary field of academic research addressing the interdependence and coevolution of human economies and natural ecosystems, both inter-temporally and spatially (Xepapadeas 2008a).

> **Neoclassical economics** is an approach to economics focusing on the determination of goods, outputs, and income distributions in markets through supply and demand. This determination is often mediated through a hypothesized maximization of utility by income-constrained individuals and of profits by firms facing production costs and employing available information and factors of production, in accordance with rational choice theory (Xepapadeas 2008b).

> **Environmental economics** is a sub-field of economics concerned with environmental issues. Environmental Economics attempts to undertake theoretical and/or empirical studies of the economic effects of national or local environmental policies around the world (National Bureau of Economic Research).

One of the signatures of debates in the literature regarding resource depletion and the importance of oil is the divergence of opinion between conventional economic thought, the perceived effectiveness of current fiscal strategies, and other schools of thought. Various schools of thought that were useful in understanding the world around us since the end of WWI have not been so successful or useful since 2008 in particular.

One of the outcomes of ecological economics is that peak oil and declining energy returns on energy investment for oil and other primary energy resources (Murphy and Hall, 2010) are then likely to limit economic growth and cause recession (Martinez-Alier, 2016; Tverberg, 2012). Once a viable replacement system for oil, petroleum and ICE technology is developed, there will also be a period of disruption while the new system becomes fully established. The time period for this transition would be approximately 20 years (Hirsch 2005 and 2010). This time period could be reduced to 10 years if the all economies undertook the forced pace of industrial activity that was undertaken in the United States during WWII (Hirsch 2005 and 2010).

Kallis *et al* 2016 did an excellent systems based study which attempts to enrich the standard causal model implied by ecological economists, according to which the depletion of oil resources increases their prices and acts as a brake to the economy. A very basic model that allows the complex mechanism of oil price to interact with both GDP and oil reserves was developed (Figure 11)

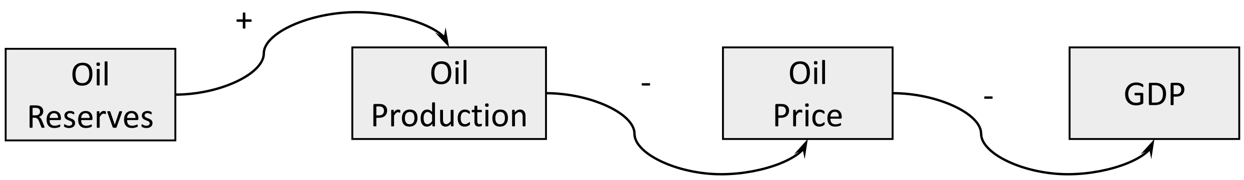

Figure 11. A simple casual model linking oil and the economy (Redrawn from Kallis et al 2016)

A system model was built to explore and study the influence and impact of the movements of oil price (Figure 12) as the economy fucntions now. A number of nodes were considered (Oil Price and GDP) and a number of interaction terms were considered (how for example oil price could influence wages, labeled as R1, R2, R3, etc.).

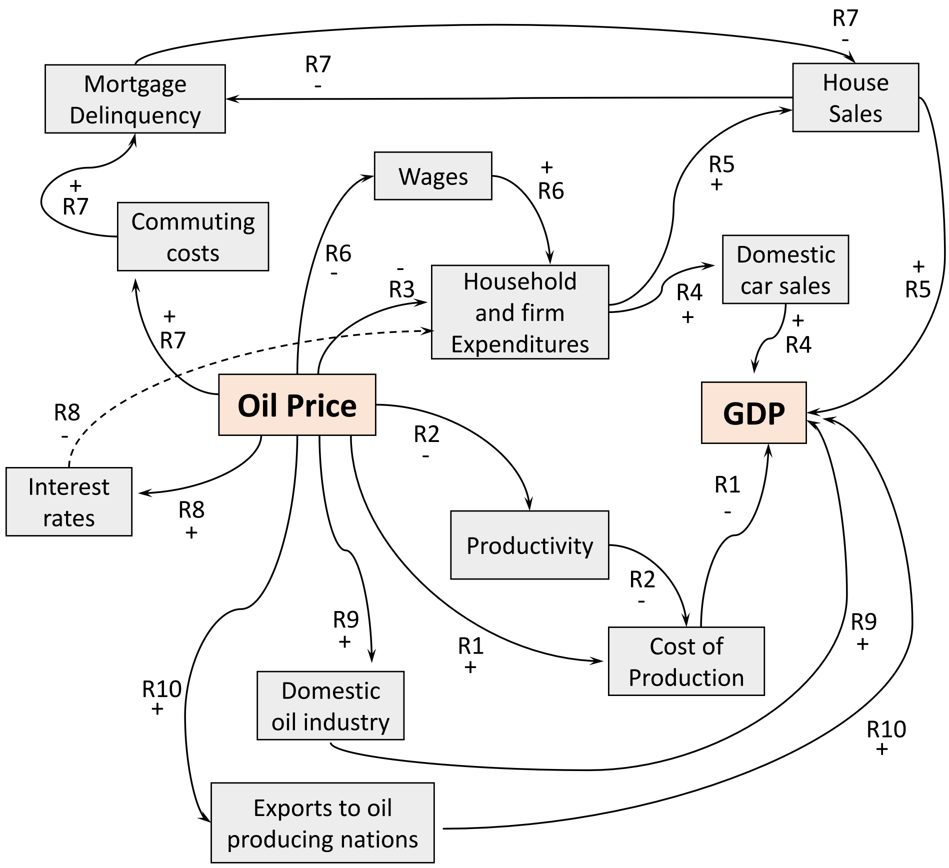

Figure 12. How oil prices may affect the economy (Redrawn from Kallis et al 2016)

There is much evidence to suggest that oil in some form is at the very heart of the modern industrial society. The price of oil can influence economic activity both through the supply side (production) and the demand side (consumption). Section 10 of this report examines the difference between a supply constrained model for oil and a demand constrained model in context of oil capital investment. Rising oil prices can increase the cost of production of firms, especially of energy-intensive ones (interaction R1, Figure 12), and/or reduce labor productivity (interaction R2, Figure 12), also raising the costs of production. The production channel is the one that implicitly concerns ecological economists.

A number of ecological economic papers have discussed and documented empirically that low energy prices are related to increases in labor productivity (Cleveland *et al* 1984) and economic growth (Ayres and Warr, 2009).

Periods of high economic growth of the US economy have been associated with low expenditures on energy, where positive growth requires expenditures less than 11% of GDP. This could be modeled in terms of a minimum EROI (energy return on energy investment) of 11:1 (Fizaine & Court, 2016).

Edelstein and Kilian (2009) examined the period 1970–2006, find that the effects of oil prices on expenditures were generally small, although much larger than what energy's cost share alone would suggest. While energy price shocks explained historical US consumption growth, they were by no means the dominant factor. According to Edelstein and Kilian (2009), oil shocks make themselves felt "primarily through reduced demand for cars and new houses" (i.e. interactions R4 & R5, Figure 12) (Kilian, 2008). In a later study that focuses on the period 2007–2008 and the Global Financial Crisis (GFC) economic crisis, Hamilton (2009) finds a much more significant effect. Hamilton (2009) postulates that the rise in energy prices accounts, he argues, for about half of the gap between predicted and actual consumption spending.

Oil prices are determined, at least in part, by the supply or production of oil (interaction S1, Figure 13) and the demand for it (interaction S2, Figure 13). The supply of oil is affected by:

- Acute events and disruptions in production, due, for example, to war (interaction S3, Figure 13);
- Geological factors and constraints (S4, Figure 13); and
- Investments in new capacity or new technologies (interaction S5, Figure 13).

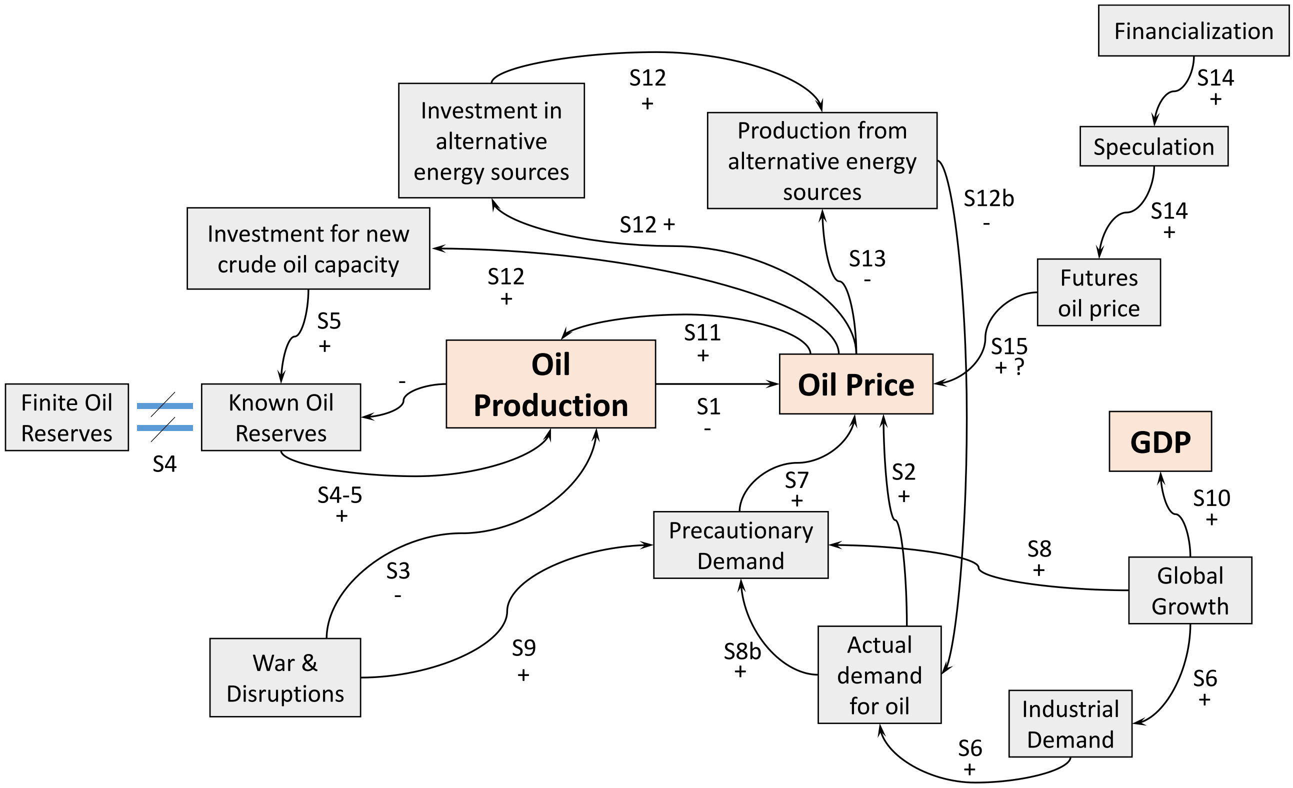

Figure 13. Determinants of oil prices (Redrawn from Kallis et al 2016)

Kilian (2009a) distinguished between increases in demand due to increasing industrial activity and growing global demand for all industrial commodities (interaction S6, Figure 12) versus changes in demand due to changing expectations about future oil demand and supply (interaction S7, Figure 12).

The system model shown in Kallis 2016 provides an interesting approach to examining the influence of oil on the current economic environment. There is quite a lot of empirical data to show this basic concept is valid.

As the biophysical economists have shown global economic growth is closely correlated with growth in energy consumption. Professor Minqi Li of Utah University's Department of Economics, shows that between 2005 and 2016, that an increase in economic growth rate by one percentage point is associated with an increase in primary energy consumption by 0.96% (Li 2018). Figure 14 compares the historical world economic growth rates and the primary energy consumption growth rates from 1991 to 2017. In 2017, world primary energy consumption grew by 1.9 percent, a rate that is 0.4% below what is implied by the historical trend. So energy consumption relates to economic growth rate by moving up and down the relationship shown in Figure 14, where other influences are also in play.

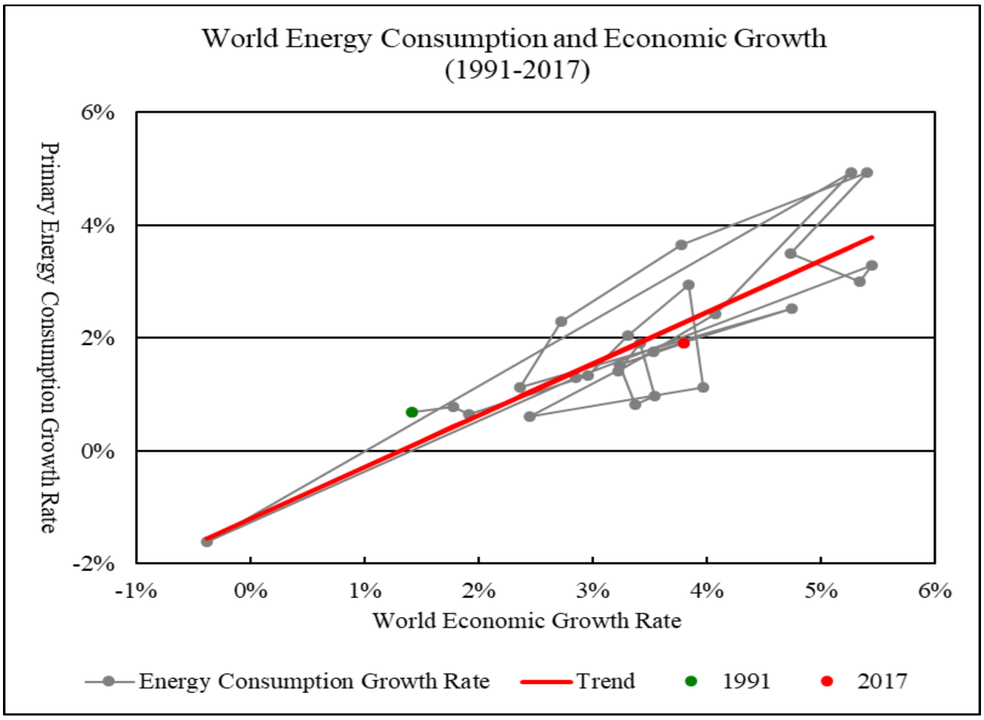

Figure 14. World energy consumption and economic growth (Source: Li 2018, World primary energy consumption from 1990 to 2017 is from BP (2018). Gross world product in constant 2011 international dollars from 1990 to 2016 is from World Bank (2018), extended to 2017 using growth rate reported by IMF 2018, Statistical Appendix, Table A1)

Oil price is the heart beat of the global industrial economy. If the oil price goes too high, economic growth cannot happen. GDP is required to growth to service the maintenance of existing debt. Figure 15 shows the percent of world oil consumption of world GDP. It also shows the approximate regions of oil price where economic growth can or cannot happen.

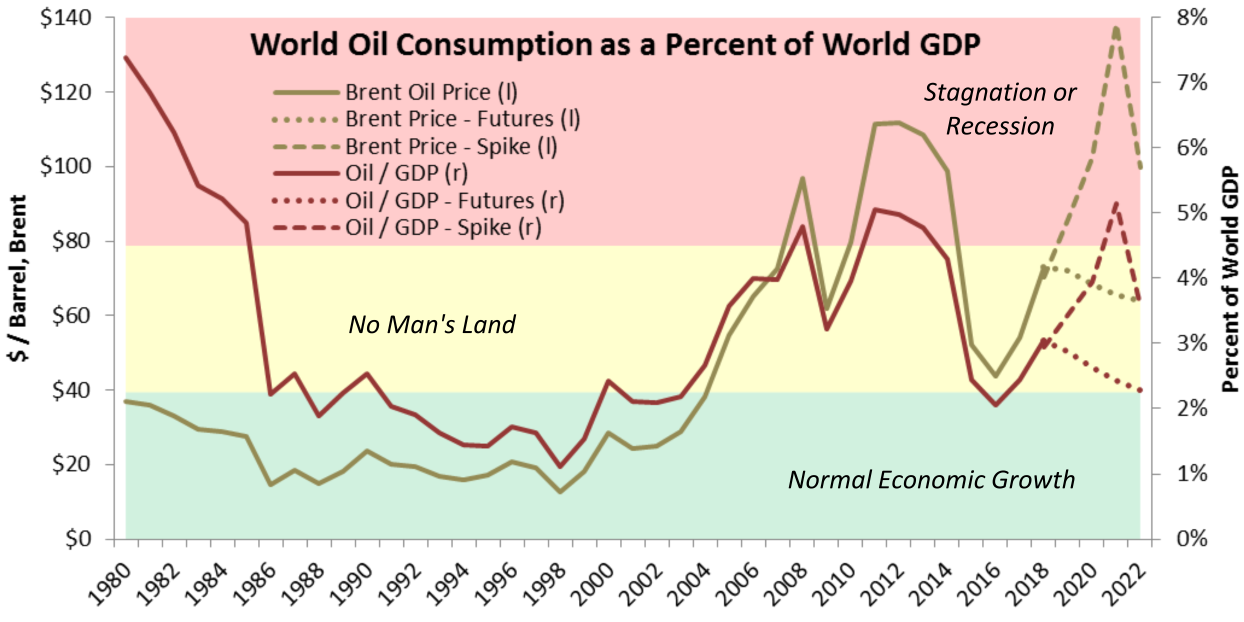

Figure 15. World Oil Consumption as a Percent of World GDP. LHS axis Brent Oil Price. RHS axis % of World GDP (Source: Stephen Kopits – Princeton Energy Advisors, http://www.prienga.com/, Hufford 2018)

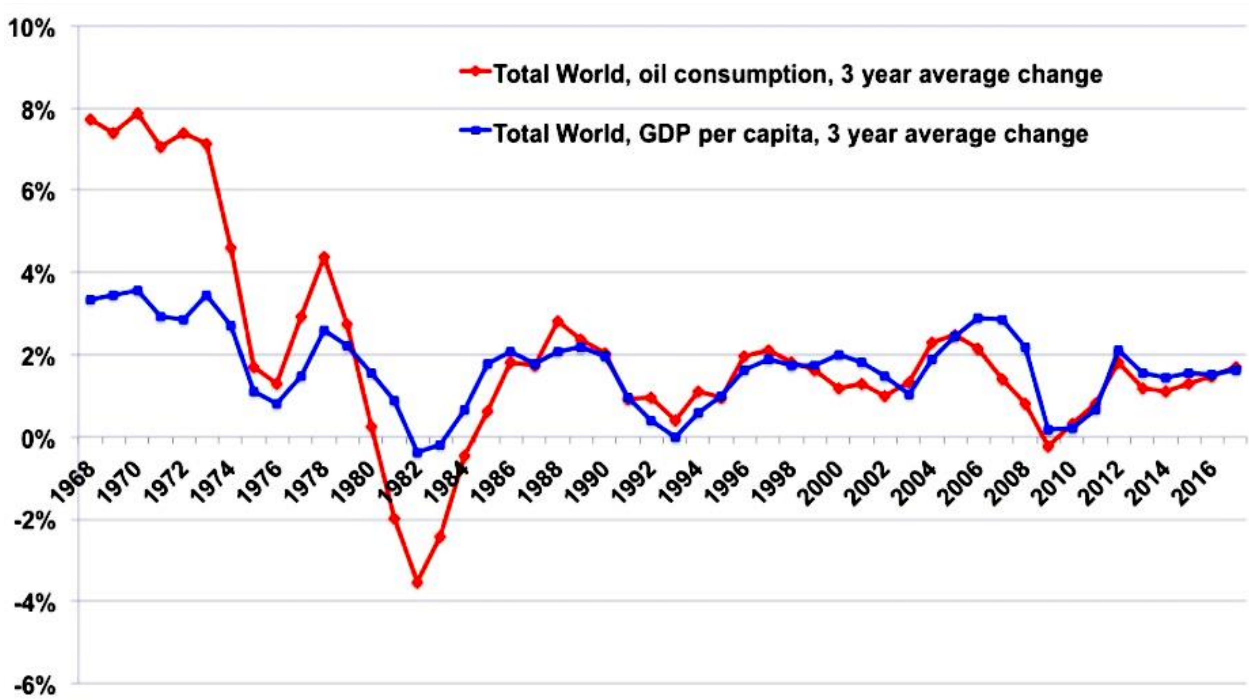

Figure 16. Correlation between the annual relative change in world oil consumption and GDP per capita averaged over three years
(Source: Data from BP Statistical Review 2018, World Bank)

Figure 16 shows the strong correlation between the economic activity index global GDP, global energy consumption and global oil consumption. The importance of this cannot be overstated. In our current form, industrial society correlates directly with our ability to consume energy. Oil in particular is important to understand. As can be seen in Figure 16, oil consumption correlates with both GDP and energy consumption. This is because current society is a petroleum driven economy (Heinberg 2011, Martenson 2011, Morse 2001, Ruppert 2004, Tverberg 2014 and Wiedenhofer 2013).

1.3 Energy and population growth

Population growth is another fundamental driver to this current set of circumstances. Consumption is a function of the number of people who consume. An increase in production or an achieved efficiency has to be put in context of the population growth across that time frame. Population has grown in a manner that strongly correlates with the increase in energy consumption once all sources have been summed together (Bartlett 1994). Since the start of the industrial revolution, population has been empowered by technology coupled with increased energy density (coal vs biomass wood, followed by the introduction of oil).

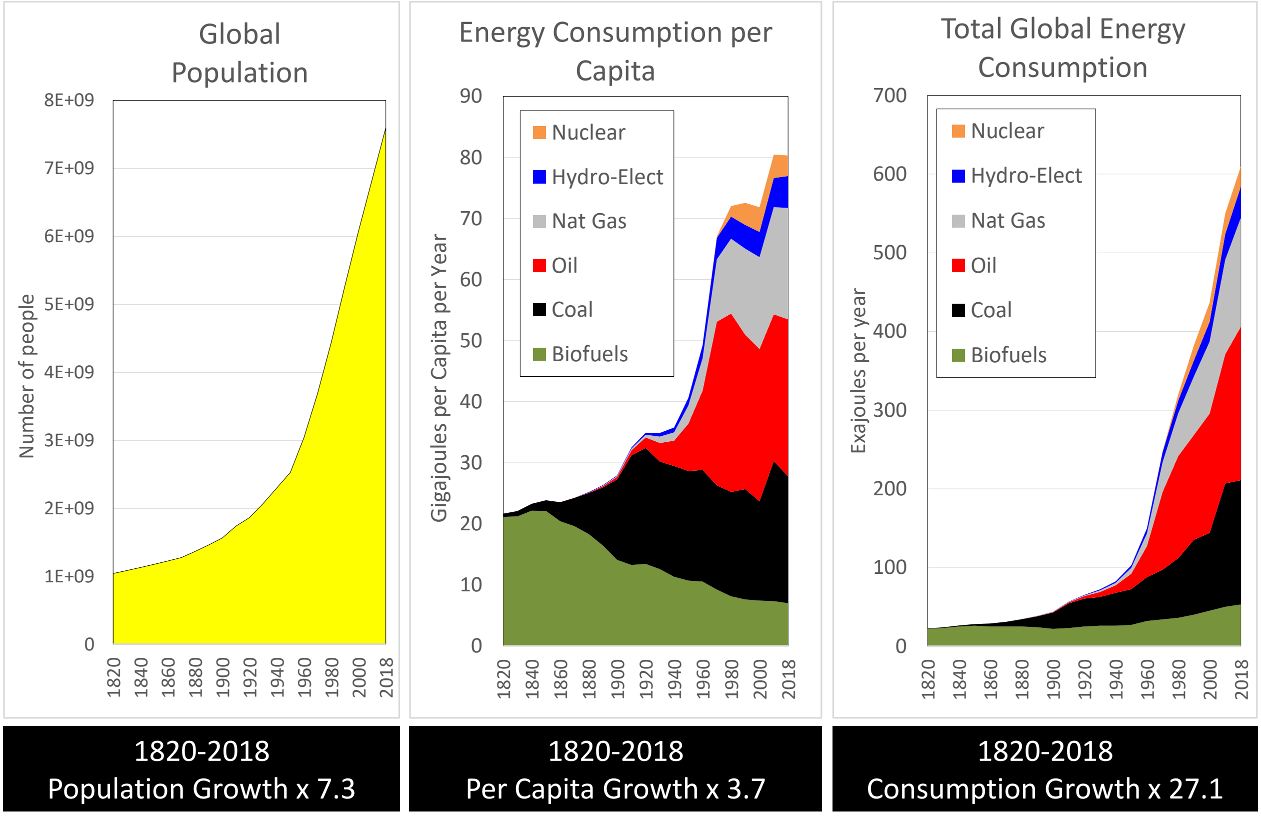

Figure 17. World population, per capita-, and total energy consumption, 1820-2018
(Source: Data from Tverberg, G. https://ourfiniteworld.com/, and BP Statistical Review of the World Energy 2019, US Census Bureau)

Note in Figure 17 how the middle chart has Per Captia Consumption for energy. This highlights how increasing complexity of technology has resulted in an increase per person in terms of energy requirements (the same can be shown for all natural resources). In summary, the energy requirements per capita have increased over time in line with technological development and complexity. In conjunction to this, human population consuming and operating this technology is growing at an exponential rate. The right-hand-side plot shows that the combination of the two have resulted in a multiplication times 50, the demands on our energy resource sector (89% finite non-renewable resources).

The implications for Figure 17 are also that the global human population, and the society that population inhabits, needs energy to function. At this time, the majority of that energy is dependent on finite non-renewable natural resources like oil, gas and coal. This highlights the importance of understanding the true supply status of fossil fuels and the true viability of any replacement system.

Figure 18 shows the increase per capita for individual energy resources.

- Oil has sharply increased since its inception and then declined per capita since 1970
- Natural gas has increased steadily since its inception
- Coal rose steadily from the start of the industrial revolution and plateaued in 1910, was stable till it sharply increased in the year 2000

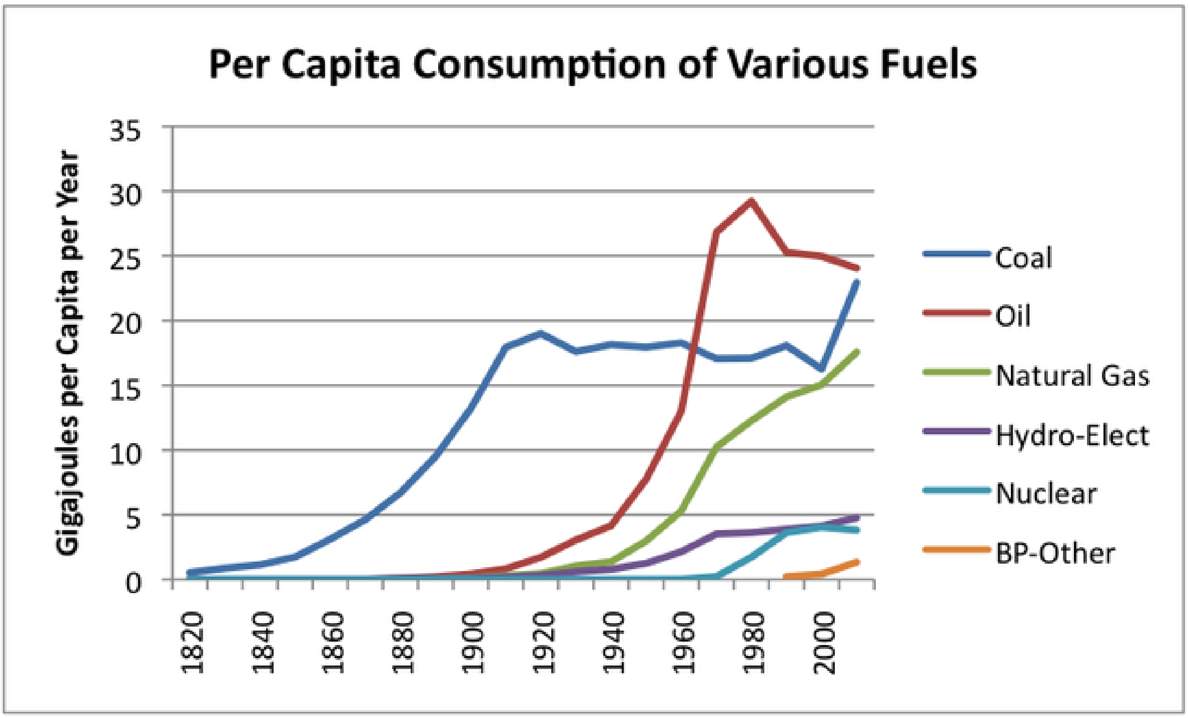

Figure 18. Per capita consumption of various fuels
(Source: Tverberg 2015, OurFiniteWorld.com)

Figure 19 show the total global energy consumption normalized for population growth. As can be seen, energy consumption was on a rough plateau from 1970 to 2001. From 2001 to about 2005 there was an increase, followed by a bumpy plateau. There was a peak in per capita energy consumption in 2013.

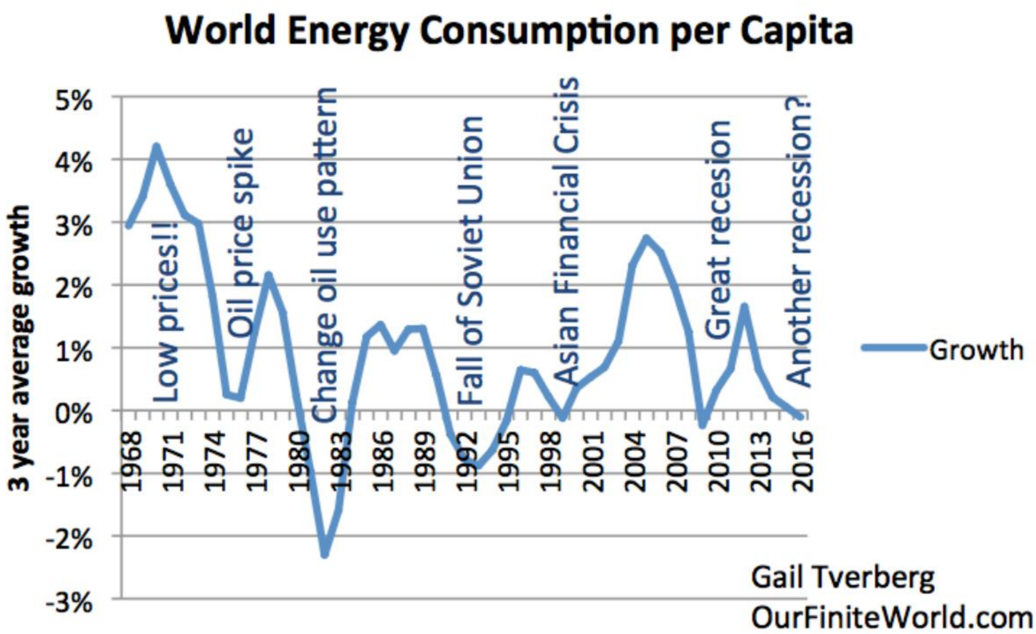

Figure 19. Average growth per capita consumption of energy
(Source: Tverberg 2015, OurFiniteWorld.com)

As can be observed in Figures 19, energy and oil consumption correlate with economic activity. Also it can be shown that the most useful way to look at population based data structures is in a per capita context.

1.4 Oil consumption and industrial output

The production of steel is a useful proxy for industrial activity (as is cement production). The combination of steel and cement (concrete) forms the basic foundation or structure of most industrial actions. Figure 20 shows the international production of steel by country.

At the end of World War II, the global industrial capacity was distributed reasonably evenly across all continents (not perfectly of course). Now, industrialization and large scale heavy industry manufacture is dominated by just one nation state: China. In 2018, China accounted for 48% of global crude steel production. This makes China a useful proxy for the global industrial market.

Figure 21 shows the market share of global consumption of raw material resources. As can be seen China consumes enough raw materials and dominates enough heavy industry (steel and cement production are proxies for this) that Chinese industrial output could be considered as a proxy for the global industrial market.

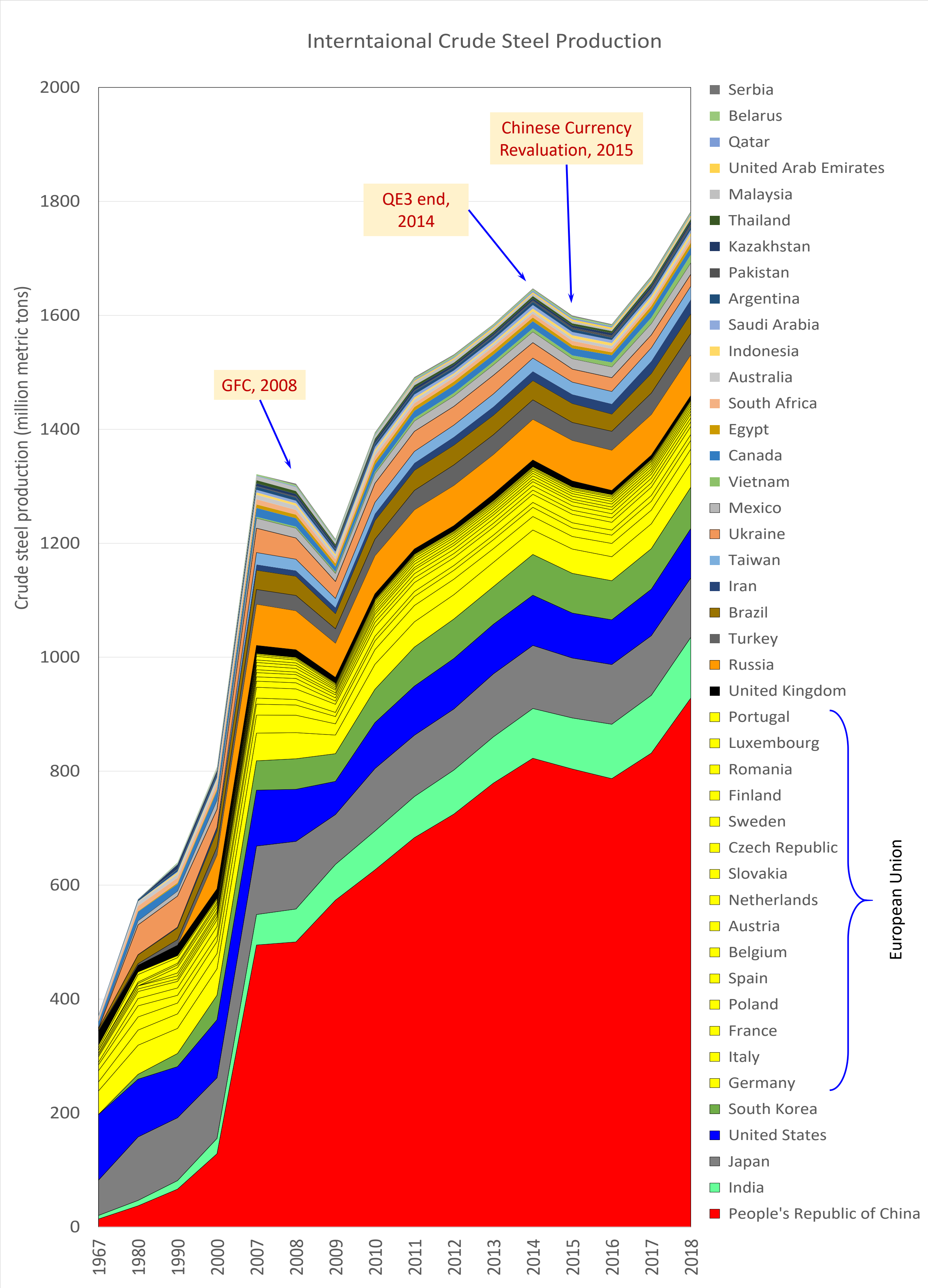

Figure 20. Crude steel production in 1967, 1980, 1990, 2000 and from 2007 to 2018. All countries with annual production of crude steel at least 2 million metric tons are listed.
(Source: based on data provided from World Steel Association)

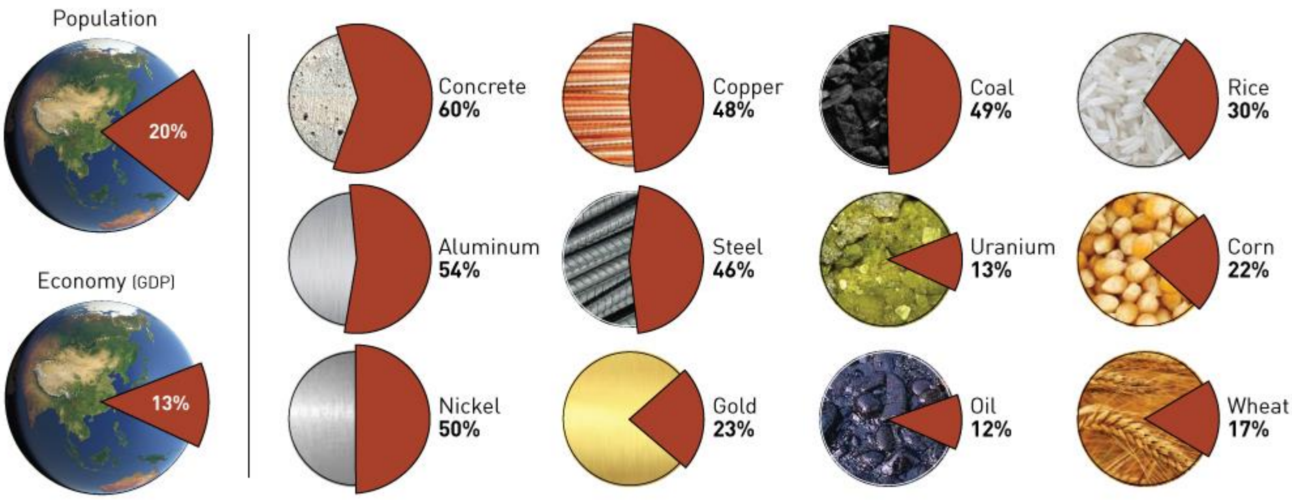

Figure 21. Chinese consumption of natural resources in 2015 as a fraction of global consumption (Source: visualcapitalist.com) (Copyright: https://www.visualcapitalist.com/frequently-asked-questions/)

To prove the point that oil is connected to industrialization, global oil consumption is then examined in context of industrial output. Figure 22 shows the global steel production plotted against global oil consumption. There clearly is a correlation, but that correlation is interrupted by structural change as an external influence. The years 2009 to 2014 correlate in a consistent relationship, then there was a structural setback (possibly the end of the third round of Quantitative easing by the U.S. Federal bank QE3). The years 2016 to 2018 have a similar gradient to 2009 to 2014. This suggests that oil consumption can be used as a proxy for industrial activity when there is no global scale structural change (like the Global Finance Crisis).

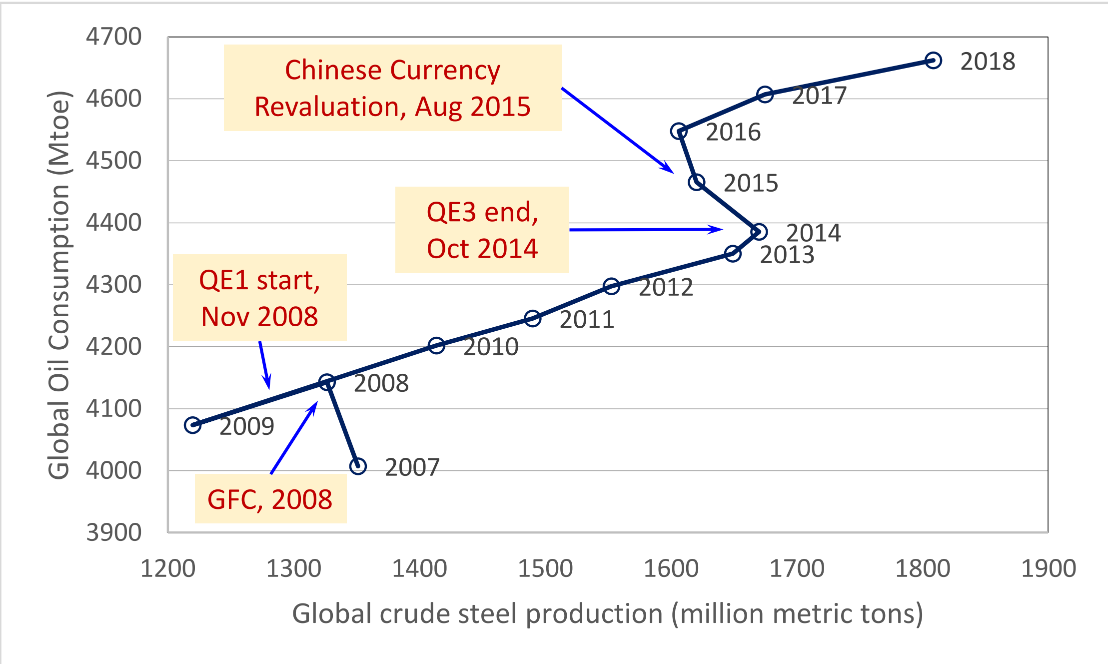

Figure 22. Global oil consumption compared to global steel production. (Source: BP Statistical Review of the World Energy 2019, BP Statistical Review of the World Energy 2011, World Steel Association)

What is interesting is that 71% of steel is produced using coal. Oil has no clear relationship to its production or application. Figure 23 shows global steel production to global coal consumption. Compared to Figure 22, the relationship shown in Figure 23 is not nearly as smooth, while the same structural changes can be seen.

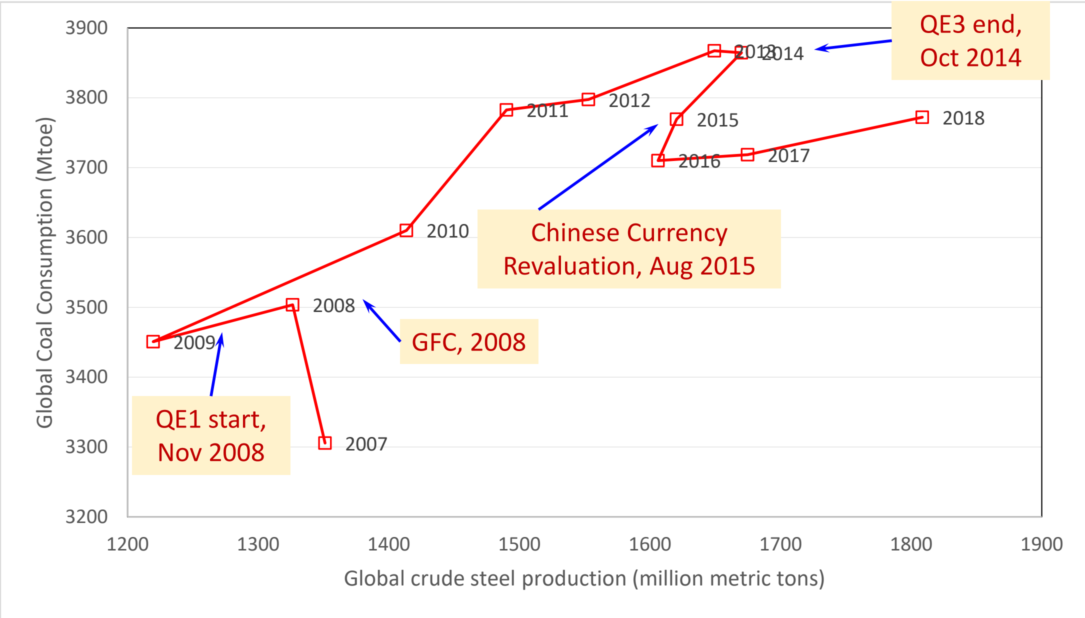

Figure 23. Global coal consumption compared to global steel production. (Source: BP Statistical Review of the World Energy 2019, BP Statistical Review of the World Energy 2011, World Steel Association)

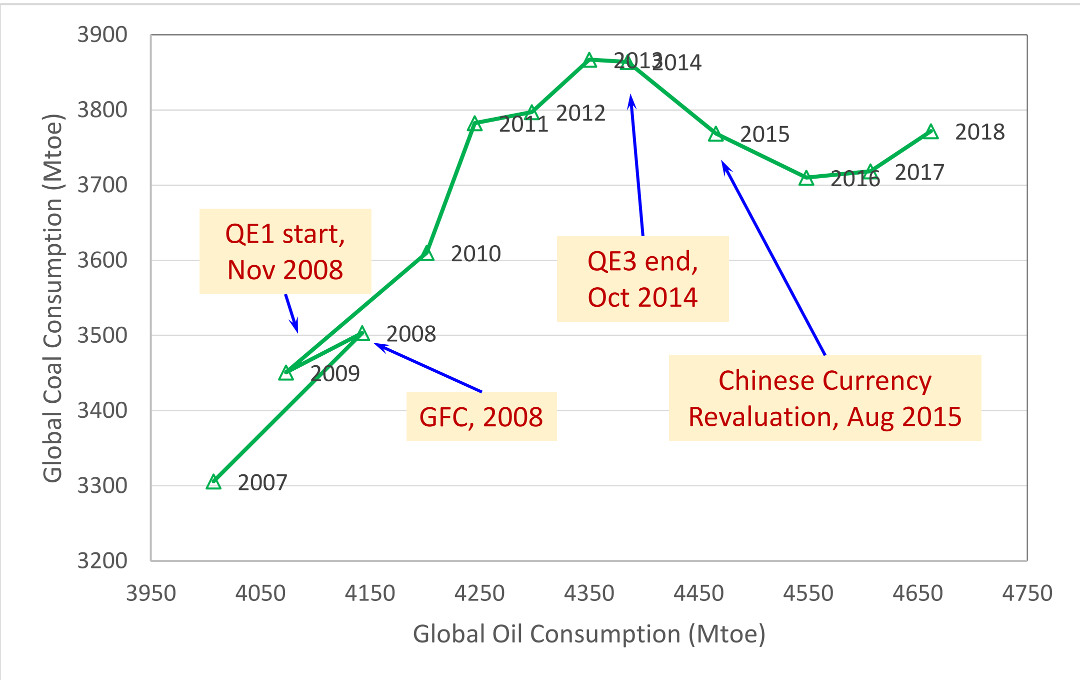

Figure 24. Global oil consumption compared to global coal consumption. (Source: BP Statistical Review of the World Energy 2019, BP Statistical Review of the World Energy 2011, World Steel Association)

Figure 24 shows the relationship between oil consumption and coal consumption. This is not a linear relationship. They are both vital energy fuels that do very different things. Note the change in relationship when QE1 starts, and QE3 finishes.

Figure 25 and 26 shows the correlation relationship between the change in Chinese industrial output (Year on Year % change) and a change in Brent oil price on the international market (Year on Year % change).

Industrial activity represents real physical work, and the YOY % Industrial output is a measured index of physical work done and goods manufactured by Chinese heavy industry. China dominates the industrial activity in the global market, controlling the majority of mining, refining recycling and manufacture (Wübbeke *et al* 2016). This means that a change in Chinese industrial activity is a useful proxy for global industrial activity. Energy is the ability to do work, and the YOY % change in the price of oil is a proxy for the stability of the energy system. A correlation between the two strongly supports

As can be observed these is a correlation. It can also be noted in Figures 27 and 28 that there is three different time periods that have different signatures.

During the crash of 2008 (Global Financial Crisis), there is a strong correlation as both indexes dip sharply followed by temporary recovery (this signature is the most prominent in the whole data set from 1991 to 2018), followed by a steady decrease. Prior to the GFC crash in 2008, there is a second time period where the two indexes correlate (but not as strongly). The relation between the two proxies is clearly involving multiple parameters. After the GFC is a third time period were the two indexes do not correlate at all. The change in Chinese industrial output decreases steadily, where the change in oil price does not. This is another signature of the contraction of the real economy.

On August 11, 2015, the People's Bank of China (PBOC) conducted three consecutive devaluations of the yuan renminbi or yuan (CNY), removing over 3% off its value. Between 2005 and 2015, China's currency had appreciated 33% against the U.S. dollar, and the first devaluation marked the most significant single drop in 20 years (Investopedia 2019).

This is significant as in Figures 25 and 26, there is a crash in the YOY % change in the average monthly Brent oil spot price in 2015. This crash is of similar size to the Global Financial Crisis (GFC). At a similar time, the industrial Baltic Dry Index (The Baltic Dry Index or BDI measures how much it costs to ship "dry" commodities in the international market — raw materials like grain and steel) crashed to an all-time low of 291 in February 12th 2016 (Bloomberg BDIY Quote 2019). So Chinese industrial output, the price of oil, and the global maritime trade of dry goods all had a signature in 2015 as significant as the GFC in 2008. This happened just as the U.S. Federal Reserve 3rd Quantitative Easing program (QE3) ended. The Baltic Dry Index has been used as a leading indicator for an economic slowdown (Martin 2016). Economic slowdowns are a signature of what the industrial ecosystem is doing. Oil is a fundamental raw material supply to the industrial ecosystem at all scales. Thus while the BDI is a lagging signature in context of the oil market, it is still useful in mapping outcomes.

This suggests a structural move happened in the global economy in 2015 that significantly affected the real economy (the production of physical goods and services as opposed to financial products like derivatives).

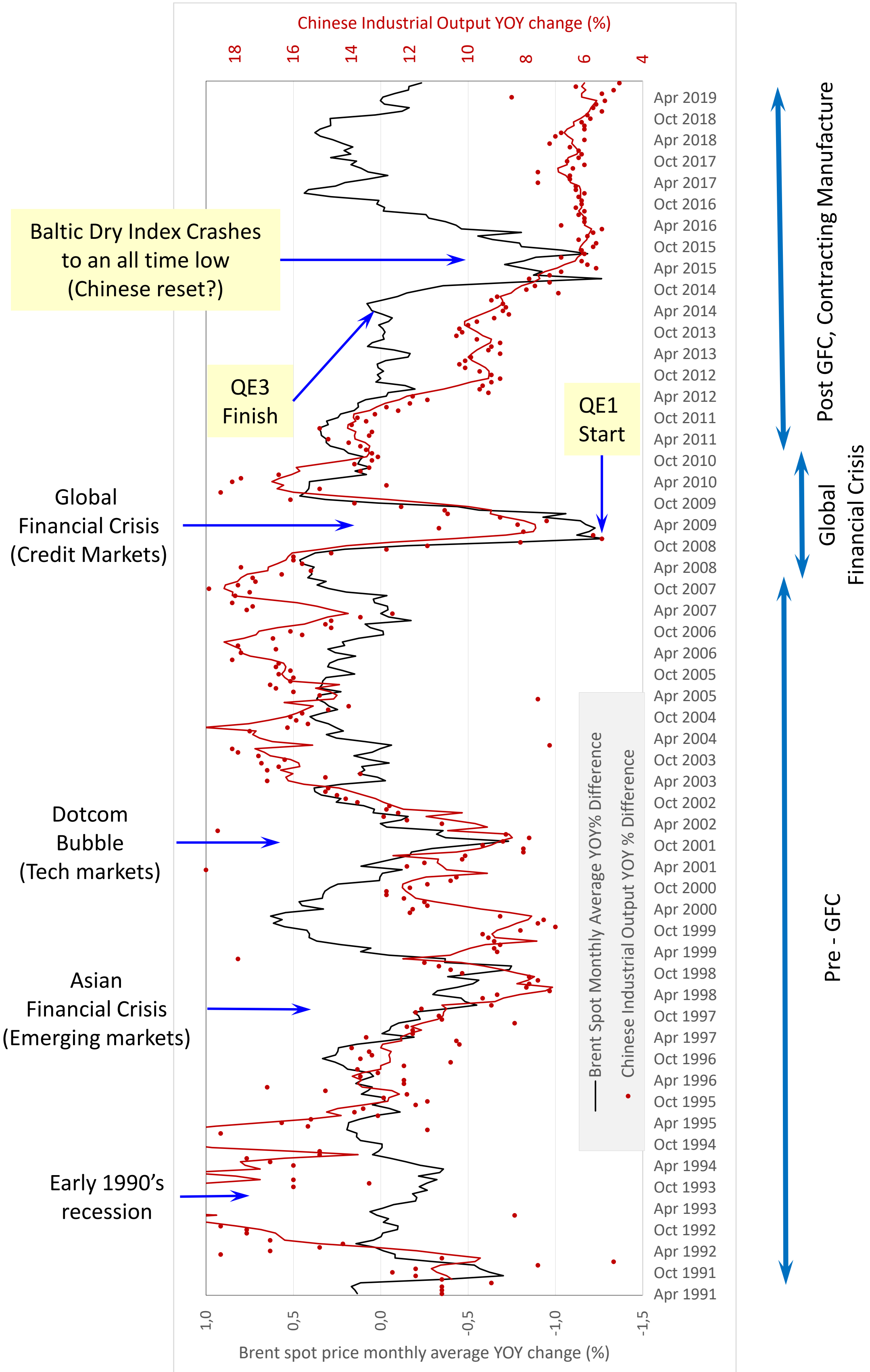

Figure 25. Chinese Industrial output and the price of oil, 1991 - 2018
(Source: National Bureau of Statistics of China, Nasdaq Stock Exchange, https://www.nasdaq.com/markets/crude-oil-brent.aspx)

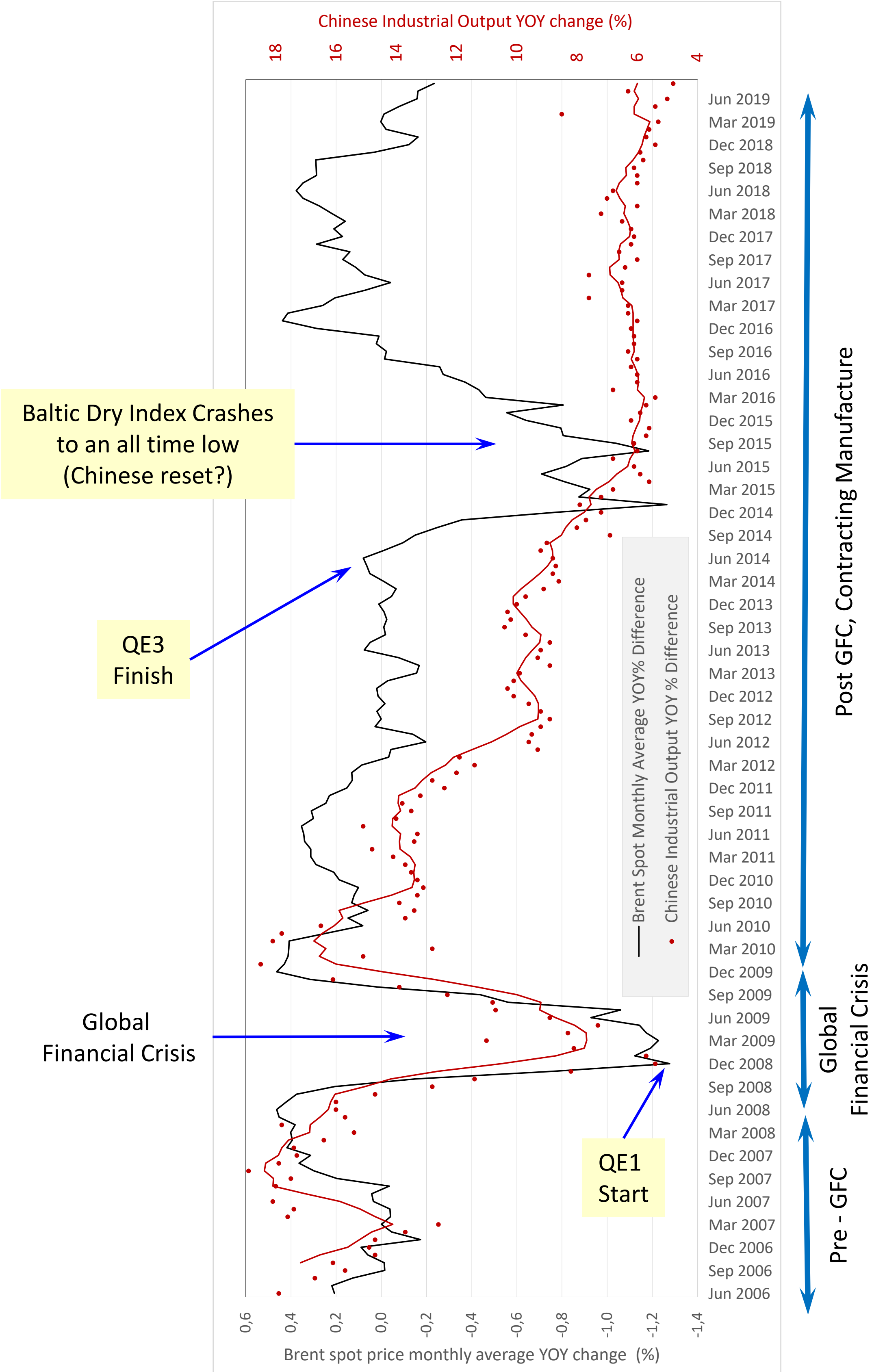

Figure 26. Chinese Industrial output and the price of oil, 2006 - 2018
(Source: National Bureau of Statistics of China, Nasdaq Stock Exchange, https://www.nasdaq.com/markets/crude-oil-brent.aspx)

1.5 Fossil fuel energy and the European CRM map

To address the growing concern of securing valuable raw materials for the EU economy, the European Commission (EC) launched the European Raw Materials Initiative in 2008. It is an integrated strategy that establishes targeted measures to secure and improve access to raw materials for the EU:

- Securing a fair and sustainable supply of raw materials from international markets;
- Fostering sustainable supply within the EU; and
- Boosting resource efficiency and promoting recycling.

One of the priority actions of the Initiative was to establish a list of critical non-energy raw materials at EU level. The first list was established in 2011 and it is updated every three years (European Commission 2010, 2014 and 2017).

Of the 61 candidate raw materials assessed by the European Commission (58 individual and 3 grouped materials), 26 raw materials and groups of raw materials (Table 1) were identified as critical.

Table 1. The 2017 list of Critical Raw Materials (Source: Deloitte et al 2017)

2017 Critical Raw Materials (26)			
Antimony	Gallium	Magnesium	Scandium
Baryte	Germanium	Natural graphite	Silicon metal
Beryllium	Hafnium	Natural Rubber	Tantalum
Bismuth	Helium	Niobium	Tungsten
Borate	HREEs	PGMs	Vanadium
Cobalt	Indium	Phosphate rock	
Fluorspar	LREEs	Phosphorus	

Figure 27 shows the Critical Raw material map that the European Commission has developed since 2010, for the minerals listed in Table 1.

This map was developed to study the possible mineral and metal supply shortages that could disrupt the European industrial ecosystem. Without energy (the master resource) to facilitate the active of actual work done, most of these minerals are irrelevant. These materials would simply be stored in stockpiles of raw minerals. They have to be manufactured into something which requires energy to do so.

Figure 28 shows a graphic the European Commission is using to describe and develop the Circular Economy (European Commission 2019). In many of the meetings where the Circular Economy is discussed in an exchange of ideas context, the CRM list in Table 1 is discussed, but the actual mining of these minerals from primary sources is rarely discussed. The sourcing of these minerals and metals is from market purchases and/or recycling of waste. Energy and energy resources (oil, gas, coal and uranium) is not discussed at all. This was a policy decision taken in 2008 when the CRM list was first assembled.

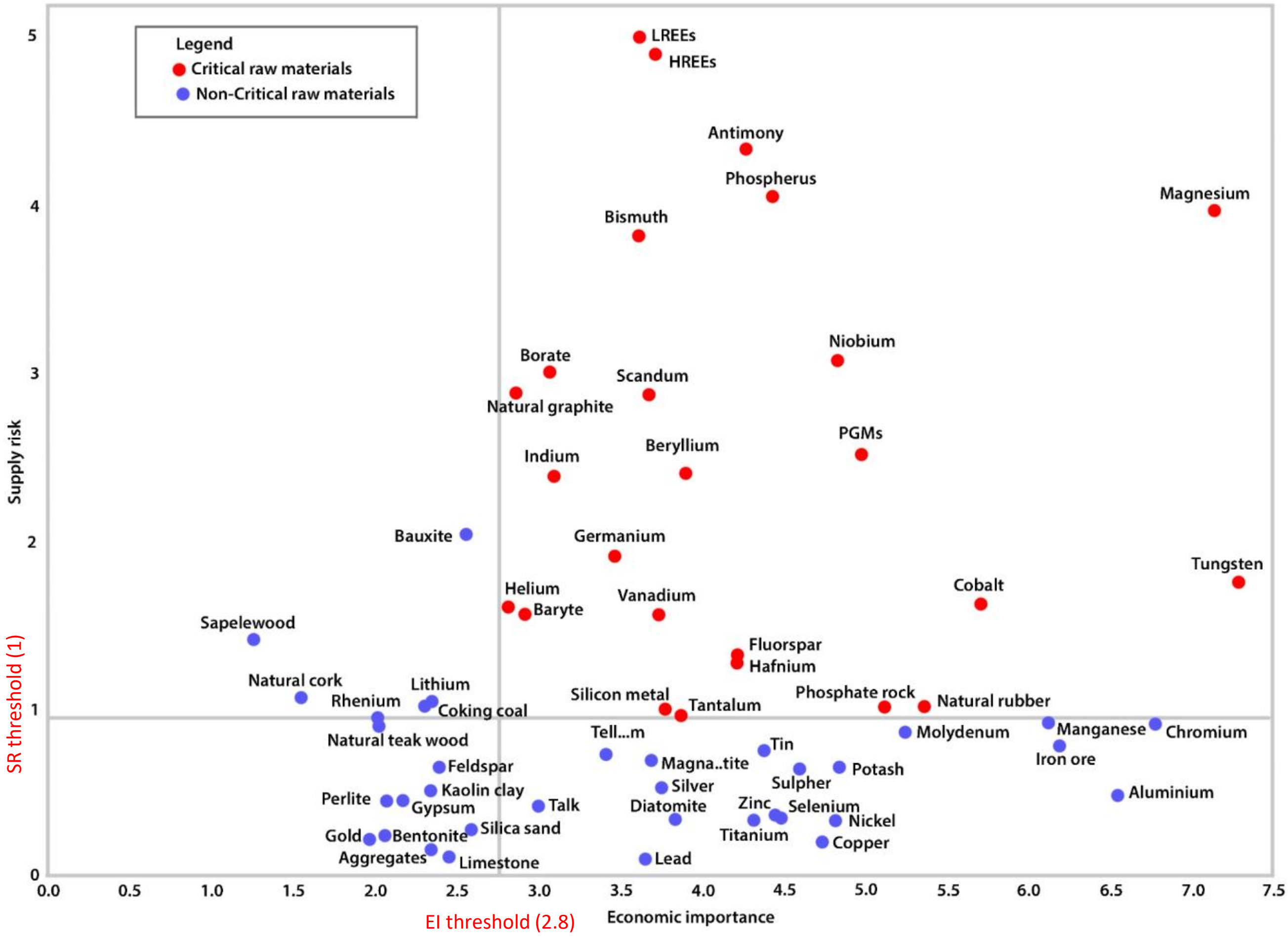

Figure 27. The CRM map of economic importance and supply risk results of 2017 criticality assessment (Source: Deloitte et al 2017) (Image: Tania Michaux)

Figure 28. The circular economy to develop the future European industrial ecosystem (Source: EIT Raw Materials)

2 OIL AND ITS INDUSTRIAL USES AND APPLICATIONS

With the technological breakthroughs of the 20th century, oil emerged as the preferred energy source. The key drivers of that transformation were the electric light bulb and the automobile. Automobile ownership and demand for electricity grew exponentially and, with them, the demand for oil.

Crude oil is a mixture of hydrocarbons that formed from plants and animals that lived millions of years ago. Crude oil is a fossil fuel, and it exists in liquid form in underground pools or reservoirs, in tiny spaces within sedimentary rocks, and near the surface in tar (or oil) sands. Petroleum products are fuels made from crude oil and other hydrocarbons contained in natural gas. Petroleum products can also be made from coal, natural gas, and biomass.

The internal combustion (IC) engine has been the dominant prime mover in our society since its invention in the last quarter of the 19th century (Heywood 1988). Its purpose is to generate mechanical power from the chemical energy contained in the fuel and released through combustion of the fuel inside the engine. It is this specific point, that fuel is burned inside the work-producing part of the engine.

Internal combustion engines are used in applications ranging from marine propulsion and power generating sets with capacity exceeding 100 MW to hand-held tools where the power delivered is less than 100 W (Heywood 1988). This implies that the size and characteristics of today's engines vary widely between large diesels having cylinder bores exceeding 1,000 mm and reciprocating at speeds as low as 100 rpm to small gasoline two-stroke engines with cylinder bores around 20 mm. Within these two extremes lie medium-speed diesel engines, heavy-duty automotive diesels, truck and passenger car engines, aircraft engines, motorcycle engines and small industrial engines. From all these types, the passenger car gasoline and diesel engines have a prominent position since they are, by far, the largest produced engines in the world; as such, their influence on social and economic life is of paramount importance.

Figure 29. Internal combustion engines power most trucks and automobiles
(Source: Image by Monika Neumann LHS and Jan-Marco Gessinger RHS from Pixabay)

Initially, kerosene, used for lighting and heating, was the principal product derived from petroleum. However, the development of drilling technology for oil wells in mid-19th century America put the petroleum industry on a new footing, leading to mass-consumption of petroleum as a highly versatile fuel powering transportation in the form of automobiles, ships, airplanes and so on, applied to generate electricity, used for heating and to provide hot water supplies. By 1919, gasoline sales exceeded those of kerosene. Oil-powered ships, trucks and tanks, and military airplanes in World War One proved the role of oil as not only a strategic energy source, but also a critical military asset.

The most common use of petroleum now is in the internal combustion engine, used across all industries, especially transport. Petroleum products are used to propel vehicles, to heat buildings, and to produce electricity. In the industrial sector, the petrochemical industry uses petroleum as a raw material (a feedstock) to make products such as plastics, polyurethane, solvents, and hundreds of other intermediate and end-user goods. Figure 30 shows the oil and oil product application in the European Union.

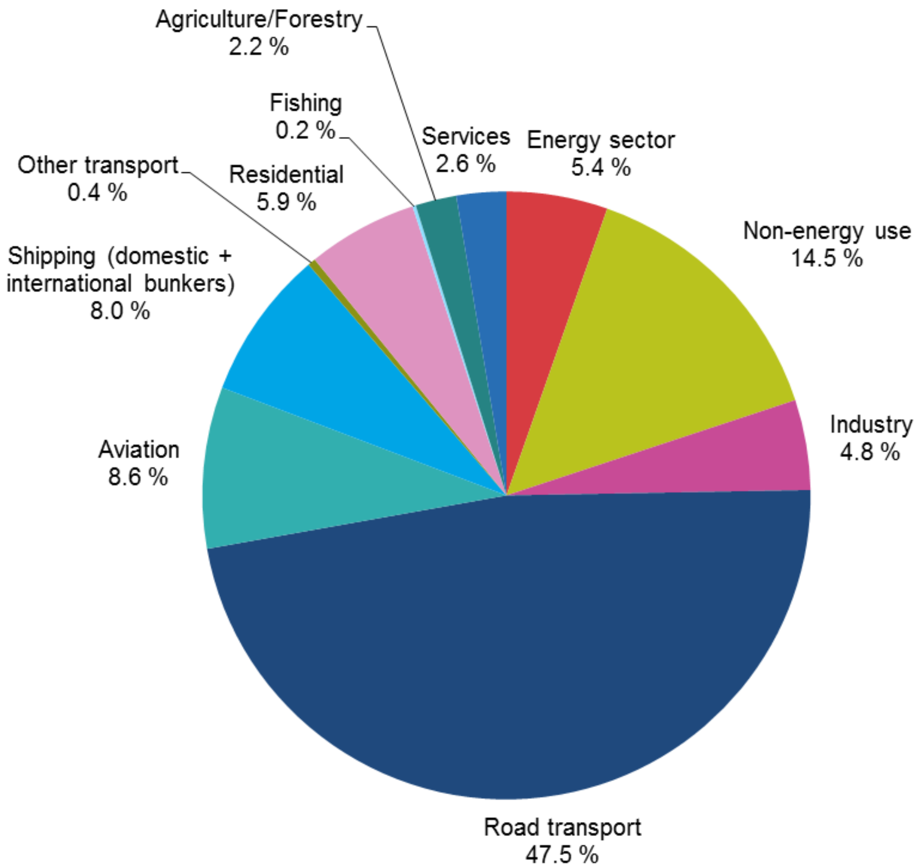

Figure 30. Consumption of oil and petroleum products by industry EU-28, as of 2014
(Data Source: Eurostat) (Copyright License: https://creativecommons.org/licenses/by-nc-sa/4.0/)

A partial list of products made from Petroleum (144 of 6000 items). One 42-gallon barrel of oil creates 19.4 gallons of gasoline. The rest (over half) is used to make products similar to shown in Table 2.

Table 2: Products that are made from petroleum products and oil derived products (Source: EIA)

Solvents	Diesel fuel	Motor Oil	Bearing Grease
Ink	Floor Wax	Ballpoint Pens	Football Cleats
Upholstery	Sweaters	Boats	Insecticides
Bicycle Tires	Sports Car Bodies	Nail Polish	Fishing lures
Dresses	Tires	Golf Bags	Perfumes
Cassettes	Dishwasher parts	Tool Boxes	Shoe Polish
Motorcycle Helmet	Caulking	Petroleum Jelly	Transparent Tape
CD Player	Faucet Washers	Antiseptics	Clothesline
Curtains	Food Preservatives	Basketballs	Soap
Vitamin Capsules	Antihistamines	Purses	Shoes
Dashboards	Cortisone	Deodorant	Footballs
Putty	Dyes	Panty Hose	Refrigerant
Percolators	Life Jackets	Rubbing Alcohol	Linings
Skis	TV Cabinets	Shag Rugs	Electrician's Tape
Tool Racks	Car Battery Cases	Epoxy	Paint
Mops	Slacks	Insect Repellent	Oil Filters
Umbrellas	Yarn	Fertilizers	Hair Coloring
Roofing	Toilet Seats	Fishing Rods	Lipstick
Denture Adhesive	Linoleum	Ice Cube Trays	Synthetic Rubber
Speakers	Plastic Wood	Electric Blankets	Glycerin
Tennis Rackets	Rubber Cement	Fishing Boots	Dice
Nylon Rope	Candles	Trash Bags	House Paint
Water Pipes	Hand Lotion	Roller Skates	Surf Boards
Shampoo	Wheels	Paint Rollers	Shower Curtains
Guitar Strings	Luggage	Aspirin	Safety Glasses
Antifreeze	Football Helmets	Awnings	Eyeglasses
Clothes	Toothbrushes	Ice Chests	Footballs
Combs	CD's & DVD's	Paint Brushes	Detergents
Vaporizers	Balloons	Sun Glasses	Tents
Heart Valves	Crayons	Parachutes	Telephones
Enamel	Pillows	Dishes	Cameras
Anesthetics	Artificial Turf	Artificial limbs	Bandages
Dentures	Model Cars	Folding Doors	Hair Curlers
Cold cream	Movie film	Soft Contact lenses	Drinking Cups
Fan Belts	Car Enamel	Shaving Cream	Ammonia
Refrigerators	Golf Balls	Toothpaste	Gasoline

Petroleum products are made from crude oil and from natural gas processing, including gasoline, distillate fuels (mostly diesel fuel), jet fuel, residual fuel oil, and propane. Biofuels refer to ethanol and biodiesel. The form these uses take are:

- Gasoline is used in cars, motorcycles, light trucks, and boats. Aviation gasoline is used in many types of airplanes.
- Distillate fuels (diesel) are used mainly by trucks, buses, and trains and in boats and ships.
- Jet fuel is used in jet airplanes and some types of helicopters.
- Residual fuel oil is used in ships.
- Biofuels are added to gasoline and diesel fuel.
- Natural gas, as compressed natural gas and liquefied natural gas, is used in cars, buses, trucks, and ships. Most of the vehicles that use natural gas are in government and private vehicle fleets.
- Natural gas is also used to operate compressors to move natural gas in pipelines.
- Propane (a hydrocarbon gas liquid) is used in cars, buses, and trucks. Most of the vehicles that use propane are in government and private vehicle fleets.
- Electricity is used by public mass transit systems and by electric vehicles.

2.1 Calorific value of petroleum products

Not all fuels are equal in terms of energy density. Oil based products are the most calorifically dense fuel currently used in the transport sector.

Table 3. Refined Petroleum Products (Source: OECD Data Statistics Database and Table 4)

Fuel	Global Consumption in 2018	Energy Content of Fuel	ICE Technology	Energy Efficiency of ICE Technology
Crude Oil	4662.1 Mtoe	41.87 MJ/kg	N/A	
Diesel Fuel Oil	10 439 million barrels	45.6 MJ/kg	Diesel Engine	35-42%
Heavy Fuel Oil	194 499 kt	41.8 MJ/kg	Diesel Engine	35-42%
Petrol (Gasoline)	9 307.5 million barrels	46.4 MJ/kg	Petrol Engine	25-50%
Jet Fuel	2 260 million barrels	43.0 MJ/kg	Jet Turbine	36-48%

2.2 Energy Content of Fuels

Energy content or calorific value is the same as the heat of combustion, and can be calculated from thermodynamically values, or can be experimentally measured. The combustion process generates water vapor and certain techniques may be used to recover the quantity of heat contained in this water vapor by condensing it. Figure 31 shows the thermal chemical energy in petroleum products.

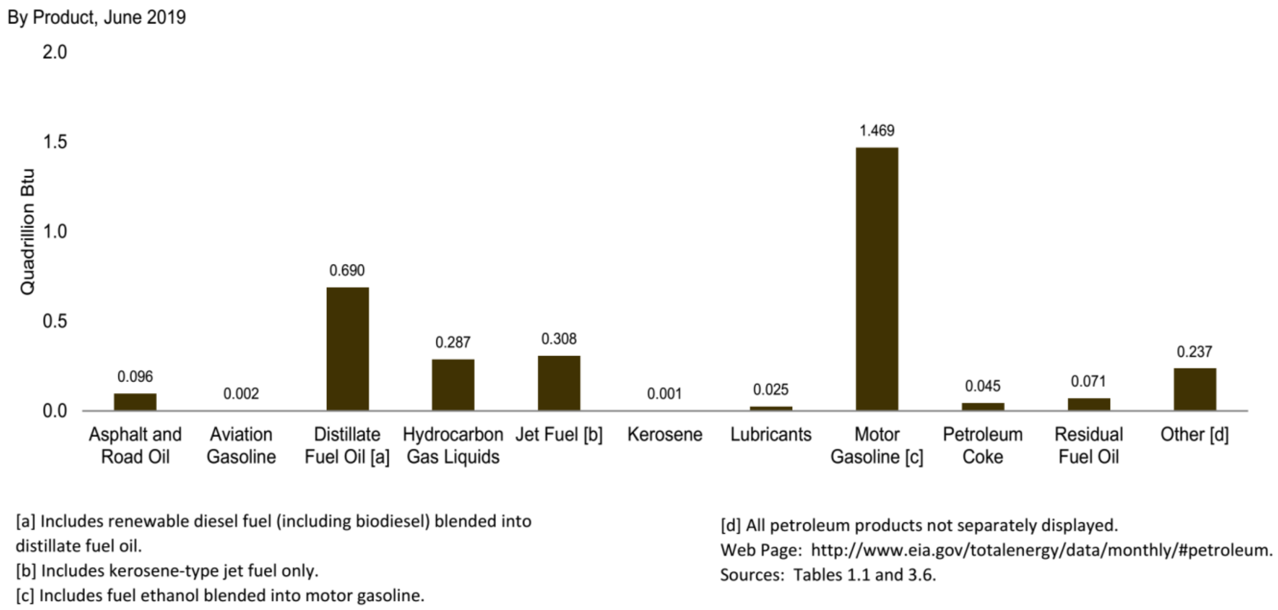

Figure 31. The thermal heat content of different petroleum products
(Source: EIA Monthly Energy Review, Tables 1.1 and 3.6)
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A known amount of the fuel is burned at constant pressure and under standard conditions (0°C and 1 bar) and the heat released is captured in a known mass of water in a calorimeter. If the initial and final temperatures of the water is measured, the energy released can be calculated using the equation:

$$H = \Delta T \, mC_p \qquad \text{Equation 1}$$

where :

H = heat energy absorbed (in J)

ΔT = change in temperature (in °C)

m = mass of water (in g),

Cp = specific heat capacity (4.18 J/g°C for water)

The resulting energy value divided by grams of fuel burned gives the energy content (in J/g).

In terms of engineering material characterization, energy sources are differentiated between gross and net heating values:

2.2.1 Gross (or high, upper) Heating Value

The gross or high heating value is the amount of heat produced by the complete combustion of a unit quantity of fuel. The gross heating value is obtained when all products of the combustion are cooled down to the temperature before the combustion the water vapor formed during combustion is condensed In engineering thermodynamics, the term standard heat of combustion corresponds to Gross heating value.

- Higher Calorific Value (= Gross Calorific Value - GCV = Higher Heating Value - HHV) - the water of combustion is entirely condensed and the heat contained in the water vapor is recovered

2.2.2 Net (or lower) Heating Value

The net or lower heating value is obtained by subtracting the latent heat of vaporization of the water vapor formed by the combustion from the gross or higher heating value.

- Lower Calorific Value (= Net Calorific Value - NCV = Lower Heating Value - LHV) - the products of combustion contains the water vapor and the heat in the water vapor is not recovered

Table 4 gives the gross and net heating value of fossil fuels as well as some alternative bio-based fuels. Higher and lower calorific values for some common fuels - coke, oil, wood, hydrogen and others.

Table 4. Higher and Lower Calorific Values of fuels (Source: The Engineering Toolbox https://www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html)

Fuel	Density		Higher Heating Value (HHV) (Gross Calorific Value - GCV)					Lower Heating Value (LHV) (Net Calorific Value - NCV)				
	@0°C/32°F, 1 bar											
Gaseous fuels	[kg/m^3]	[g/ft^3]	[kWh/kg]	[MJ/kg]	[Btu/lb]	[MJ/m^3]	[Btu/ft^3]	[kWh/kg]	[MJ/kg]	[Btu/lb]	[MJ/m^3]	[Btu/ft^3]
Acetylene	1,10	31,10	13,90	49,90	21453,00	54,70	1468,00					
Ammonia				22,50	9690,00							
Hydrogen	0,09	2,55	39,40	141,70	60920,00	12,70	341,00	33,30	120,00	51591,00	10,80	290,00
Methane	0,72	20,30	15,40	55,50	23874,00	39,80	1069,00	13,90	50,00	21496,00	35,80	964,00
Natural gas (US market)*	0,78	22,00	14,50	52,20	22446,00	40,60	1090,00	13,10	47,10	20262,00	36,60	983,00
Town gas						18,00	483,00					
	@15°C/60°F, 1 bar											
Liquid fuels	[kg/l]	[g/gal]	[kWh/kg]	[MJ/kg]	[Btu/lb]	[MJ/l]	[Btu/gal]	[kWh/kg]	[MJ/kg]	[Btu/lb]	[MJ/l]	[Btu/gal]
Acetone	0,79	2,98	8,83	31,80	13671,00	25,00	89792,00	8,22	29,60	12726,00	23,30	83580,00
Butane	0,60	3,07	13,64	49,10	21109,00	29,50	105875,00	12,58	45,30	19475,00	27,20	97681,00
Butanol	0,80		10,36	37,30	16036,00	30,20	108359,00	9,56	34,40	14789,00	27,90	99934,00
Diesel fuel*	0,85	3,20	12,67	45,60	19604,00	38,60	138412,00	11,83	42,60	18315,00	36,00	129306,00
Dimethyl ether (DME)	0,67	2,52	8,81	31,70	13629,00	21,10	75655,00	8,03	28,90	12425,00	19,20	68973,00
Ethane	0,57	2,17	14,42	51,90	22313,00	29,70	106513,00	13,28	47,80	20550,00	27,30	98098,00
Ethanol (100%)	0,79	2,99	8,25	29,70	12769,00	23,40	84076,00	7,42	26,70	11479,00	21,10	75583,00
Diethyl ether (ether)	0,72	2,71	11,94	43,00	18487,00	30,80	110464,00					
Gasoline (petrol)*	0,74	2,79	12,89	46,40	19948,00	34,20	122694,00	12,06	43,40	18659,00	32,00	114761,00
Gas oil (heating oil)*	0,84	3,18	11,95	43,00	18495,00	36,10	129654,00	11,89	42,80	18401,00	36,00	128991,00
Glycerin	1,26	4,78	5,28	19,00	8169,00	24,00	86098,00					
Heavy fuel oil*	0,98	3,71	11,61	41,80	17971,00	41,00	146974,00	10,83	39,00	16767,00	38,20	137129,00
Kerosene*	0,82	3,11	12,83	46,20	19862,00	37,90	126663,00	11,94	43,00	18487,00	35,30	126663,00
Light fuel oil*	0,96	3,63	12,22	44,00	18917,00	42,20	151552,00	11,28	40,60	17455,00	39,00	139841,00
LNG*	0,43	1,62	15,33	55,20	23732,00	23,60	84810,00	13,50	48,60	20894,00	20,80	74670,00
LPG*	0,54	2,03	13,69	49,30	21195,00	26,50	94986,00	12,64	45,50	19561,00	24,40	87664,00
Marine gas oil*	0,86	3,24	12,75	445,90	19733,00	39,20	140804,00	11,89	42,80	18401,00	36,60	131295,00
Methanol	0,79	2,99	6,39	23,00	9888,00	18,20	65274,00	5,54	19,90	8568,00	15,80	56562,00
Methyl ester (biodiesel)	0,89	3,36	11,17	40,20	17283,00	35,70	128062,00	10,42	37,50	16122,00	33,30	119460,00
MTBE	0,74	2,81	10,56	38,00	16337,00	28,20	101244,00	9,75	35,10	15090,00	26,10	93517,00
Oils vegetable (biodiesel)*	0,92	3,48	11,25	40,50	17412,00	37,30	133684,00	10,50	37,80	16251,00	34,80	124772,00
Paraffin (wax)*	0,90	3,41	12,78	46,00	19776,00	41,40	148538,00	11,53	41,50	17842,00	37,40	134007,00
Pentane	0,63	2,39	13,50	48,60	20894,00	30,60	109854,00	12,60	45,40	19497,00	28,60	102507,00
Petroleum naphtha*	0,73	2,75	13,36	48,10	20679,00	34,90	125145,00	12,47	44,90	19303,00	32,60	116819,00
Propane	0,50	1,89	13,99	50,40	21647,00	25,10	89963,00	12,88	46,40	19927,00	23,10	82816,00
Residual oil*	0,99	3,75				41,80	150072,00	10,97	39,50	16982,00	39,20	140470,00
Tar*			10,00	36,00	15477,00							
Turpentine	0,87	3,27	12,22	44,00	18917,00	38,10	136555,00					
Solid fuels*			[kWh/kg]	[MJ/kg]	[Btu/lb]			[kWh/kg]	[MJ/kg]	[Btu/lb]		
Anthracite coal			9,06	32,60	14015,00							
Bituminous coal			8,39	30,20	12984,00			8,06	29,00	12468,00		
Carbon			9,11	32,80	14101,00							
Charcoal			8,22	29,60	12726,00			7,89	28,40	12210,00		
Coke			7,22	26,00	11178,00							
Lignite (brown coal)			3,89	14,00	6019,00							
Peat			4,72	17,00	7309,00							
Petroleum coke			8,69	31,30	13457,00			8,19	29,50	12683,00		
Semi anthracite			8,19	29,50	12683,00							
Sub-Bituminous coal			6,78	24,40	10490,00							
Sulfur (s)			2,56	9,20	3955,00			2,55	9,20	3939,00		
Wood (dry)	0,701		4,50	16,20	6965,00			4,28	15,40	6621,00		

* Fuels which consist of a mixture of several different compounds may vary in quality between seasons and markets. The given values are for fuels with the given density. The variation in quality may give heating values within a range 5 -10% higher and lower than the given value. Also the solid fuels will have a similar quality variation for the different classes of fuel.

2.2.3 Diesel Engines Efficiency

The diesel engine (also known as a compression-ignition or CI engine), named after Rudolf Diesel, is an internal combustion engine in which ignition of the fuel, which is injected into the combustion chamber, is caused by the elevated temperature of the air in the cylinder due to the mechanical compression (adiabatic compression) (Kiameh 2013).

Diesel engines work by compressing only the air. This increases the air temperature inside the cylinder to such a high degree that atomized diesel fuel injected into the combustion chamber ignites spontaneously. With the fuel being injected into the air just before combustion, the dispersion of the fuel is uneven; this is called a heterogeneous air-fuel mixture.

The diesel engine has the highest thermal efficiency (engine efficiency) of any practical internal or external combustion engine due to its very high expansion ratio and inherent lean burn which enables heat dissipation by the excess air. Diesel engines, large capacity industrial engines, deliver efficiencies in the range of 35 – 42 % (Kiameh 2013).

While diesel fuel is mainly used for transport applications, a small portion of it is used for electric power generation. As of July 2018, global fuel oil power generation capacity was 255.8 GW (Global Energy Observatory 2018).

2.2.4 Petrol Engines Efficiency

A petrol engine (known as a gasoline engine) is an internal combustion engine (ICE) with spark-ignition, designed to run on petrol (gasoline) and similar volatile fuels.

In most petrol engines, the fuel and air are usually mixed after compression (although some modern petrol engines now use cylinder-direct petrol injection). The pre-mixing was formerly done in a carburetor, but now it is done by electronically controlled fuel injection, except in small engines where the cost/complication of electronics does not justify the added engine efficiency (Kiameh 2013). Modern gasoline engines have a maximum thermal efficiency of about 25% to 50% when used to power a car.

2.2.5 Jet Fuel Turbine Engine Efficiency

A jet engine is a type of reaction engine discharging a fast-moving jet that generates thrust by jet propulsion. This broad definition includes airbreathing jet engines (turbojets, turbofans, ramjets, and pulse jets). In general, jet engines are combustion engines.

The term "jet engine" is commonly used only for air breathing jet engines. These typically feature a rotating air compressor powered by a turbine, with the leftover power providing thrust through the propelling nozzle – this process is known as the Brayton thermodynamic cycle (Kiameh 2013). Jet aircraft use such engines for long-distance travel.

Jet engines use a number of rows of fan blades to compress air which then enters a combustor where it is mixed with fuel (typically JP fuel) and then ignited. The burning of the fuel raises the temperature of the air which is then exhausted out of the engine creating thrust. A modern turbofan engine can operate at as high as a range of 36 - 48% efficiency (Griggs *et al* 2014).

2.3 Energy consumption and industrial agriculture

Oil consumption has an even more fundamental relationship to the functioning of our society. It correlates strongly with the production of food. Industrial agriculture is operating in a fashion where its operation destroys future capability to deliver food and is classed at an inappropriately low ERoEI. We consume about 2000 or 2500 kcal per day. It is convenient to remember that 2400kcal equals 10MJ (megajoules), so that per year we consume endosomatically about 3.6GJ (gigajoules). The exosomatic use of energy in rich countries per person per year reaches 150 or 200GJ on average, reflecting the fact that most energy (from fossil fuels, biomass, hydroelectricity, nuclear fission, wind) goes to production and consumption processes different from those directed to basic food needs (Martinez-Alier 2011).

The systems that produce the world's food supply are heavily dependent on fossil fuels (Green 1978), which was initiated in what was termed the Green Revolution.

The Green Revolution, or Third Agricultural Revolution, refers to a set of research and the development of technology transfer initiatives occurring between 1950 and the late 1960s, that increased agricultural production worldwide, particularly in the developing world, beginning most markedly in the late 1960s (Farmer 1986). With the benefit of hindsight, the late 1930's was when the petrochemical supported Green Revolution was initiated. After the Second World War, increased deployment of technologies including pesticides, herbicides, and fertilizers as well as new breeds of high yield crops greatly increased global food production.

Petrochemical technology applied to the processing of phosphorous (sourced from phosphate rock), nitrogen and potassium developed a spectrum of capabilities that accelerated the ability to manufacture food (NPK fertilizer and pesticides). The initiatives resulted in the adoption of new technologies, including high-yielding varieties (HYVs) of cereals, especially dwarf wheat's and rice's, in association with chemical fertilizers and agro-chemicals, and with controlled water-supply (usually involving irrigation) and new methods of cultivation, including mechanization. All of these together were seen as a 'package of practices' to supersede 'traditional' technology and to be adopted as a whole.

Figure 32: How NPK fertilizer was marketed as part of the petrochemical Green Revolution. Test cropping in 1940s Tennessee Franklin D. Roosevelt Presidential Library and Museum
(Source: Faradji & de Boer 2016).
(Copyright: Public Domain https://commons.wikimedia.org/wiki/File:TVA_Results_of_Fertilizer.gif)

In summary, petrochemical fertilizers and pesticides are needed to ensure a constantly high level of crop yields. These, in turn, are necessary to meet the world's food demand and provide a living for the farmer engaging in planting and harvesting the crops. Most of the fertilizers consumed have phosphate rock as their primary ingredient. Currently, for every calorie of food consumed, there was 10 calories of fossil fuel energy consumed to create and deliver that food (Ruppert 2004, Martenson 2011 and Turner 2008).

Vast amounts of oil and gas are used as raw materials and energy in the manufacture of fertilizers and pesticides, and as cheap and readily available energy at all stages of food production: from planting, irrigation, feeding and harvesting, through to processing, distribution and packaging. In addition, fossil fuels are essential in the construction and the repair of equipment and infrastructure needed to facilitate this industry, including farm machinery, processing facilities, storage, ships, trucks and roads. The industrial food supply system is one of the biggest consumers of fossil fuels.

Figure 33 shows the FAO Food Price Index (an index used by the World Bank to model a basket of food based commodities in the production of food at a global scale) and the North Sea Brent Oil price.

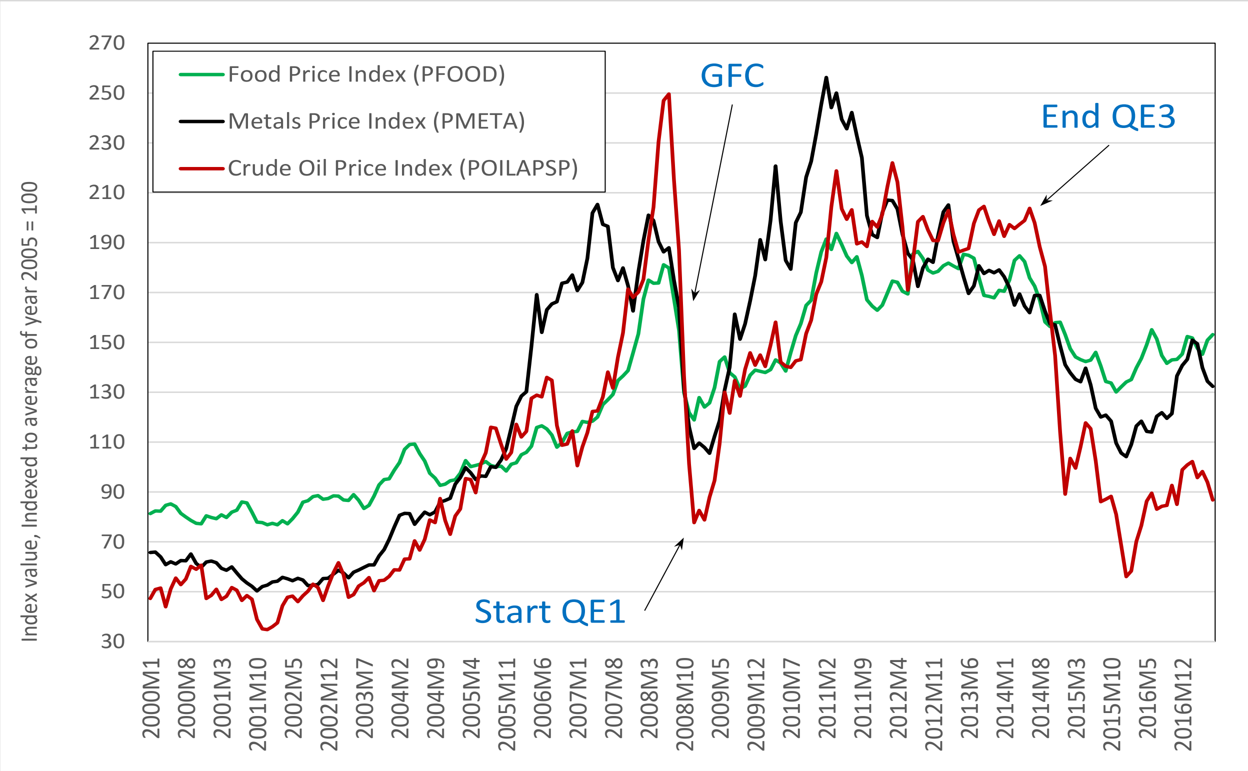

Figure 33. Correlation between global food price, metal price and crude oil
(Source: IMF Primary Commodity Price System, http://www.imf.org/external/np/res/commod/External_Data.xls)

As can be seen, industrial agriculture food production (Food price Index) strongly correlates with the oil price index (which reflects demand). Initially, the concept of food being dependent on oil seems counter intuitive. For every calorie of food that is produced in the United States, 10 calories of fossil fuel energy are put into the system to grow that food in terms of production, storage and transport (Green 1978, Canning *et al*. 2017). Figure 34 shows how this happens. This is a systems modelling approach to examine and model farming. The words in red show the sections that depend on fossil fuels either directly (consumption of diesel fuel) or indirectly (consumption of electricity generated from fossil fuels).

"Modern agriculture is the use of land to convert petroleum to food"

-Dr Albert Allen Bartlett 1996

The manufacture of phosphate to make petrochemical fertilizer is also dependent on oil and gas (Green 1978). Phosphate rock first has to be mined then refined. This requires energy as well, including oil and gas.

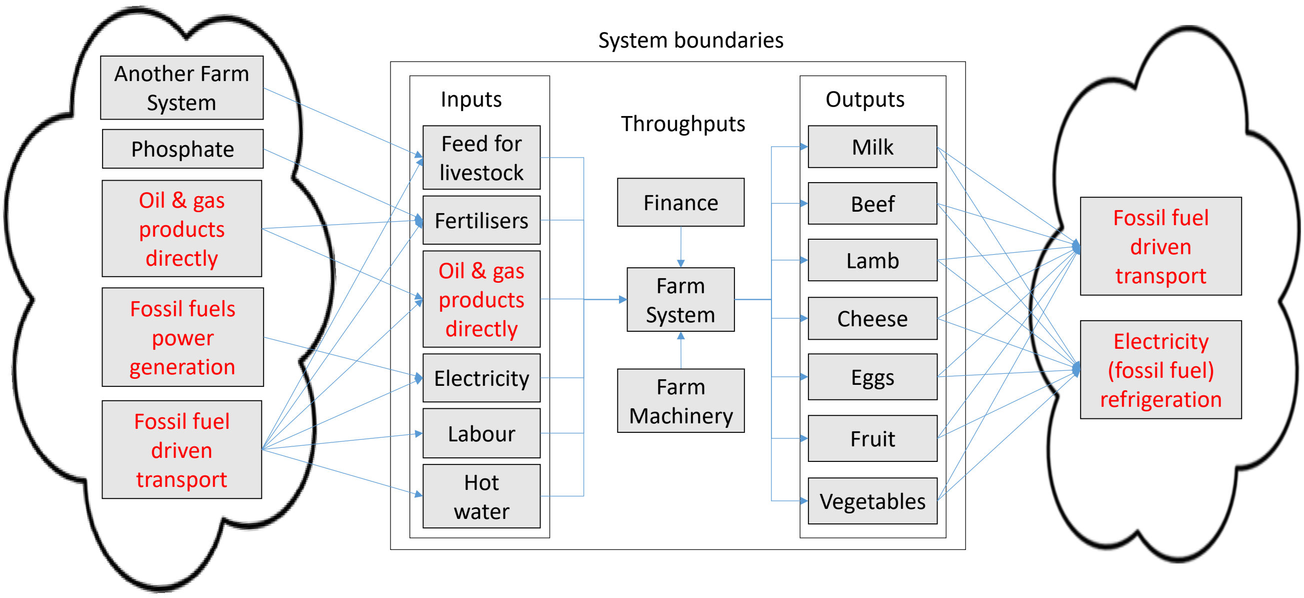

Figure 34. Industrial agriculture farming modelled as a system

There is however a complication in the analysis of food to oil correlation. What was considered arable agricultural land for food production is now being diverted to the production of biofuels (Muller *et al*. 2007).

Food versus fuel is the dilemma regarding the risk of diverting farmland or crops for biofuels production to the detriment of the food supply. The biofuel and food price debate involves wide-ranging views, and is a long-standing, controversial one in the literature. There is disagreement about the significance of the issue, what is causing it, and what can or should be done to remedy the situation. This complexity and uncertainty is due to the large number of impacts and feedback loops that can positively or negatively affect the price system. Moreover, the relative strengths of these positive and negative impacts vary in the short and long terms, and involve delayed effects. The academic side of the debate is also blurred by the use of different economic models and competing forms of statistical analysis.

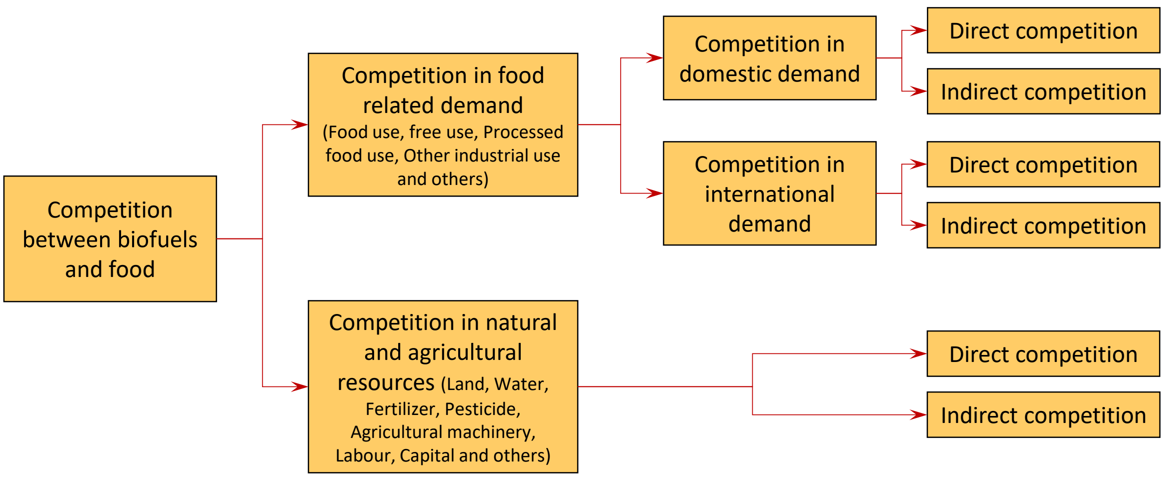

Figure 35. Competition between biofuels and food for arable land use

Biofuel production has increased in recent years. Some commodities like maize (corn), sugar cane or vegetable oil can be used either as food, feed, or to make biofuels. For example, since 2006, a portion of land that was also formerly used to grow other crops in the United States is now used to grow corn for biofuels, and a larger share of corn is destined to ethanol production, reaching 25% in 2007. Second generation biofuels could potentially combine farming for food and fuel and moreover, electricity could be generated simultaneously, which could be beneficial for developing countries and rural areas in developed countries.

With global demand for biofuels on the increase due to the oil price increases taking place since 2003 and the desire to reduce oil dependency as well as reduce GHG emissions from transportation, there is also fear of the potential destruction of natural habitats by being converted into farmland. Environmental groups have raised concerns about this trade-off for several years, but now the debate reached a global scale due to the 2007–2008 world food price crisis. On the other hand, several studies do show that biofuel production can be significantly increased without increased acreage.

However, the ERoEI ratio for biofuels makes this an irrelevant issue, as shown in Figure 198. Biofuels are not a credible energy source to replace fossil fuels (usually oil is the target product for substitution).

In December 2007, the United Nations Food and Agriculture Organization (UN FAO) calculated that world food prices rose 40% in 12 months prior, and the price hikes affected all major biofuel feedstocks, including sugarcane, corn, rapeseed oil, palm oil, and soybeans. On 17 December 2007, the International Herald Tribune quoted FAO head Jacques Diouf warning of “a very serious risk that fewer people will be able to get food,” particularly in the developing world. In the summary proceedings of the First FAO Technical Consultation Bioenergy and Food Security, held in April 2007 in Rome, authors from a group of UN agencies cautioned that “possible income gains to producers due to higher commodity prices may be offset by negative welfare effects on consumers, as their economic access to food is compromised.” (“Welfare” here refers to standard of living, not government payments.)

Studies have found that there is a close correlation between global food prices and the incidence of riots in North Africa and the Middle East (Figure 36) (Lagi et al. 2011). In 2008 more than 60 riots occurred worldwide in 30 different countries during a peak in food prices. After declining temporarily in 2009 (mirroring the fall in oil price), even higher prices at the end of 2010 and the beginning of 2011 coincided with additional food riots as well as the larger protests and revolts that have become popularly known as the Arab Spring. In contrast, there were relatively few incidents of collective violence when food prices were low. (This does not include incidence of rioting in China, or the food index data from China in these time periods).

Incidence of civil unrest and instances of political violence seem to becoming more frequent. It can be argued that this increasing frequency and impact is linked to a range of trends showing growing complex interdependencies (Ahmed 2016).

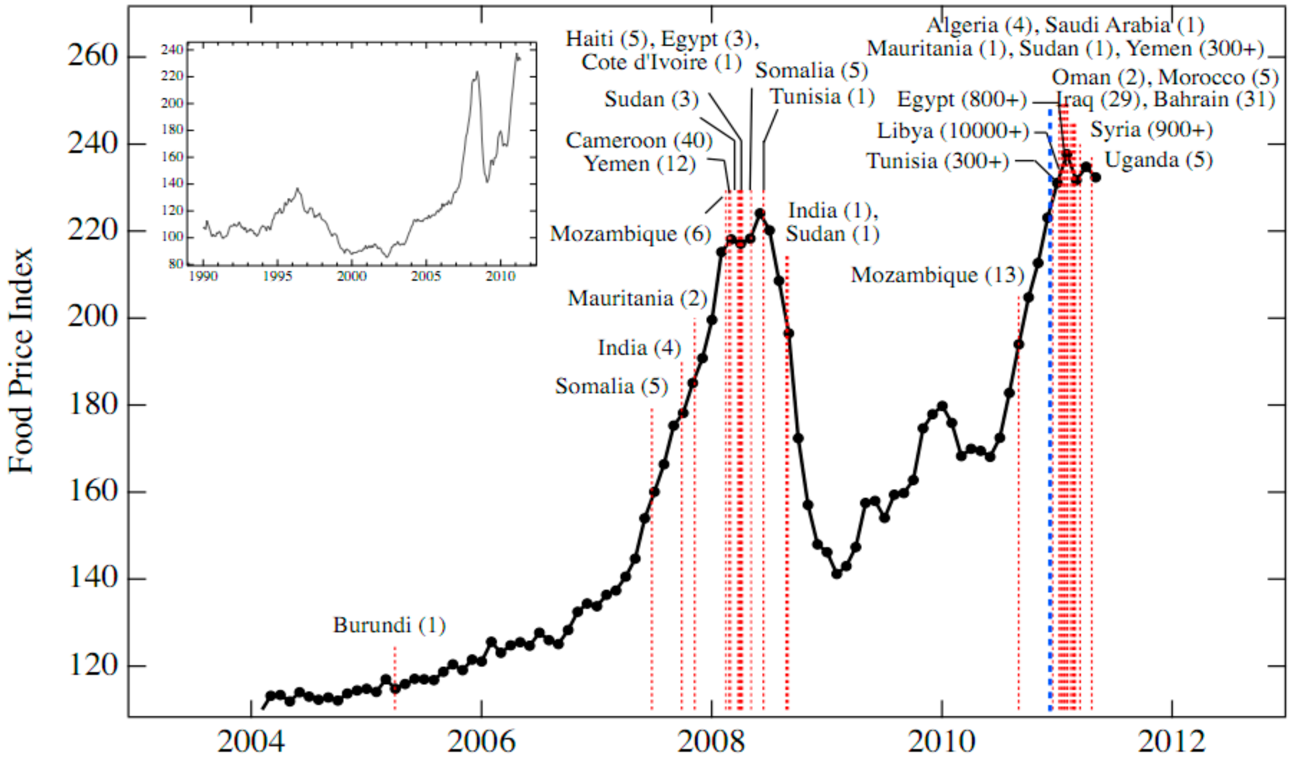

Figure 36. FAQ Food Index and incidence of civil unrest
(Source: Lagi et al. 2011)

A previous study found the identical pattern in the British Isles in the 1800's, with peaks of civil unrest in 1800 1810, 1815 correlating with peaks in food price (Johnson 2011, Archer 2000). In nearly all cases the riots were preceded by a sharp rise in price and once the price fell the incidence of riots fell with it. This isn't to suggest that wheat price alone was the cause, or that a rise in price always resulted in a riot. But it does suggest that the two were correlated and that a rise in food price promoted the same kind of social discord that lay behind incidents of collective violence.

To put the peaks seen in Figure 36 and Archer 2000 context, the dates are compared to a global study of civil unrest. Lloyd's Risk Advisory published a report on political violence in a global context between 1950 and 2013 (Wilkinson 2016). They identified three sub-categories of civil unrest.

- Type A - Anti-imperialist, independence movements, removing occupying force
- Type B - Mass pro-reform protests against national government
- Type C - Armed insurrection, insurgency, secessionist, may involve ideology (e.g. Marxism, Islamism)

Type C (armed insurrection, insurgency, secessionist, may involve ideology) appears to represent by far the most contagious form of political violence (although this may also reflect the wider trend of civil conflict representing by far the most prevalent form of armed conflict today). Type B (mass pro-reform protests against national governments) pandemics tend to be more cyclical and occur in spikes, and appear to precede the incidence of Type C outbreaks or, in other words, popular mass uprisings may trigger or at least contribute to the spread of armed insurrections.

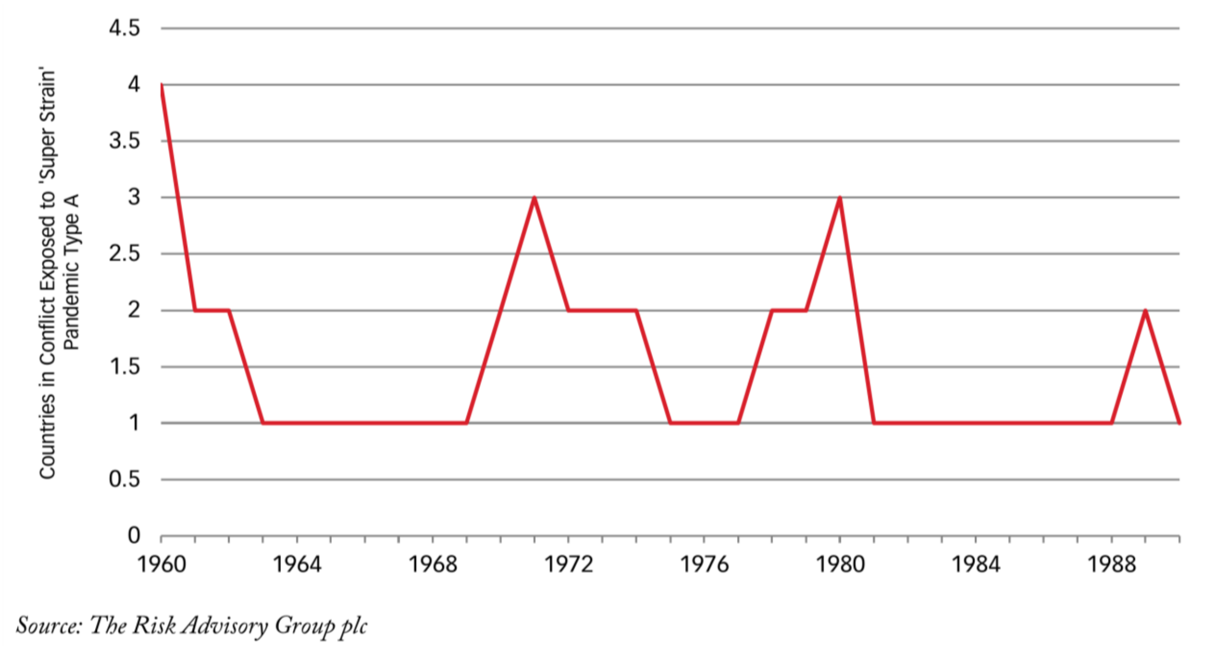

Figure 37. Political violence pandemic frequency (Type A) 1960-2013
(Source: The Risk Advisory Group, Wilkinson 2016)

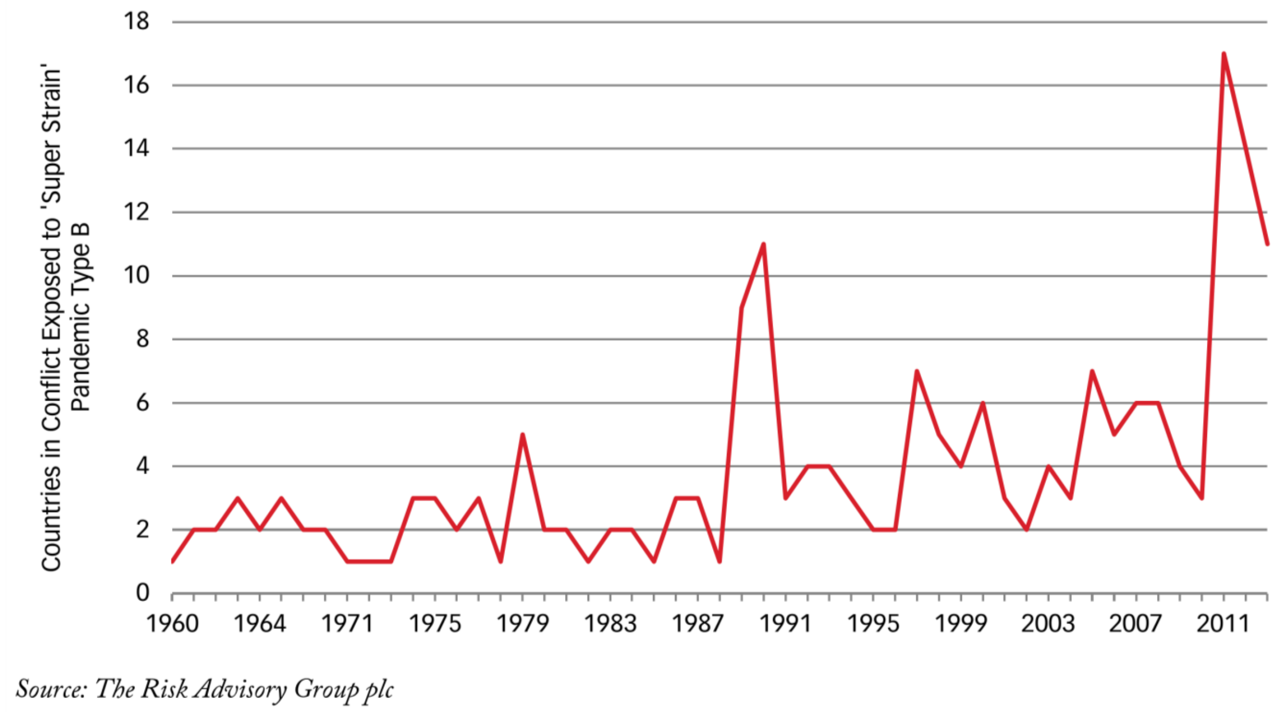

Figure 38. Political violence pandemic frequency (Type B) 1960-2013
(Source: The Risk Advisory Group, Wilkinson 2016)

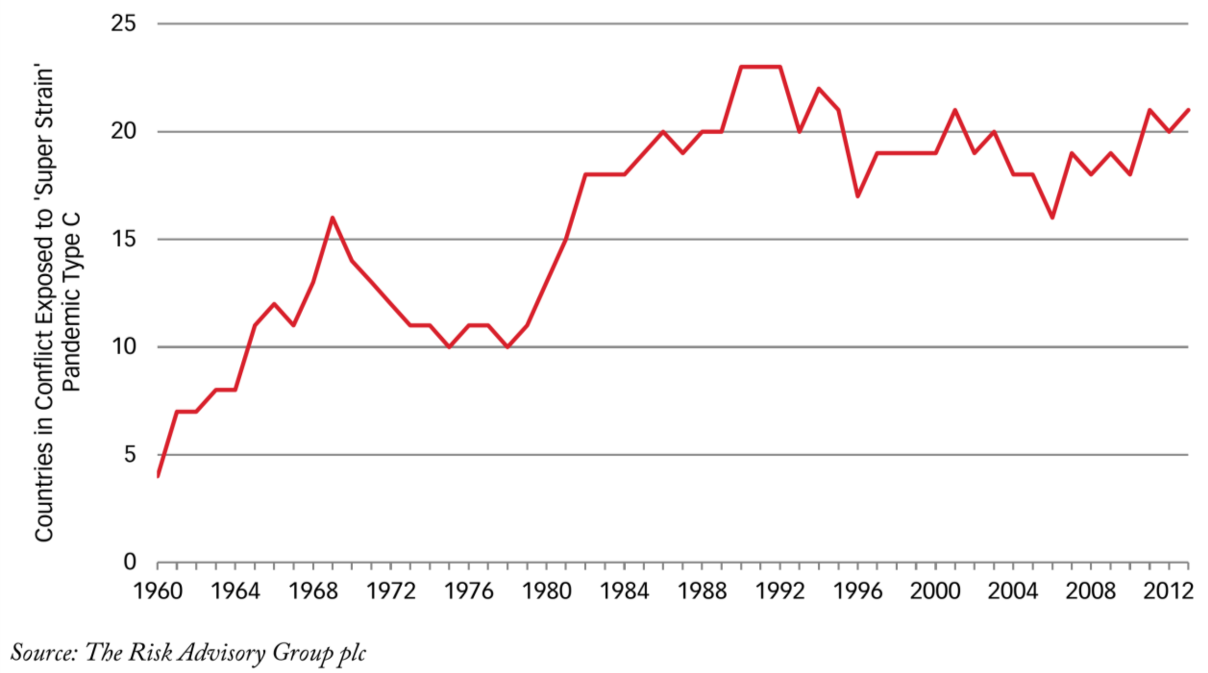

Figure 39. Political violence pandemic frequency (Type C) 1960-2013
(Source: The Risk Advisory Group, Wilkinson 2016)

Figures 37, 38 and 39 show all the recorded incidents of civil unrest (unclear if all China examples are included). This suggests that the incidents of civil interest shown in Figures 37 are of Type B, which spiked in 2011 at a much greater rate than any other part of the data set. So the civil unrest correlating with the rising cost of food are the largest seen in decades, and are driven by public dissatisfaction with their governments. In speculation, the rioters were demanding a change in behavior from their governments that would fix the rising cost of food.

For some time now there has been widespread civil unrest in China, which has not been reported in the Western media due to state imposed controls by the People's Republic of China government. The cause of the civil unrest in China could be due to a number of factors, the severity of which are unknown outside China.

Figure 40 shows two possible interactions between oil, food and civil unrest. The blue labels show the interaction that created the peaks seen in Figures 33 and 36. The blue label interaction is what would happen while oil is available but the oil price rises.

The green labels in Figure 40 show an interaction in context of the concepts develop later in this report (Figures 260, 276 and 277). This could happen when oil price drops due to market consumers unable to support a higher price. This would case a chain reaction of oil producers not able to produce, which leads to the needed volume of oil not being supplied to the market, including food producers, where the oil price is unable in increase high enough.

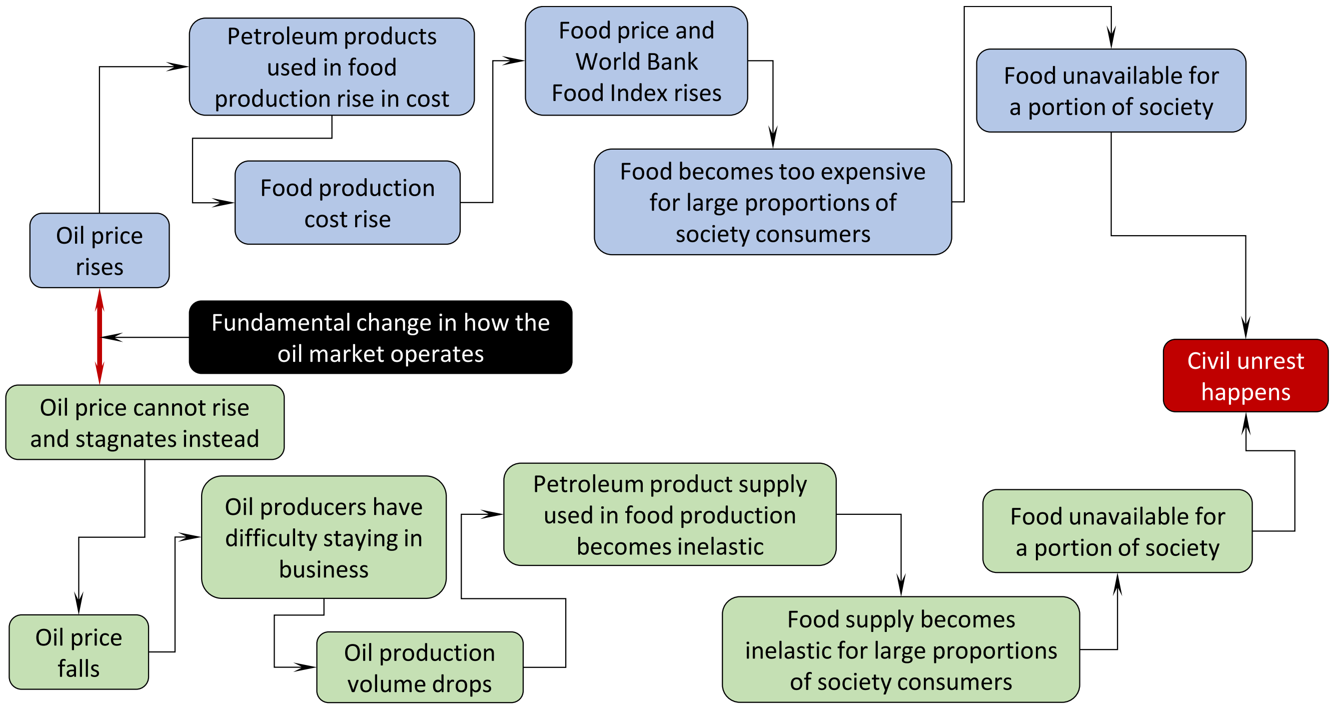

Figure 40. Two possible interactions between oil, food production and civil unrest

So in summary, currently:

- Lack of food = civil unrest
- Currently, oil = food
- In some cases food is replaced by an oil substitute (ethanol)
- <u>Oil price directly correlates to society to function in terms of capability to supply food</u>

When oil supply becomes inelastic and unreliable:

- Lack of food = civil unrest
- Oil = food for industrial agriculture, but not for small scale organic agriculture
- In some cases food is replaced by an oil substitute (ethanol)
- <u>Accessible oil volume supply will directly correlates to society to function in terms of capability to supply food in large volumes</u>

Figure 41 shows the global vulnerability to increase food prices in 2009.

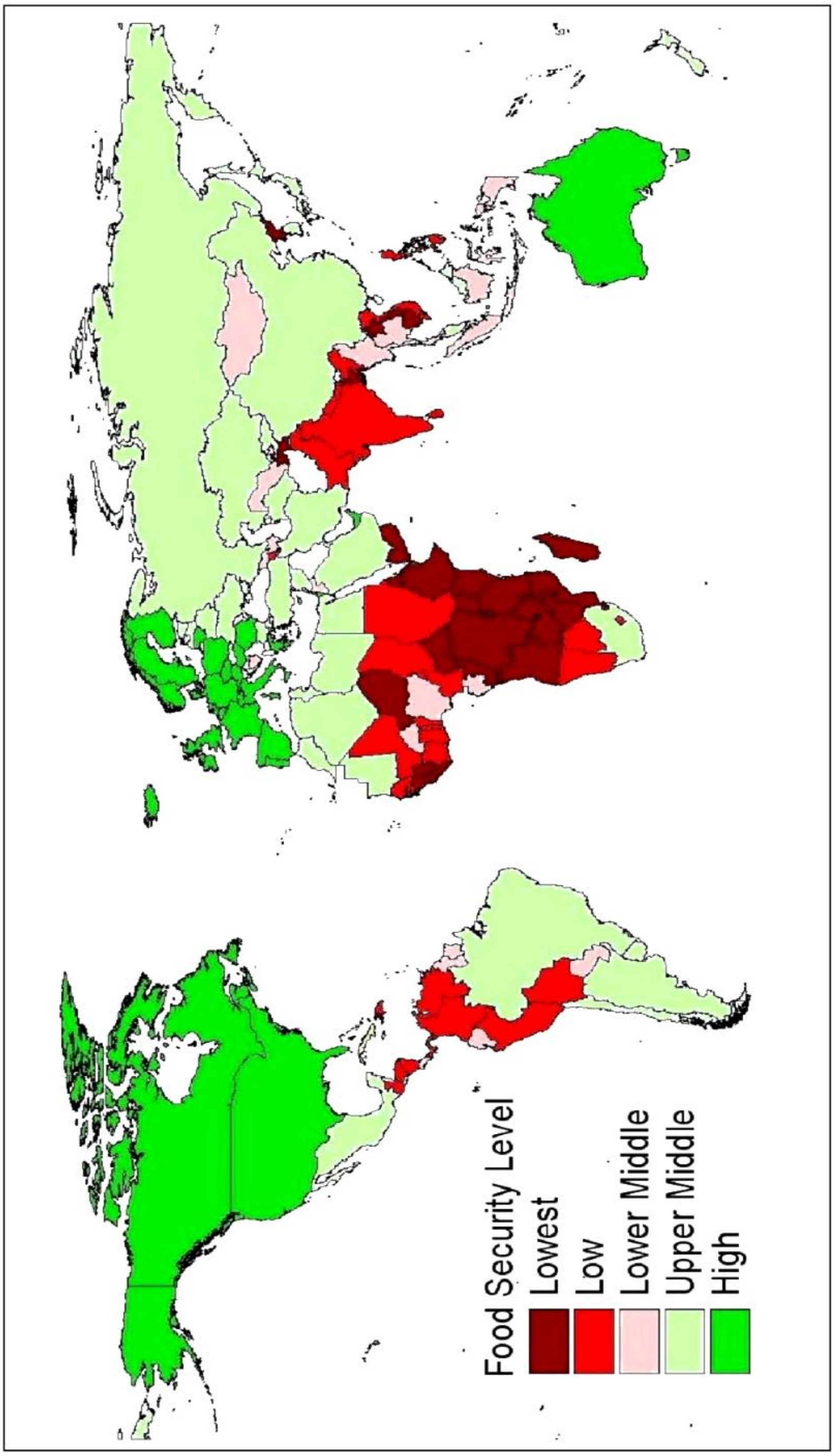

Figure 41. Food security levels in the face of high food prices
(Source: Bingxin Yu et al 2009)

2.4 Fossil fuel Dependency to Manufacture Plastics

About 10% of total world refinery output, or around 650 Million tons per year, is used by the plastics industry for its feedstock and energy needs. Countless numbers of manufactured products are either made from plastics, or contain plastic components. Very few consumer products in today's market-place contain no plastic parts at all.

The range of plastics on the market is enormous. But reduced to their common origins, commercial plastics are variants of a small originating family of organic compounds, made from the simplest components of crude oil and natural gas, the low molecular weight alkanes (the gases methane, ethane and propane).

The modern polymer industry was effectively created by Wallace Carothers at DuPont in the 1930s. Currently in 2019, over 70 million tons of thermoplastics per year are used in textiles, mostly clothing and carpeting. More than 90 percent of synthetic fibers, largely polyethylene terephthalate, are produced in Asia.

Currently, petrochemicals are the first link in a chain of industries that ultimately use hydrocarbons as raw materials. This industry is at the head of an industrial supply chain that generates a vast range of goods. Plastics, pharmaceuticals, synthetic rubber and textiles are a few of the many industries that rely on a supply of raw material from petrochemicals and in turn from fossil fuels. Synthetic fertilizers are another major user of hydrocarbon feedstocks. There are two broad bush categories of plastics being produced (Figure 42). In the value chain, the primary chemicals are produced into three secondary categories: polymers, agrochemicals and specialty chemicals (Figure 43)

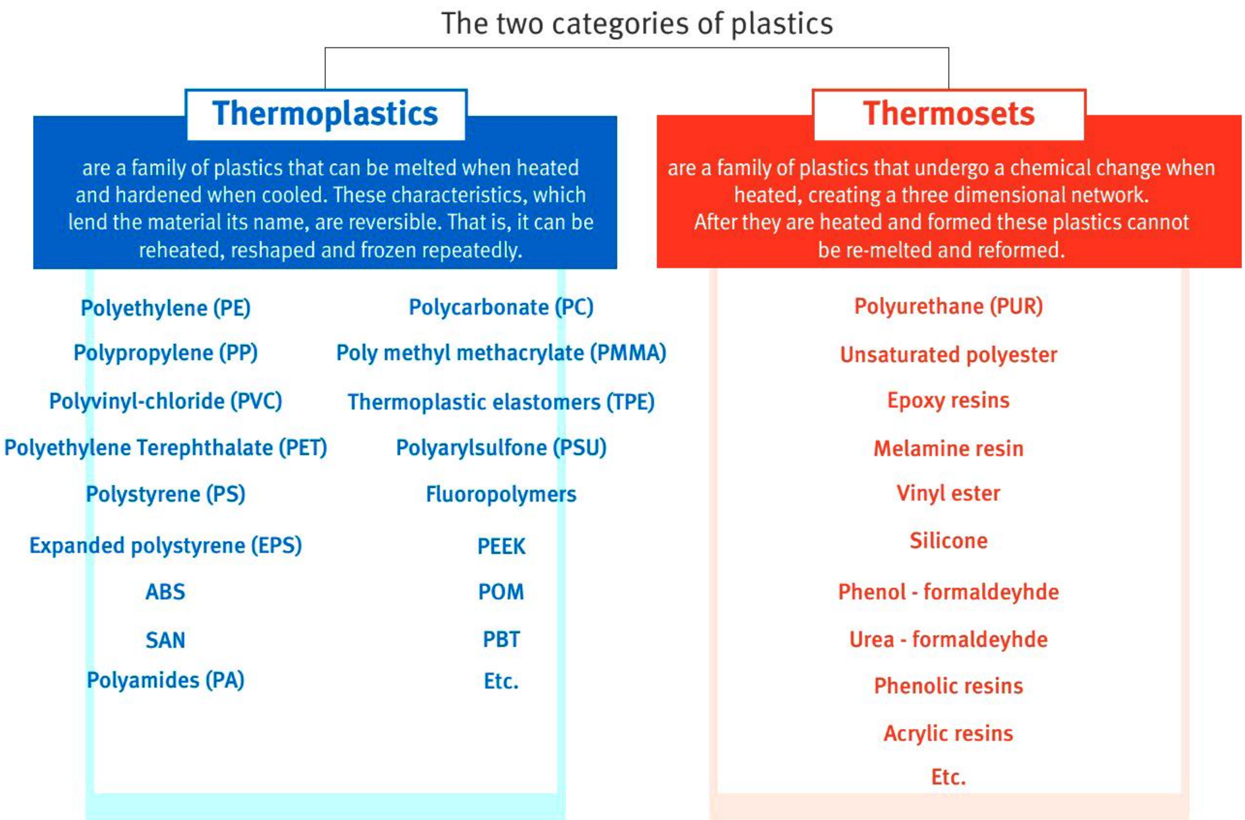

Figure 42. The family of plastics (Source: Plastics Europe 2018)
(Copyright License: https://www.iea.org/media/copyright/Termsandconditions_2019update_FINAL.docx.pdf)

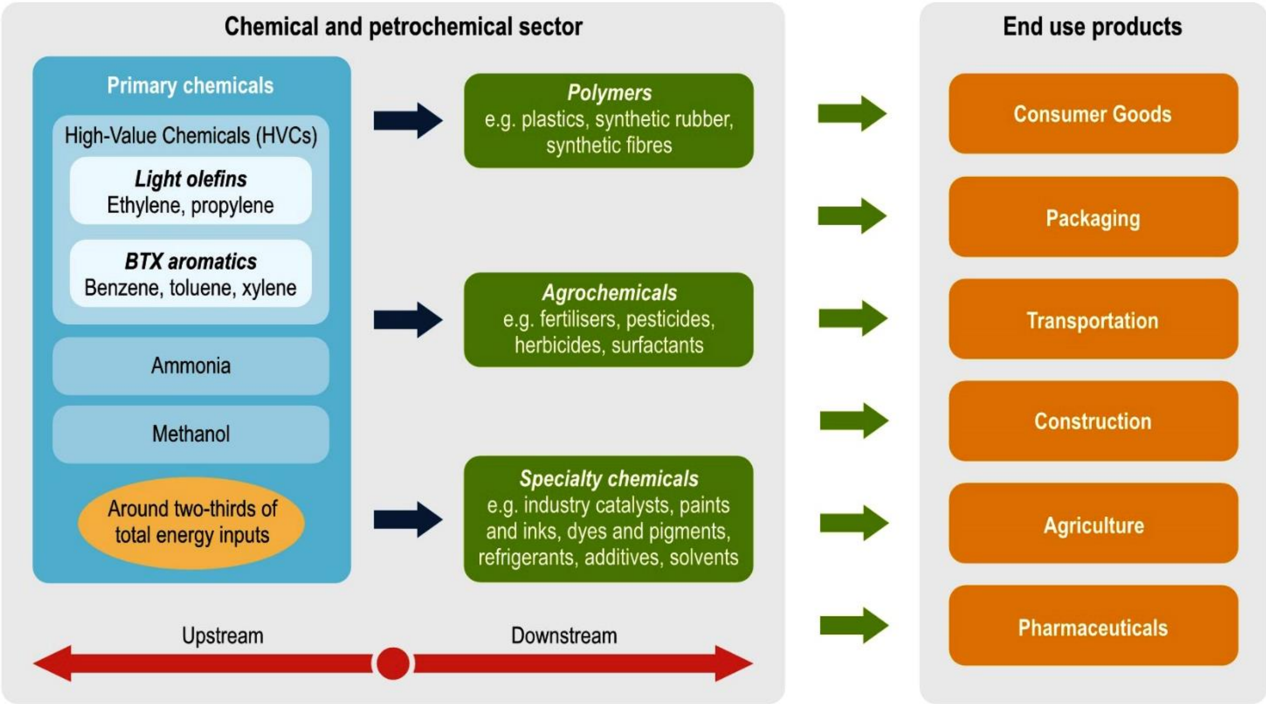

Figure 43. Primary chemicals in context of plastic manufacture (IEA 2018)
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Already a major component of the global energy system, the importance of petrochemicals is growing even more. Demand for plastics – the most familiar of petrochemical products – has outpaced all other bulk materials (such as steel, aluminum or cement), nearly doubling since the start of the millennium. The United States, Europe, and other advanced economies currently use up to 20 times as much plastic and up to 10 times as much fertilizer as India, Indonesia, and other developing economies on a per capita basis, underscoring the huge potential for growth worldwide (IEA 2018b).

Chemicals produced from oil and gas make up around 90% of all raw materials, which are known as feedstocks; the rest comes from coal and biomass (Figure 45). About half of the petrochemical sector's energy consumption consists of fuels used as raw materials to provide the molecules to physically construct products. The growing role of petrochemicals is one of the key "blind spots" in the global energy debate. The diversity and complexity of this sector means that petrochemicals receive less attention than other sectors, despite their rising importance.

The raw materials for most plastic resins are found in fossil fuels, predominantly natural gas and oil resources (ACC 2015). While an increasing share of plastic resins are made with bio-based materials from plants and algae, fossil fuels continue to provide the vast majority of hydrocarbon raw materials, called feedstocks, for plastic resins.

These feedstocks are broken down to create the building blocks that are recombined into plastic resins. Nearly three-quarters of U.S. plastic resin feedstock is derived from natural gas and natural gas liquids (NGLs). Roughly a quarter of feedstock comes from petroleum-based feedstocks.

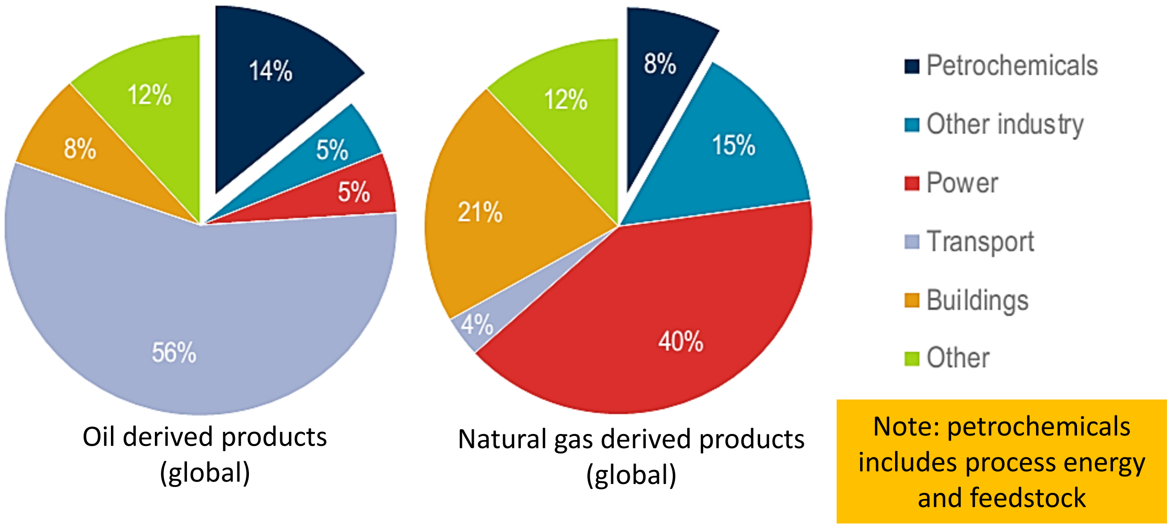

Figure 44. Primary oil (LHS) and natural gas (RHS) demand in 2017 by sector
(Source: IEA 2018 and BP Statistical Review of World Energy 2018)
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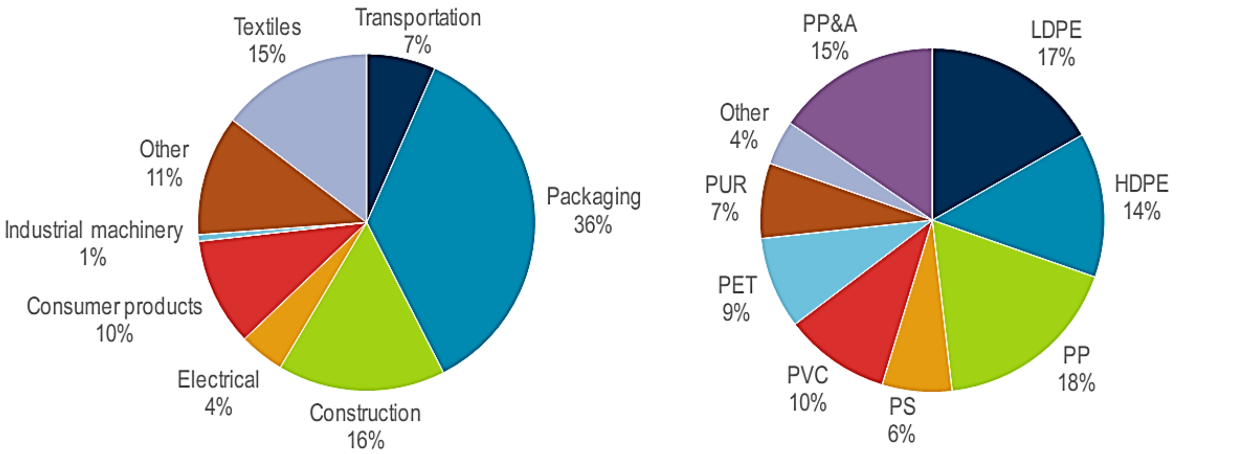
Feedstocks from natural gas liquids include ethane and propane that are especially important for petrochemical (and plastic resin) manufacturing.

Plastics are often produced from natural gas, feedstocks derived from natural gas processing, and feedstocks derived from crude oil refining. Petrochemical feedstock naphtha and other oils refined from crude oil are used as feedstock for petrochemical crackers that produce the basic building blocks for making plastics. However, the petrochemical industry also consumes large quantities of hydrocarbon gas liquids (HGL), which may be produced by petroleum refineries or natural gas processing plants.

There are several key building block chemicals that are used to produce plastic resins. These building block chemicals are linked together to form long chains called polymers. Each polymer has its own portfolio of performance characteristics (i.e., strength, permeability, etc.). One of the most prevalent and largest-volume building block chemicals is ethylene. Ethylene is used to produce thousands of products, including plastic resins such as polyethylene (PE), polyvinyl chloride (PVC), and polyethylene terephthalate (PET).

Another important building block chemical for resin production is propylene. Ethylene is a critical feedstock for the production of polyethylene, polyvinyl chloride (PVC), polyethylene terephthalate (PET), and polystyrene, which combined represent approximately 61% of global plastics production by weight. Propylene is the platform chemical for polypropylene. Therefore, the overwhelming majority of plastics can be traced to the product streams of just two industrial chemicals: ethylene and propylene (European Union 2018, A European Strategy for Plastics in a Circular Economy).

Until recently, most propylene was produced in oil refineries as a byproduct of fuel production. With shale gas, supplies of propane (a natural gas liquid) have become abundant. New technologies have emerged to convert propane into propylene which, like ethylene, has many uses, including the resin polypropylene (PP). Packaging is the leading end-use of plastic consumption globally (Figure 45). The most important types of plastic by volume are polyethylene (PE) and polypropylene. Multiple feedstocks can be utilized to make the same product, but with significant variations between the amount of input required (Figure 46).



Notes: Resins may exclude additives. Estimates based on data are for Europe, the United States, China, and India for 2002-14. Polyester, polyamide and acrylic (PP&A) fibres are assigned exclusively to the textile sector, and the charts excludes synthetic fibres. LDPE = low-density polyethylene; PUR = polyurethane; LDPE includes linear LDPE.

Figure 45. Estimated consumption of plastic by end-use sector (LHS) and resin (RHS)
(Source: Geyer *et al* 2017 and IEA 2018)
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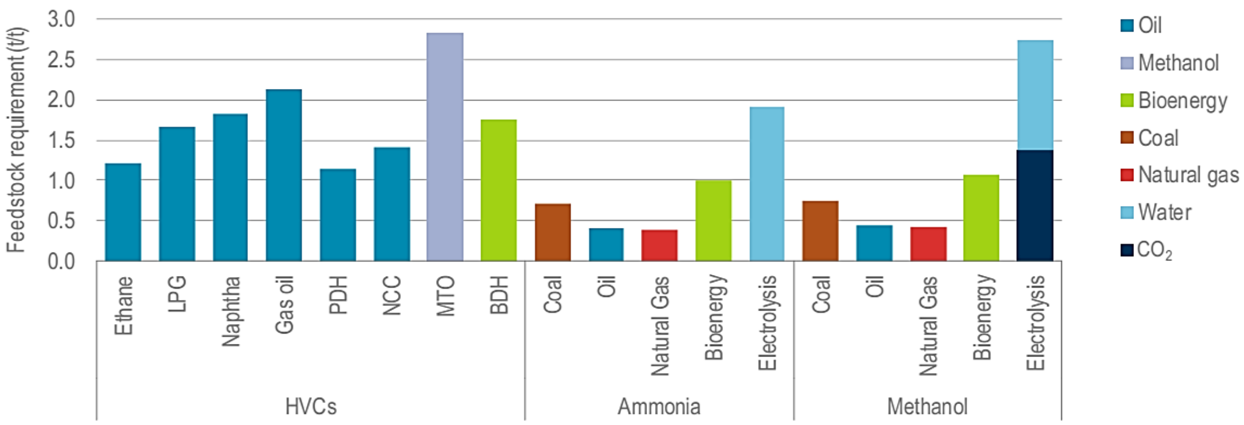

Notes: BDH = bioethanol dehydration; LPG = liquefied petroleum gas; NCC = naphtha catalytic cracking. The quantity pertaining to BDH is in terms of bioethanol.

Figure 46. Feedstock options by chemical product
(Source: IEA 2018b, The Future of Plastics)
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Because energy resources—which account for up to 70% of total costs for plastic resin producers—are the primary raw materials to make plastic resins, the price of energy feedstocks is critical to the global competitiveness of plastic resin producers. In the case of ethylene, ethane is the predominant feedstock in the U.S. In Europe and Asia, producers use naphtha, an oil-based feedstock. Ultimately, because the price of ethylene is effectively the same across the world, the competitiveness of one region over the other depends on the relative price of these feedstocks. Thus, the spread (difference) between naphtha and ethane prices is key to understanding petrochemical competiveness.

Oil products used as chemical feedstock may come from refinery operations or NGL fractionation. In volume terms, oil demand for chemical feedstock is dominated globally by the fractionation products of NGLs. Refineries do not produce ethane to any meaningful extent, and their LPG yields are typically below 5%. Thus, ethane, which accounts for almost a third of all chemical feedstock, and most of the LPG used as chemical feedstock, are supplied by NGL fractionation plants. In contrast, refineries provide the bulk of heavier feedstocks, including naphtha, which is the most popular feedstock, and other distillates. Average refinery naphtha yields are around 7%.

The proportion of chemical feedstocks sourced from refineries is limited, not only because an average barrel of crude oil contains only a limited amount of light fractions (LPG), but also because of competition for straight-run yields of light distillates (naphtha) for gasoline blendstocks, to supplement that part coming from the upgrading of residual oils. Moreover, LPG and naphtha usually have negative margins (i.e. priced lower than crude oil), discouraging refineries from increasing their yields.

Petrochemicals are rapidly becoming the largest driver of global oil consumption. They are set to account for more than a third of the growth in oil demand to 2030, and nearly half to 2050, ahead of trucks, aviation and shipping (IEA 2018b). Petrochemicals are also predicted to consume an additional 56 billion cubic meters (bcm) of natural gas by 2030, equivalent to about half of Canada's total gas consumption today. Approximately 190 Mt of chemicals, two-thirds of which are HVCs, are also produced as byproducts in the refining sector, making their way into the chemical sector for further processing. The remainder of these refinery chemicals, butylene – also produced as a co-product in steam cracking within the chemical sector – is used for various fuel applications and forms the base of most synthetic rubber.

Approximately 12 million barrels per day (mb/d) of oil products, 105 billion cubic metres (bcm) of natural gas and 80 million tonnes (Mt) of coal enter the sector as feedstock and undergo a complex series of chemical transformations, eventually leaving the sector embedded in chemical products.

- More than 90% of the oil – mostly in the form of ethane or naphtha – entering the chemical sector as feedstock is transformed into high-value chemicals (HVCs). Very small amounts are used for methanol and ammonia production, with the rest being used for other chemicals, notably, carbon black.
- About 25% of gas demand for chemical feedstock is used to produce methanol, with the majority of the rest used to produce ammonia.
- Coal feedstock usage is split in fairly even proportions across methanol and ammonia.

More than 500 million tonnes of oil equivalent (Mtoe) of feedstock is consumed per year to make approximately 1 billion tonnes of chemical products. Oil is the dominant feedstock for HVC's whereas gas and coal are used for ammonia and methanol.

Nitrogen fertilizers, plastics, synthetic fibers and rubber account for more than 70% of the total mass production of chemicals. The remainder of the products consist of a host of monomers and other intermediate chemicals that go on to be transformed into thousands of small volume downstream chemicals and products. The complexity at the margins in the chemical sector is hard to overstate. Figure 47 shows the passage of fossil fuels through the global plastics industry. Figure 48 shows a more complex picture in how plastics relate and compare to fertilizer manufacture.

Globally in 2017, recycling of major plastic resins is estimated to have reached 16% of available waste, while global production capacity of bio-plastics stood at just over 2 Mt (European Bioplastics, 2018) (the latter equivalent to less than 1% of annual global plastic demand, if fully utilized). Theoretically, the chemical sector could do without fossil fuels altogether, but feedstock containing carbon and hydrogen will remain a requirement (IEA 2018b).

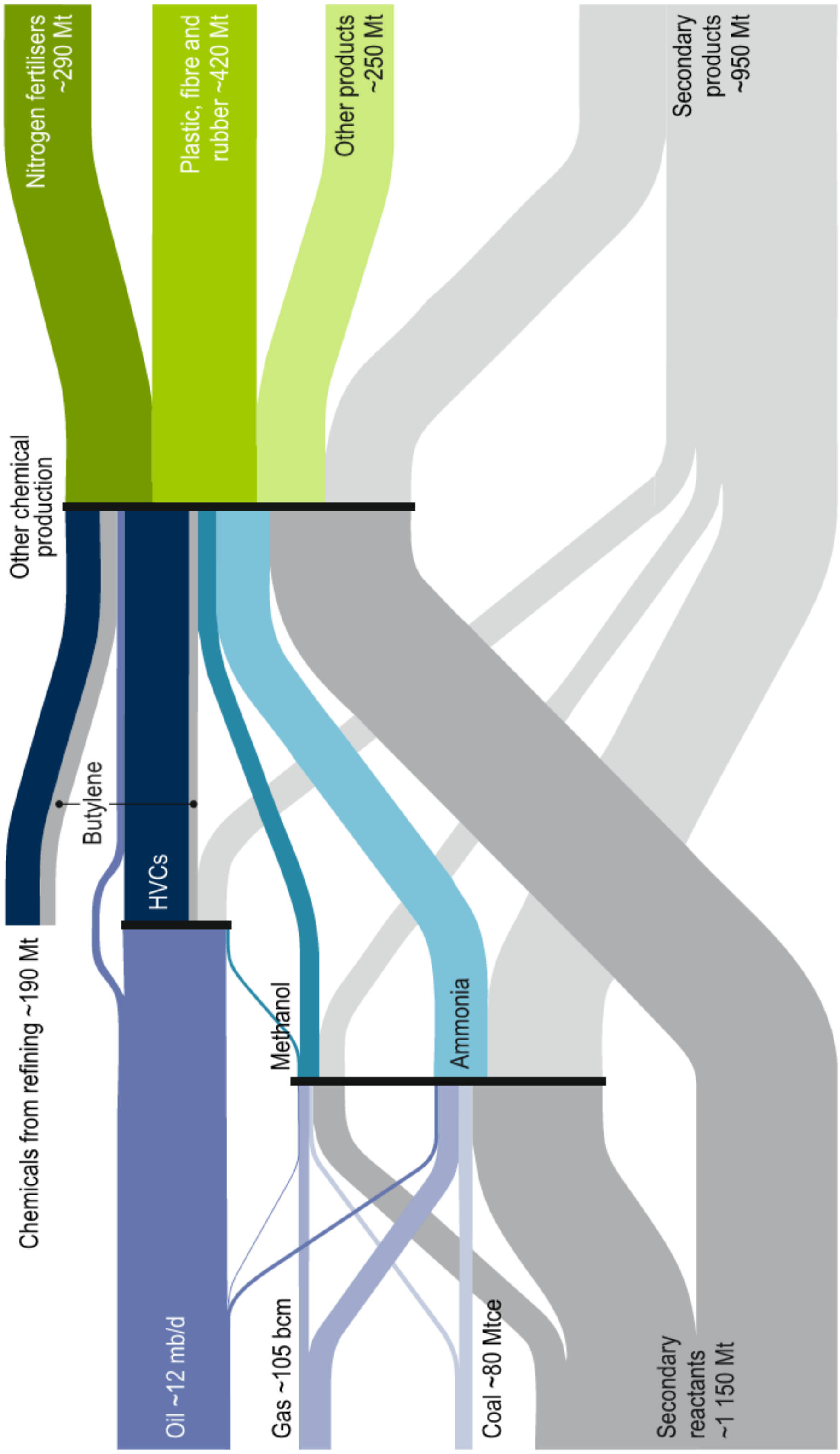
There are alternatives to making plastics from fossil fuels. They are not nearly as effective but they are economically viable. Oil produced from pyrolysis of plastics have been known for its higher calorific value than wood-based oil, in which comparable to conventional diesel. Even though many studies have been conducted on pyrolysis of plastics, the findings of those studies are not applied and reported yet according to the real portion of plastic waste.

A variety of carbon- and hydrogen-containing materials can replace oil, natural gas and coal as chemical feedstocks (IEA 2018b). Key among these are bioenergy products, which are a source of both carbon and hydrogen. Alternatively, each element can be sourced separately, for instance from gases arising from the iron and steel industry (e.g. coke oven gas (COG)) or from CO^2 and water. The main advantage of alternative feedstocks is that they can offer a net reduction in

CO^2 emissions – process emissions during production and end-of-life emissions – relative to traditional feedstocks. The reductions stem from the fact that these substances would have otherwise gone unutilized (even if originally sourced from fossil fuels), or because they are renewable and therefore do not contribute to accumulation of CO^2 in the atmosphere (on a long-term basis).

While not all fossil fuels are used to make plastic, all (or virtually all) plastic is made from fossil fuels. In addition, the largest players in each industry — DowDuPont, ExxonMobil, Shell, Chevron, BP, and Sinopec — are all integrated companies that produce both fossil fuels and plastics.

There is no accepted viable substitution for plastics in current technology nor the fossil fuel feedstocks to make them.



Notes: All flows in the diagram are sized on a mass basis. Secondary reactants and products are the compounds specified within chemical reactions that do not form part of the feedstock or main products. Key examples include water, CO_2, oxygen, nitrogen and chlorine. Some of the secondary products entering the sector on the left of the figure may well coincide with those leaving it on the right – CO_2 emitted from ammonia facilities and utilised in urea production is a key example. Mtce = Million tonnes of coal-equivalent.

Figure 47. Passage of fossil fuel feedstock through the petrochemical industry in 2017
(Source: IEA 2018b, The Future of Plastics)

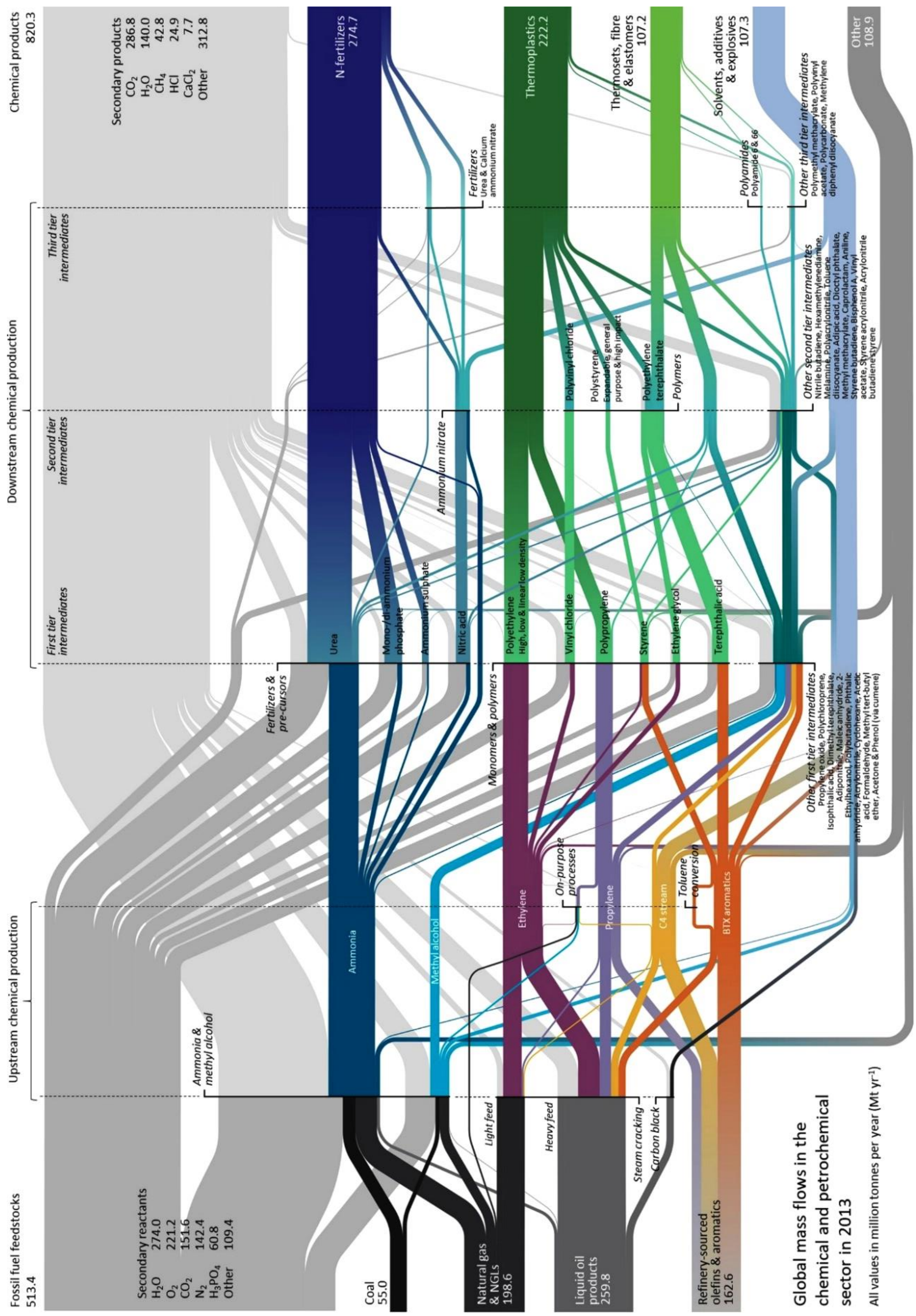


Figure 48. Sankey diagram depicting the passage of feedstock through the chemical sector: from fossil fuel feedstocks to chemical products. NGLs: Natural gas liquids, N-fertilizers: Nitrogenous fertilizers. (Source: Levi & Cullen 2018) (Copyright License: https://www.iea.org/media/copyright/Termsandconditions_2019update_FINAL.docx.pdf)

3 PETROLEUM PRODUCTS CONSUMPTION

Petroleum products are materials derived from crude oil (petroleum) as it is processed in oil refineries. Unlike petrochemicals, which are a collection of well-defined usually pure chemical compounds, petroleum products are complex mixtures. The majority of petroleum is converted to petroleum products, which includes several classes of fuels (Irion & Neuwirth 2005).

According to the composition of the crude oil and depending on the demands of the market, refineries can produce different shares of petroleum products. The largest share of oil products is used as "energy carriers", i.e. various grades of fuel oil and gasoline. These fuels include or can be blended to give gasoline, jet fuel, diesel fuel, heating oil, and heavier fuel oils. Heavier (less volatile) fractions can also be used to produce asphalt, tar, paraffin wax, lubricating and other heavy oils.

3.1 Global use of petroleum products

Table 5 shows the global consumption of petroleum products, where 87% of these products are used in transport applications (Source: EIA). Appendix B – Refined Petroleum Products Consumption

Table 5. Refined petroleum products daily consumption in 2018 by Region
(Source: OECD Data Statistics Database and Appendix b)

Region	Daily Consumption (bbls/day)
Global	109 265 942
United States	19 690 000
European Union EU-28	12 890 000
China	11 750 000
India	4 489 000
Russia	3 594 000

Figure 49 and 50 shows world liquid consumption for the previous two years and a prediction for the next two years. As can be seen it is expected that demand for petroleum products will continue to rise for the next few years.

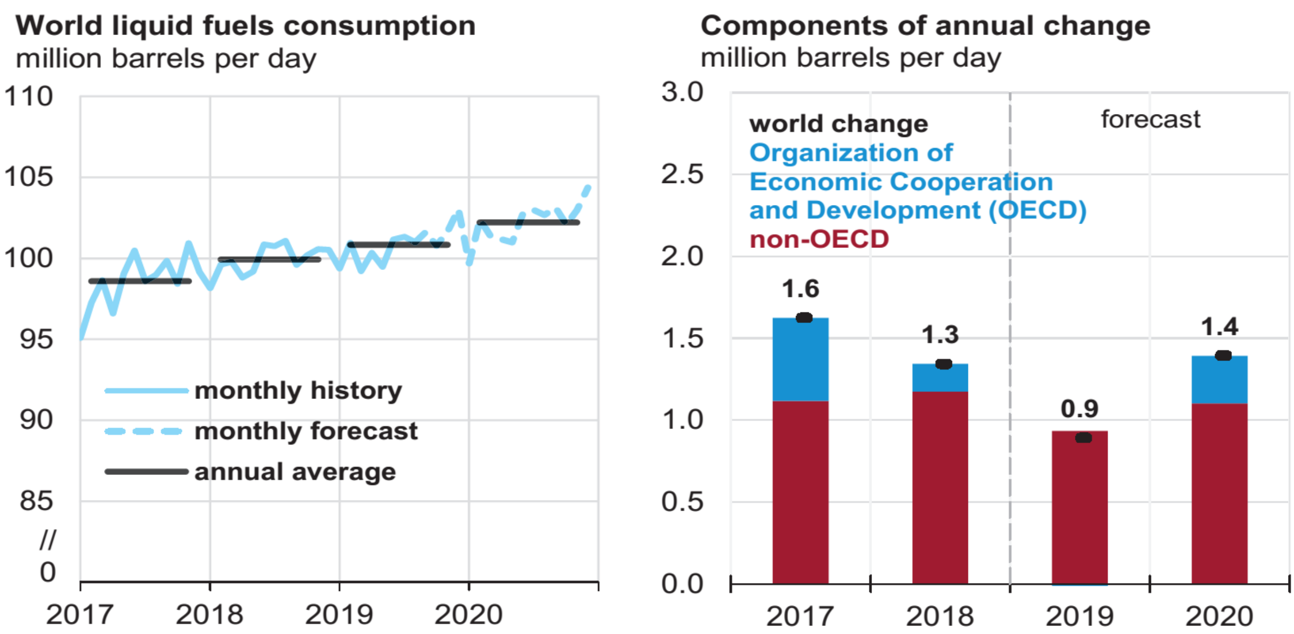


Figure 49. World liquid fuels consumption million barrels per day (LHS), Components of annual change million barrels per day (RHS) (Source: EIA 2019) (Copyright License: https://www.eia.gov/about/copyrights_reuse.php)

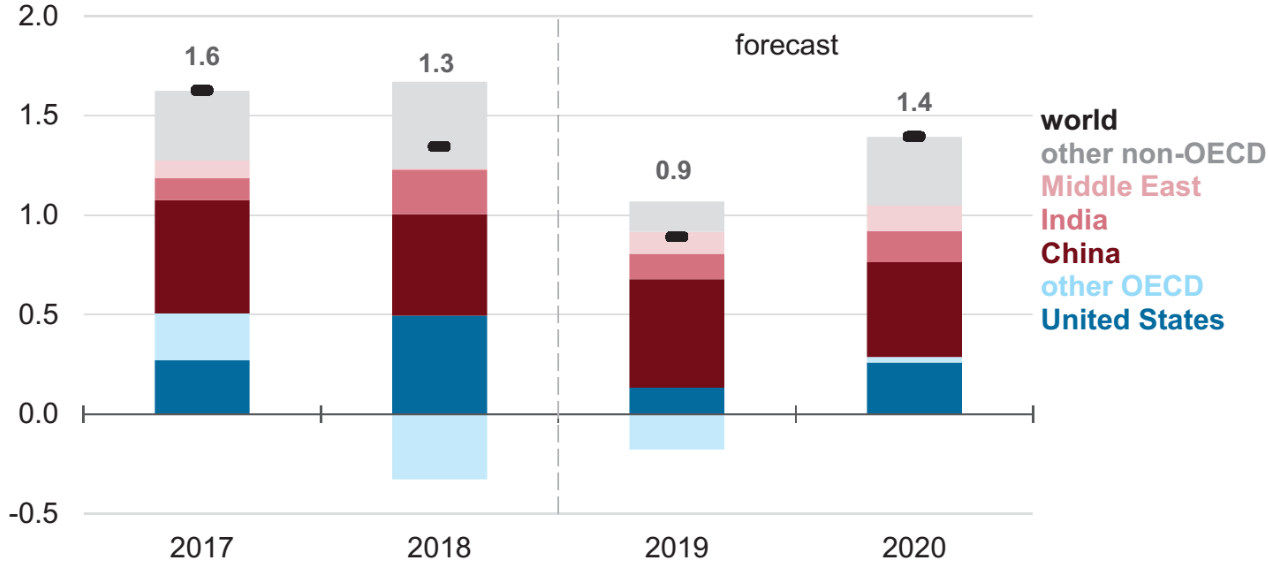


Figure 50. Annual change in world liquids fuels consumption, million barrels a day (Source: EIA 2019) (Copyright License: https://www.eia.gov/about/copyrights_reuse.php)

3.2 Oil consumption and imports in Europe

The European Union relied on net imports (imports minus exports) for 86.7 % of the oil products consumed in 2017. The dependency on foreign petroleum in the last few years is at its peak, the highest rate being recorded in 2015 (89.2 %). The lowest import dependency for oil was observed in 1995, namely a rate of 73.9 %. Detailed national data are available in Table 6.

Table 6. Net imports pf selected petroleum products, EU-28, years 1990-2017 (Source: Eurostat, online data code nrg_bal_c)

(million tonnes of oil equivalent)

	1990	1995	2000	2005	2010	2015	2016	2017
Crude oil & Natural gas liquids (NGL)	469.1	470.2	499.7	569.9	527.2	534.2	525.5	541.2
Refinery feedstocks	33.0	21.6	11.2	13.7	13.2	15.9	15.3	14.1
Liquified petroleum gas (LPG)	6.0	5.9	5.6	6.6	9.0	13.5	13.5	12.9
Naphtha	13.6	12.9	10.4	12.3	13.7	12.7	11.9	15.8
Motor gasoline	-8.8	-14.7	-16.8	-39.1	-45.2	-55.8	-55.6	-57.9
Kerosene-type jet fuel	-2.8	-2.2	4.8	13.8	16.0	17.4	18.3	18.3
Gas oil and diesel oil	13.4	-0.1	8.0	25.0	27.7	25.4	28.3	24.1
Fuel oil	6.2	13.1	1.3	-8.8	-3.0	-16.6	-15.3	-15.7
All other products	0.2	3.3	8.1	10.3	2.9	-5.8	-6.9	-9.5

Import dependency on oil is calculated as the ratio of net imports (imports minus exports) to gross inland energy consumption (but including international maritime bunkers) of crude oil and petroleum products. Positive values over 100 % indicate a stock build, while negative dependency rates indicate a net exporter country.

To determine the industrial sectors that are dependent on petroleum product imports, Eurostat developed the concept of Sectorial oil dependency rate. Sectoral oil dependency refers to the ratio of oil consumption in a specific sector to the total fuel consumption of that sector. The dependence on oil for transport and for fishing is the highest of all sectors, although both decreased in 2017 compared with 1990 (see Table 7). However, the industry sector, residential and services have decreasing dependency rates towards 11-10 % dependency on oil.

Table 7. Sectoral oil dependency, EU-28, years 1990-2017 (Source: Eurostat, online data code nrg_bal_c)

(%)

	1990	1995	2000	2005	2010	2015	2016	2017
Consumption in Energy Sector	45.2	46.2	45.2	45.0	40.6	38.8	38.9	38.0
Final Non-energy Consumption	82.6	85.3	85.2	86.0	85.1	83.4	83.6	83.5
Industry sector	17.7	18.1	16.9	15.1	13.3	11.2	10.9	10.3
Transport sector	97.7	97.7	97.6	96.5	93.6	92.9	93.1	92.7
Residential	22.1	21.7	19.8	17.7	13.6	12.2	11.5	11.2
Fishing	99.7	99.9	96.3	94.3	88.9	88.8	87.5	86.8
Agriculture/Forestry	59.9	62.3	62.0	60.3	54.7	54.1	52.5	53.0
Services	24.6	21.5	18.6	16.2	12.0	10.6	10.6	10.4

Imports of crude oil are by far the most important component of trade in oil statistics. The imports of crude oil are complemented by imports of already manufactured petroleum products such as:

- Gas/diesel oil (24.1 million tonnes in 2017)
- Kerosene type jet fuel (18.3 million tonnes)
- Naphtha (15.8 million tonnes)
- Liquefied petroleum gas (12.9 million tonnes)

The EU-28 also exports manufactured petroleum products to third countries. In 2017, EU-28 exported 57.9 million tonnes of motor gasoline and 15.7 million tonnes of fuel oil. Trade of other petroleum products (lubricants, bitumen, other hydrocarbons, etc.) is of a smaller magnitude and in 2017 resulted in net exports of 9.5 million tonnes (Source: Eurostat). Figures 51 to 59 show the petroleum product import, use and consumption in Europe.

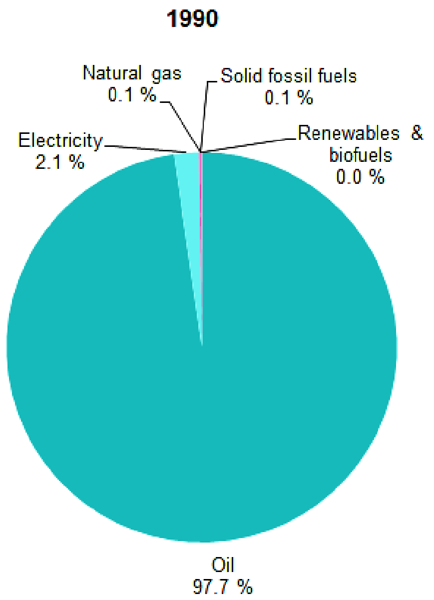


Figure 51. Use of fuels in transport, EU-28, 1990 and 2017
(Source: Eurostat – online data code: nrg_bal_c) (Copyright License: https://creativecommons.org/licenses/by-nc-sa/4.0/)

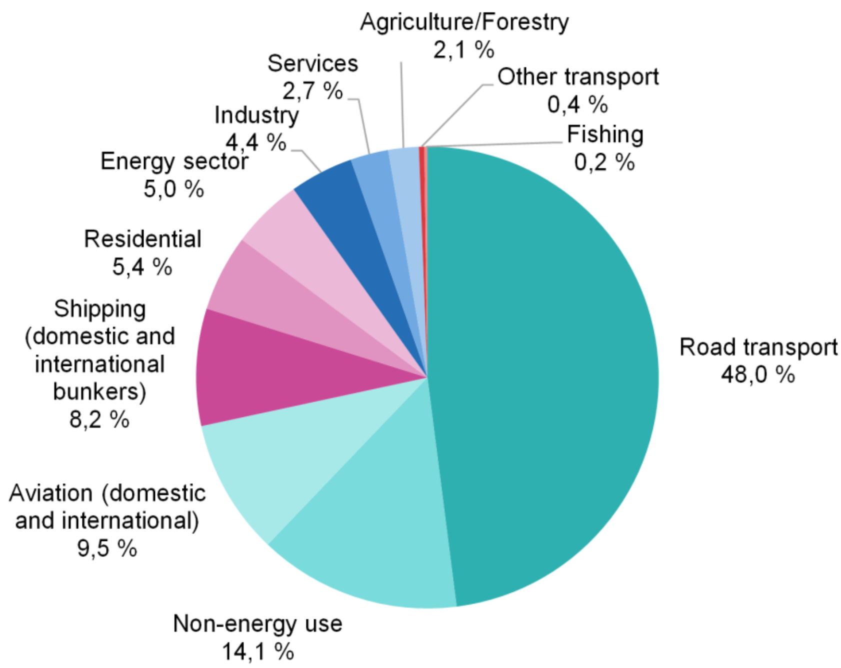


Figure 52. Consumption of oil in selected sector, EU-28, 2017
(Source: Eurostat)
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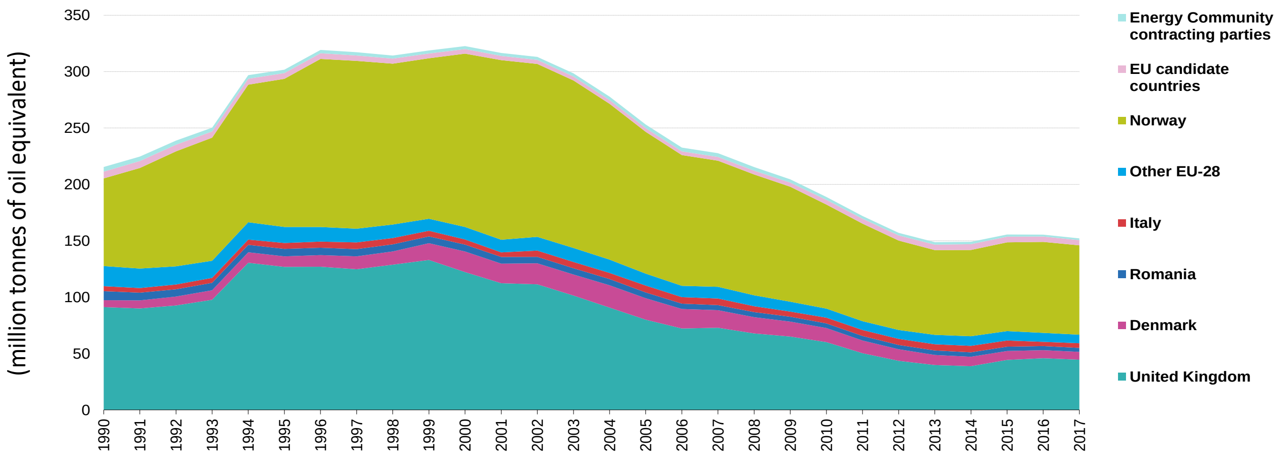

Figure 53. Primary production of crude oil, 1990-2017
(Source: Eurostat – online data code: nrg_bal_c) (Copyright License: https://creativecommons.org/licenses/by-nc-sa/4.0/)

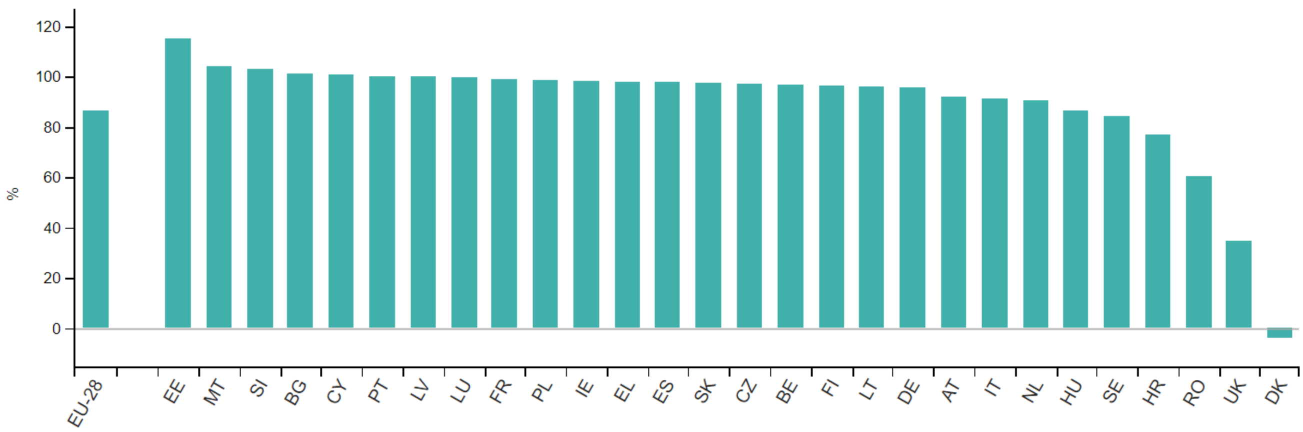

Figure 54. EU-28 Oil import dependency in 2017 (% of net imports in gross available energy based on tonnes of oil equivalent)
(Source: Eurostat – online data code: nrg_ind_id) (Copyright License: https://creativecommons.org/licenses/by-nc-sa/4.0/)

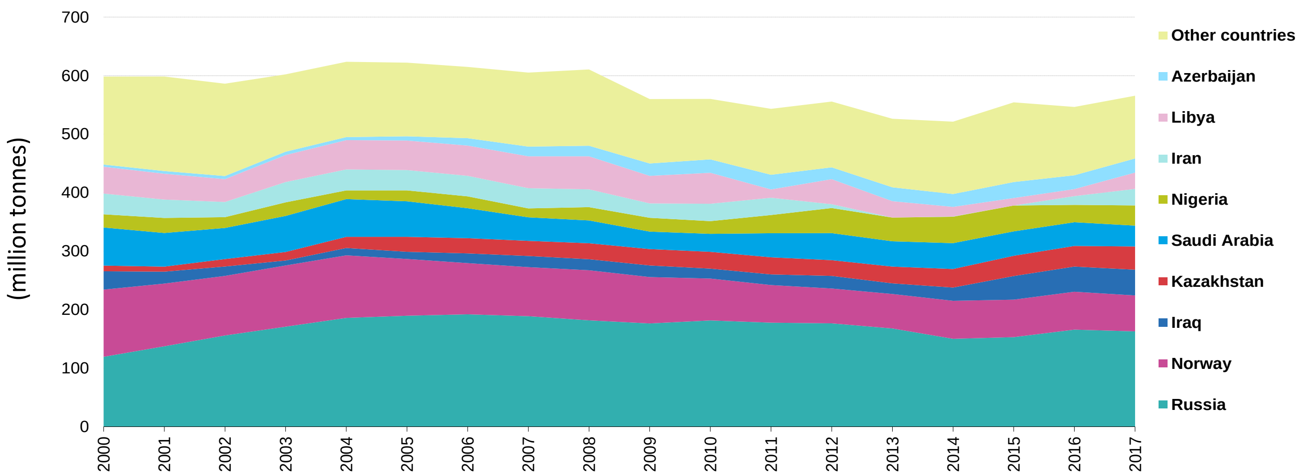

Figure 55. Crude oil imports by country of origin, EU-28, 2000-2017
(Source: Eurostat – online data code: nrg_bal_c) (Copyright License: https://creativecommons.org/licenses/by-nc-sa/4.0/)

Figures 56 shows how much energy from each source was used over time and the application the energy sources were consumed. Note that crude oil was used for power generation (the red unit).

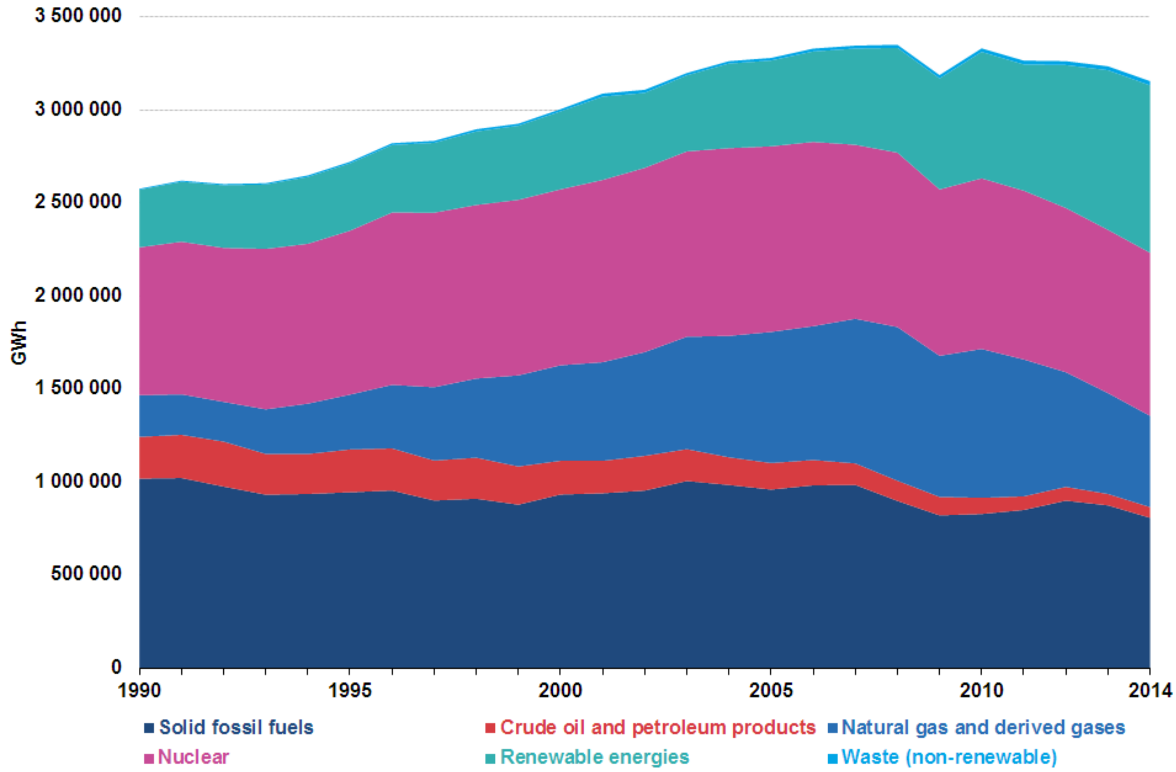

Figure 56: Gross electricity production by fuel, GWh, EU-28, 1990-2014
(Source: Eurostat) (Copyright License: https://creativecommons.org/licenses/by-nc-sa/4.0/)

3.3 Use of petroleum products for transport in Europe

Petroleum products include transportation fuels, fuel oils for heating and electricity generation, asphalt and road oil, and feedstocks for making the chemicals, plastics, and synthetic materials that are in nearly everything society uses.

The difference between crude oil, petroleum products, and petroleum is that crude oil is a mixture of hydrocarbons that exists as a liquid in underground geologic formations and remains a liquid when brought to the surface. Petroleum products are produced from the processing of crude oil and other liquids at petroleum refineries, from the extraction of liquid hydrocarbons at natural gas processing plants, and from the production of finished petroleum products at blending facilities. Petroleum is a broad category that includes both crude oil and petroleum products. The terms oil and petroleum are sometimes used interchangeably.

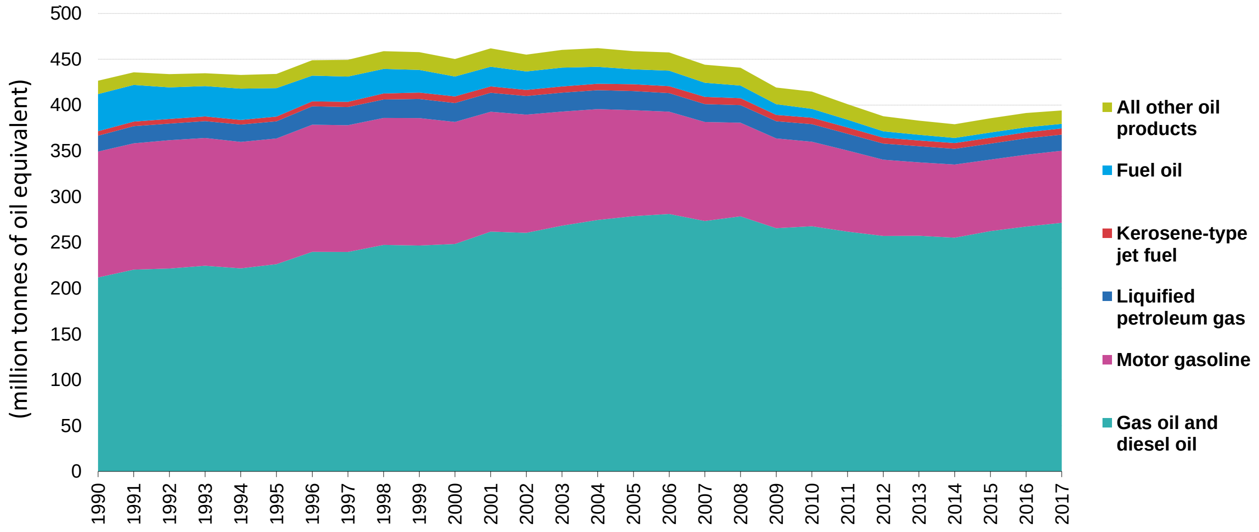

Figure 57. Final energy consumption of petroleum products by product, EU-28, 1990-2017
(Source: Eurostat – online data code: nrg_bal_c) (Copyright License: https://creativecommons.org/licenses/by-nc-sa/4.0/)

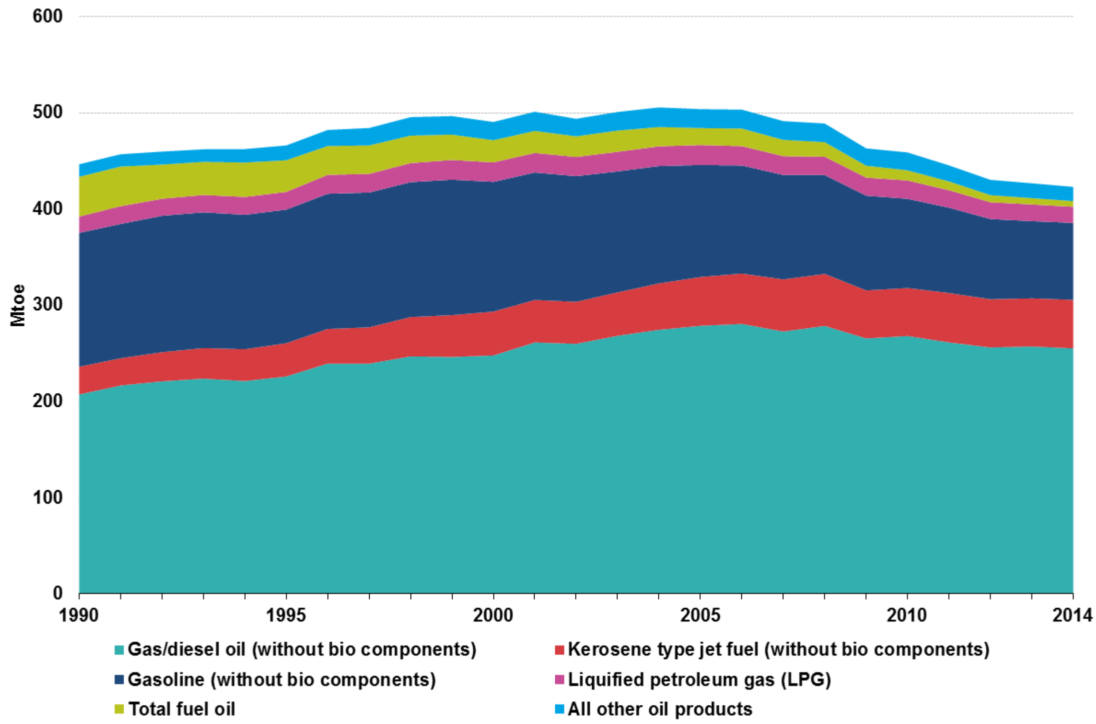

Figure 58. Consumption of oil EU-28, 1990-2014, Mtoe
(Data Source: Eurostat) (Copyright License: https://creativecommons.org/licenses/by-nc-sa/4.0/)

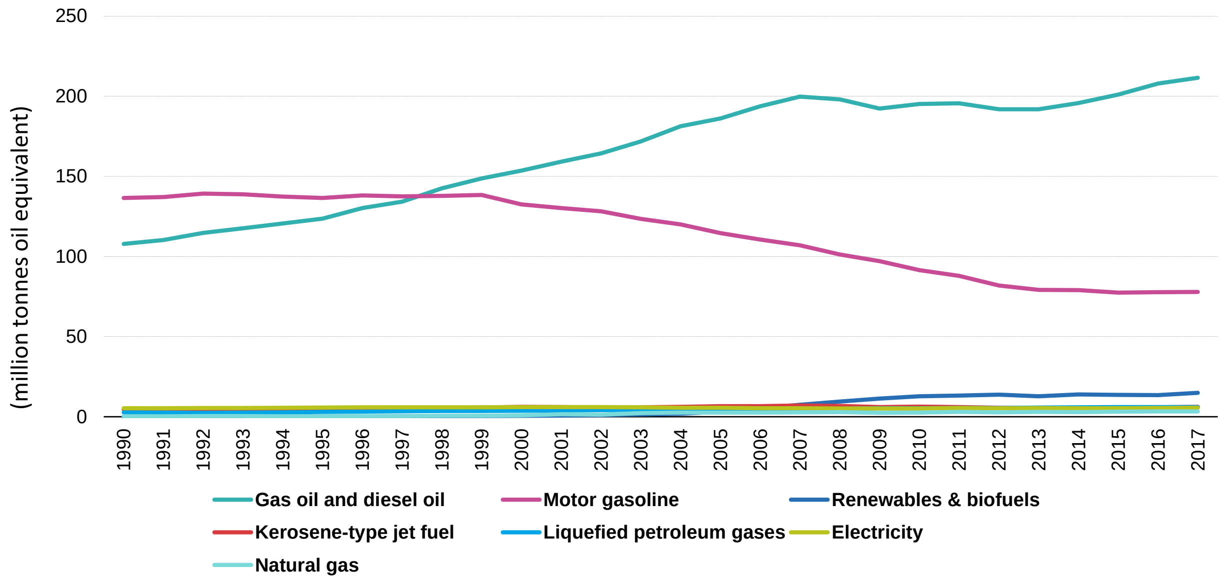

Figure 59: Use of fuels in transport, EU-28, 1990-2017
(Source: Eurostat) (Copyright License: https://creativecommons.org/licenses/by-nc-sa/4.0/)

3.4 Petroleum products in the United States

For decades, the United States was the primary global consumer of oil and petroleum products. Currently the U.S. accounts for 16.6% of world oil consumption, where China accounts for 23.6% (BP World Energy Statistical Review 2019). The U.S. is used as an example because the American institutions EIA and IEA collect excellent quality data that is public domain. This can be used as a proxy for the rest of the world in context of all developing countries wish to evolve into something like current Western Culture with a corresponding economy.

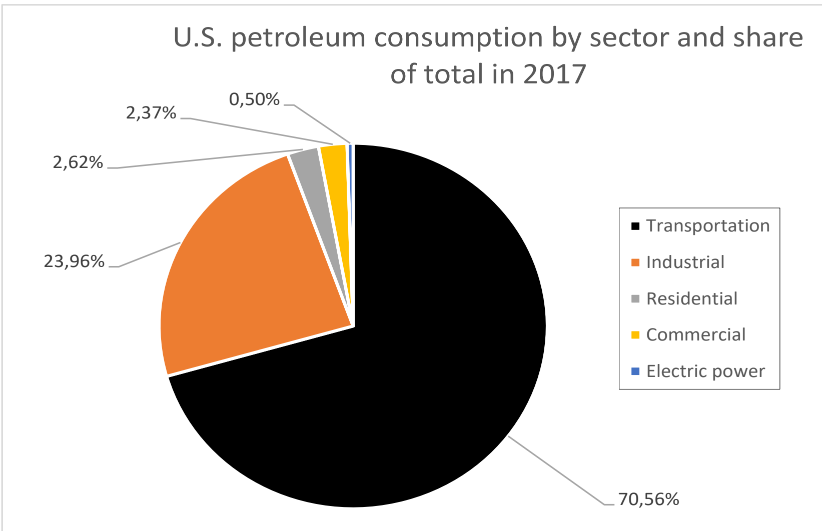

Figure 60. U.S. petroleum consumption by sector and share of total in 2017
(Source: EIA – Crude Oil and Petroleum products)
(Copyright License: https://www.eia.gov/about/copyrights_reuse.php)

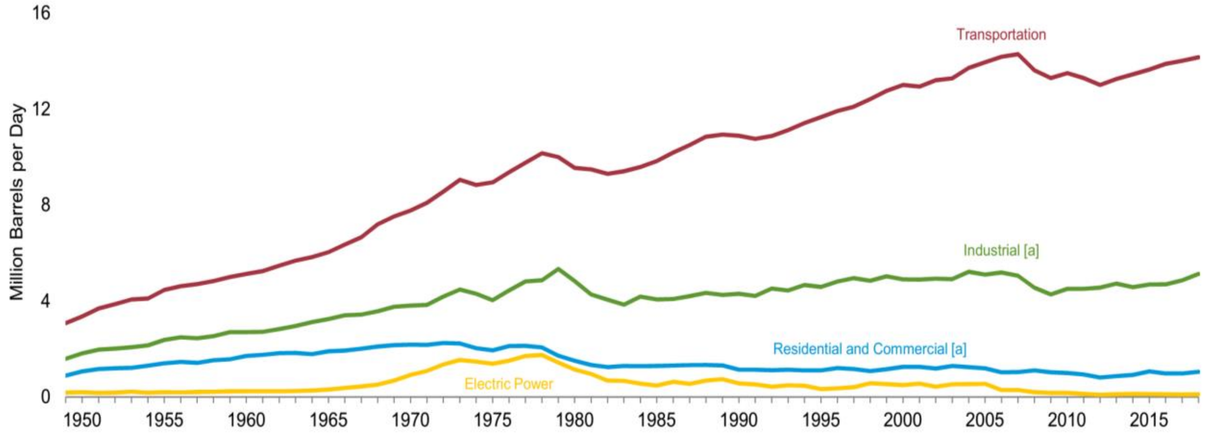

Figure 61. Petroleum product consumption by sector in the United States 1949 -2018
(Source: U.S. Energy Information Administration – monthly energy review July 2019)
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Figure 60 shows the proportion of use for the petroleum products consumed by sector in 2017 in the United States. Figure 61 shows the petroleum products consumed in the U.S. between 1949 and 2018, by industrial sector. Figure 62 shows the proportion of use for the petroleum products consumed in the United States, by product. Figure 63 use for the petroleum products consumed between 1949 and 2018 in the United States, by product.

As can be observed consumption is increasing, not decreasing over time.

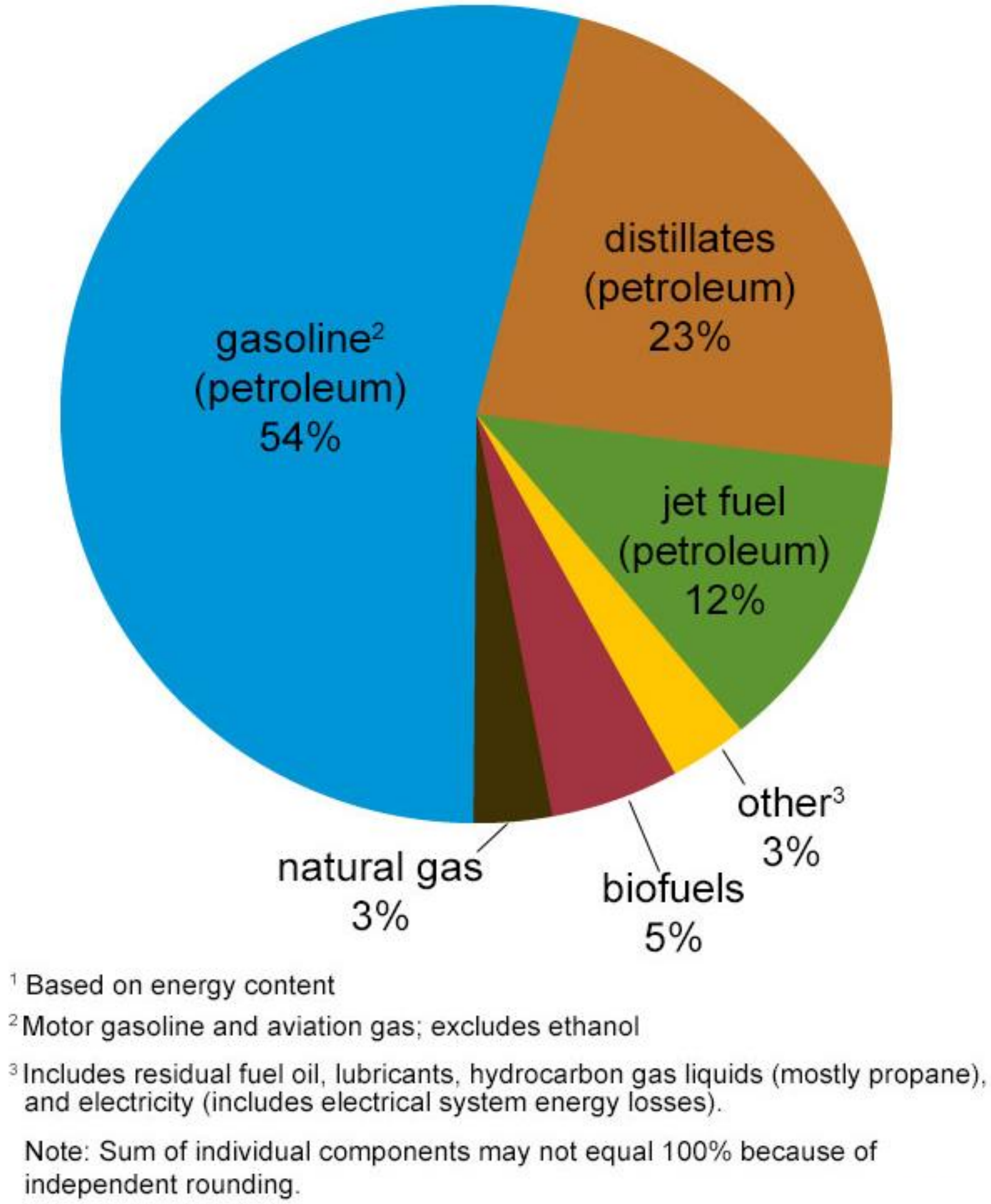

Figure 62. U.S. transportation energy by source/fuel
(Source: EIA, Energy Review, Tables 2.5, 3.8c, and 10.2b, April 2019)
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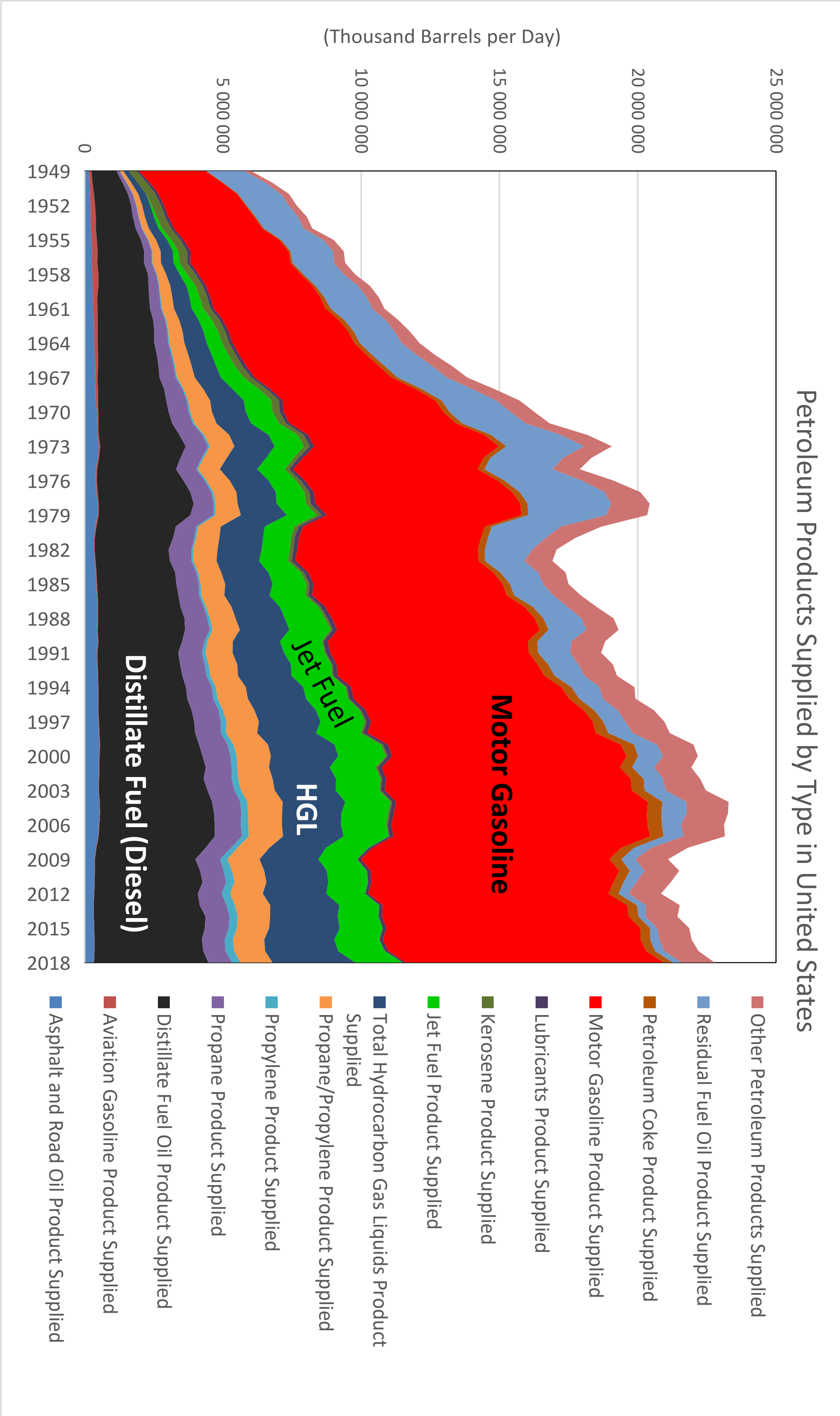

Figure 63. Petroleum products consumed in the United States. Data in Appendix B (Source: U.S. Energy Information Administration, July 2019 Monthly Energy Review, Table 3.5) (Copyright License: https://www.eia.gov/about/copyrights_reuse.php)

In 2018, of the approximately 7.5 billion barrels of total U.S. petroleum consumption, 46% was motor gasoline (includes fuel ethanol), 20% was distillate fuel (heating oil and diesel fuel), and 8% was jet fuel (Source: EIA- Petroleum products and their applications). These petroleum products accounted for about 92% of the total U.S. transportation sector energy use. Biofuels, such as ethanol and biodiesel, contributed about 5%. Natural gas accounted for about 3%, most of which was used in natural gas pipeline compressors. Electricity provided less than 1% of total transportation sector energy use and nearly all of that in mass transit systems. Distillate fuels, mostly diesel, accounted for 23%, and jet fuel for 12%. Where:

- In 2018, gasoline was the dominant transportation fuel in the United States, followed by distillate fuels (mostly diesel fuel) and jet fuel.
- Gasoline includes aviation gasoline and motor gasoline.
- Motor gasoline includes petroleum gasoline and fuel ethanol added to petroleum gasoline.
- Fuel ethanol includes ethanol (a biofuel) and petroleum denaturants.
- The petroleum component of gasoline (excluding ethanol) accounted for 54% of total U.S. transportation energy use in 2018.

4 OIL DEMAND

Most of energy generated is supported by a nonrenewable natural resource as a fuel. Currently we are a petroleum dominated society (Martenson 2011, Ruppert 2007, Tainter 1988), with a heavily dependency on other fossil fuels like gas and coal. Nuclear power is no different. It requires uranium to be mined then refined. This is a finite resource like any other and has a limit (Zittel *et al* 2013). Renewable power sources like photovoltaic solar require minerals to manufacture solar panels in vast numbers. These minerals are also nonrenewable natural resources.

The different sources of energy are not equal in calorific content. Nor are they used in the same applications. Transfer of energy source to power technology from one resource to another is often not possible. With the exception of oil and to a lesser extent gas, once these energy resources are used to generate power, those power stations have to run at a consistent supply to grid level or suffer degradation in their infrastructure. Oil and gas are flexible in use, coal and nuclear are not.

The global resources consumed to produce energy is shown since the beginning the industrial revolution (IR2 and IR3). The majority proportion of energy consumption has always been fossil fuels and projected to be so in the future. Also note that the demand for the resources has been increasing consistently in an exponential fashion (as opposed to our dependence decreasing).

Global energy consumption increased by 2.9% in 2018. Growth was the strongest since 2010 and almost double the 10 year average. The demand for all fuels increased but growth was particularly strong in the case of gas (168 mtoe, accounting for 43% of the global increase) and renewables (71 mtoe, 18% of the global increase) (BP Statistical review of World Energy 2019). Over the last decade, world primary energy consumption grew at an average annual rate of 1.8 percent. It's important to note, that in per-capita terms the rate of energy growth has significantly slowed since the 1980s, increasing at an average annual rate of 0.4% since that time, compared to 1.2% in the century prior (Jancovici 2011).

Oil demand was reduced due to above ground influences. First there was the oil shocks of 1973 and 1979, which were geopolitically motivated, not geological constraints. Then, as a direct consequence, alternative energy systems were developed, where a greater proportion of natural gas and nuclear power derived energy were introduced into the energy system (substitution) and efficiency gains was realized.

In 2005-2008, there was a third oil shock. This time, oil production did separate from oil supply (conventional oil supply plateaued) and a speculative fueled price spike created a market crash, resulting in demand destruction.

The situation for oil is particularly critical, especially given that it is by far the world's major source of liquid fuel, powering 95% of all transport. At this time, approximately 60–80% of conventional oil fields are in terminal decline (Fustier et al. 2016).

If 80% of the 2018 global supply of crude oil (94 718 thousand bbls/day – Appendix D) declined at a rate of 5% per year (Fustier *et al* 2016), by 2040, global crude oil supply would be 43 459 thousand barrels per day. To maintain 2018 global production rates of 94 718 kbbls/day, an extra 51 258 kbbs/day of production would have to be delivered to the market. This is 4.17 times the 2018 Saudi Arabian production rate (12 287 kbbls/day – Appendix D). Alternatively, if the Saudi Arabian elephant field Ghawar continues to produce 3.8 million barrels a day, then an extra 13.5 new oil fields the same size of Ghawar would need to be discovered, then developed to operate by 2040, just to maintain 2018 rates of global supply.

If the projected global demand in 2040 is to be met (120 million barrels per day - EIA International Energy Outlook 2019 with projections to 2050), an extra 25 282 thousand barrels per day of consistent production capacity would have to be found in addition to the 2018 production capacity. To put this in perspective, this extra capacity would be a further 6.65 Ghawar fields.

In summary, to account for projected existing field decline (80% of existing reserves will decline at 5% per year) and to account for predicted growth of global demand in 2040 (120 million barrels a day - EIA International Energy Outlook 2019 with projections to 2050), a total of an additional 76 540 thousand barrels per day (or another 20 new Ghawar fields) needs to be discovered and developed (stating with exploiting existing reserves that are untapped).

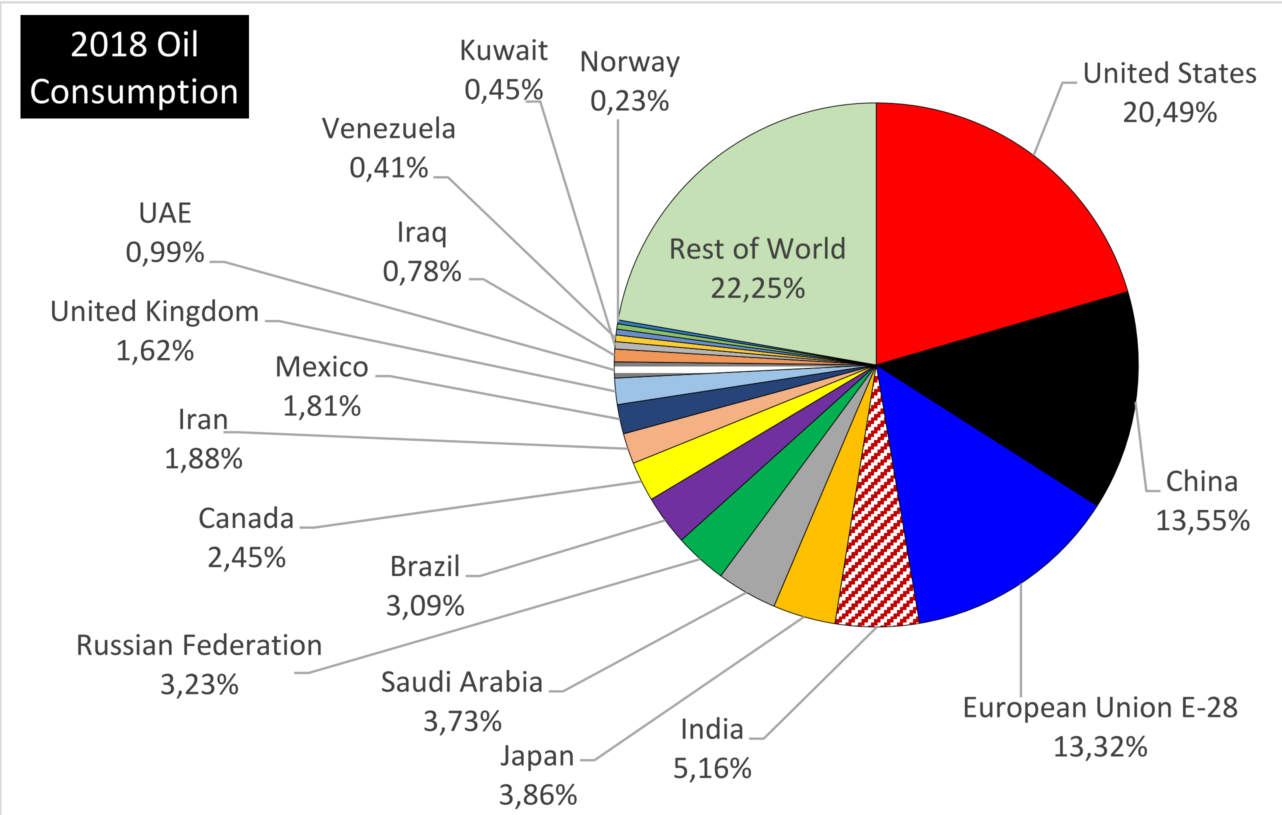

Figure 64. Oil consumption demand in 2018. Consumption of biogasoline (such as ethanol), biodiesel and derivatives of coal and natural gas are also included.
(Source: data from BP Statistical Review of World Energy 2019)

Figure 64 shows the market share for countries in 2018. The three main consumers are the United States, European Union and China, accounting for 47.4% of the global market.

Figure 65 shows the oil consumption between 1965 and 2018. Figure 65 shows the 2018 market share of consumption. Appendix C shows the oil consumption data between 1965 and 2018.

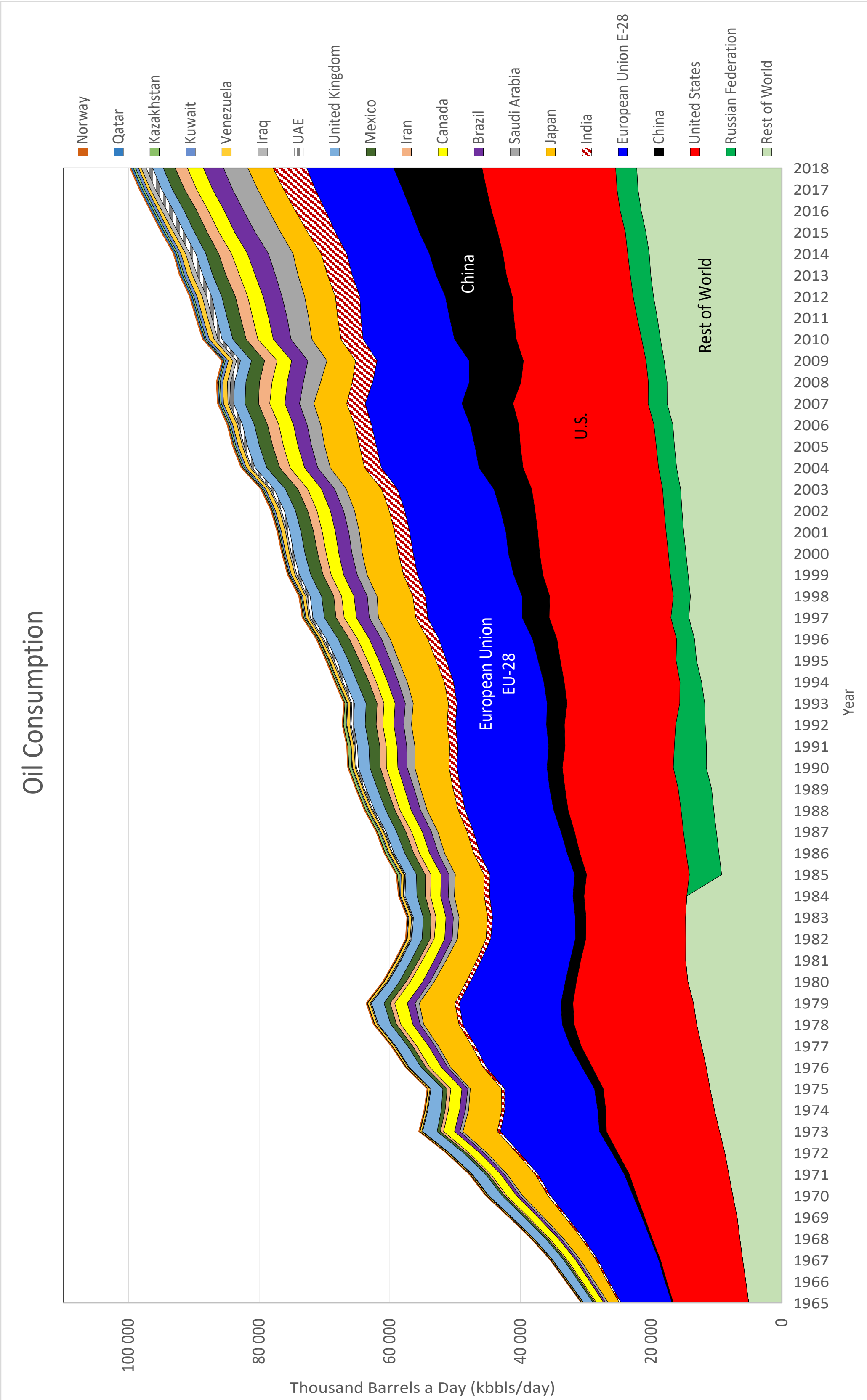

Figure 64 Oil consumption 1965 to 2018. Consumption of biogasoline (such as ethanol), biodiesel and derivatives of coal and natural gas are also included.
(Source: data from BP Statistical Review of World Energy 2019 and BP Statistical Review of World Energy 2011)

To illustrate the point that oil consumption is linked to GDP, compare the proportions shown in Figure 66 (GDP of major economies) to Figure 65 (oil consumption of the major economies). Gross Domestic Product (GDP) is a monetary measure of the market value of all the final goods and services produced in a specific time period, usually annually. GDP at purchaser's prices is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in 2018 U.S. dollars. Note that 3 major GDP market values are the same countries as the 3 major oil consumers.

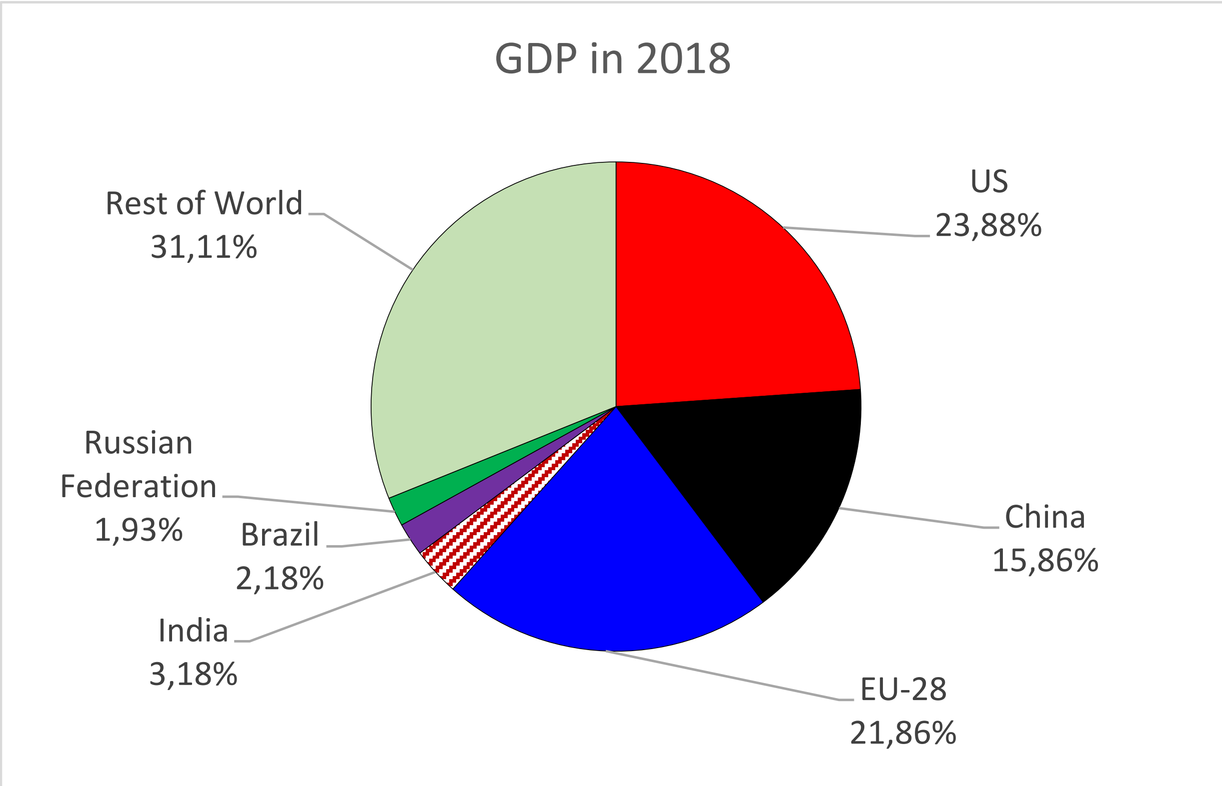

Figure 66. GDP in 2018, calculated in $USD 2018,
(Dollar figures for GDP are converted from domestic currencies using single year official exchange rates.)
(Source: World Bank national accounts data, and OECD National Accounts data files.)

4.1 Future oil demand scenarios

Much of the debate around long-term prospects for oil demand is dominated by the issue of penetration of the light duty vehicle (LDV) fleet by Electric Vehicles (EVs) to make obsolete the internal combustion engine (ICE) technology (IEA 2019). Of course this is one of the key uncertainties, but there are a few other important points to highlight (Fustier et al 2016):

- Passenger cars are only a part of the market: LDVs are only responsible for around a quarter of world oil demand.
- Other forms of transport (trucks, aviation, marine and rail) consume in total more than LDVs, and although substitution is happening, widespread disruption on the potential scale facing LDVs look far less achievable (Michaux 2020). Demand growth prospects for both aviation and commercial trucks look extremely strong across all the reference scenarios we assessed, driven mainly by non-OECD markets (Fustier et al 2016).
- Petrochemicals demand currently accounts for around 13% of global oil demand and has been a key source of growth; aggregate chemicals demand growth of ~50% (6mbd) by 2040 is probably feasible. All attempts to become more efficient have not delivered a reduction in volume demand.

Figures 68 to 76 show the prediction for future demand for oil, liquids and petroleum products, as published in the International Energy Outlook 2019 with projections to 2050 (EIA 2019 b). This is an analysis of long-term world energy markets in sixteen regions through 2050.

Many of these figures show data for OECD countries separate to the non-OECD countries. The Organization for Economic Co-operation and Development (OECD) is an intergovernmental economic organization with 36 member countries, founded in 1961 to stimulate economic progress and world trade.

The U.S. Energy Information Administration's (EIA) International Energy Outlook (IEO) Reference case projections is not considered a predictions of what is most likely to happen, but rather they are modeled projections under various alternative assumptions (EIA 2019 b). As stated in the EIA 2019 International Energy Outlook (IEO):

> *The Reference case reflects current trends and relationships among supply, demand, and prices in the future. It is a reasonable baseline case to compare with cases that include alternative assumptions about economic drivers, policy changes, or other determinants of the energy system to estimate the potential impact of these assumptions.*

The Reference case includes some anticipated changes over time:

- Expected regional economic and demographic trends, based on the views of leading forecasters
- Planned changes to infrastructure, both new construction and announced retirements
- Assumed incremental cost and performance improvements in known technologies based on historical trends

This case does not include some of the potential future changes:

- Changes to national boundaries and international agreements
- Major disruptive geopolitical or economic events
- Future technological breakthroughs

Changes to current policies as reflected in laws, regulations, and stated targets that indicate future activity.

World primary energy consumption is projected (EIA 2019 reference case) to rise by approximately 50% between 2018 and 2050 (Figure 67).

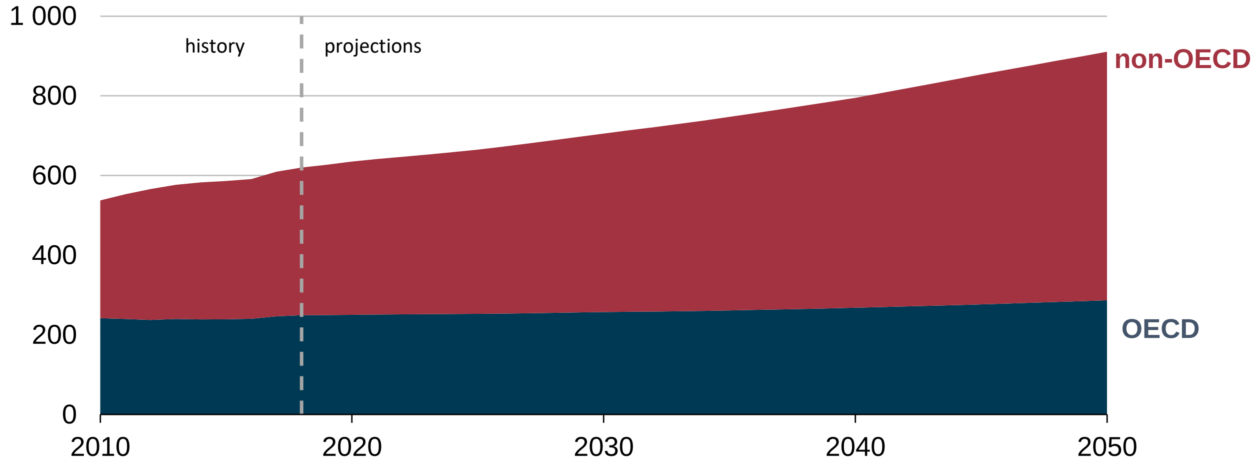

Figure 67. World primary energy consumption quadrillion British thermal units
(Source: EIA International Energy Outlook 2019 with projections to 2050)
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Figure 68 shows the predicted production of petroleum liquids by OPEC and non-OPEC group. Most of the future production is predicted to be in non-OPEC countries, where non-OPEC countries produce slightly more than half of crude oil output through the projection period, accounting for 55% of global production in 2050 (EIA International Energy Outlook 2019 with projections to 2050).

This predicted production of crude oil, lease condensate, natural gas plant liquids (NGPLs) and other liquid fuels from 2018 to 2050, reaching 127 million barrels per day (b/d) in 2050, or about 30% more than 2018 levels (EIA International Energy Outlook 2019 with projections to 2050). This prediction has global demand approximately 120 million barrels per day in 2040.

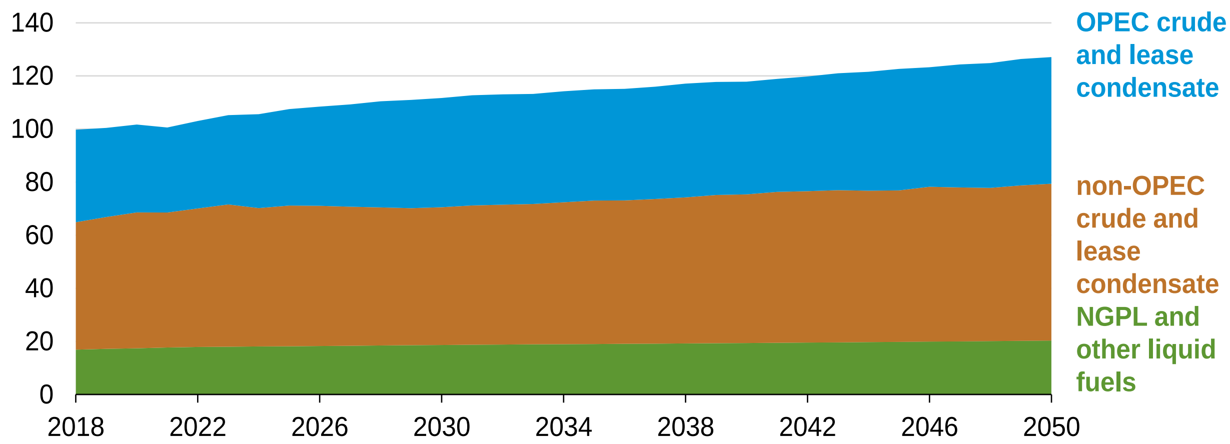

Figure 68. World petroleum and other liquid fuels production million barrels per day
(Source: EIA International Energy Outlook 2019 with projections to 2050)
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Figure 69 shows predicted global energy demand by sector. As can be seen, the industrial sector is the largest consumer of primary energy (accounting for more than half of demand).

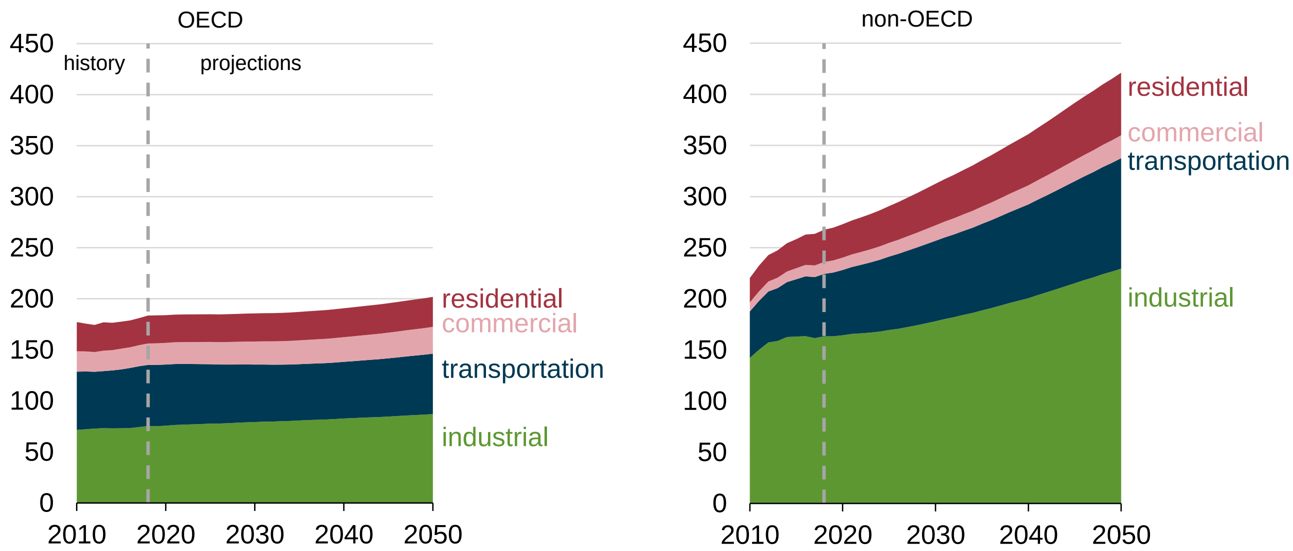

Figure 69. Energy consumption by sector quadrillion British thermal units
(Source: EIA International Energy Outlook 2019 with projections to 2050)
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The industrial sector, which includes refining, mining, manufacturing, agriculture, and construction, accounts for the largest share of energy consumption of any end-use sector—more than 50% of end-use energy consumption during the entire projection period. World industrial sector energy use increases by more than 30% from 2018 to 2050, reaching about 315 quadrillion British thermal units (Btu) by 2050.

As shown in in Figure 69, most of the increase in industrial sector energy use occurs in non-OECD nations. Industrial sector energy use in non-OECD countries grows by more than 1.0% per year in the Reference case compared with an increase of 0.5% per year in OECD countries. The persistent pattern of growth in energy demand being in non-OPEC countries, could be due to most industrial production being in those countries. This implies that OPEC countries have largely become consumers, and are now dependent on non-OPEC countries for supply of oil derived manufactured goods.

Transportation is the second largest sector of predicted primary energy demand. Liquid fuels, because of energy density, cost, and chemical properties, continue to be the predominant transportation fuel and an important industrial feedstock. The population growth in Africa, which nearly doubles from 2018 to 2050 in the Reference case, leads to an increase in travel demand and passenger vehicle travel.

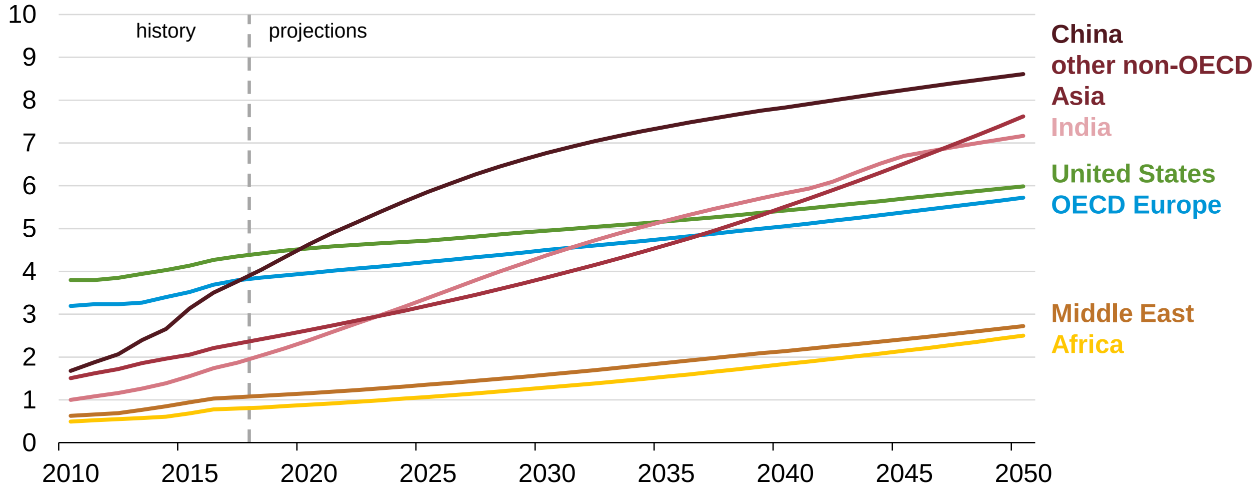

Figure 70. Passenger vehicle travel (select regions) trillion vehicle miles traveled
(Source: EIA International Energy Outlook 2019 with projections to 2050)

Figure 70 shows the predicted growth in passenger vehicles. Figure 71 shows the predicted growth in light-duty vehicles.

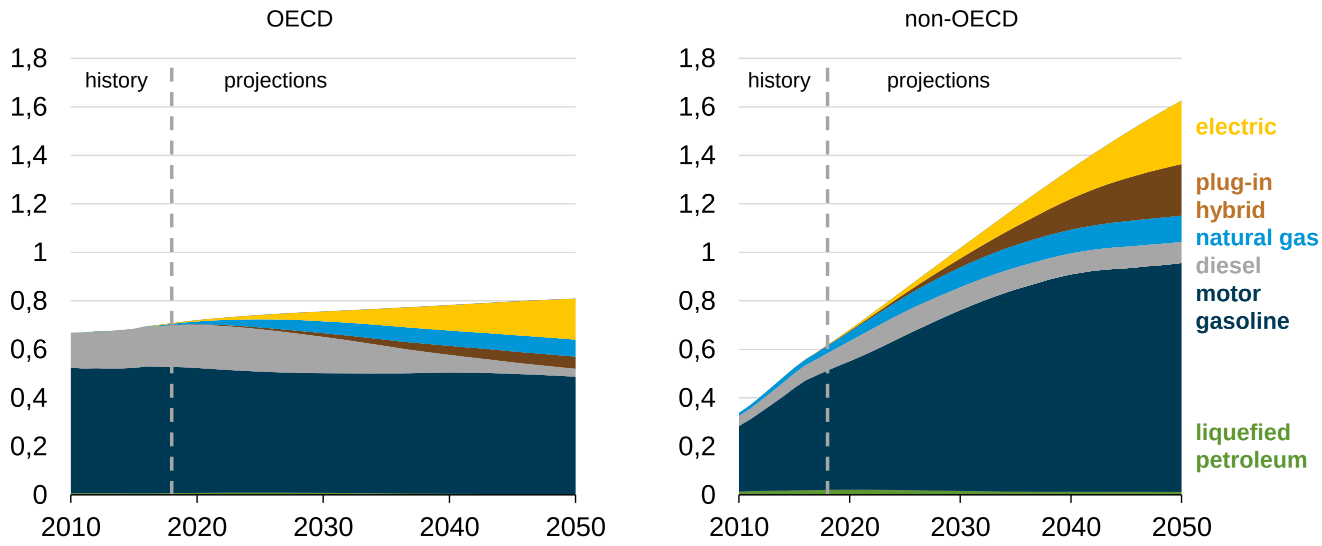

Figure 71. Light-duty vehicle stock billion vehicles
(Source: EIA International Energy Outlook 2019 with projections to 2050)
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It is predicted that from 2018 to 2050, the light-duty vehicle fleet transitions from primarily gasoline and diesel vehicles; by 2050, electricity and natural gas powers over one-third of the light-duty vehicle fleet in the Reference case (EIA International Energy Outlook 2019 with projections to 2050). Much of the decline in diesel consumption in OECD countries comes as Europe gradually transitions from diesel powered light-duty vehicles to electric vehicles. Because stocks reflect existing vehicles, the rate of growth in vehicle stocks is lower than that of new vehicle sales. Many regions, including non-OECD Europe and Eurasia, the Middle East, and Africa, maintain mostly petroleum-fueled light-duty fleets throughout the projection period. These regions continue to operate largely gasoline and diesel vehicle fleets because of many reasons, such as cost, infrastructure, climate, and geography.

The worldwide transportation sector is predicted to account for 59% of total end-use sector liquid fuels (residual fuel oil, diesel, motor gasoline, and jet fuel) consumption in 2050 (EIA International Energy Outlook 2019 with projections to 2050). This is about the same as in 2018. Within the transportation sector, the use of refined petroleum and other liquid fuels is predicted to continue to increase through 2050, but its share decreases from 94% to about 82% as alternative fuel use slowly increases. Motor gasoline, including biofuel additives such as ethanol, remains the primary fuel for transportation purposes, accounting for 32% of the world's transportation-related energy use in 2050. A continuing global rise in air travel demand leads to jet fuel consumption more than doubling from 2018 to 2050.

The EIA predicts that global liquid fuels demand will increase by more than 20% between 2018 and 2050, with total consumption reaching more than 240 quadrillion British thermal units (Btu) in 2050. Finished petroleum products such as motor gasoline, diesel, and jet fuel are increasingly consumed in the transportation sector. Other liquids are also consumed in large quantities, including natural gas plant liquids (NGPL) as an industrial feedstock.

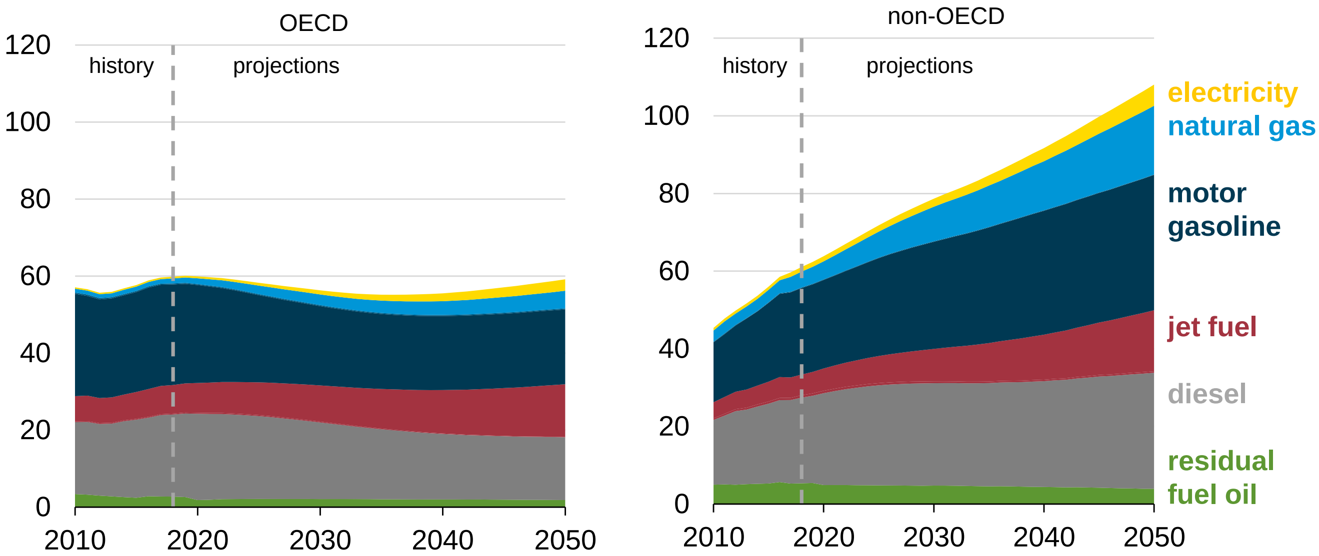

Figure 72. Transportation energy consumption British thermal units
(Source: EIA International Energy Outlook 2019 with projections to 2050)

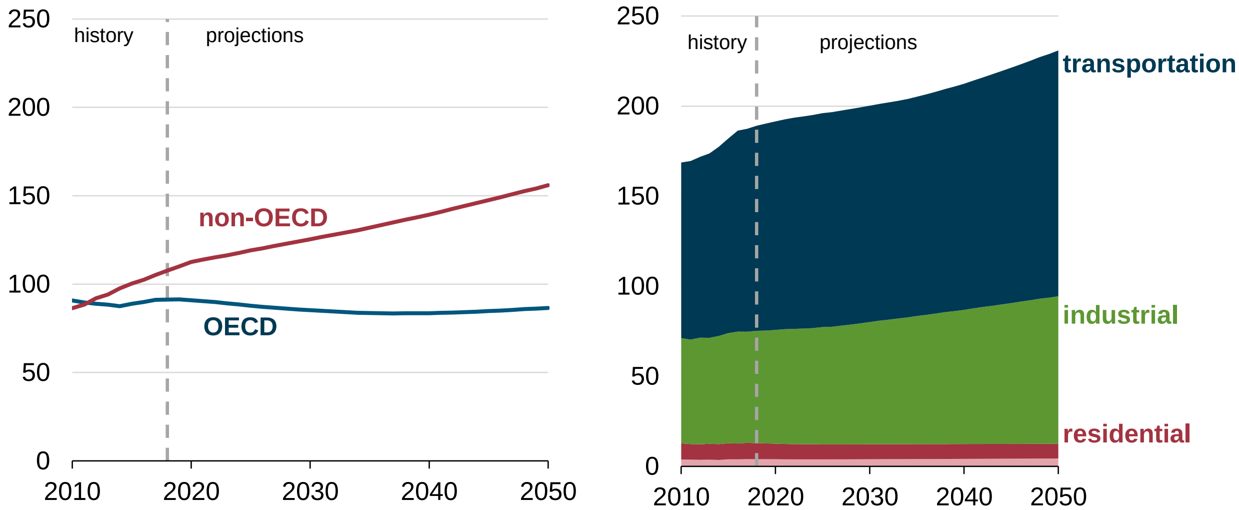

Figure 73. Petroleum and other liquids consumption British thermal units
(Source: EIA International Energy Outlook 2019 with projections to 2050)

Figures 74 and 75 show predicted global consumption of petroleum products. Non-OECD countries account for nearly all growth in liquid fuels consumption between 2018 and 2050, as growing populations and expanding economies increasingly consume energy. Non-OECD liquid fuels consumption increases 45% during the projection period, growing from 108 quadrillion Btu in 2018 to 156 quadrillion Btu by 2050. Non-OECD Asia accounts for about three-quarters of the global increase in liquid fuels consumption. India, in particular, experiences rapid industrial growth and increased demand for motorized transportation.

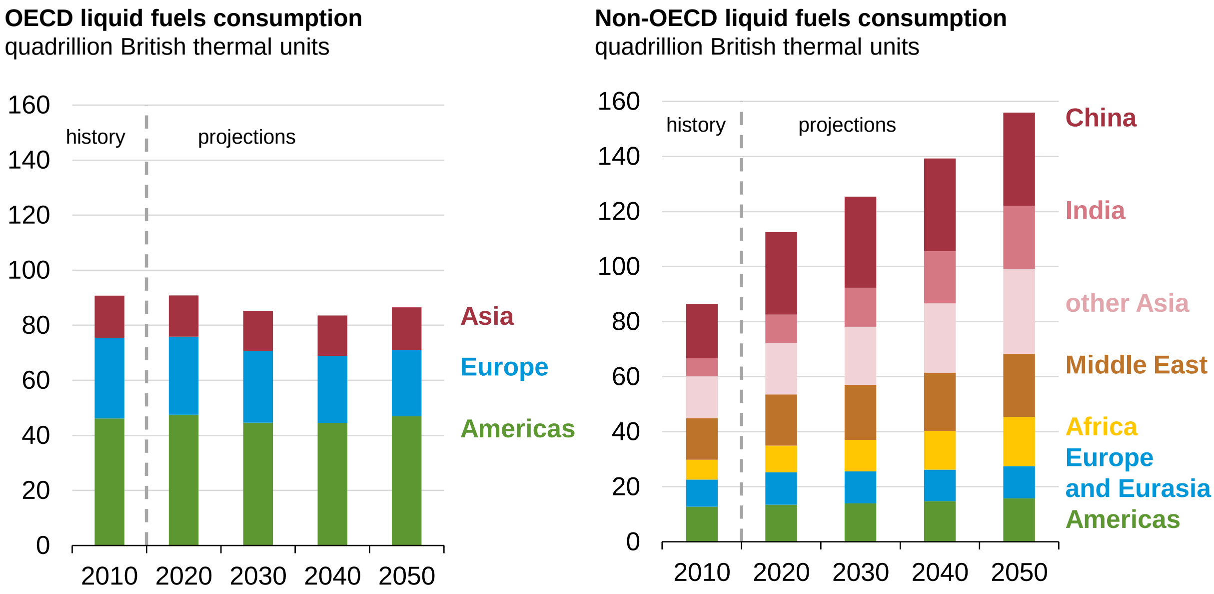

Figure 74. World petroleum and other liquid fuels consumption British thermal units
(Source: EIA International Energy Outlook 2019 with projections to 2050)

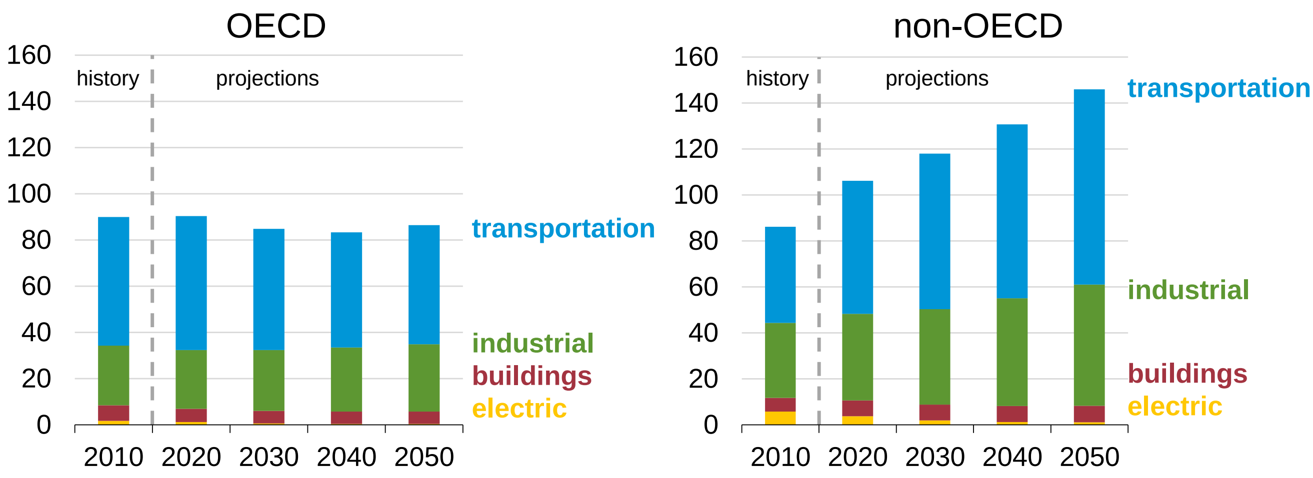

Figure 75. Refined petroleum and other liquids consumption by sector British thermal units
(Source: EIA International Energy Outlook 2019 with projections to 2050)

Across the range of the demand scenarios studied (HSBC 2016), none of the “reference cases” (that the banking finance sector use to manage capital investment) point to a peak in oil demand through the forecasting period (to 2040), and even the most conservative of these studies points to 2040 global demand more than 8mbd above that of 2015. The broad consensus amongst energy commentators and forecasters is that global oil demand is likely to continue growing for a period, driven by rising prosperity in fast-growing developing economies.

Ideally, that pace of growth is likely to slow overtime and eventually plateau, as efficiency improvements accelerate and a combination of technology advances, policy measures and changing social preferences lead to an increasing penetration of other fuels in the transportation sector. Many of these external influences are not certain in their capacity to deliver real change though. Some projections show oil demand peaking during the period they consider, others beyond their forecast horizons.

Figure 76 shows a series of demand scenarios from alternatives sources, based around declining demand associated with the Electric Vehicle (EV) revolution. Only one scenario considers oil production declining at 3% per annum (Fustier 2016).

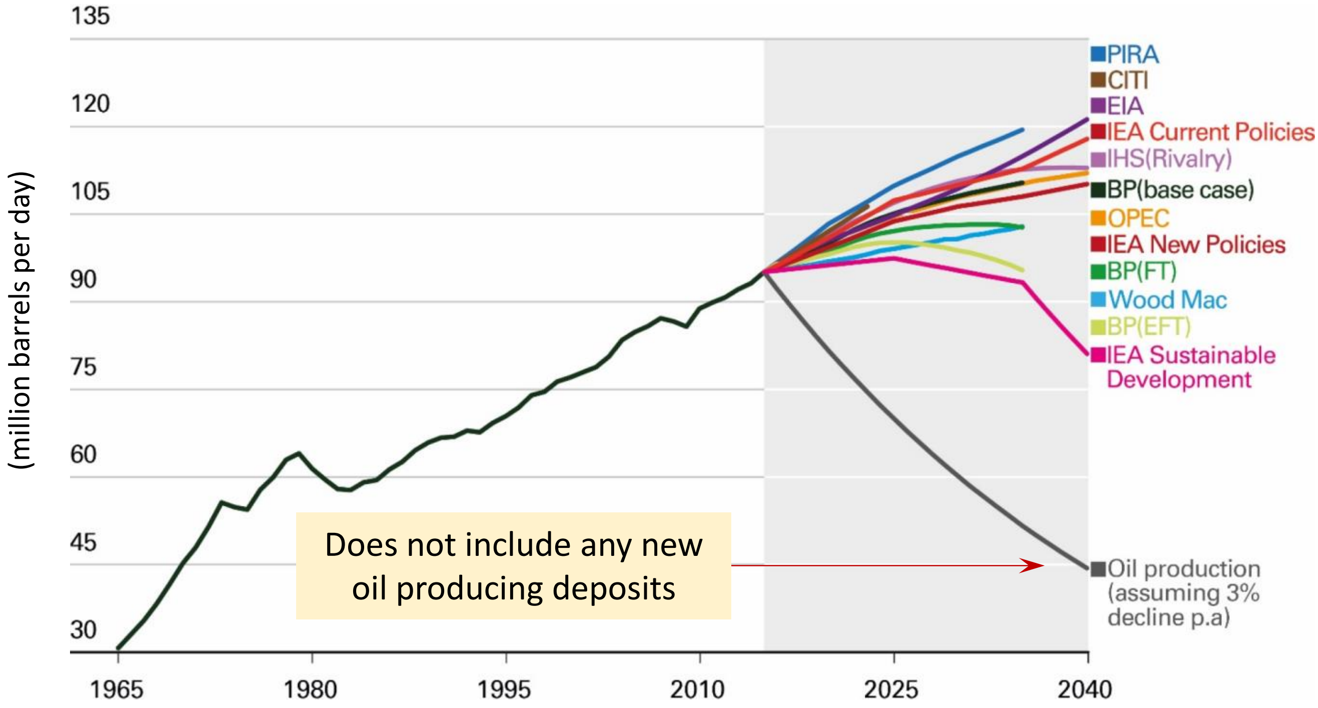

Figure 76. A range of forecast for oil demand over the next 25-30 years from a variety of public and private sector organizations (Source: BP Energy Outlook 2018)

Oil demand is still growing by ~1mbd every year, and no central scenarios that are publically accessible see oil demand peaking before 2040. The global supply mix relies increasingly on small fields, where the typical new oilfield size has fallen from 500-1,000mb 40 years ago to only 75mb in just this decade.

New discoveries are limited. In the year 2015, the exploration success rate hit a record low of 5%, and the average discovery size was 24 million barrels. Improved production & drilling efficiency can reduce declines, but only temporarily (Fustier et al. 2016). The volume of new discoveries reached an all-time low in 2017, not accounting how much of that is economically viable.

The point at which oil demand is likely to peak is very uncertain and depends on many assumptions, and as such is very difficult to predict. Existing reserves in 2018 was reported as 1729 billion barrels (BP Statistical Review of World Energy 2019, Appendix E). Some of these reserves are untapped, which is how many new operations have been brought online while net reserve additions actually peaked in 1981 (see Figure 221 and Section 13).

Even once oil demand has peaked, consumption is unlikely to fall very sharply (Fustier *et al* 2016). This implies the global demand is likely to consume significant amounts of oil for the foreseeable future (EIA International Energy Outlook 2019 with projections to 2050), with no real practical alternative visible in planning (Michaux 2020).

4.2 Oil import/export profile for oil consumers

Figure 77 shows the yearly consumption of oil subtracted from the production of oil for the three largest economies, the United States, European Union and China. Europe is heavily dependent on crude oil imports (a deficit of 11 769 kbbls/day in 2018 or 88.5% of EU demand). The United States is a net importer of crude oil, in spite of the success of the tight oil plays being developed since 2006 (shown as the sharp upward movement from 2006 in Figure 87). The United States deficit of crude oil in 2018 was of 5 145 kbbls/day in 2018 or 25.2% of U.S. demand. China was a net exporter of crude oil and was self-sufficient until 1993. Since then, China has become heavily dependent on crude oil imports (a deficit in 2018 of 9 727 kbbls/day, or 72% of Chinese demand). On one hand, China now represents the bulk of the real economy (similar to the US position in 1944 when the Bretton-Woods agreement was signed). Oil has can be seen correlates with the ability for an economy to do useful physical work (the real economy). The data for Figure 77 is shown in Appendix C and D.

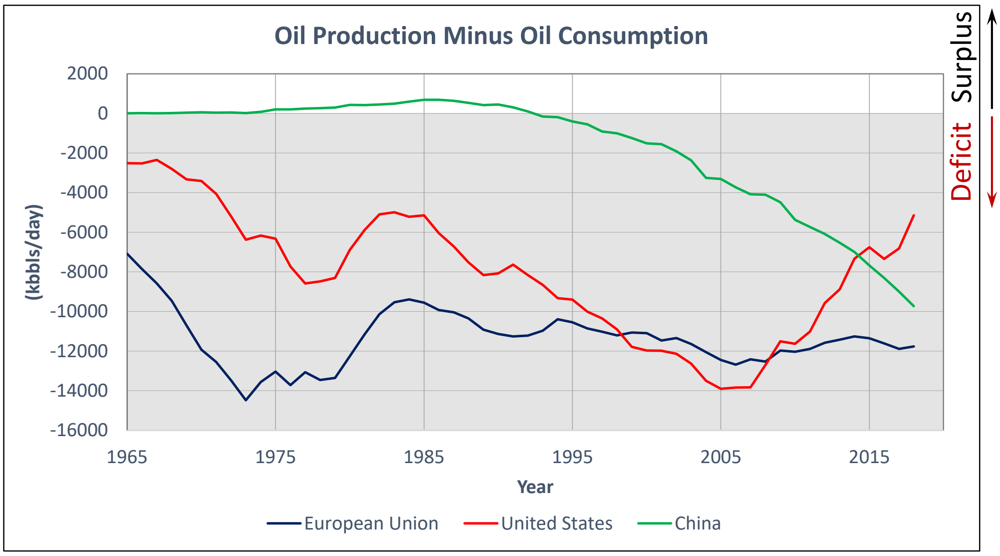

Figure 77. The net dependency of EU, US and China on oil imports
(Source: data from BP Statistical Review of World Energy 2019 and BP Statistical Review of World Energy 2011)

The three economies shown in Figure 77 represent 65% of the global GDP in 2018 (Global GDP in 2018 was 85.8 trillion, where the European Union's GDP was estimated to be $18.8 trillion (nominal) in 2018, representing ~22% of global economy (Nominal global GDP), United States GDP: $21.4 trillion, or 25% of global, China GDP: $15.5 trillion, or 18.1% of Nominal global GDP. Source: World Bank). This implies that the stability of economies for 65% of world GDP is dependent on oil imports from other countries. This shows how fragile the energy system is and how close to inelastic the global system could become.

Figures 78 to 82 show the production, consumption and net import requirements for the largest consumers in the oil market. The countries shown in Figure 78 to 82 represent 55.6% of consumption in the 2018 global oil market.

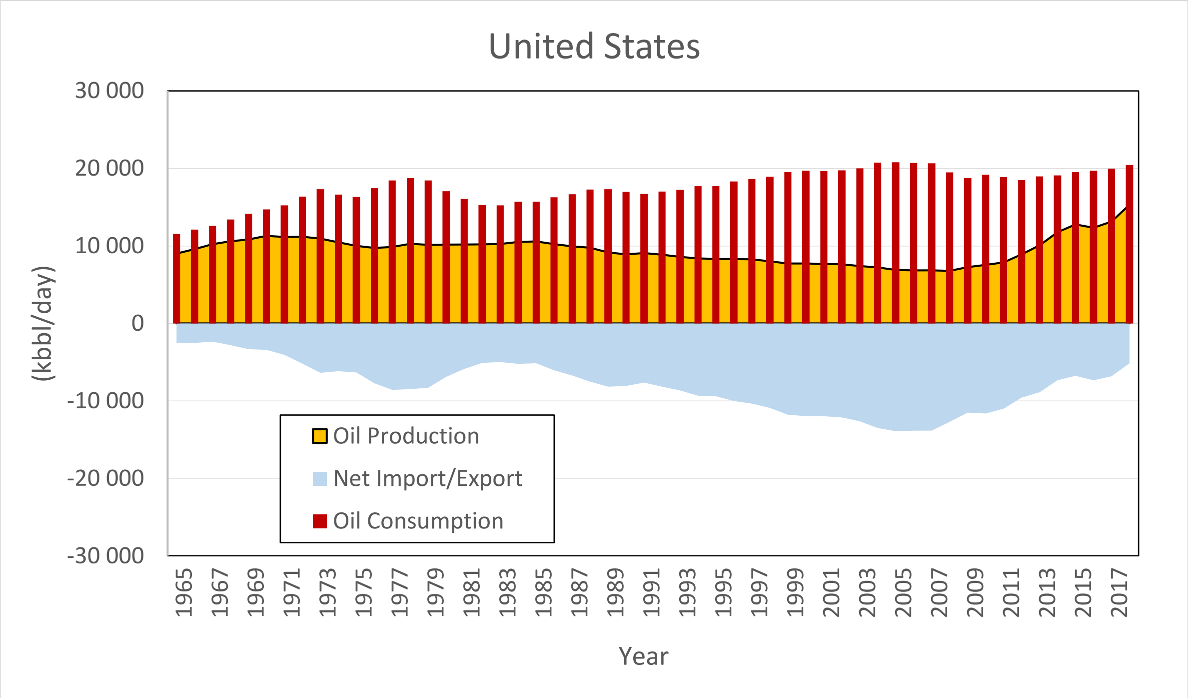

Figure 78. United States oil consumption, production and net import
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

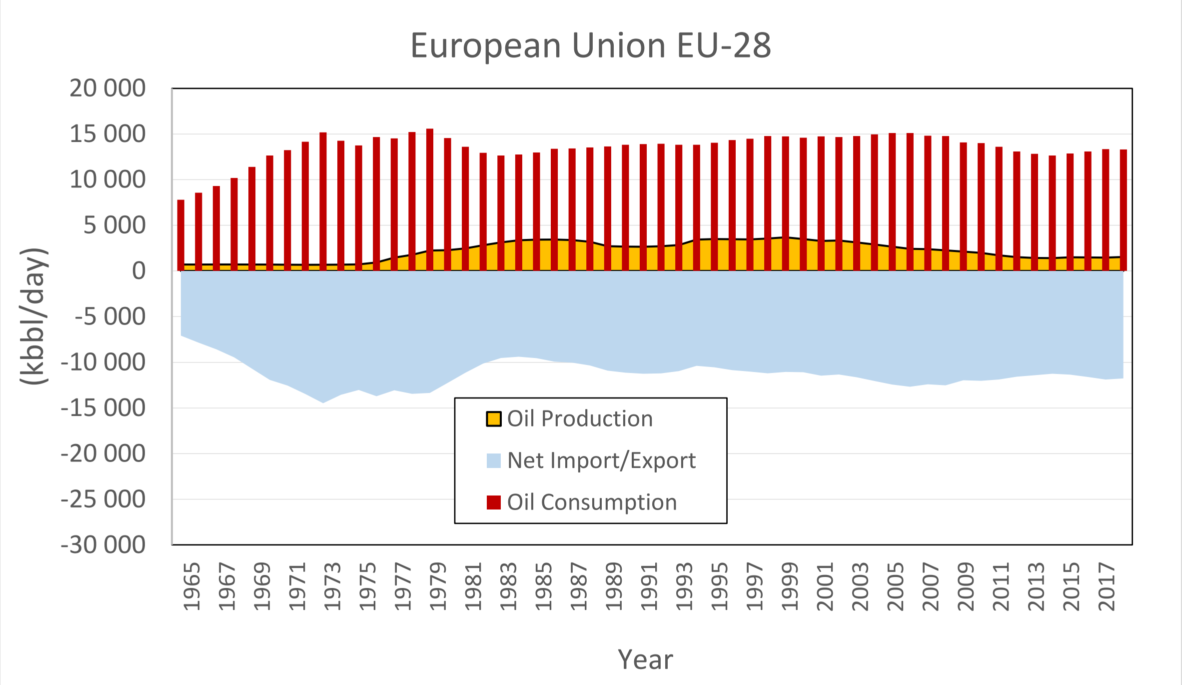

Figure 79. European Union oil consumption, production and net import
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

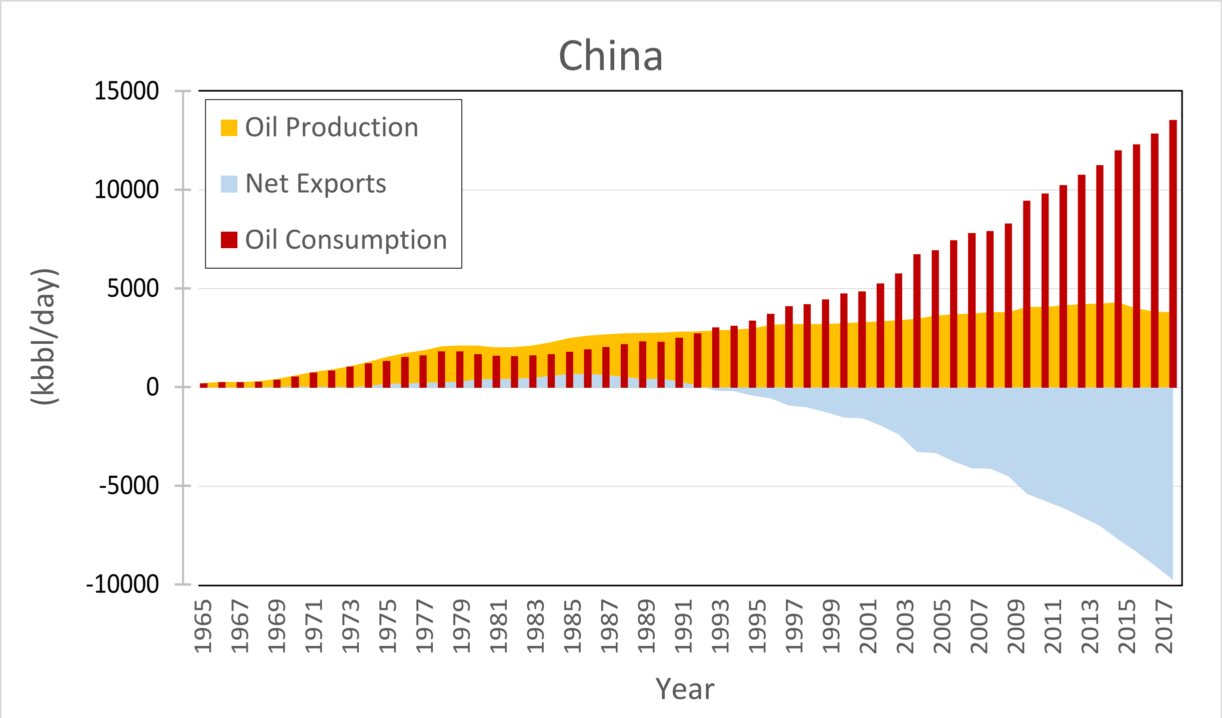

Figure 80. Chinese oil consumption, production and net import
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

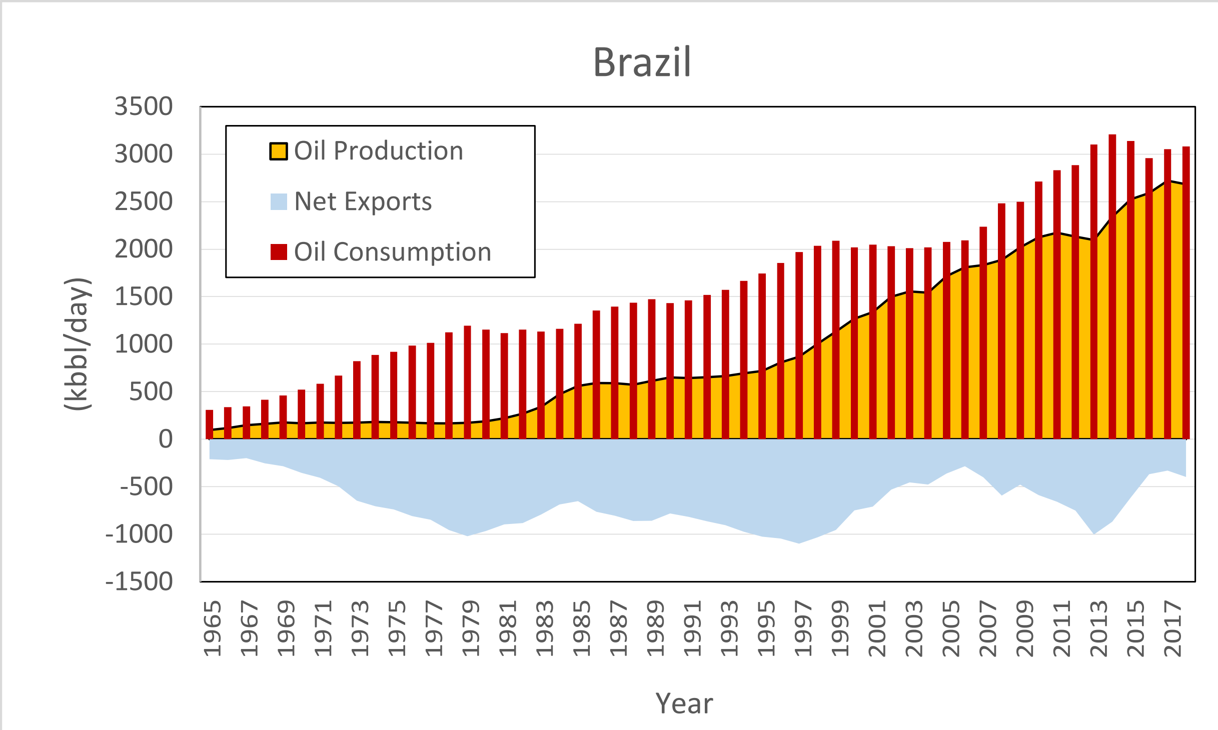

Figure 81. Brazilian oil consumption, production and net import
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

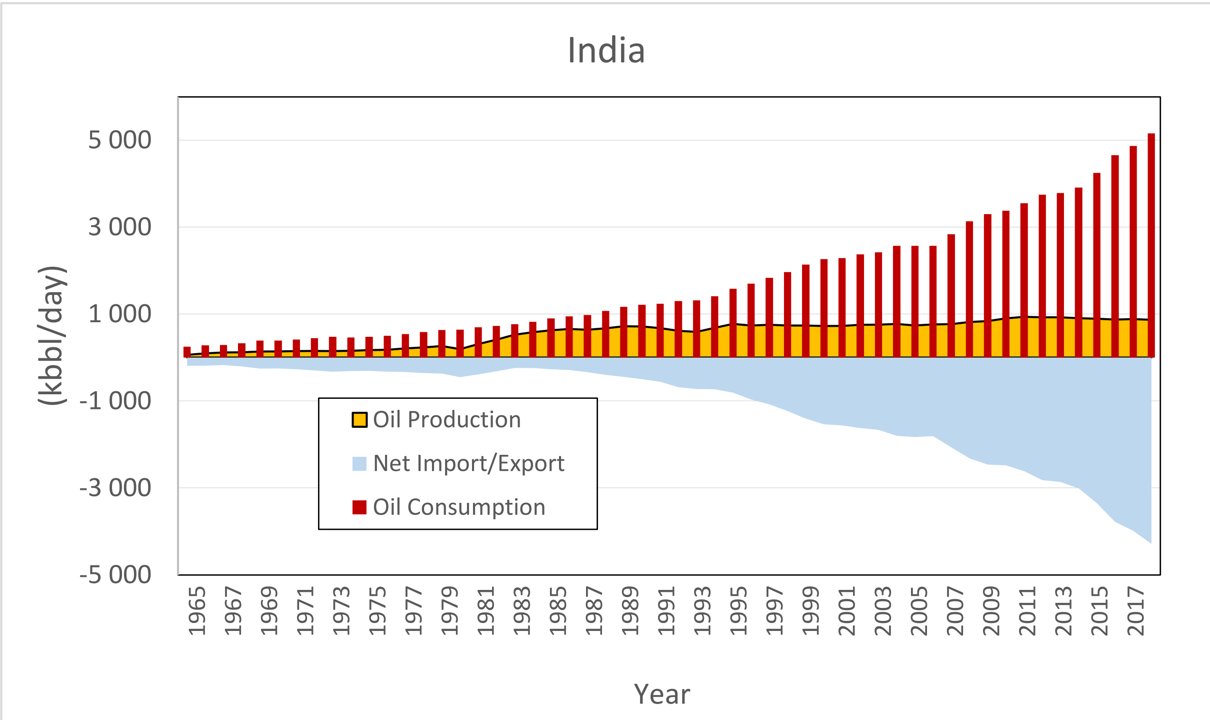

Figure 82. Indian oil consumption, production and net import
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

4.3 Increased demand from emerging economies

All of the demand scenarios discussed in this report so far have been based around assumptions that the world will continue as it has for the last few decades. The progression of the United States and the European Union (a large portion of the 'developed' world) has been relatively known, where the projected future footprint has been understood by the global market. However, each of these economies are heavily dependent on raw materials of all kinds being imported.

What is also happening is there are a number of emerging economies that are projected to evolve in complexity, with the objective of becoming developed economies in a similar profile to the Germany (Germany has a high GDP, a complex and sophisticated manufacturing sector, high standard of living, a high rate of application of renewable energy sources, and has complex developed infrastructure).

Economies of note are Brazil, Russia, India and China, which represent 23% of 2018 global GDP, and 41% of global population in 2018. Table 8 and Figure 83 show an estimation of the projected oil consumption demand, if these economies developed the same industrial profile to Germany.

Table 8. Projected oil consumption as all economies become as developed as the German Economy (Source: data from BP Statistical Review of World Energy 2019, Appendix DC & FC, World Bank data, United Nations, Department of Economic and Social Affairs, Population Division (2017). World Population Prospects: The 2017 Rev)

Country	Population 2018 (000's)	Oil Consumption in 2018 (kbbls/day)	2018 oil consumption per capita (kbbls/day/capita)	Oil consumption at German 2018 rate per capita (kbbls/day/capita)
Brazil	208 500	3 081	0,0148	5 945
Russia	146 900	3 228	0,0220	4 189
India	1 354 000	5 156	0,0038	38 606
China	1 392 730	13 525	0,0097	39 711
Germany	81 402	2 321	**0,0285**	
World	7 594 000	99 843	0,0131	216 526

If the BRIC economies are successful in becoming as industrially developed as Germany in 2018, an extra 63460 thousand barrels of oil a day (63.5 million barrels a day) would have to be brought to the market representing a 254% increase in oil consumption on the 2018 daily rate. To put this in perspective, an extra 16.7 new oil fields, the size of the Saudi Arabia Ghawar elephant field (producing 3.8 million barrels a day, would need to be discovered, developed and extra refining capacity commissioned.

If the entire global system was successful in developing industrially similar capacity to Germany in 2018, extra 116 683 thousand barrels of oil a day (116.7 million barrels a day) would have to be brought to the market. This would need an extra 30.1 new oil fields, the size of the Saudi Arabia Ghawar elephant field. This represents a 117% expansion of oil consumption on top of global 2018 demand.

Due to the rate of oil deposit discovery falling since the mid 1960's (see Section 13), and the record low for discovery being in 2017 (Rystad 2018, Davis 2017), this is probably not possible.

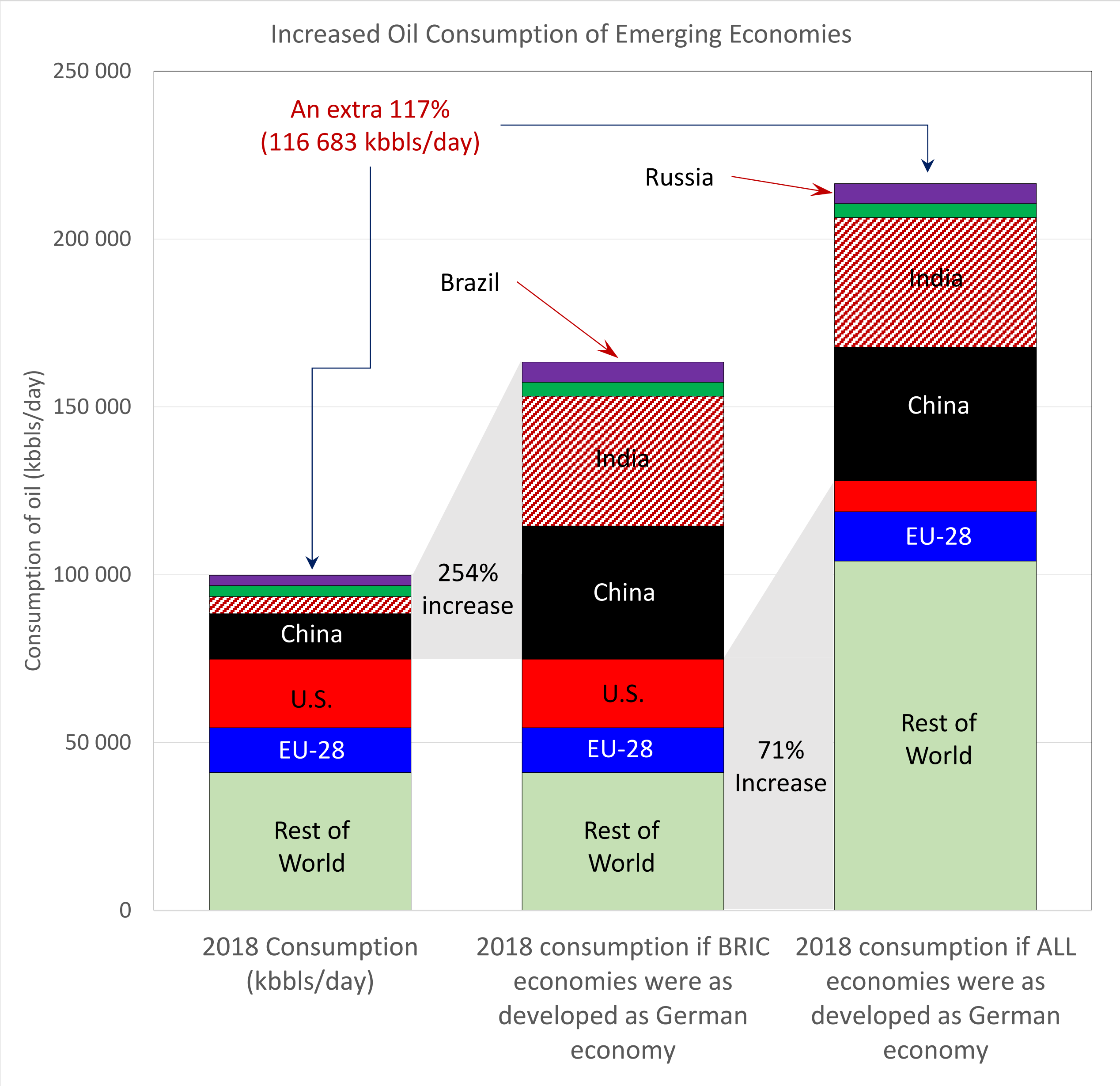

Figure 83. Projected oil consumption as all economies become as developed as the German Economy (Source: data from BP Statistical Review of World Energy 2019, Appendix C and D, World Bank data, United Nations, Department of Economic and Social Affairs, Population Division (2017). World Population Prospects: The 2017 Rev)

5 CRUDE OIL PRODUCTION

Figure 84 and Table 9 show the global crude oil production by country. Figure 84 shows oil production by country between 1965 and 2018. As can be seen, the international market is dominated by three major producers, the United States, Saudi Arabia and the Russian Federation. Table 9 also shows the net export after consumption of the producing country is accounted for. The three biggest net producers are Saudi Arabia, Russian Federation and Iraq.

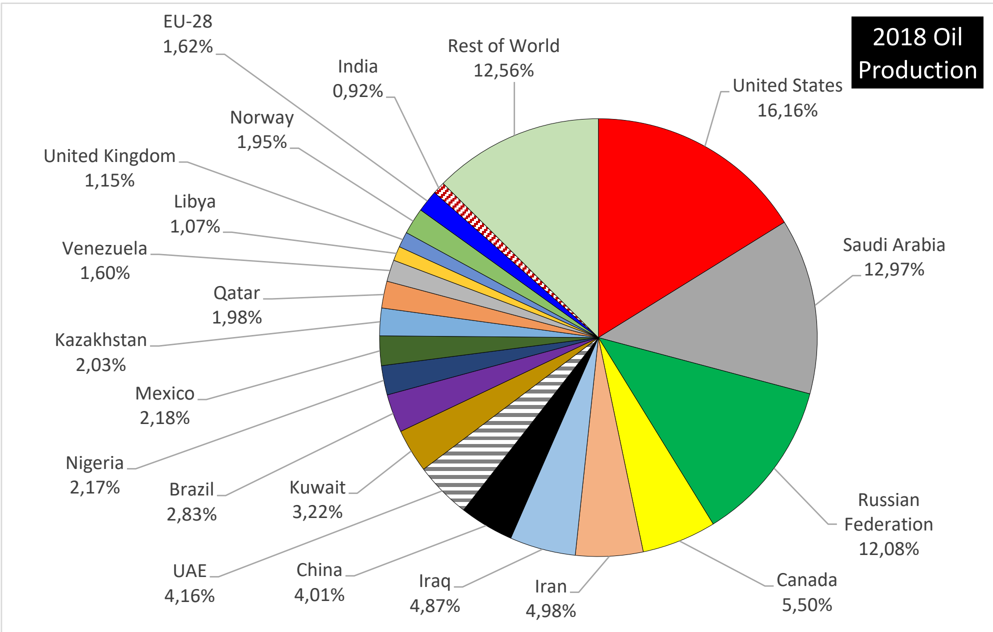

Figure 84. Global crude oil production in 2018
(Source: BP Statistical review of World Energy 2019)

Table 9. Crude oil production in 2018. (Source: BP Statistical review of World Energy 2019)

Country	Proven Reserves (bllion barrels)	Production (kbbls/day)	Consumption (kbbls/day)	Net Export (kbbls/day)
United States	61,2	15 311	20 456	-5 145
Saudi Arabia	297,7	12 287	3 724	8 563
Russian Federation	106,2	11 438	3 228	8 210
Canada	167,8	5 208	2 447	2 761
Iran	155,6	4 715	1 879	2 836
Iraq	147,2	4 614	777	3 837
China	25,9	3 798	13 525	-9 727
United Arab Emirates	97,8	3 942	991	2 951
Kuwait	101,5	3 049	451	2 598
Brazil	13,4	2 683	3 081	-398
Nigeria	37,5	2 051		
Mexico	7,7	2 068	1 812	256
Kazakhstan	30,0	1 927	357	1 570
Qatar	25,2	1 879	328	1 551
Venezuela	303,3	1 514	409	1 105
Libya	48,7	1 010		
United Kingdom	2,5	1085	1618	-533
Norway	8,6	1 844	234	1 610
Rest of World	91,9	14 295	44 526	
Global Total	1 729,7	94718	99843	

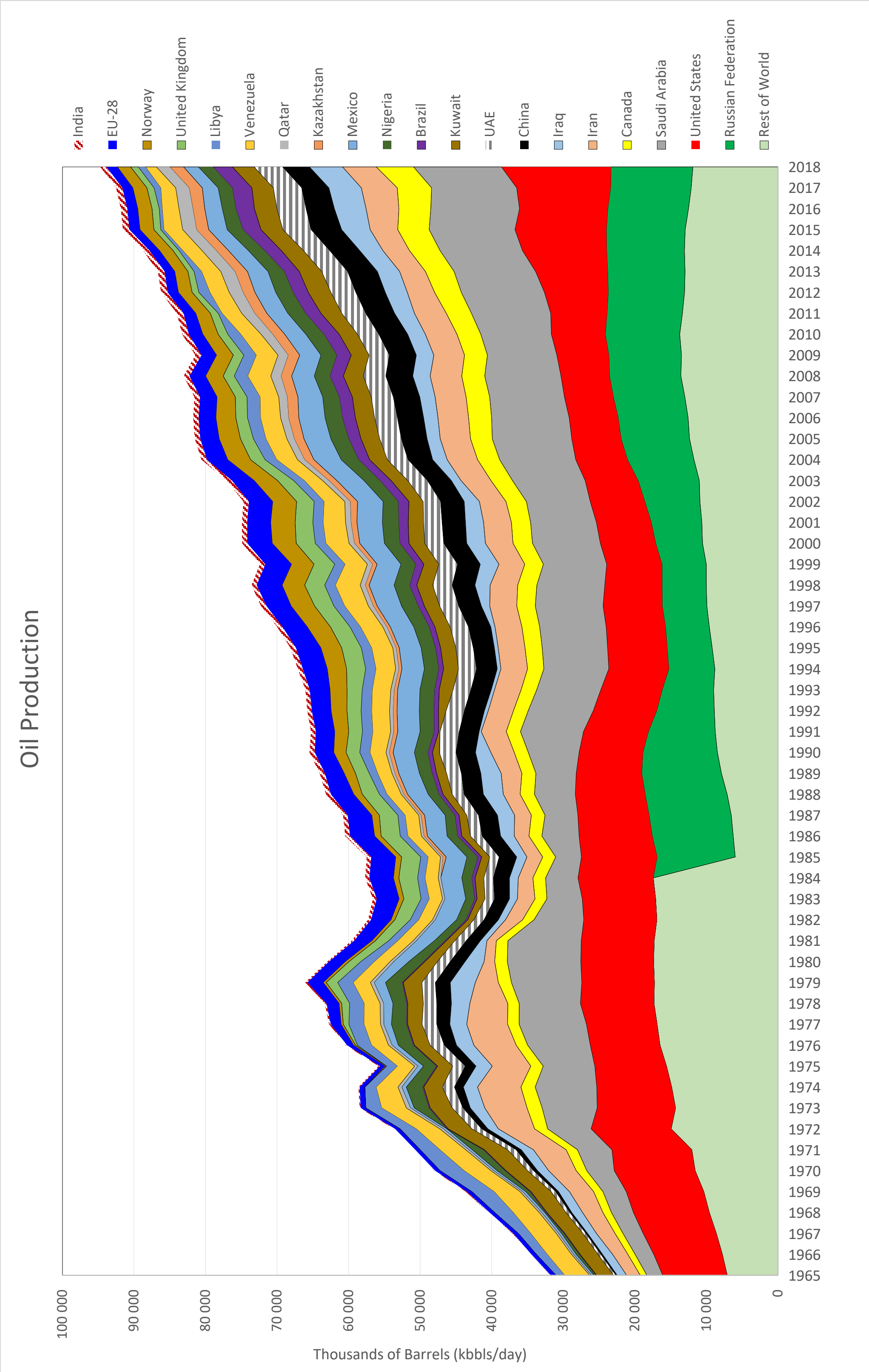

Figure 85. Global crude oil production in 2018. Includes crude oil, shale oil, oil sands, condensates (both lease condensate and gas plant condensate) and NGLs (natural gas liquids – ethane, LPG and naphtha separated from the production of natural gas). Excludes liquid fuels from other sources such as biomass and derivatives of coal and natural gas. (Source: BP Statistical review of World Energy 2019 and BP Statistical review of World Energy 2011)

Examining just oil production by ranking the producers is not appropriate. Each of the producing countries (often with nationalized oil companies doing the producing) also have a consumption rate. Foucer and Brown 2007, developed the Export Land Model, where the rising oil consumption of oil producers were considered in an internal loop affecting oil export. The two basic conclusions of their work were:

1. For oil exporting nations, the higher the level of their domestic oil consumption as a fraction of their production, the more the changes in production volume will amplify the resulting change in net exports.

2. The domestic oil consumption of oil exporting nations will, over long periods, tend to grow faster than the domestic oil consumption of oil importers because of the windfall effect of oil revenues, and will tend to continue to grow even past the production peak, especially whilst net exports remain positive. Only a few oil producers like Saudi Arabia were able to net increase oil production in this fashion.

In a country that is past its peak of oil production, the above dynamics operate together to cause the net export decline rate to be much higher than the production decline rate. If this effect appears simultaneously in many exporters, for instance due to global peak oil, the accelerated decline in net exports will disproportionately strike nations which are heavily dependent on imported oil. Since 2007, the shale oil revolution has stabilized the global oil markets. This highlights the dependency of the global oil demand now has on the U.S. tight oil sector with its capacity to expand production. Table 10 shows the net change over 5 years, 10 years and 20 years for the major oil producers.

Table 10. (1 of 2). Change in net export over time for producers
(Source: BP Statistical review of World Energy 2019 and BP Statistical review of World Energy 2011)

Action	Country	1998 (kbbls/day)	2008 (kbbls/day)	2013 (kbbls/day)	2018 (kbbls/day)	20 year total change	10 year total change	5 year total change
Production	Mexico	3499	3165	2875	2068	-40,9 %	-34,7 %	-28,1 %
Consumption	Mexico	1868	2080	2034	1812	-3,0 %	-12,9 %	-10,9 %
Net Export/Import	Mexico	1631	1085	841	256	-84,3 %	-76,4 %	-69,6 %
Production	Kazakhstan	537	1485	1737	1927	258,9 %	29,8 %	10,9 %
Consumption	Kazakhstan	173	240	260	357	106,5 %	48,8 %	37,3 %
Net Export/Import	Kazakhstan	364	1245	1477	1570	331,3 %	26,1 %	6,3 %
Production	Qatar	701	1432	1991	1879	167,9 %	31,2 %	-5,6 %
Consumption	Qatar	52	178	287	328	531,8 %	84,3 %	14,3 %
Net Export/Import	Qatar	650	1254	1704	1551	138,8 %	23,7 %	-9,0 %
Production	Venezuela	3480	3228	2680	1514	-56,5 %	-53,1 %	-43,5 %
Consumption	Venezuela	479	716	782	409	-14,6 %	-42,9 %	-47,7 %
Net Export/Import	Venezuela	3001	2512	1898	1105	-63,2 %	-56,0 %	-41,8 %
Production	United Kingdom	2807	1549	864	1085	-61,4 %	-30,0 %	25,6 %
Consumption	United Kingdom	1743	1738	1532	1618	-7,2 %	-6,9 %	5,6 %
Net Export/Import	United Kingdom	1064	-189	-668	-533	-150,1 %	182,0 %	-20,2 %
Production	Norway	3138	2458	1832	1844	-41,2 %	-25,0 %	0,7 %
Consumption	Norway	219	218	230	234	6,7 %	7,3 %	1,7 %
Net Export/Import	Norway	2919	2240	1602	1610	-44,8 %	-28,1 %	0,5 %

Table 10. (2 of 2). Change in net export over time for producers
(Source: BP Statistical review of World Energy 2019 and BP Statistical review of World Energy 2011)

Action	Country	1998 (kbbls/day)	2008 (kbbls/day)	2013 (kbbls/day)	2018 (kbbls/day)	20 year total change	10 year total change	5 year total change
Production	United States	8011	6783	10073	15311	91,1 %	125,7 %	52,0 %
Consumption	United States	18917	19490	18961	20456	8,1 %	5,0 %	7,9 %
Net Export/Import	United States	-10906	-12707	-8888	-5145	-52,8 %	-59,5 %	-42,1 %
Production	Saudi Arabia	9502	10665	11393	12287	29,3 %	15,2 %	7,8 %
Consumption	Saudi Arabia	1489	2622	3451	3724	150,0 %	42,0 %	7,9 %
Net Export/Import	Saudi Arabia	8012	8043	7942	8563	6,9 %	6,5 %	7,8 %
Production	Russian Federation	6169	9965	10807	11438	85,4 %	14,8 %	5,8 %
Consumption	Russian Federation	2613	2861	3134	3228	23,5 %	12,8 %	3,0 %
Net Export/Import	Russian Federation	3555	7104	7673	8210	130,9 %	15,6 %	7,0 %
Production	Canada	2672	3207	4000	5208	94,9 %	62,4 %	30,2 %
Consumption	Canada	1898	2323	2398	2447	28,9 %	5,3 %	2,0 %
Net Export/Import	Canada	774	884	1602	2761	256,7 %	212,3 %	72,3 %
Production	Iran	3855	4415	3609	4715	22,3 %	6,8 %	30,6 %
Consumption	Iran	1198	1925	2064	1879	56,8 %	-2,4 %	-9,0 %
Net Export/Import	Iran	2657	2490	1545	2836	6,8 %	13,9 %	83,6 %
Production	Iraq	2121	2428	3103	4614	117,6 %	90,0 %	48,7 %
Consumption	Iraq	261	481	716	777	198,2 %	61,5 %	8,5 %
Net Export/Import	Iraq	1860	1947	2387	3837	106,3 %	97,1 %	60,7 %
Production	China	3212	3814	4216	3798	18,2 %	-0,4 %	-9,9 %
Consumption	China	4216	7914	10750	13525	220,8 %	70,9 %	25,8 %
Net Export/Import	China	-1004	-4100	-6534	-9727	868,8 %	137,2 %	48,9 %
Production	UAE	2687	3113	3577	3942	46,7 %	26,6 %	10,2 %
Consumption	UAE	403	603	852	991	145,7 %	64,3 %	16,3 %
Net Export/Import	UAE	2284	2510	2725	2951	29,2 %	17,6 %	8,3 %
Production	Kuwait	2232	2781	3125	3049	36,6 %	9,6 %	-2,4 %
Consumption	Kuwait	218	406	508	451	106,7 %	11,1 %	-11,2 %
Net Export/Import	Kuwait	2014	2375	2617	2598	29,0 %	9,4 %	-0,7 %
Production	Brazil	1003	1887	2096	2683	167,5 %	42,2 %	28,0 %
Consumption	Brazil	2036	2481	3100	3081	51,3 %	24,2 %	-0,6 %
Net Export/Import	Brazil	-1033	-594	-1004	-398	-61,5 %	-33,0 %	-60,4 %

Figures 86 to 106 show the oil production, consumption and net export/import of the major oil producers in the international oil market.

The United States is the largest producer of crude oil in 2018, but it also is the largest consumer.

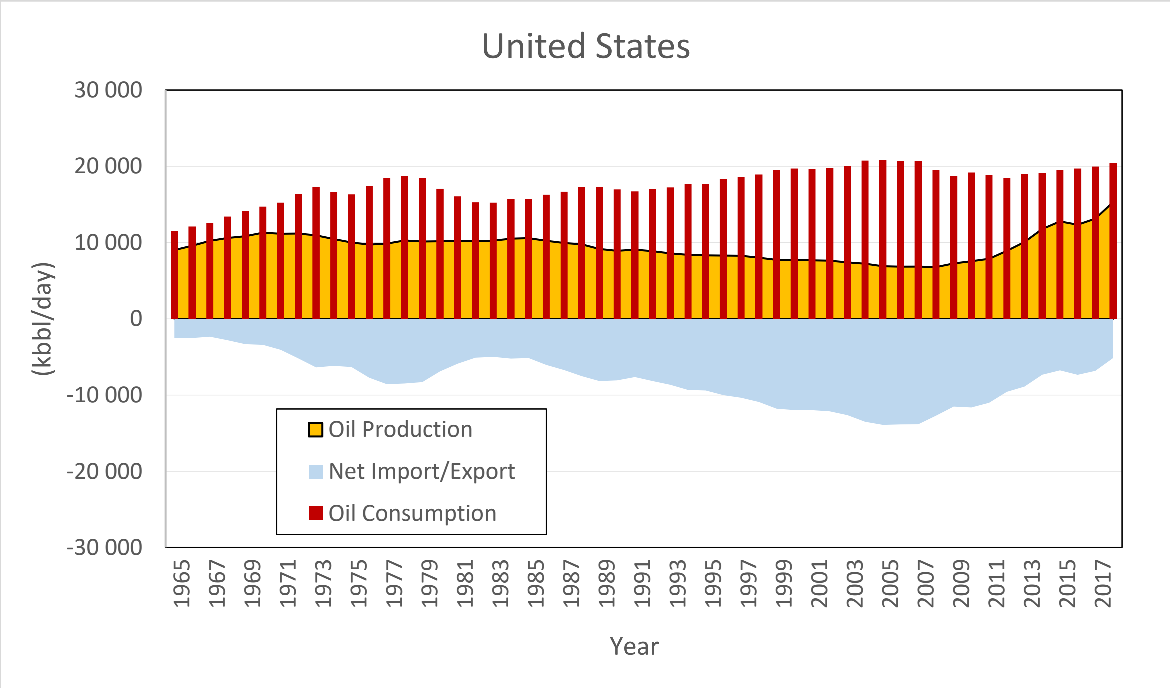

Figure 86. United States oil consumption, production and net import, 1965 to 2018
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

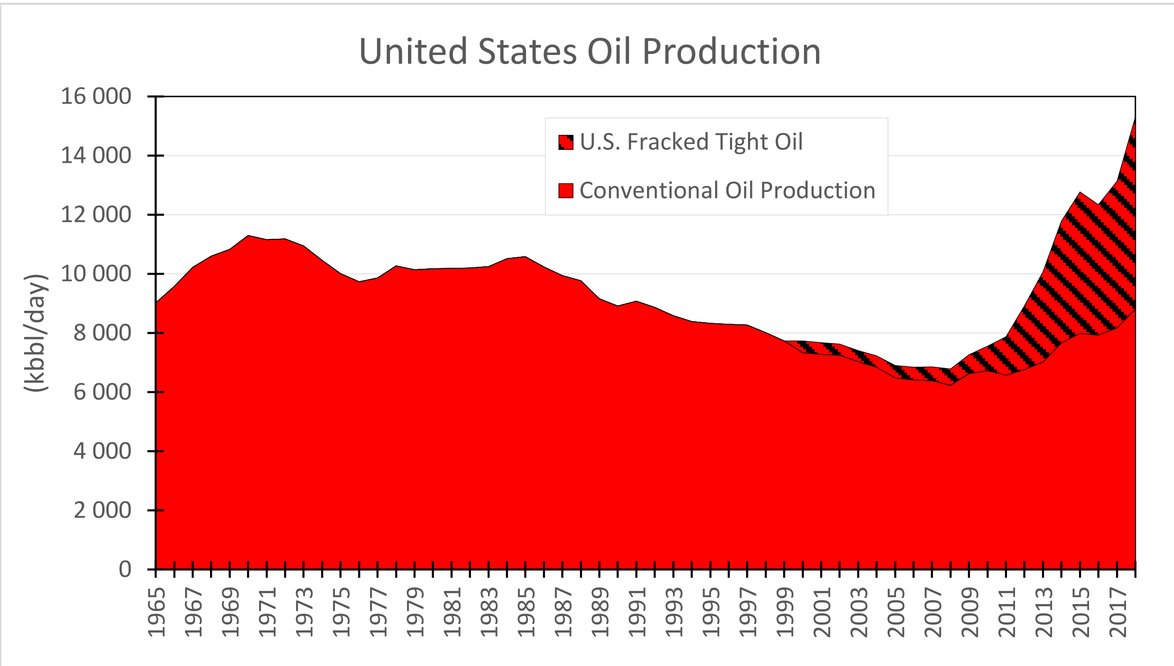

Figure 87. United States oil production, conventional oil and tight oil
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

The increased productivity of the U.S. Tight Oil sector (see Section 7) has projected that in October 2019, the United States will become a net exporter of crude oil for the first time in decades (Princeton Energy Advisors 2019 Oct 10th) (Figure 88). The importance of the U.S. oil production in context of supporting increasing world demand is discussed in Section 7.

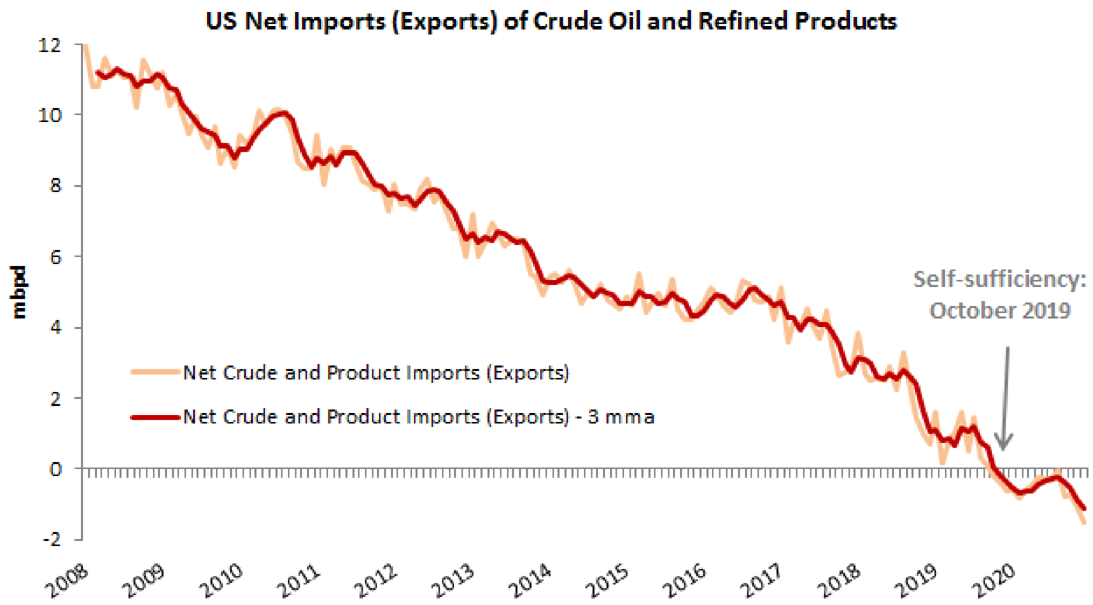

Figure 88. United States oil consumption, production and net import
(Source: Princeton Energy Advisors, www.prienga.com, Stephen Kopits)

The combination of oil sands production and tight oil production in the U.S. was able to stabilize global demand between 2005 and 2014 (see Figure 147 and Section 7). This is significant as conventional oil production plateaued in 2005, whole demand continued to increase.

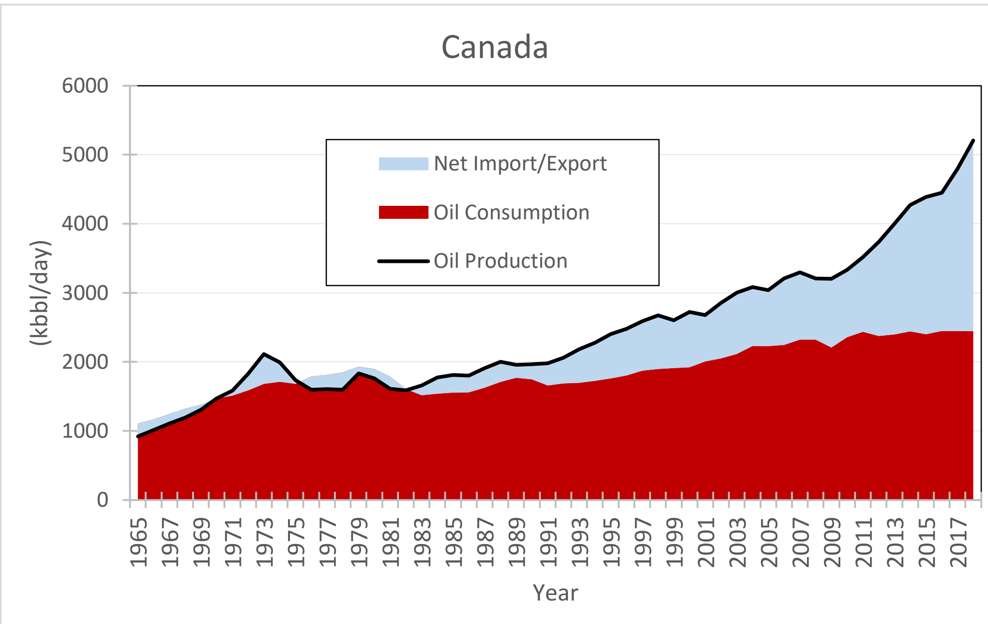

Figure 89. Canadian oil consumption, production and net export, 1965 to 2018
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

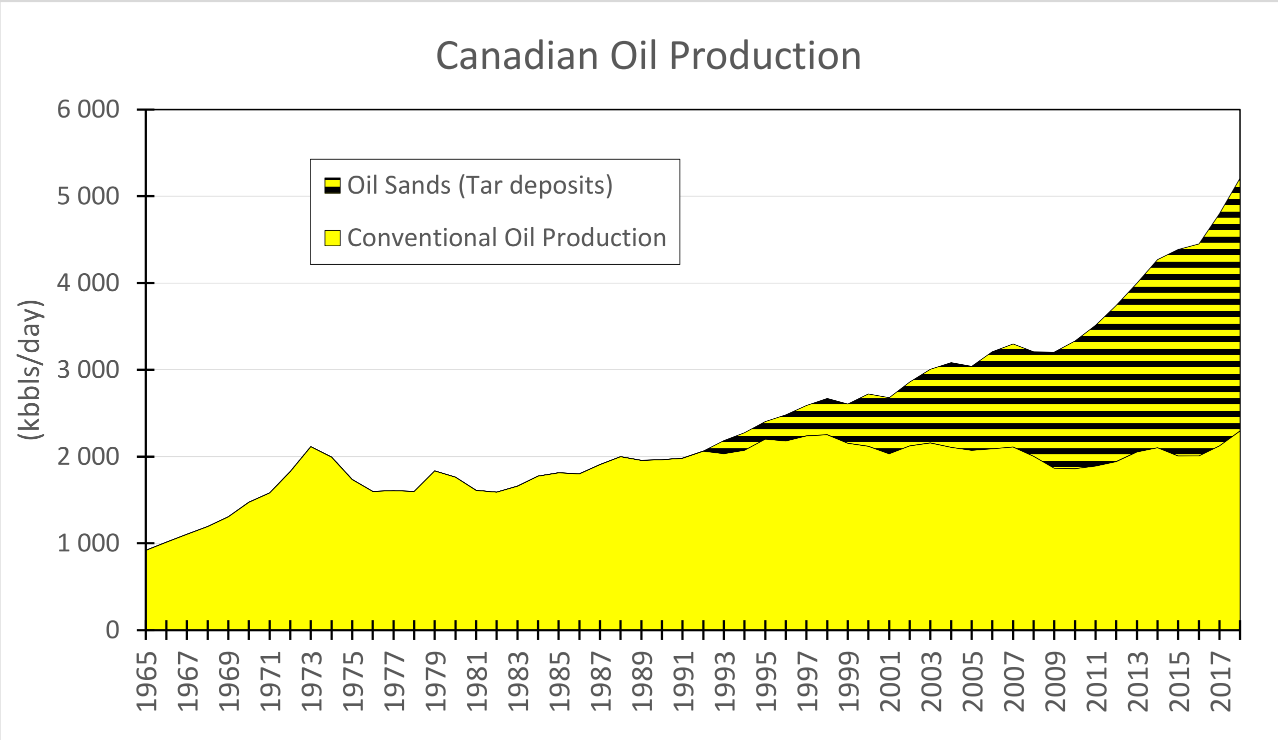

Figure 90. Canadian oil production, conventional oil and oil sands
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

Comparing Figure 89 and 90, it can be observed that almost all Canadian oil export over and above domestic consumption is dependent on oil sands production capacity.

Saudi Arabia was the foundation of the global oil market for decades and was the largest producer until recently (the United States surpassed Saudi Arabia in 2014). The Saudi net export over time is shown in Figure 91. In the early 1980's Saudi Arabia cut production in response to the global oil glut in the international market at the time.

The 1980s oil glut was a serious surplus of crude oil caused by falling demand following the 1970s energy crisis. The world price of oil had peaked in 1980 at over US$35 per barrel (equivalent to $109 per barrel in 2019 $USD, when adjusted for inflation); it fell in 1986 from $27 to below $10 ($63 USD to $23 USD in 2019 dollars) (using CPI Inflation Calculator). The glut began in the early 1980s as a result of slowed economic activity in industrial countries due to the crises of the 1970s, especially in 1973 and 1979, and the energy conservation spurred by high fuel prices.

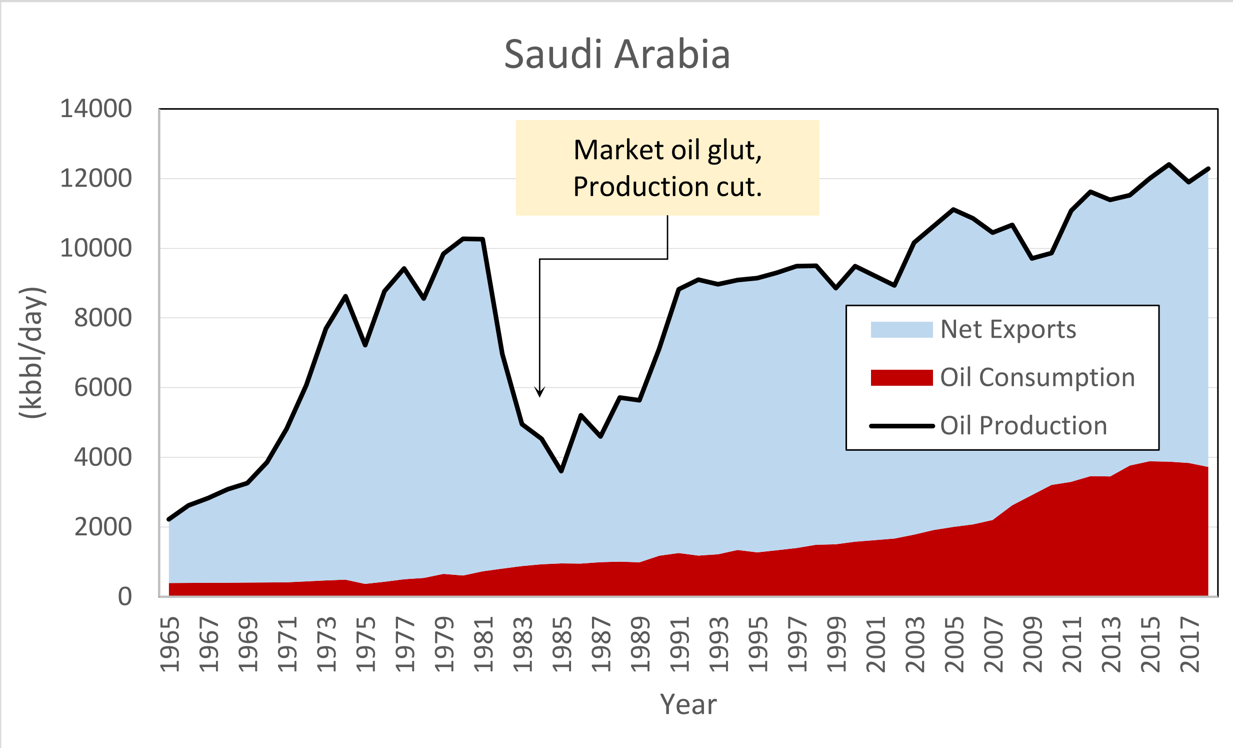

Figure 91. Saudi Arabian oil consumption, production and net export, 1965 to 2018
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

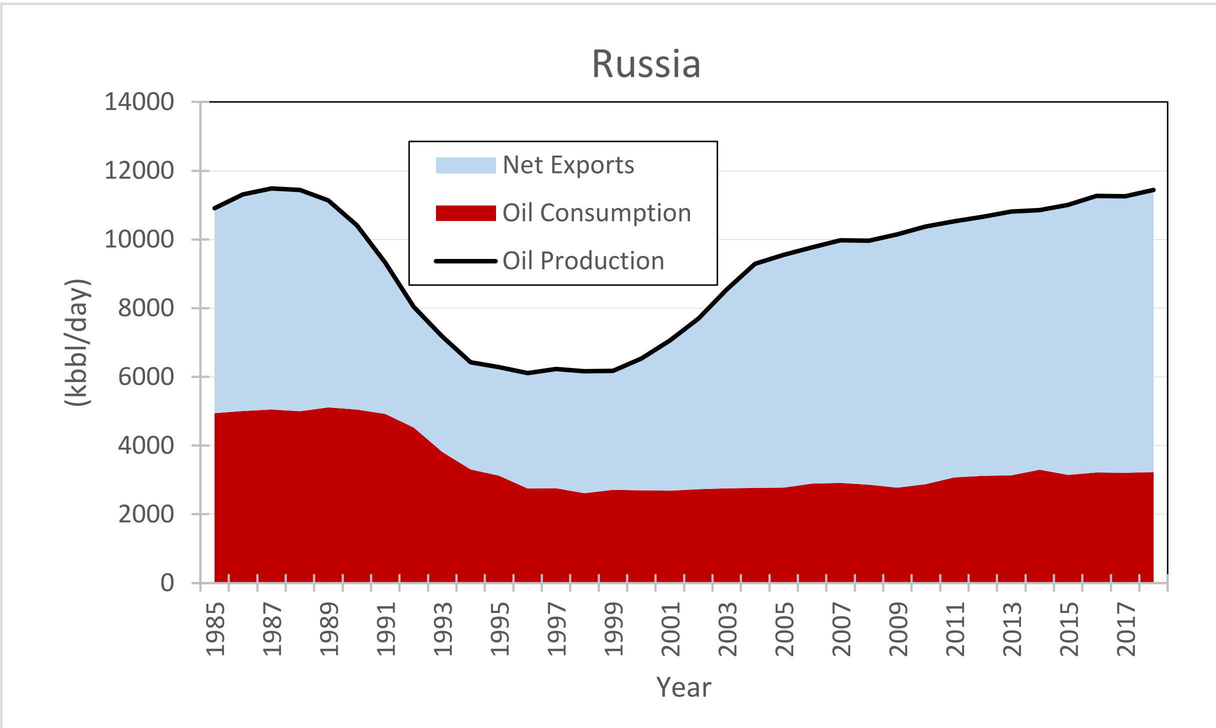

Figure 92. Russian Federation oil production 1985 to 2018 oil production, consumption and net export
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

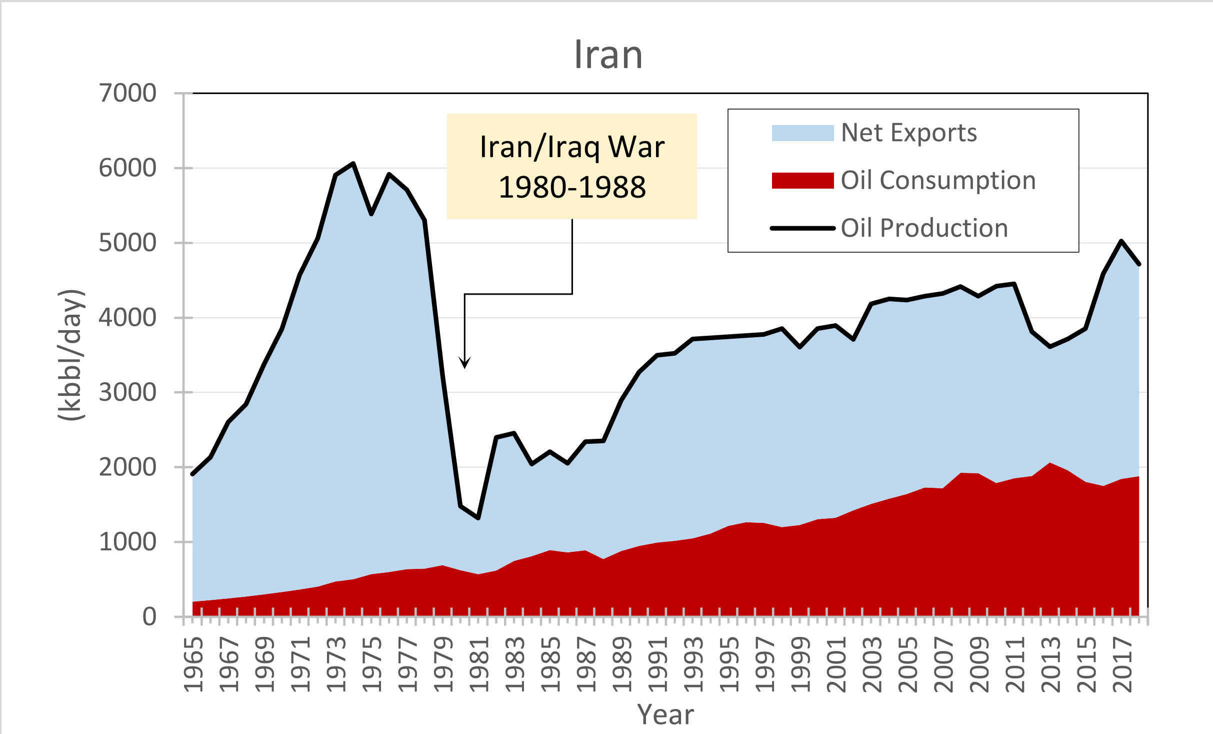

Figure 93. Iranian oil consumption, production and net export, 1965 to 2018
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

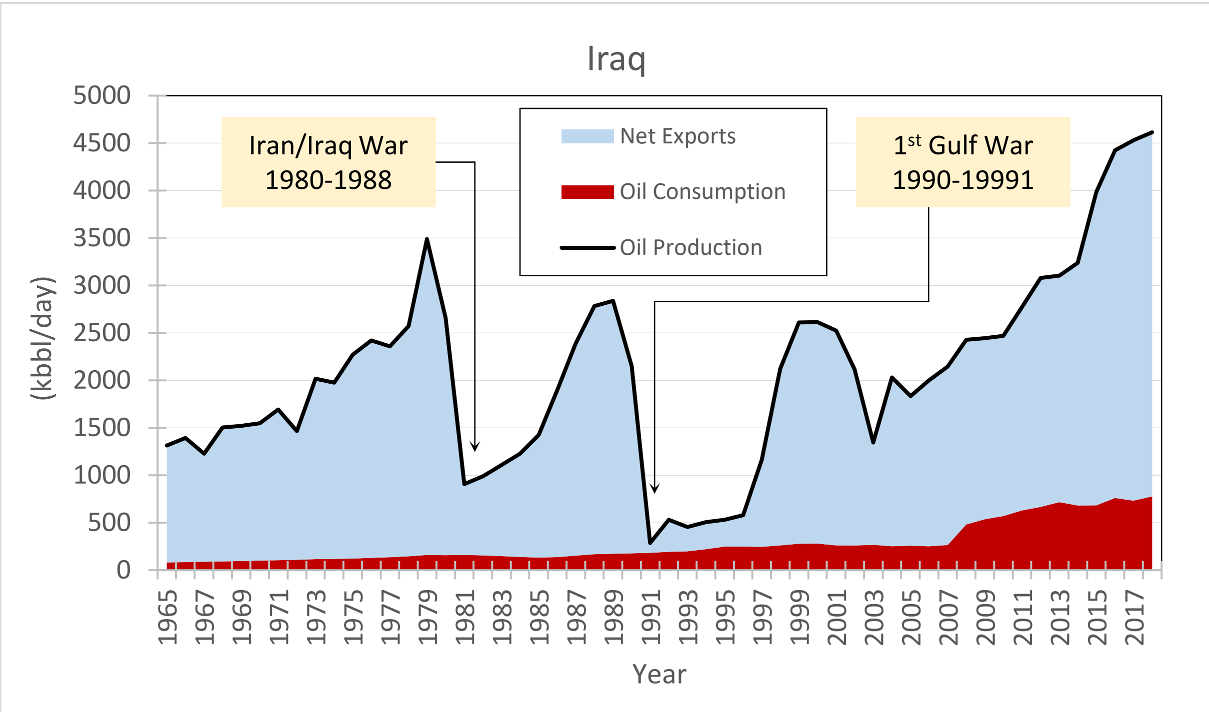

Figure 94. Iraqi oil consumption, production and net export, 1965 to 2018
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

Figure 95 shows the oil production and consumption of China, which was the second largest consumer in 2018.

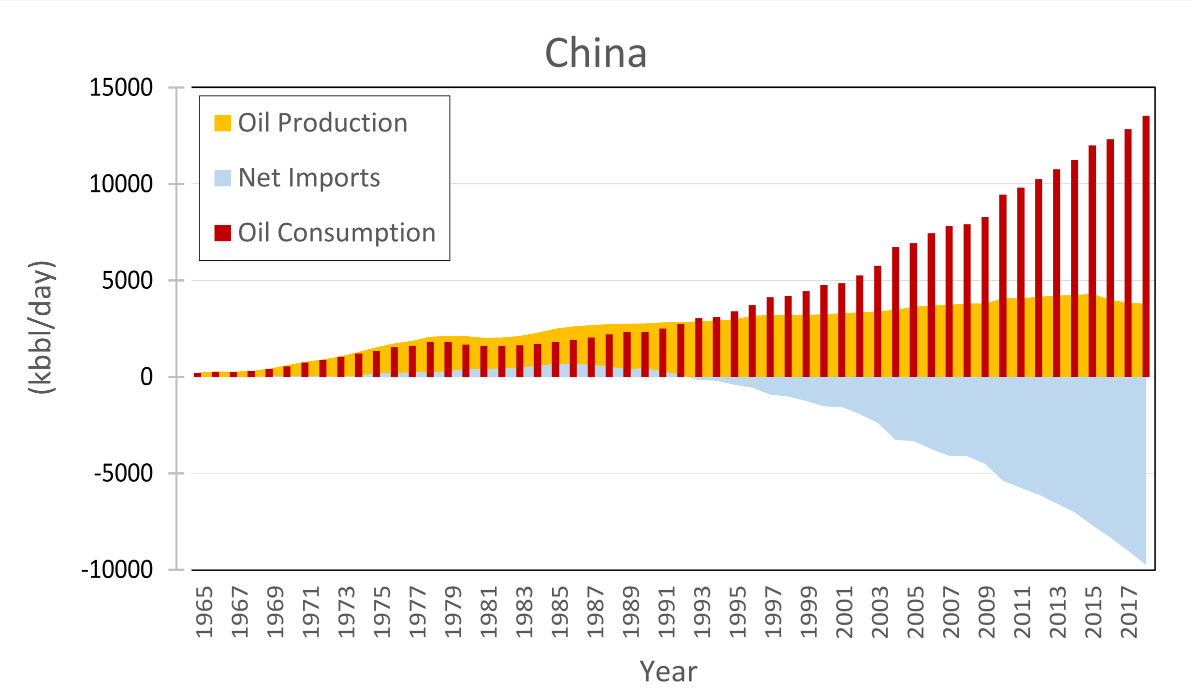

Figure 95. Chinese oil production, consumption, and net import, 1965 to 2018
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

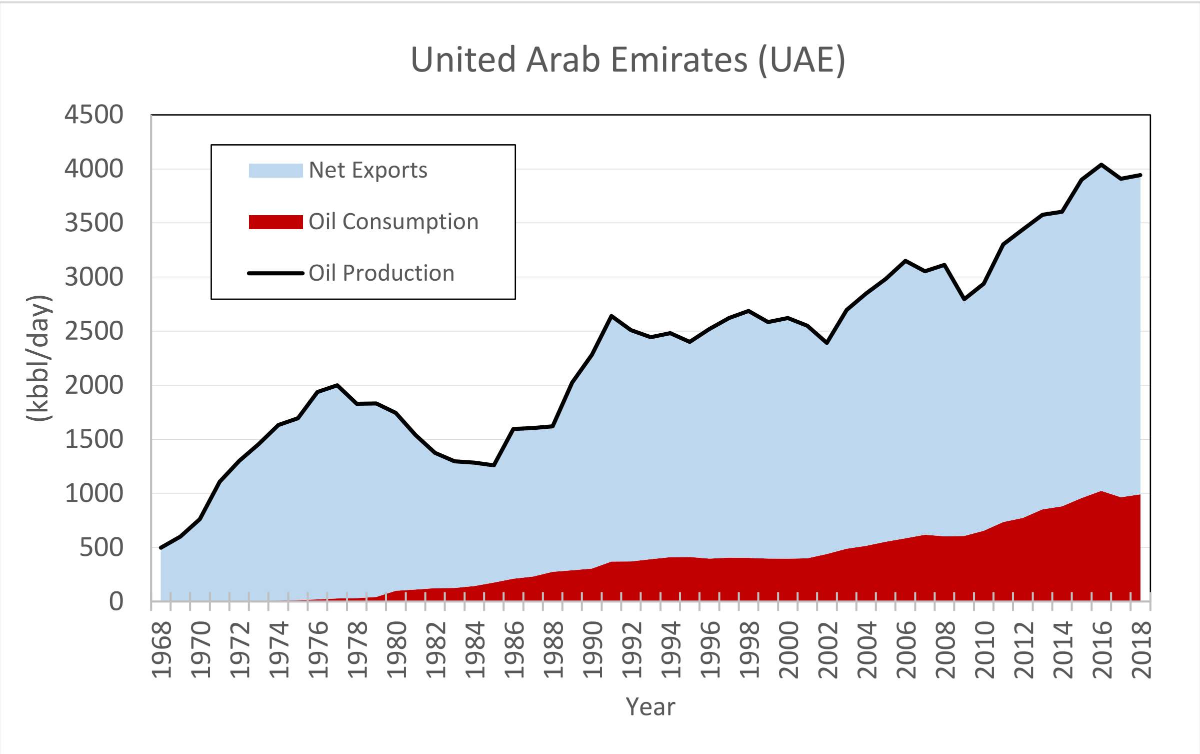

Figure 96. United Arab Emirates oil production, consumption, and net export, 1968 to 2018
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

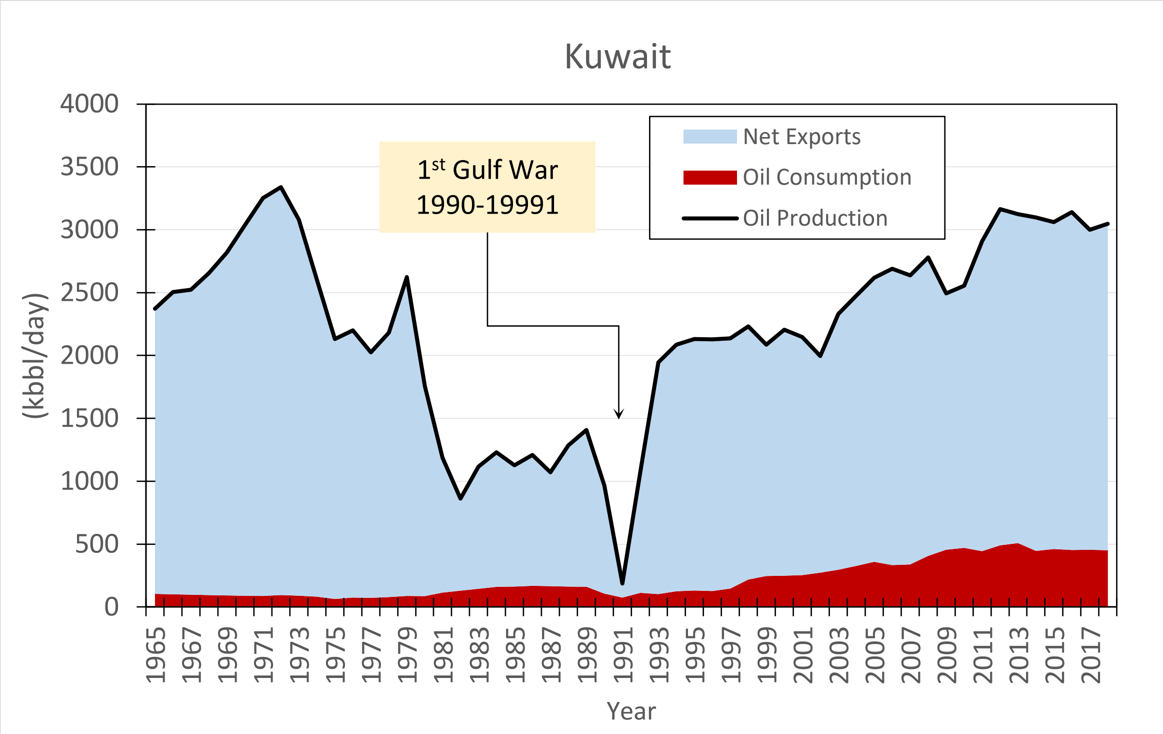

Figure 97. Kuwaiti oil consumption, production and net export, 1965 to 2018
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

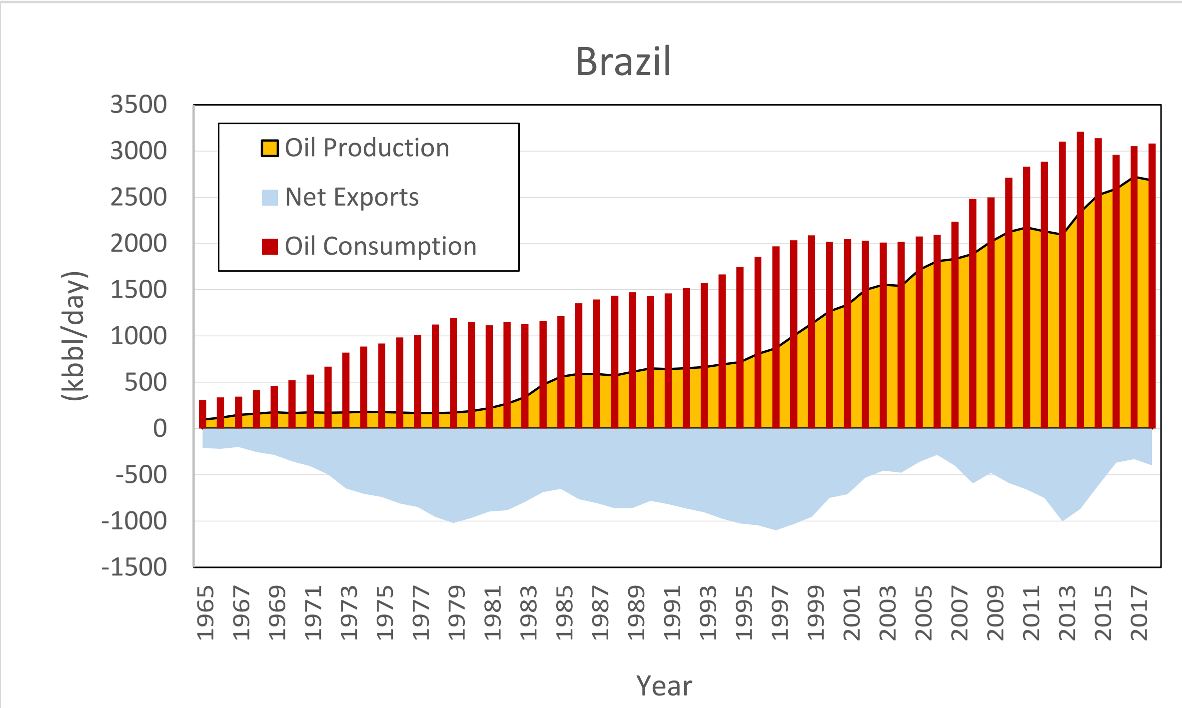

Figure 98. Brazilian oil consumption, production and net import
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

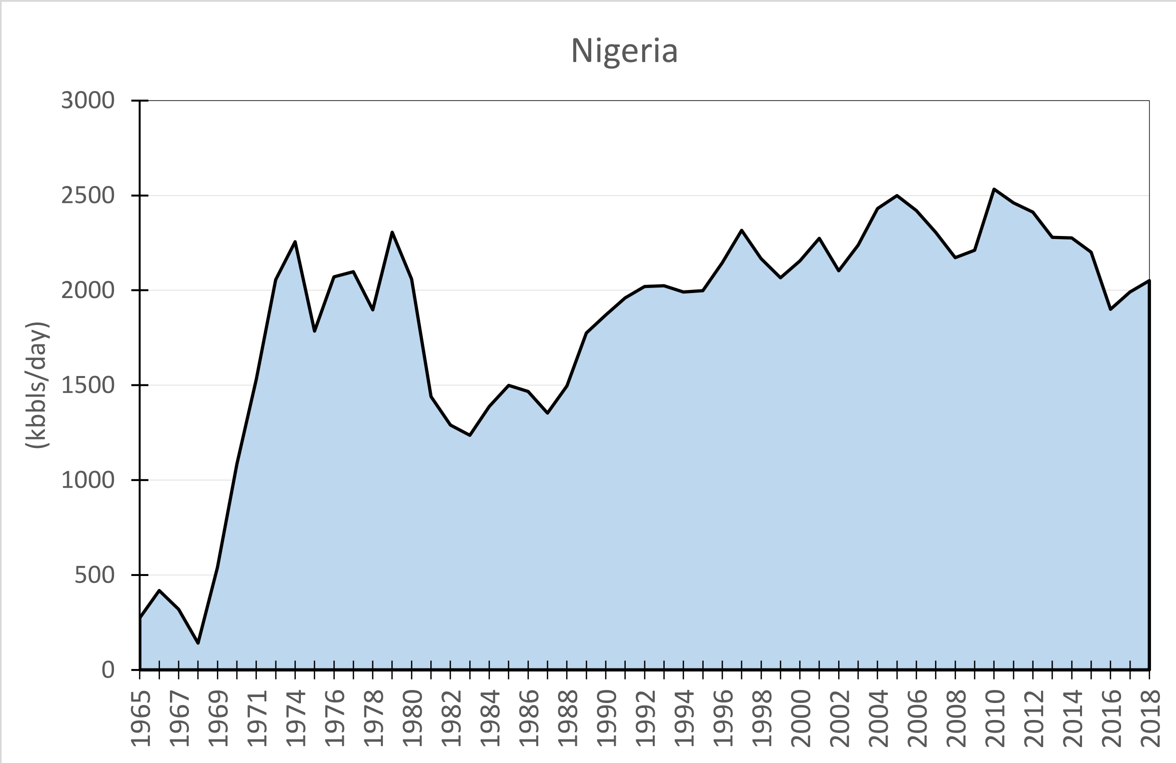

Figure 99. Nigerian oil production 1965 to 2018 (consumption unavailable)
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

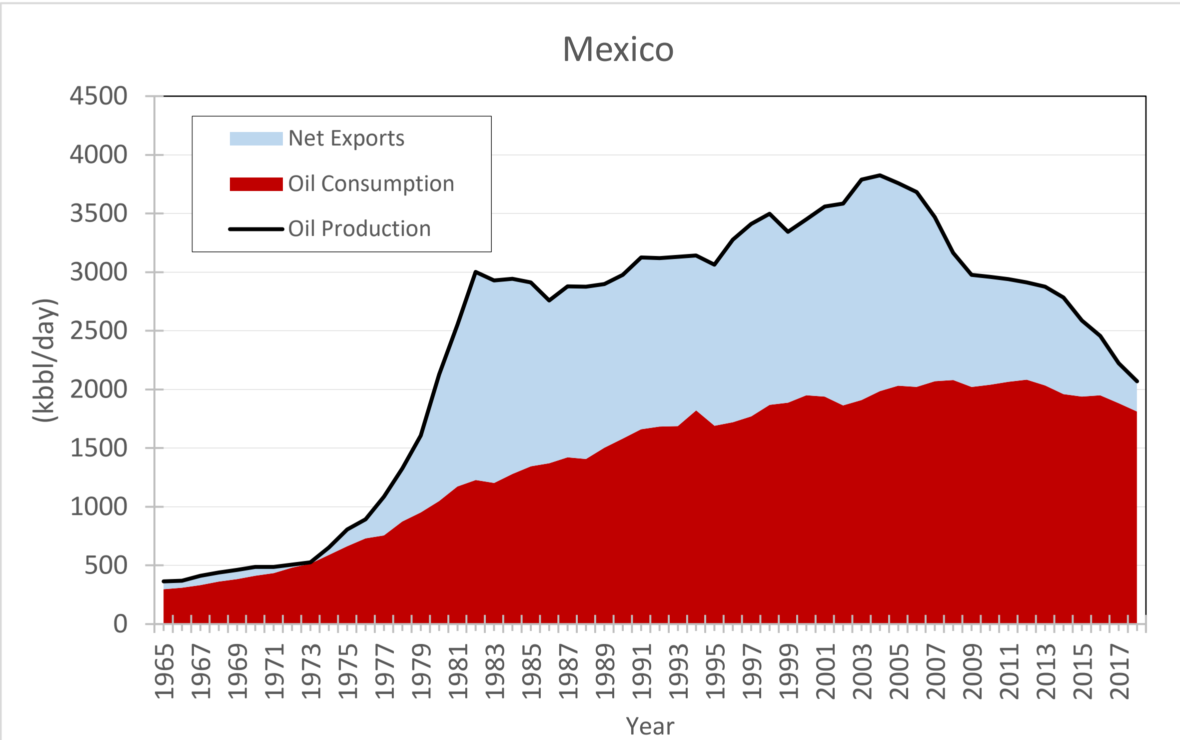

Figure 100. Mexican oil consumption, production and net export
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

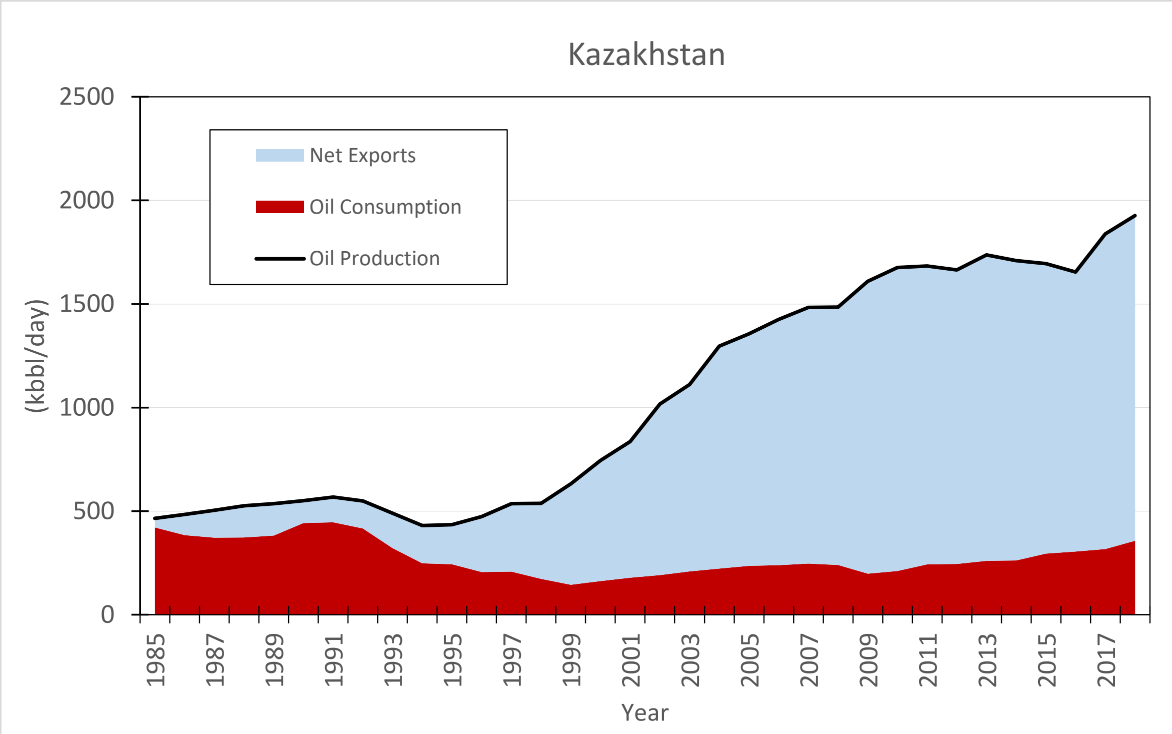

Figure 101. Kazakhstani oil production 1985 to 2018 consumption, production and net export
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

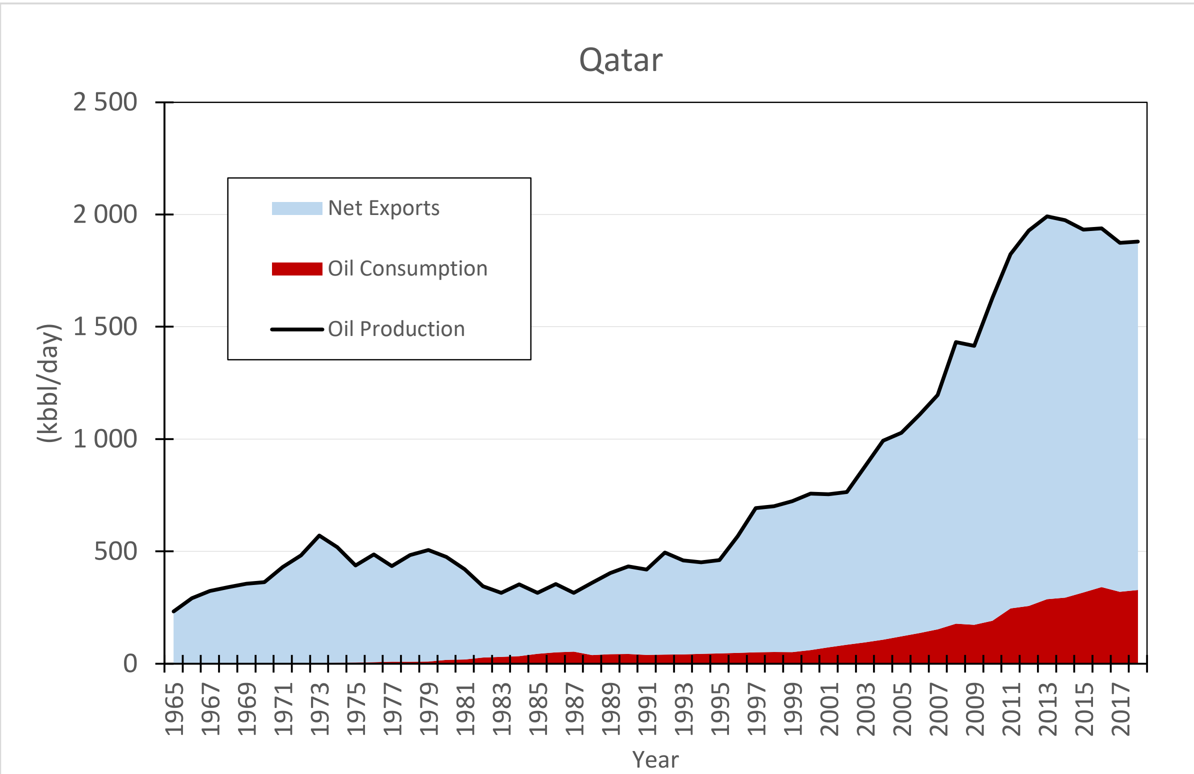

Figure 102. Qatarian oil consumption, production and net export
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

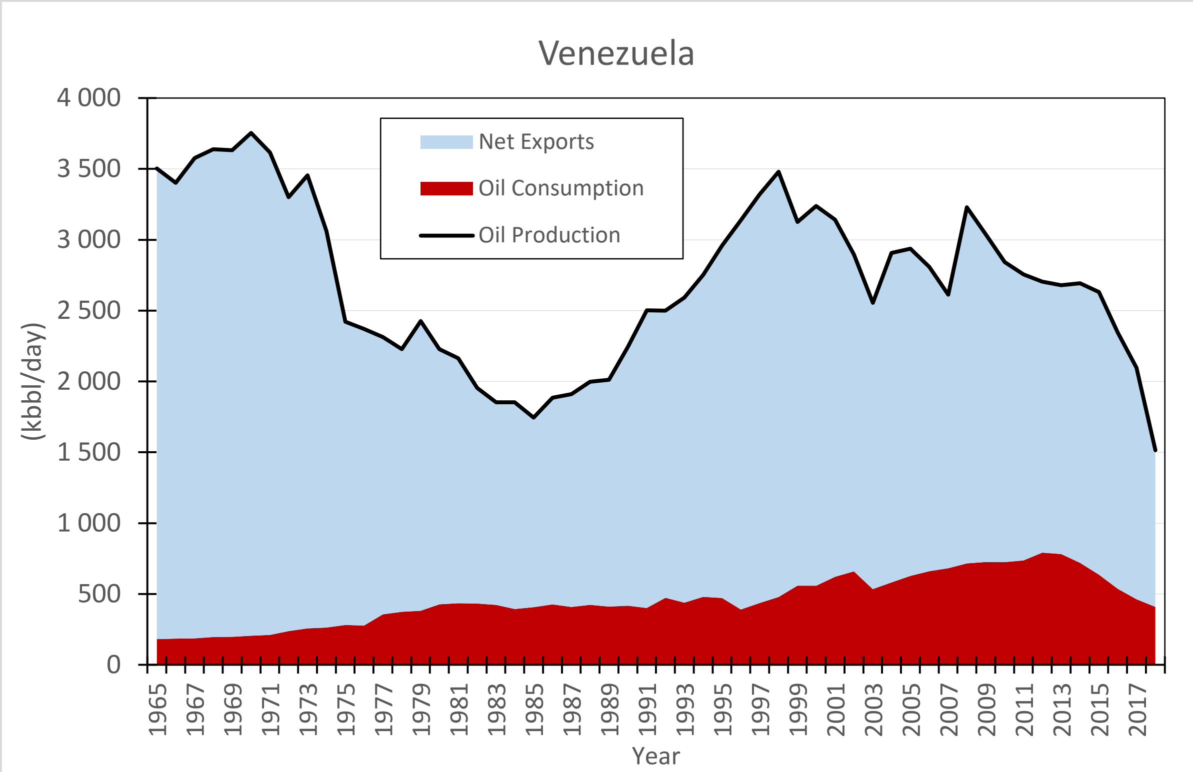

Figure 103. Venezuelan oil consumption, production and net export
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

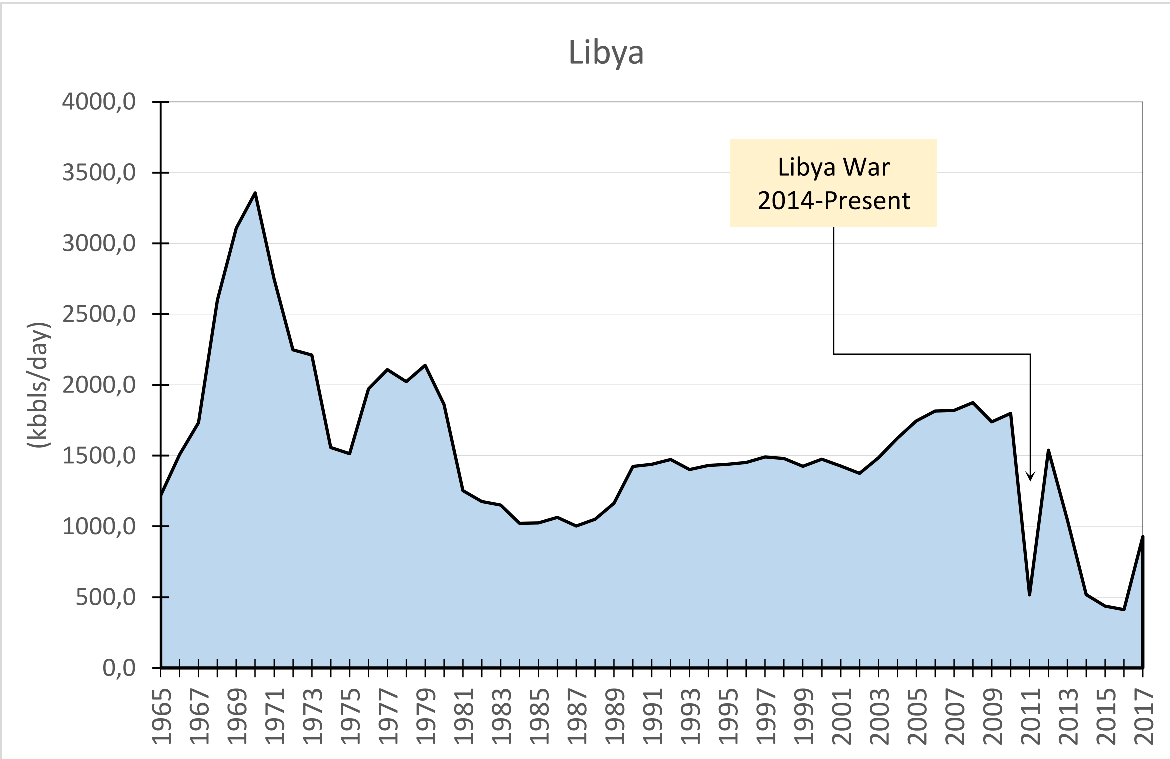

Figure 104. Libyan oil production 1965 to 2018 (consumption unavailable)
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

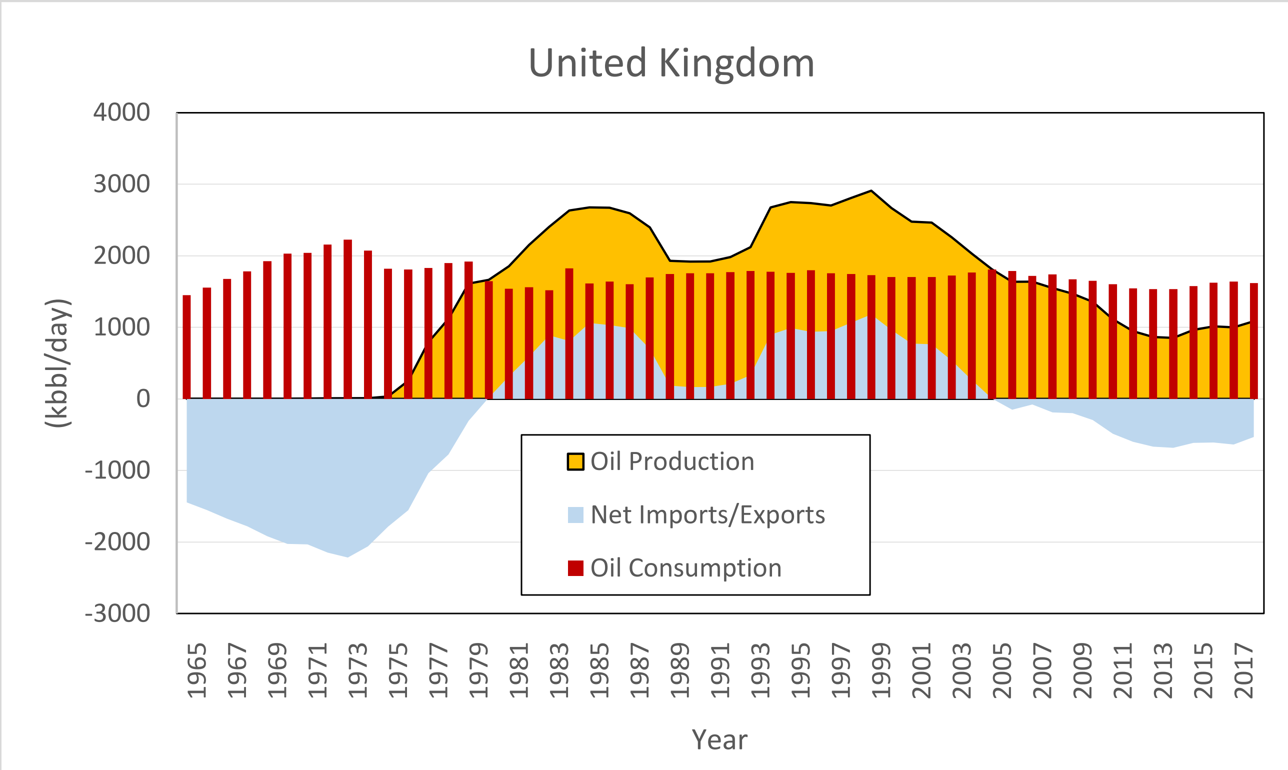

Figure 105. United Kingdom oil consumption, production and net import
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

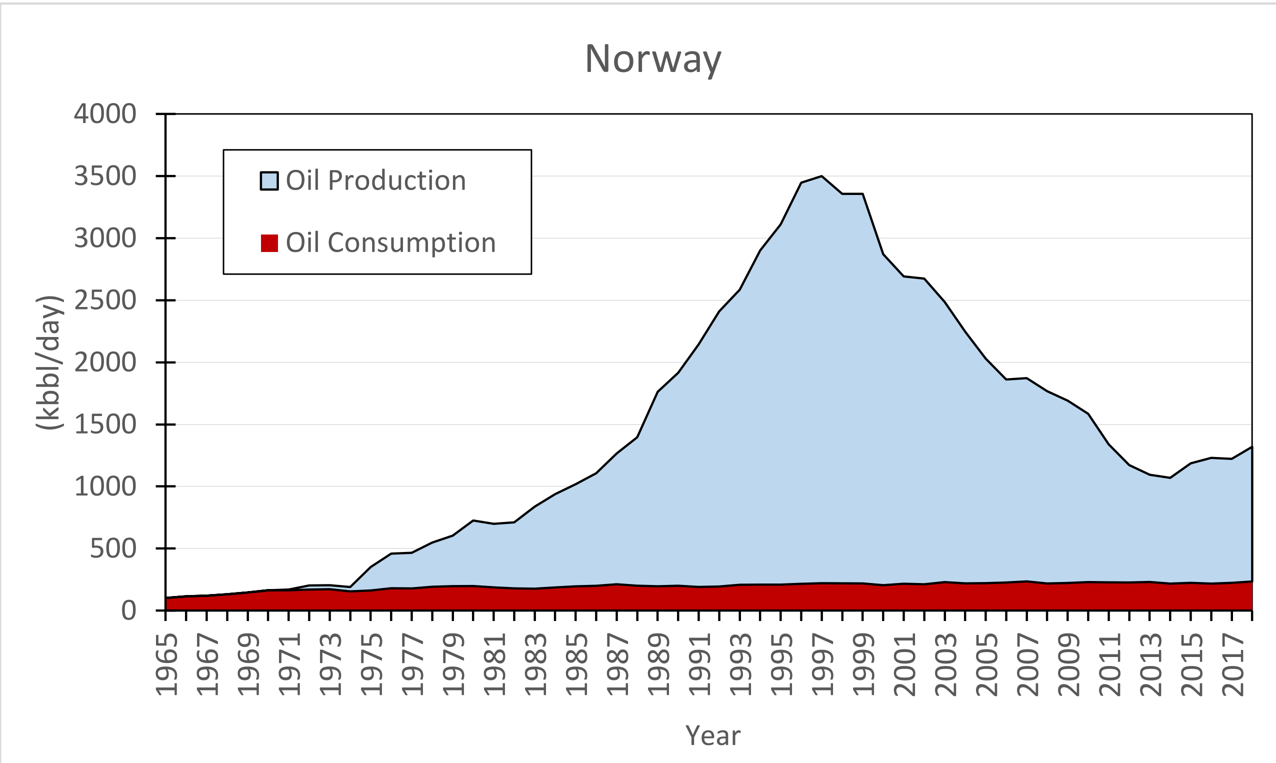

Figure 106. Norwegian oil production and consumption, 1965 to 2018 oil consumption, production and net export
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

5.1 Decline of oil production in most fields

It is estimated that 81% of world liquids production is already in decline (excluding future redevelopments) (Ahmed 2017 & Fustier *et al*. 2016). The HSBC study (Fustier et al. 2016) quoted a projected probable range for average decline rate on post-peak production is 5-7%, equivalent to around 3-4.5mbd of lost production every year from 2016 forward. Small oilfields typically decline twice as fast as large fields. What is to be remembered is that much of the oil production capacity of Iraq, Iran and Venezuela has been withheld from the global market as a consequence of warfare and economic sanctions (see Figure 239 in Section 15.7).

Production of oil correlates strongly with all indices associated with the real economy (manufacture, production of goods and services). Everything in our modern society is oil-dependent — from food production and distribution, to textiles and manufacturing, to the transportation of all goods and people. The concept of peak oil has been discussed by many analyst groups of all kinds.

Since first oil crisis of 1973, global energy consumption has doubled. Oil production increased by 163% in this period. There is no apparent pattern that suggests conservation or even efficiency by the global society that consumes this resource.

Table 11 shows the global consumption and production of oil, by geographic region and also by major economy.

Table 11. Global oil reserves, production and consumption
(Source: Appendices C, D and E, BP Statistical review of World Energy 2019)

Geographic Region	Proven Reserves (Thousand Million Barrels)	Proven Reserves (Thousand Million Tonnes)	Production (Thousand Barrels a Day)	Production (Million Tonnes)	Consumption (Thousand Barrels a Day)	Consumption (Million Tonnes of Oil Equivalent)
Global	1 729,8	244,1	94 718	4 474,2	99 843	4 662,1
Total North America	236,7	35,4	22 587	1 027,1	24 714	1 112,5
Total Central & South America	325,1	51,1	6 537	335,1	6 795	315,3
Total Europe	14,3	1,9	3 523	162,9	15 276	742,0
Commonwealth of Independant States	144,7	19,6	14 483	709,1	4 099	193,5
Middle East	836,1	113,2	31 762	1 489,7	9 136	412,1
Total Africa	125,3	16,6	8 193	388,7	3 959	191,3
Total Asia Pacific	47,6	6,3	7 633	361,6	35 863	1 695,4
Nations						
United States	61,2	7,3	15 311	669,4	20 456	919,7
China	25,9	3,5	3 798	189,1	13 525	641,2
European Union	4,8	0,6	1 533	72,7	13 302	646,8
Russian Federation	106,2	14,6	11 438	563,3	3 228	152,3

Since the comparatively modest beginnings of the oil industry in the mid-19th century, petroleum has risen to global prominence. The first oil had actually been discovered by the Chinese in 600 B.C. and transported in pipelines made from bamboo (Clark 2016). The start of the industrial use of oil in context of how it is used currently happened in 1859 with the discovery of oil in Pennsylvania (United States) and the Spindletop discovery in Texas in 1901 (Tarbell 2015). Petroleum as an energy resource soon proved much more adaptable and flexible than coal. Additionally, the kerosene that was refined originally from crude provided a reliable and relatively inexpensive alternative to "coal-oils" and whale oil for fueling lamps. Most of the other products were discarded.

In 2011, there were more than 65,000 oil and gas fields of all sizes in the world. However, 94% of known oil is concentrated in fewer than 1500 giant and major fields (Li Guoyu 2011). Of these giant and major fields, only 10 to 20 of them supply most of the global oil supply.

As much as 70% of our daily oil supply comes from oilfields that were discovered prior to 1970 (Simmons 2002). In 2002, nineteen of the world's oilfield giants are located in the Middle East. Collectively these fields still produce approximately 15 million barrels a day, over 22% of the world's total oil (Simmons 2002). The average age of these 19 largest oil fields is almost 70 years.

Of the top 10 modern producing fields the youngest was discovered in 1976 (Cantarell, Mexico – now in decline). The youngest in age of the top 20 producing fields was discovered in 1985 (Marlim, Brazil – now in decline).

In the 1990s over 400 individual oilfields were discovered. Only 2.5% of these fields (ten) produced over 100,000 barrels per day by 2001, although it's worth noting that development lead times can be long. Table 12 and 13 was first published in 2002. Since then there have been no new large oil deposit discoveries. Such that these numbers have maintained relevancy over 16 years is a flag that there may be a problem in finding enough new oil deposits for the future.

Table 12. Summary of giant oilfields (Source: Simmons 2002)

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

Table 13. Summary of giant oilfields production (Source: Simmons 2002)

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

In 2006, just 10 oilfields accounted for 29.9% of the world's estimated proven reserves and for 20.4% of the world's production. The world's top 20 oilfields (in 2006) contained ~40% of estimated proved reserves and accounted for 27.7% of the world's production. The world's top 100 oilfields contained over 65% of the world's reserves, and accounted for over 50% of the world's production (Hirsch *et al* 2010).

In 2006 there were well over 4000 discovered and producing oil fields, but as has been shown, only a few matter (Hirsch *et al* 2010). Just over 100 produce over 100,000 barrels a day, and account for over 50% of the world's production (Figure 108).

Based to HSBC analysis of Wood Mackenzie data covering 15,500 fields, the average size of new field start-ups has dropped significantly from over a billion barrels in the 1960's to ~250mbbls in the 1980's to just 75mbbls this decade (HSBC 2016)(Figure 107).

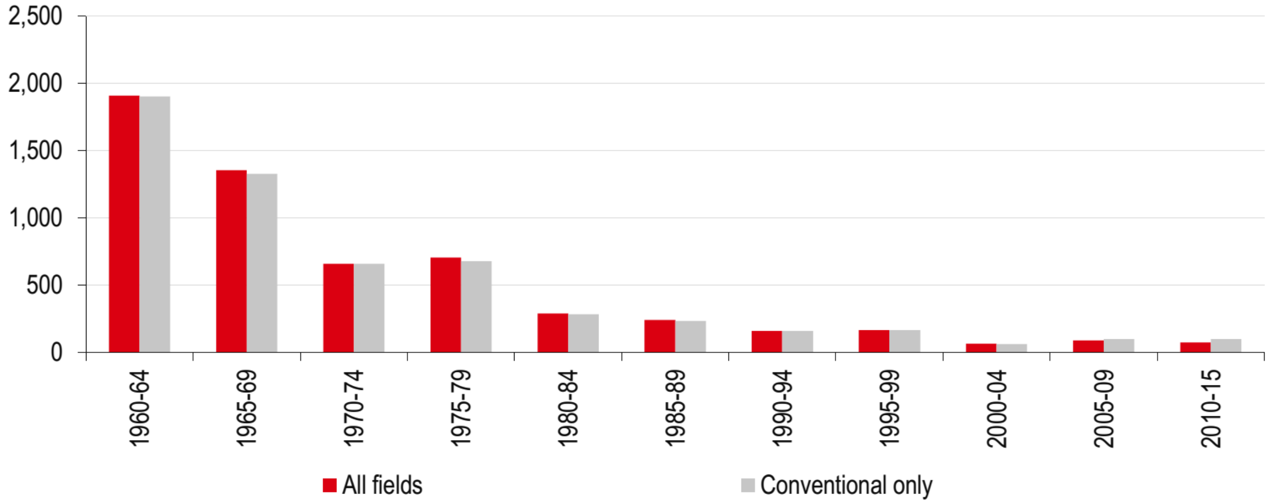

Figure 107. Average size (URR) of global oil field start-ups, mboe
(Source: Fustier et al 2016, Wood Mackenzie)

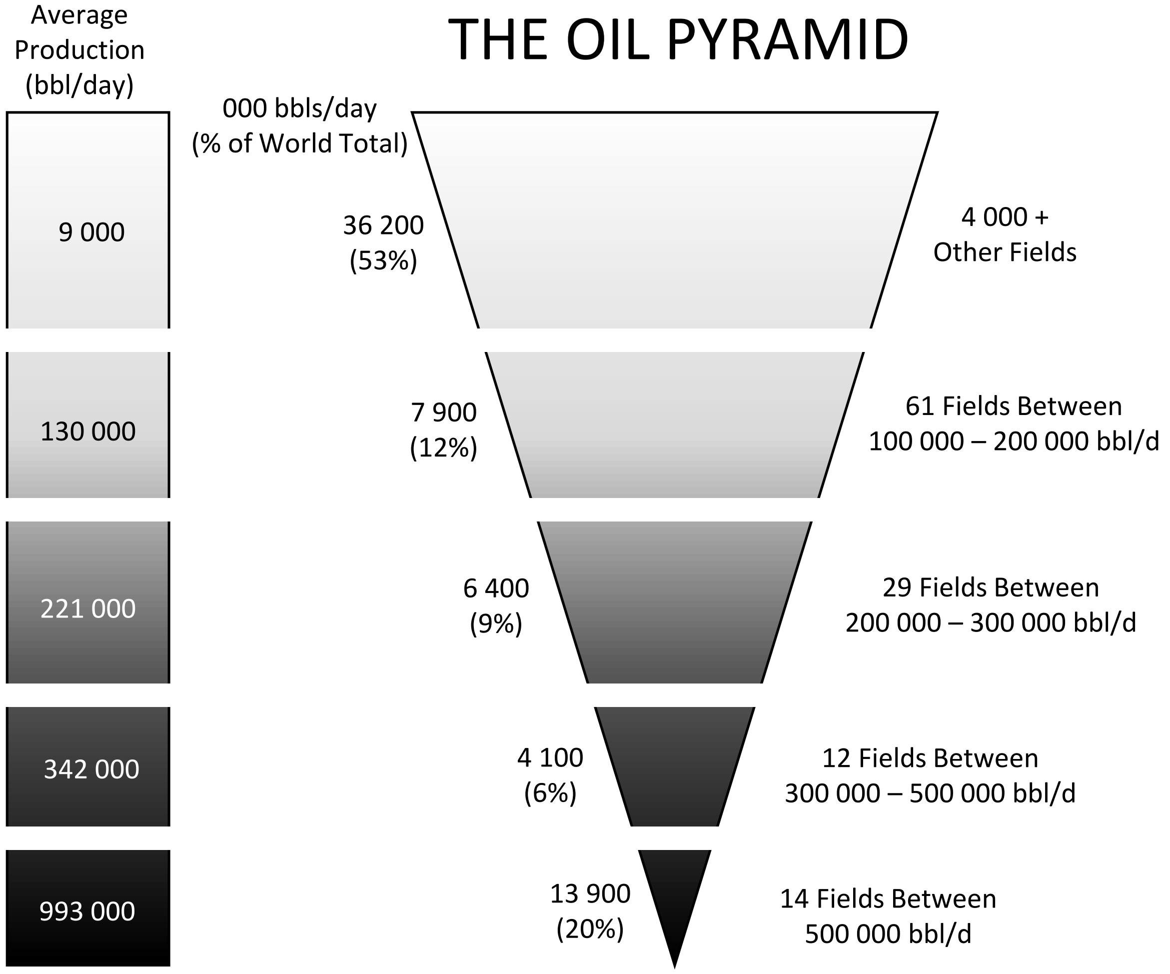

Figure 108. The World Depends upon a Few Old Fields – 2002 numbers (Redrawn from Simmons 2005)

5.2 Degradation of the quality of oil being extracted

The quality of oil varies from source to source. The market value of an individual crude stream reflects its quality characteristics. The more useful and valuable oil is the light sweet crude that is low in sulfur content. The sulfur content is a problem as it causes corrosion in refineries, thus is harder to process efficiently. The heavy sour crude as a consequence is less economically valuable. Figure 109 shows an estimated proportion of the oil grades in the global oil reserves in the year 2006. A more current estimate would show an increased proportion of the heavy sour crude and a reduction in the sweet crude.

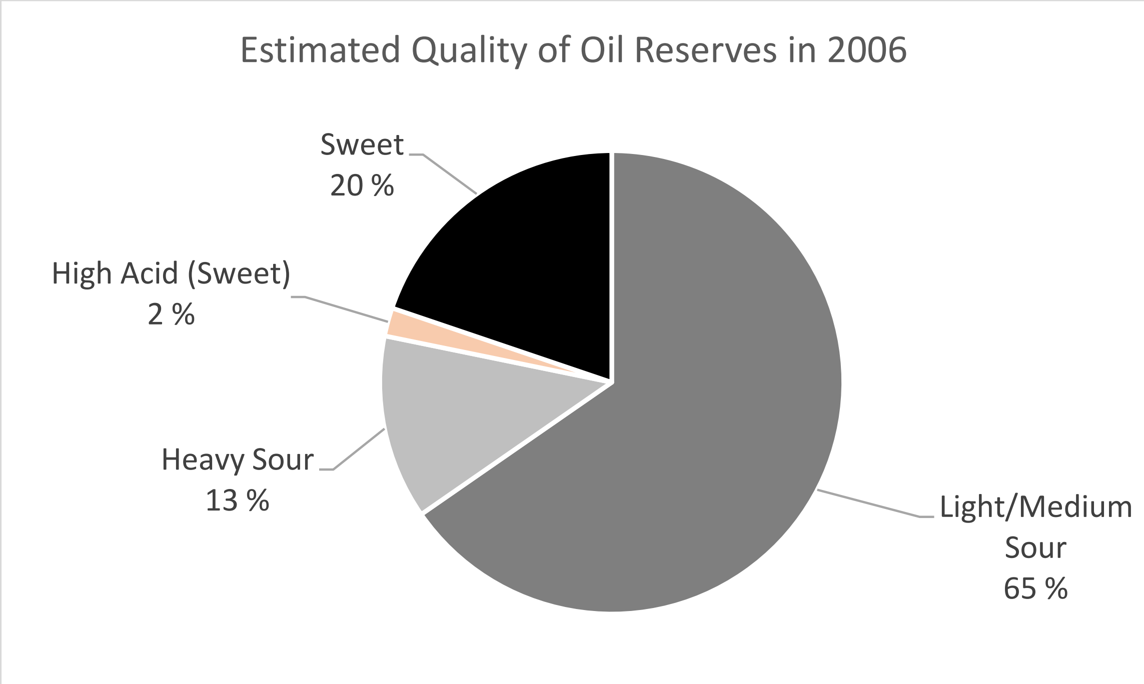

Figure 109. Estimated quality of global oil reserves 2006
(Source: Energy Information Agency EIA)
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Two of the most important quality characteristics are density (API Gravity) and sulfur content. Density ranges from light to heavy, while sulfur content is characterized as sweet or sour, where a high sulfur content is termed as sour. The lowest quality of oil is termed heavy sour, meaning heavy density and high in sulfur content.

American Petroleum Institute measure of specific gravity of crude oil or condensate in degrees, termed API Gravity. An arbitrary scale expressing the gravity or density of liquid petroleum products. The measuring scale is calibrated in terms of degrees API; it is calculated as follows:

$$\text{Degrees API} = (141.5 / \text{specific gravity of oil product at 60 degrees F}) - 131.5 \quad \text{(Equation 2)}$$

Crude oil with low sulfur content is classified as "sweet;" crude oil with a higher sulfur content is classified as "sour." Sulfur content is considered an undesirable characteristic with respect to both processing and end-product quality. Therefore, sweet crude is typically more desirable and valuable than sour crude. Figure 110 shows the increase of sulfur content in oil produced in the United States over time in a persistent trend.

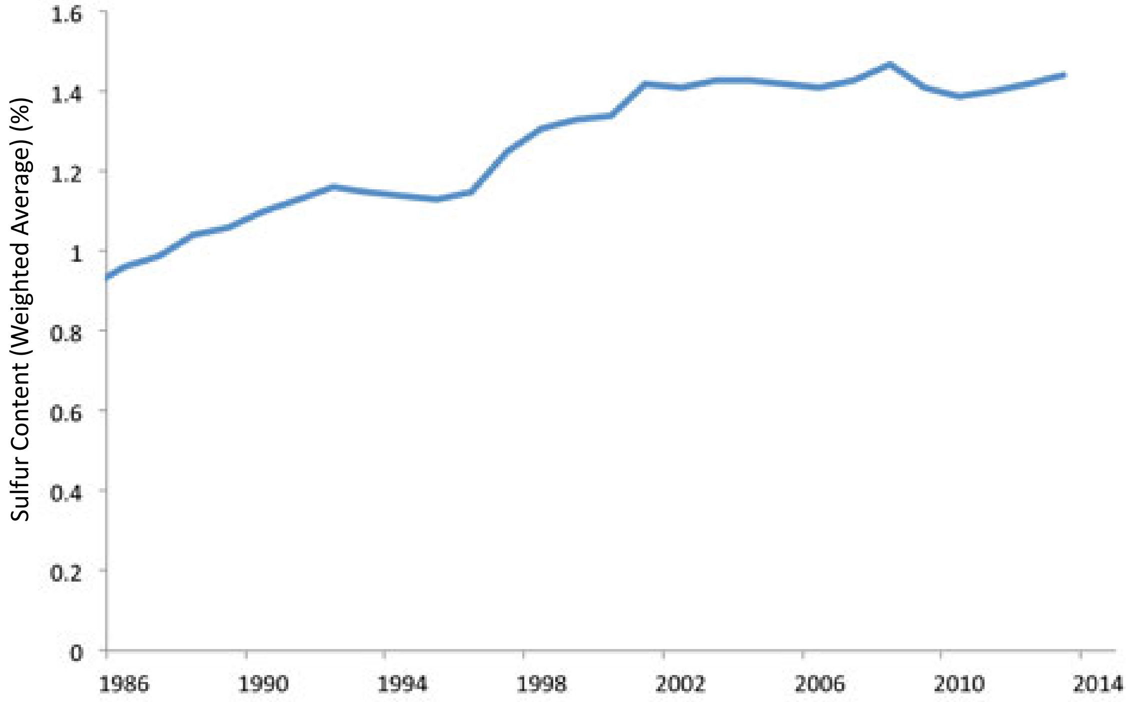

Figure 110. U.S. Sulfur Content (Weighted Average) of Crude Oil Input to Refineries (%)
(Source: Energy Information Administration EIA)
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The ‘sourness’ of crude oil technically refers to its hydrogen sulfide (H_2S) content before processing. Crude can naturally contain up to 14% sulfur content by weight, but this percentage is comprised of myriad sulfur compounds; only a small ratio is H_2S. Unfortunately, even very low levels of H_2S in crude can cause excessive corrosion and degrade catalysts in the refinery.

The reasons why one source of crude would be sour (e.g. Venezuelan crude) and another source would be sweet (e.g. Libyan crude) are complex. The sulfurization of crude occurred during its initial formation, when ancient kerogen (decomposed organic matter which has polymerized) was cooked into oil by subterranean heat; the sulfur content of the living matter in that region was thus transferred to the oil reserve.

Another sulfur enrichment factor is the presence of special hydrocarbon-degrading bacteria known as OHCB which reduce the hydrocarbon/sulfur ratio. The concentration of H_2S in the crude rises with overall sulfur content, and thermal reactions (both geologic and during refining) can produce H_2S from reactions with elemental sulfur and decomposition of unstable sulfur compounds.

The Figure 111 shows select crude types from around the world with their corresponding sulfur content and density characteristics. There are some crude oils both below and above the API gravity range shown in the chart.

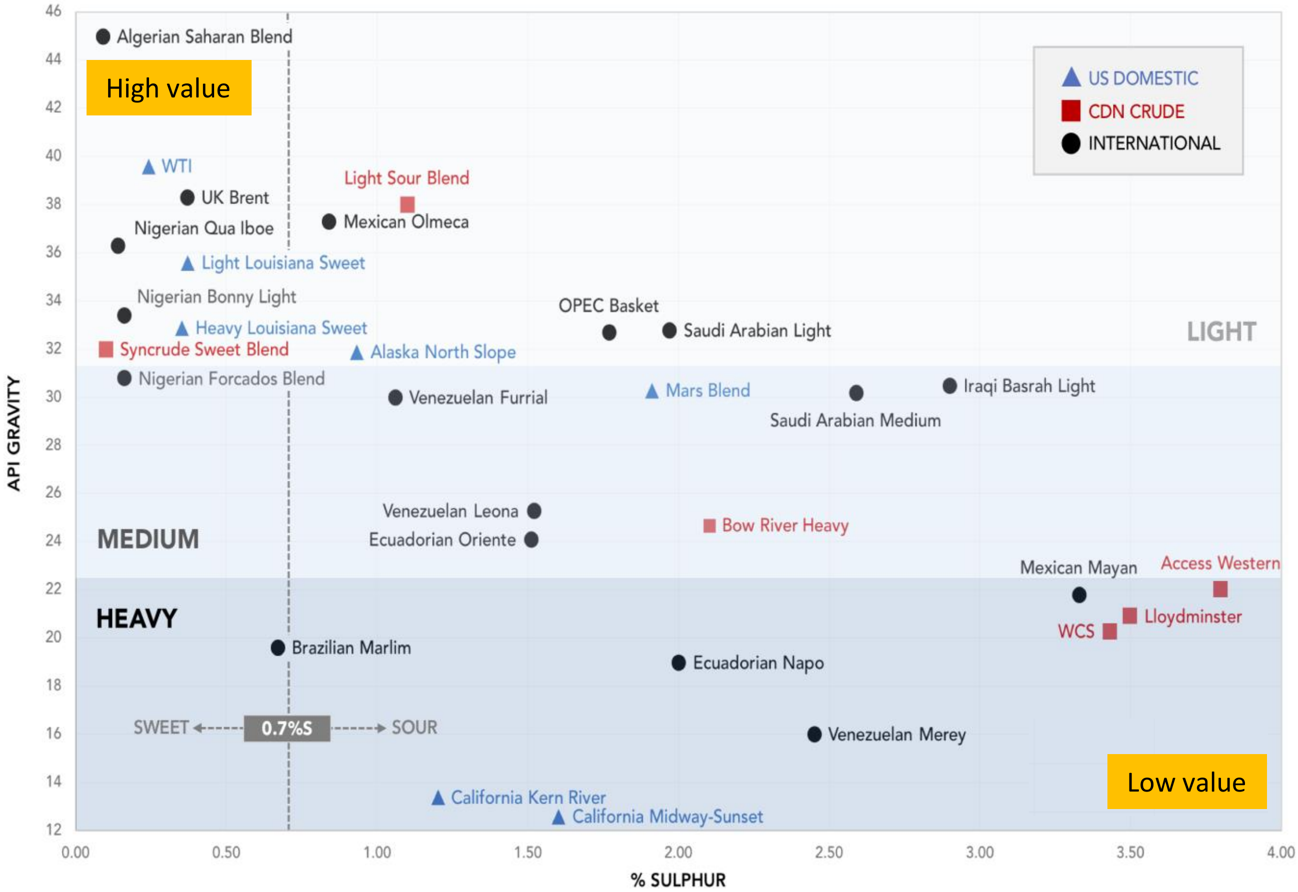

Figure 111. Density and sulfur content showing quality of selected crude oils
(Source: US Energy Information Agency EIA)
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Crude oils that are light (higher degrees of API gravity, or lower density) and sweet (low sulfur content) are usually priced higher than heavy, sour crude oils. This is partly because gasoline and diesel fuel, which typically sell at a significant premium to residual fuel oil and other "bottom of the barrel" products, can usually be more easily and cheaply produced using light, sweet crude oil. The light sweet grades are desirable because they can be processed with far less sophisticated and energy-intensive processes/refineries.

6 DIFFERENT METHODS OF OIL EXTRACTION

Current oil reserves are made up of a range of hydrocarbon qualities all of which is subject to a range of production costs. There are several categories of how oil is extracted and produced (Figure 112). The first several decades of oil production was extracted on dry land in relatively shallow drill holes.

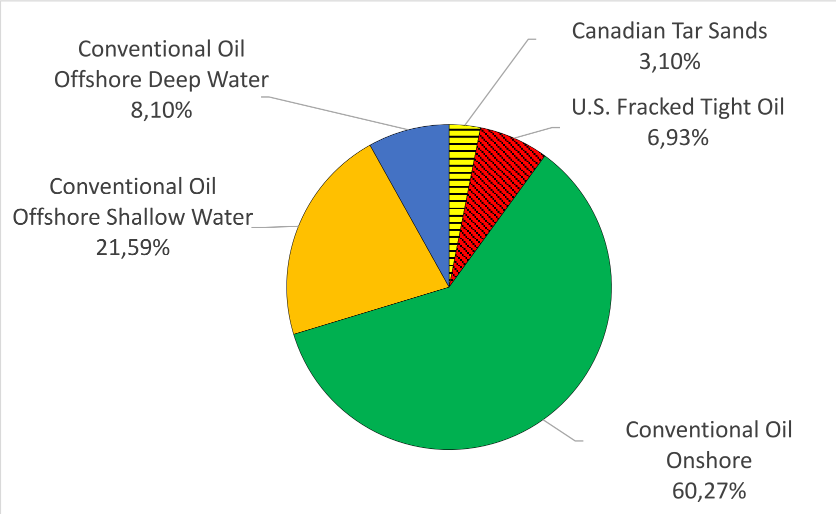


Figure 112. Oil production by extraction method in 2018. (Source: EIA monthly oil production statistics 2019, Canadian Association of Petroleum Producers 2019, Shale Profile 2019)

Most of the new capacity to produce oil in the global markets has come from the U.S. Tight Oil (fracking) and the Canadian Tar sands (also called oil sands) (Figure 113).

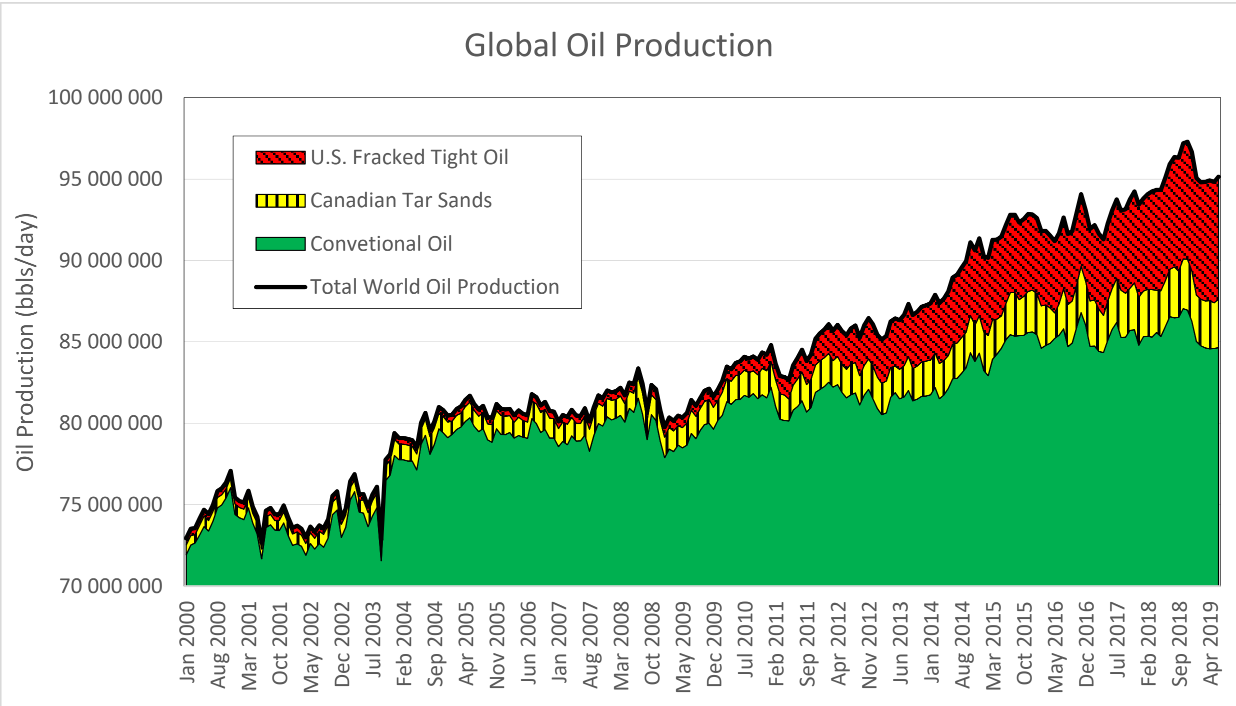


Figure 113. Global oil production split between conventional and unconventional sources. (Source: EIA monthly oil production statistics 2019, Canadian Association of Petroleum Producers 2019, Shale Profile 2019)

6.1 Conventional oil extraction

Oil and oil derivatives are refined and transformed into useful petroleum products. Conventional sources of oil are conventional oil, crude oil and lease condensate. Oil and gas are extracted from under the surface through drilling then pumping. Oil and gas are almost always extracted together in in various ratios. Often the well is defined by oil prone (more likely to produce oil) or gas prone (more likely to produce gas). The kinds of drilling are:

- Onshore or land base drilling
- Shallow offshore drilling
- Deep offshore drilling
- Arctic drilling

Originally, oil was extracted easily from comparatively shallow oil wells. Figure 114 shows a schematic and image of an on shore oil and gas derrick oil drilling platform.

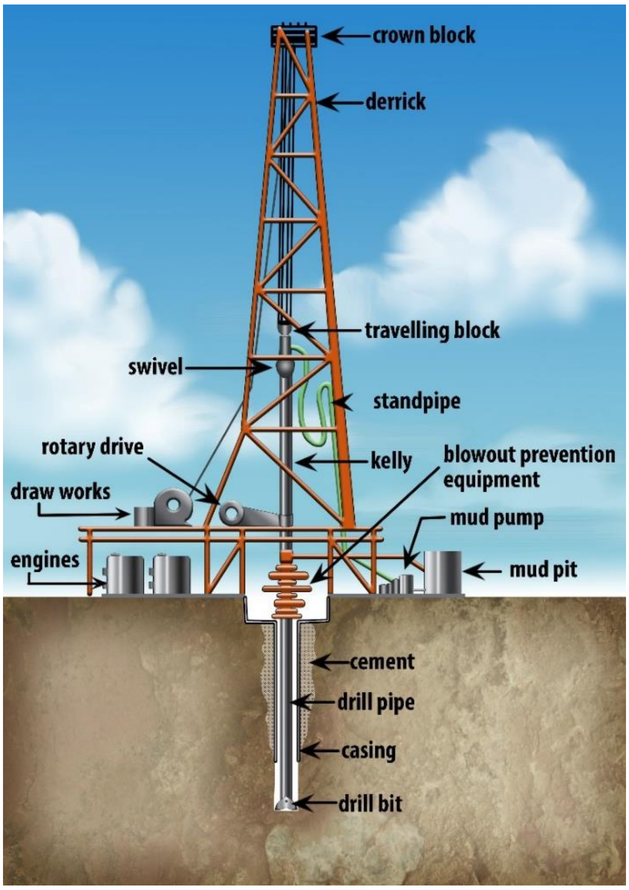


Figure 114. LHS - Schematic of an onshore oil and gas drilling platform (Image: Tania Michaux). RHS – An operating onshore drill platform (Image by Anita starzycka from Pixabay)

Once the well is drilled and has shown to be productive, a pump jack assembly is constructed over the well head. Figures 115 to 117 show the classic oil pumpjack and derrick tower for pumping out of the drilled well.

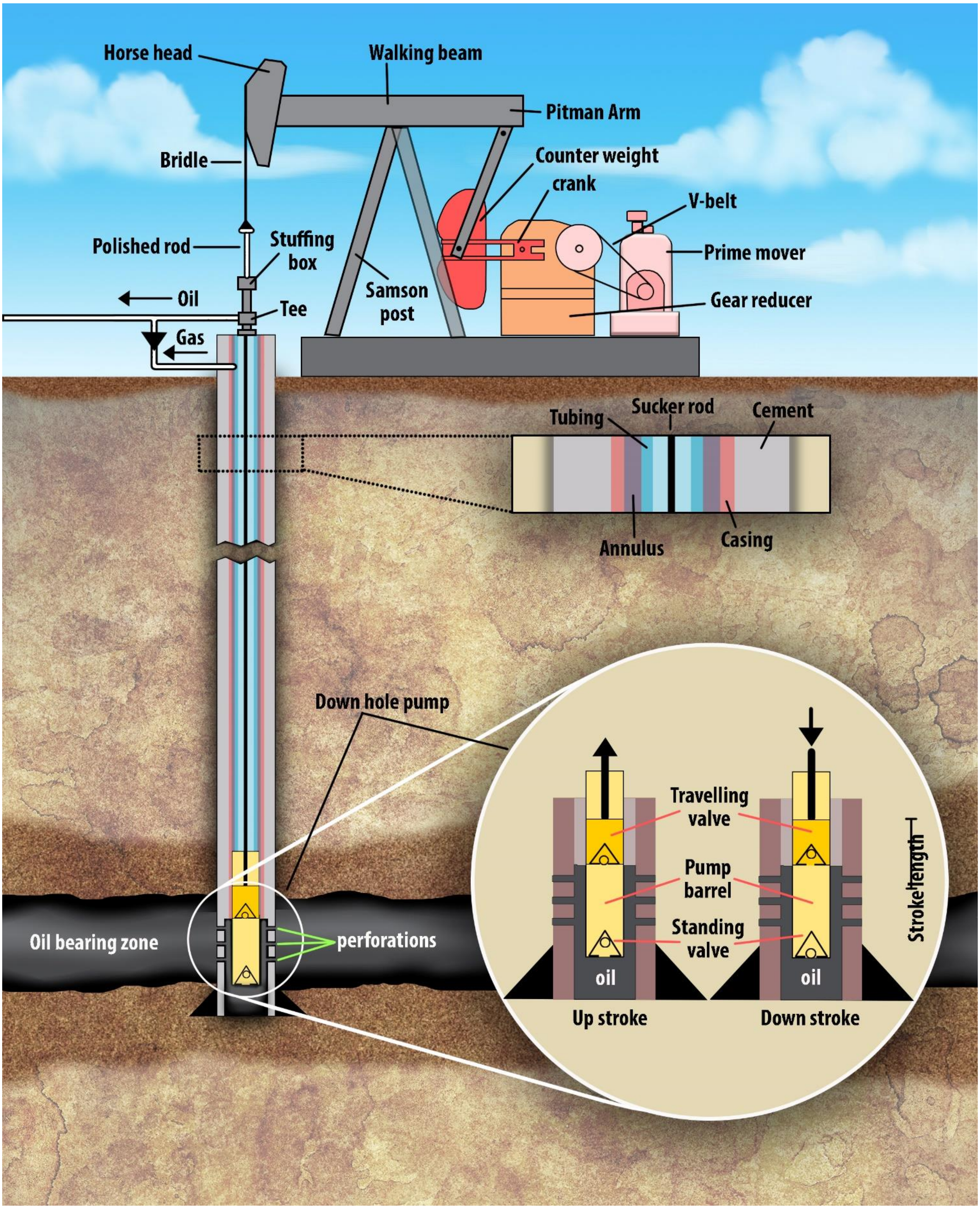


Figure 115. Oil and gas pumpjack schematic
(Image by Tania Michaux)

Figure 116. Oil fields and pumpjacks extracting oil in Texas USA
(LHS Image by John R Perry from Pixabay, RHS Image by skeeze from Pixabay)

Figure 117. Oil fields and pumpjacks extracting oil in Texas USA (Image by Johannes Plenio from Pixabay)

As drilling technology improved, the capability to drill for oil and gas into deposits under the ocean became possible. Over time, demand for oil and gas required offshore drilling platforms to be developed and operated. Approximately 29.2% of oil production in 2018 was extracted from under the ocean (EIA International Energy Outlook 2019). Figure 118 shows a basic schematic cross section of an offshore platform. As time has progressed, the scale of these structures has become ever more impressive (Figure 119 to 121).

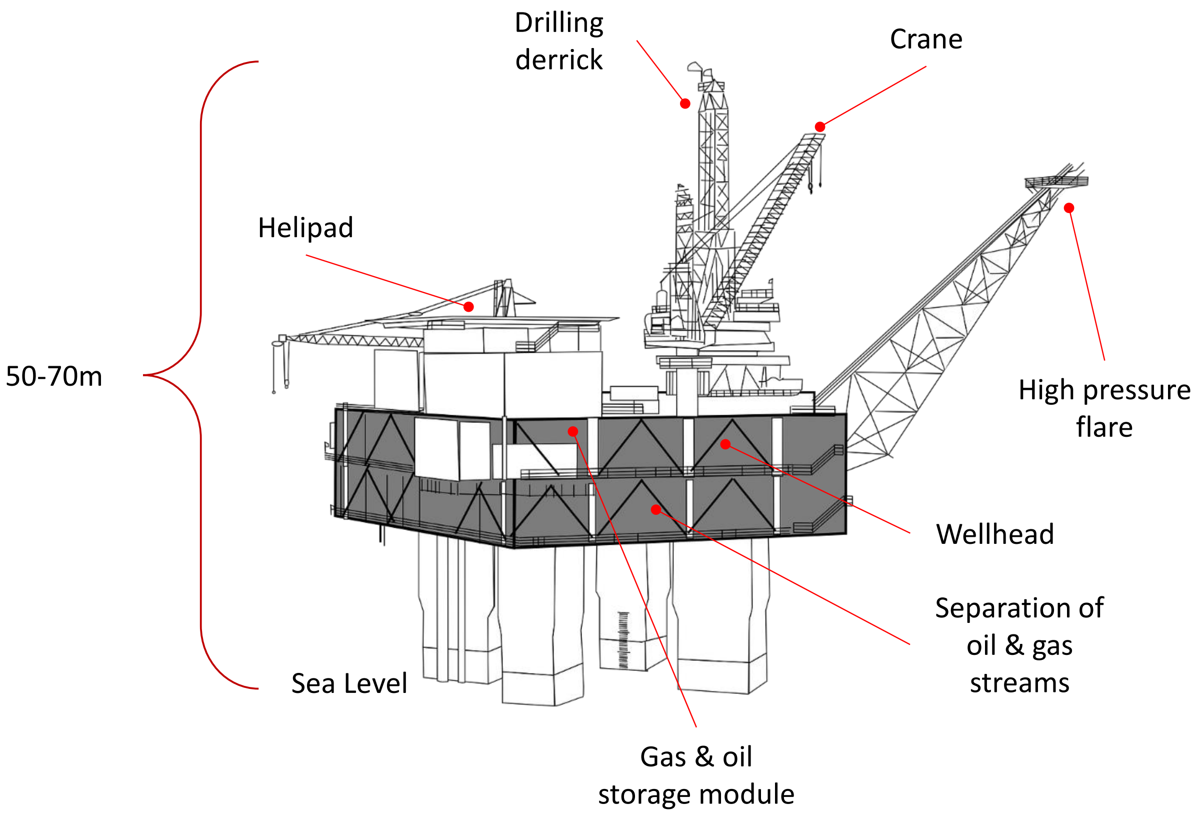


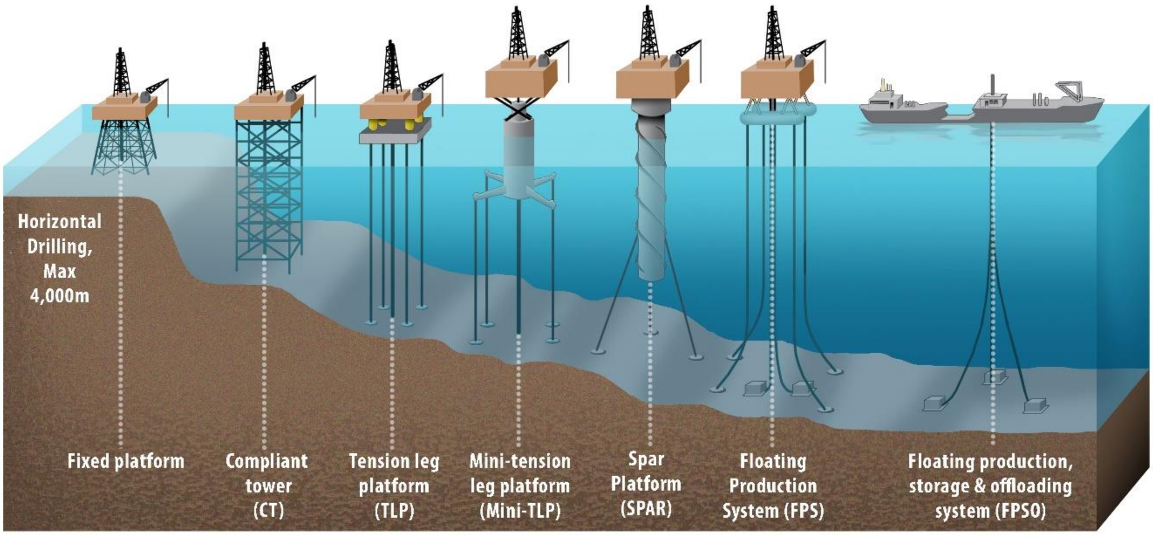
Figure 118. Offshore oil & gas drilling platform basic schematic
(Graphic: Simon Michaux, developed from Image by Clker-Free-Vector-Images from Pixabay)

Figure 119. Deep water oil & gas drilling platform (Source: Image by Kristina Kasputienė from Pixabay)

Figure 120. Deep water oil & gas drilling platform in the (Image by Bruno Glätsch from Pixabay)

Figure 121. Manufacture and maintenance of deep water oil & gas drilling platforms off the Scottish coast (Image by Elliott Day from Pixabay)

Figure 122 shows the progression of offshore platform design as the ocean depths got deeper. Currently the record ocean depth for drilling is held by offshore oil drilling group Transocean whom had set a world record of deep water drilling at a depth of 3107m.



	Fixed platform	CT	TLP	Mini-TLP	SPAR	FPS	FPSO
Water depth (m)	600m	450-900m	450-1,800m			450-2,100m	1,000-3,000m
Total drilling depth (m)	9,000+m	9,000+m	10,000+m			10,000+m	12,000+m

Figure 122. Types and depth capabilities of different offshore drilling platforms
(Image: Tania Michaux)

The record for the deepest drill hole into the earth's crust is currently held by Rosneft (Rosneft 2017). Russian drilling consortium Rosneft, as part of the Sakhalin-1 consortium, has finished drilling the world's longest well—production well O-14—at Chayvo field, offshore Sakhalin Island. Well O-14 was drilled from the Orlan drilling platform towards the south-eastern point of Chayvo field, which lies to the northeast of Russia's Sakhalin Island. The well has a record breaking measured depth of 13,500 m and a horizontal reach of 12,033 m, as of 2015 (Rosneft 2017).

6.2 Unconventional oil production

An umbrella term for oil that is produced by means that do not meet the criteria for conventional production. This is oil which requires advanced production methods due to its geologic formations and/or is heavy and does not flow on its own. Note: What has qualified as "unconventional" at any particular time is a complex interactive function of resource characteristics, the available exploration and production technologies, the current economic environment, and the scale, frequency, and duration of production from the resource. Perceptions of these factors inevitably change over time and they often differ among users of the term.

Unconventional oil includes:

- Heavy crude oil (or extra heavy crude oil)
- Oil sands
- Oil shale
- LTO - light tight oil, abbreviated LTO, known also as tight oil or shale oil.
- Tight oil
- Coal-based liquid supplies through coal liquefaction
- Biomass-based liquid supplies
- Gas to liquids (GTL)
- Kerogen (oil)

6.3 Heavy crude oil

Heavy crude oil (or extra heavy crude oil) is highly-viscous oil that cannot easily flow to production wells under normal reservoir conditions. It is referred to as "heavy" because its density or specific gravity is higher than that of light crude oil. Heavy crude oil has been defined as any liquid petroleum with an API gravity less than 20°. Physical properties that differ between heavy crude oils and lighter grades include higher viscosity and specific gravity, as well as heavier molecular composition.

In 2010, the World Energy Council defined extra heavy oil as crude oil having a gravity of less than 10° and a reservoir viscosity of no more than 10,000 centipoises. When reservoir viscosity measurements are not available, extra-heavy oil is considered by the WEC to have a lower limit of 4° API. Stated another way, oil with a density greater than 1000 kg/m^3 or, equivalently, and a specific gravity greater than 1 and a reservoir viscosity of no more than 10,000 centipoises. Heavy oils and asphalt are dense nonaqueous phase liquids (DNAPLs). They have a "low solubility and are with viscosity lower and density higher than water." "Large spills of DNAPL will quickly penetrate the full depth of the aquifer and accumulate on its bottom."

6.4 Oil bearing shale

Oil bearing shale is an organic-rich fine-grained sedimentary rock containing kerogen (a solid mixture of organic chemical compounds) from which liquid hydrocarbons called shale oil (not to be confused with tight oil—crude oil occurring naturally in shale’s) can be produced. Shale oil is a substitute for conventional crude oil; however, extracting shale oil from oil shale is more costly than the production of conventional crude oil both financially and in terms of its environmental impact. Oil is recovered using two main methods: conventional mining and in situ (Figure 123).

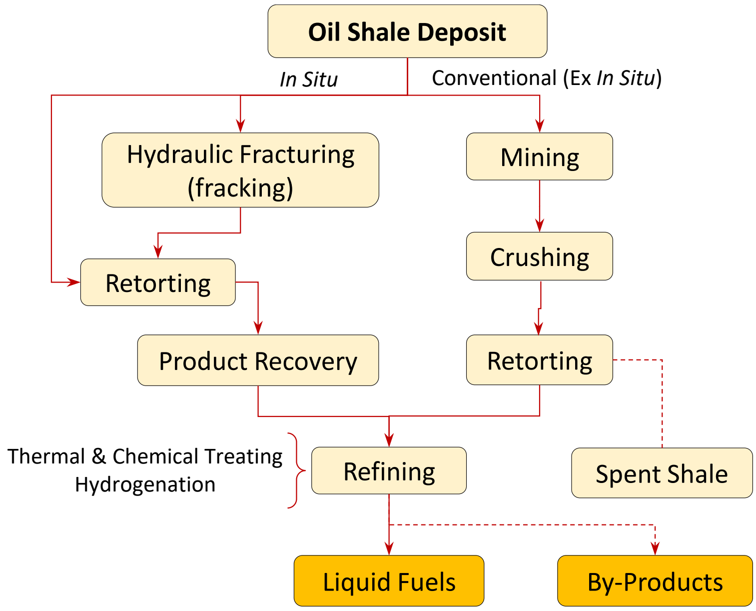


Figure 123. Overview of shale oil extraction

Approximately 80% of the oil sands reserves are too deep to be mined in an economically viable fashion. These deeper deposits would be recovered through in situ methods. Approximately 20% of the oil sands reserves are close enough to the surface to be mined using open pit methods (to a depth of 70m). Mining allows operators to recover more of the oil, while using less energy. Drilling is a more energy-intensive process but allows for a smaller footprint and does not require tailings ponds (Canadian Association of Petroleum Producers 2019 b).

6.5 Shale Oil (Tight Oil)

Shale oil is an unconventional oil produced from oil shale rock fragments by pyrolysis, hydrogenation, or thermal dissolution. These processes convert the organic matter within the rock (kerogen) into synthetic oil and gas. The resulting oil can be used immediately as a fuel or upgraded to meet refinery feedstock specifications by adding hydrogen and removing impurities such as sulfur and nitrogen. The refined products can be used for the same purposes as those derived from crude oil. The term "shale oil" is also used for crude oil produced from shale's of other very low permeability formations.

However, to reduce the risk of confusion of shale oil produced from oil shale with crude oil in oil-bearing shale's, the term "tight oil" is preferred for the latter. The International Energy Agency recommends to use the term "light tight oil" and World Energy Resources 2013 report by the World Energy Council uses the term "tight oil" for crude oil in oil-bearing shale's.

The extraction of oil from oil shale deposits conventionally has been through mining and crushing the shale 'ore' (Figure 123). Shale oil mining is often used in parallel with hydraulic fracturing technology (or fracking).

The shale oil revolution in the United States, where oil and gas has been produced by hydraulic fracturing (fracking), using horizontal drilling technology has increased supply of oil to the global market. This one sector has almost on its own been responsible for most of the increased capacity for oil production since 2005 (see Section 7).

6.6 Hydraulic Fracturing (fracking)

Hydraulic fracturing involves drilling a well then injecting it with a slurry of water, chemical additives and proppants. Wells are drilled and lined with a steel pipe that's cemented into place. A perforating gun is used to shoot small holes through the steel and cement into the shale. The highly pressurized fluid and proppant mixture injected into the well escapes and create cracks and fractures in the surrounding shale layers and that stimulates the flow of natural gas or oil. The proppants (grains of sand, ceramic beads, or sintered bauxite) prevent the fractures from closing when the injection is stopped and the pressure of the fluid is removed.

Hydraulic fracturing (also known as fracking, fraccing, frac'ing, hydrofracturing or hydrofracking) is used in tight oil formations to extract the oil. This is a well stimulation technique in which rock is fractured by a pressurized liquid (high pressure applied in a short time period, creating a shock wave). The process involves the high-pressure injection of 'fracking fluid' (primarily water, containing sand or other proppants suspended with the aid of thickening agents) into a wellbore to create cracks in the deep-rock formations through which natural gas, petroleum, and brine will flow more freely. When the hydraulic pressure is removed from the well, small grains of hydraulic fracturing proppants (either sand or aluminum oxide) hold the fractures open (Figure 125).

Fracking is used in tight oil formations, targeting shale geological units to extract the oil and gas they contain. Fracking is also used in coal bed methane, or coal seam gas (CSG) deposits (see Figure 124). CSG deposits are associated with coal seams, and are often at a shallower depth than shale oil units. Both CSG and shale oil units are often below the water table.

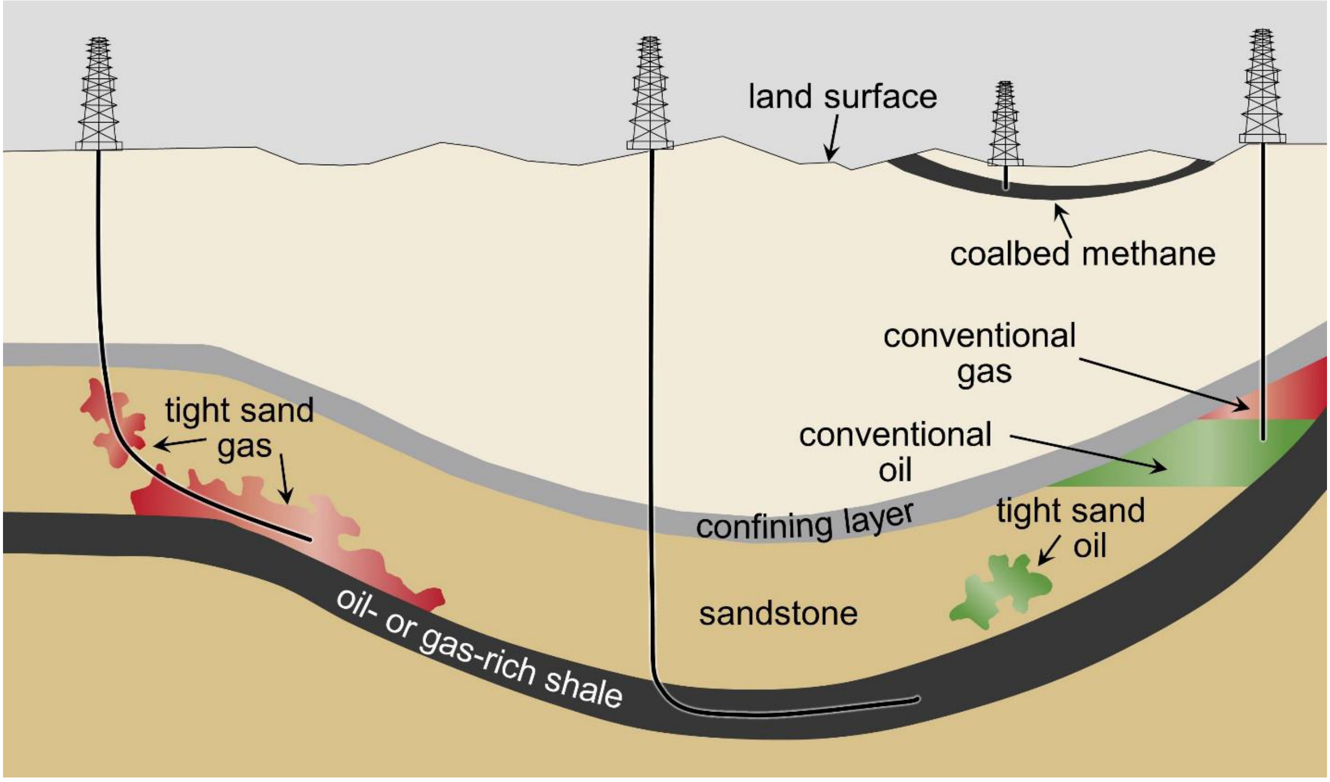


Figure 124. Difference in geological form between conventional oil & gas deposits to unconventional oil & gas deposits (Source: U.S. EPA 2015)

Before 2008, a shale oil fracking well was vertical in anticline. Vertical wells can effectively drain rock units that have a very high permeability. Fluids in those rock units can flow quickly and efficiently into a well over long distances. However, where permeability is very low (like most oil shale's), fluids move very slowly through the rock and do not travel long distances to reach a well bore. Horizontal drilling can increase the productivity in low-permeability rocks by bringing the well bore much closer to the source of the fluid.

A new drilling technology allowed for the use of horizontal drilling, where part of the drill path cuts along the dip and strike of the porous oil bearing unit. After drilling vertically a few thousand meters, the drill operation can then steer a specialized horizontal directional drill bit a further few thousand meters (Figure 126). This allows a larger section of the well to intersect the target unit, and facilitate more efficient extraction. This technology was instrumental in greatly expanding the production capacity of tight oil extraction operations, particularly in the United States.

The new innovations of horizontal drilling, multi well pads, increased use of proppant and infrastructure efficiencies have all increased production, and lowered costs, but they have not significantly increased the volume of the ultimate recoverable resource (URR) of most shale oil fields.

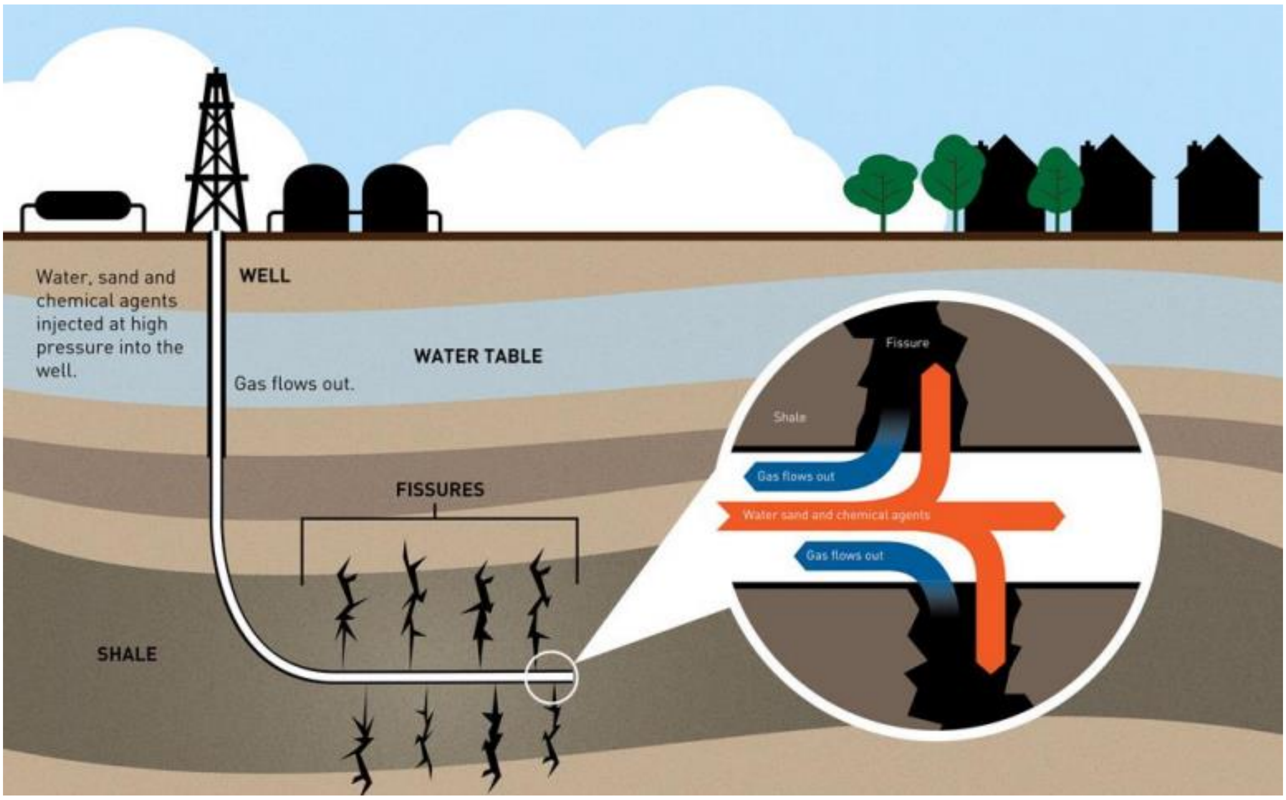


Figure 125. Hydraulic fracturing or 'fracking' process
(Source: Hughes 2019)

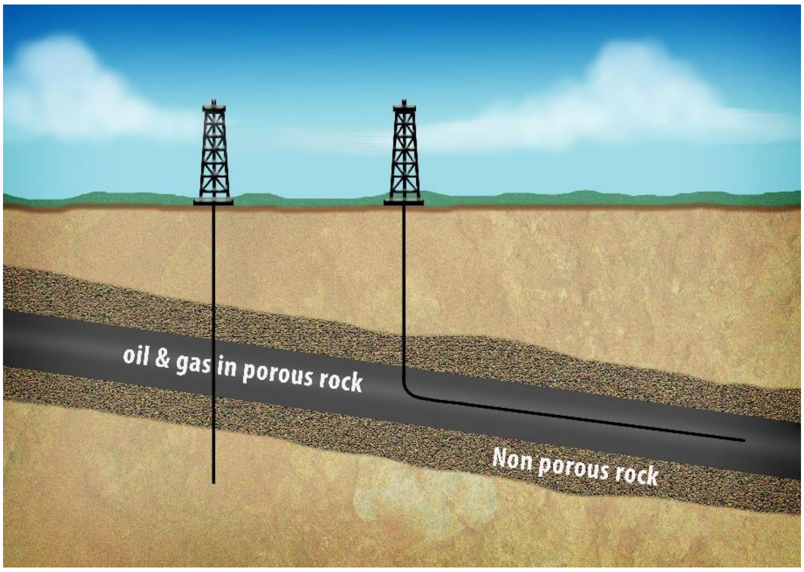


Figure 126. Horizontal drilling technology used to increase fracking productivity (Image: Tania Michaux)

There is a four stage life cycle that oil and gas extraction fracked wells all evolve through. These steps are always the same, but can speed up in the down turns of the boom/bust cycles that the oil industry is often subject too. The four stage list below was developed in a series of excellent studies done by the Post Carbon Institute (Hughes 2011, Hughes 2018 and Hughes 2019)

1. **Early Stage.** Discovery with step out drilling sweet spots. As sweet spots are located and focused upon, well productivity increases, sometimes dramatically. Well productivity gains are primarily from moving from lower, to higher quality reservoir rock. This means that the underground geology facilitates extra productivity, not technology. An example could be the Utica basin tight oil play in the U.S.

2. **Early Mature Stage.** Geological sweet spots have been fully spatially mapped and are methodically being drilled out. Increased well productivity is primarily due to technology gains. This means more effective application of horizontal drilling, extra water injection and higher volume use of proppant. Examples include parts of the Permian, Haynesville and Bakken basin tight oil plays in the U.S.

3. **Late Mature Stage.** Geological sweet spots become saturated with wells and well interference becomes evident. Well productivity declines from overcrowding wells. Maintenance drilling is required to drill in lower quality reservoir rock. Examples include Eagle Ford, parts of the Marcellus, and parts of the Permian, Woodford and Niobrara basin tight oil plays in the U.S.

4. **Late Stage.** Geological sweet spots are saturated with wells and drilling rates collapse. Production falls, offset only by limited infill and peripheral drilling. Technology helps but cannot make up for the exhaustion of high quality drilling locations. Examples include the Barnett and Fayetteville basin tight oil plays in the U.S.

Figures 127 to 129 show fracking operations in Australia in the Queensland CSG fields. The same technology is used in the United States shale oil fields, but are often operating at deeper depths. The Australian CSG fields are much smaller in size and capacity compared to the U.S. tight oil shale fields.

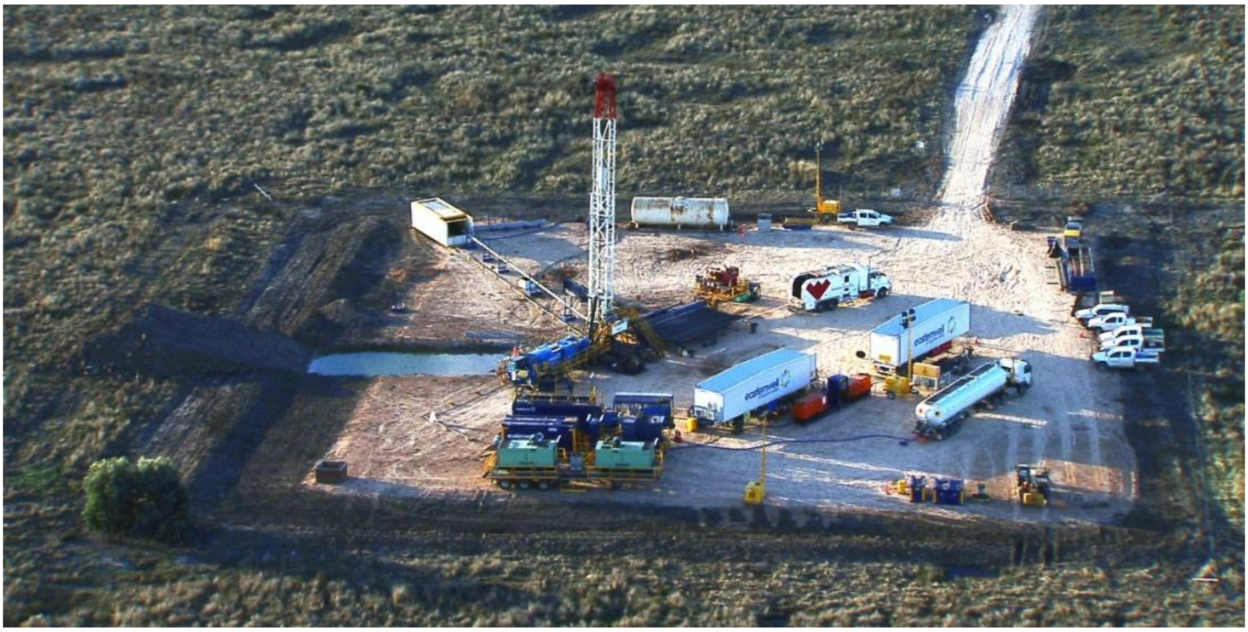


Figure 127. A hydraulic fracturing drill rig operating in a CSG deposit in Australia
(Source: Lock the Gate, https://www.lockthegate.org.au/)

Figure 128. A Coal Seam Gas (fracking) processing site operating in Queensland Australia
(Source: Lock the Gate, https://www.lockthegate.org.au/)

Figure 129. A Coal Seam Gas (CSG) fracking field in Queensland Australia
(Source: Lock the Gate, https://www.lockthegate.org.au/)
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Fracking fields are different to conventional oil and gas fields. It takes tens of thousands of fracked shale wells to equal a mere hundred conventional wells (Heinberg 2013).

What is causing this is the difference in well productivity. A fracked well, has approximately a 90% drop in productivity after 36 months, where a conventional well can last 10 years or more (Hughes 2018).

As more capacity has been developed, more extra maintenance drilling has been required to keep productivity consistent. To keep U.S. production stable and consistent at 2019 rates, 5 399 new wells for tight oil need to be drilled each year (2 335 for gas) (Hughes 2019). In 2018, 70% of new drilling was done to offset field production declines and only 30% was for increased production (Hughes 2019).

This is known in the industry as “the treadmill to hell” (Heinberg 2013). Another colloquial name that has been used is “the Red Queen problem”, a metaphor from the famous C.S. Lewis book Alice in Wonderland. The Red Queen (or Queen of Hearts) quote:

> *“My dear, here we must run as fast as we can, just to stay in place. And if you wish to go anywhere you must run twice as fast as that.”*

Lewis Carroll 1865, Alice's Adventures in Wonderland

This is shown on a national scale, as is shown in Figure 130, which compares the tight oil in the US with the conventional oil production in Saudi Arabia (which is conventional oil production and is mature in development) and Russia (which is conventional oil production and developing quickly).

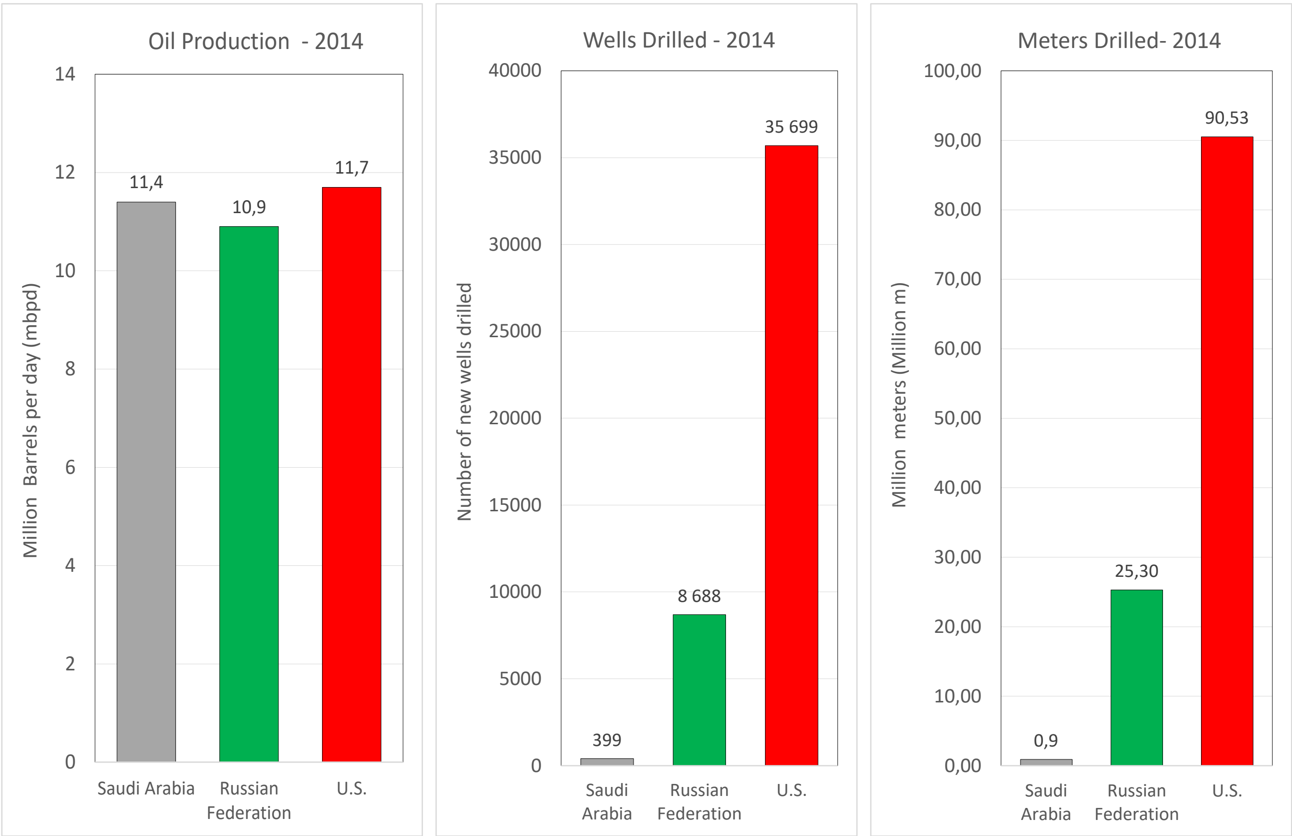

Figure 130. Global drilling of oil wells
(Source: IEA, EIA, Spears, SLB Analysis)

Figure 131 shows the progression of the number of wells being drilled to extract all oil and gas possible for a Louisiana tight oil field. The impact on communities and the impact on the environment can be significant (Fox 2010, Fox 2013 & Lock the Gate 2014). What also can be an issue is that the local community does not benefit at all for hosting fracking fields, as employment by operators is not enough to outweigh the difficulties fracking often entails.

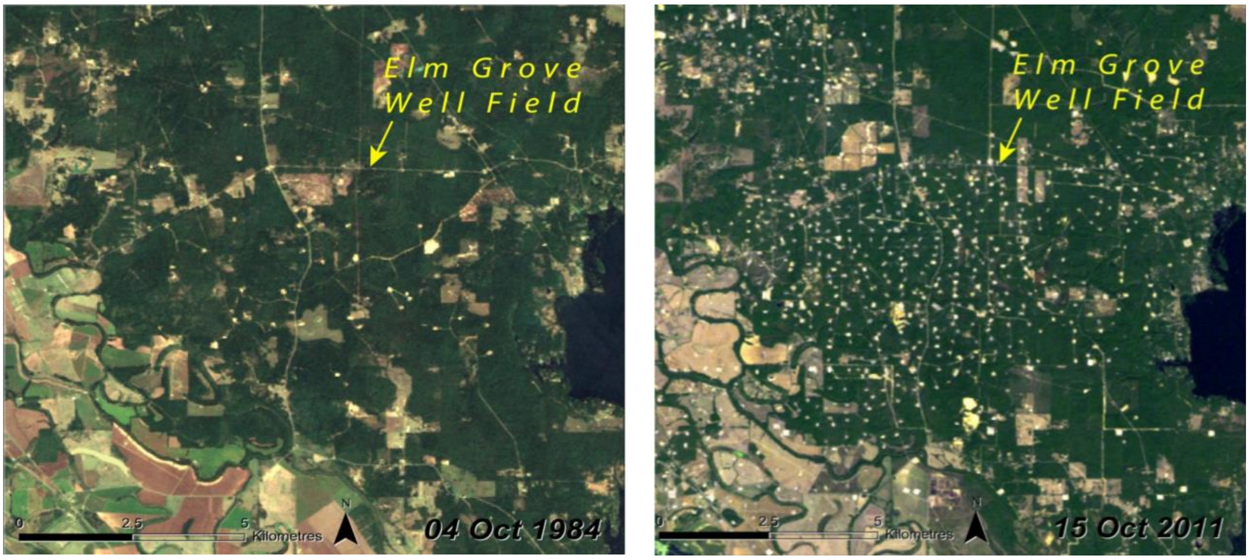

Figure 131. These two satellite images of a Louisiana shale oil field from 1984 (LHS) and 2011 (RHS) show the high density of wells where over 1000 UG well pads (small, white dots) were developed.
(Source: UNEP 2012) (Copyright License: https://www.unep-wcmc.org/terms-and-conditions)

6.7 Environmental impact of Hydraulic Fracking

Environmental impact of hydraulic fracturing in the United States has been an issue of public concern, and includes the potential contamination of ground and surface water, methane emissions, air pollution, migration of gases and hydraulic fracturing chemicals and radionuclides to the surface, the potential mishandling of solid waste, drill cuttings, increased seismicity and associated effects on human and ecosystem health. A number of instances with groundwater contamination have been documented, however opponents of water safety regulation claim hydraulic fracturing has never caused any drinking water contamination.

As early as 1987, researchers at the United States Environmental Protection Agency (EPA) expressed concern that hydraulic fracturing might contaminate groundwater. With the growth of hydraulic fracturing in the United States in the following years, concern grew. "Public exposure to the many chemicals involved in energy development is expected to increase over the next few years, with uncertain consequences" wrote science writer Valerie Brown in 2007. It wasn't until 2010 that Congress asked the EPA to conduct a full study of the environmental impact of fracking. The following documentaries available on YouTube provide good insight into the environmental impact and the impact on society communities of the use of hydraulic fracturing in oil/gas shale reserves.

Fox, J. (2010): GasLand Media documentary produced on fracking of shales and CSG in America

https://www.youtube.com/watch?v=Xvz_m5uPV4s

Fox, J. (2013): Gasland Part II. Media documentary produced on fracking of shales and CSG in America

https://www.youtube.com/watch?v=weGjWsU0Hd8

Lock the Gate Alliance (2014): Fractured Country - An Unconventional Invasion Media documentary on fracking and CSG in Australia

https://www.youtube.com/watch?v=XrE7LzZCn1E

There is mounting evidence that CSG mining (the legal term in Australia) and oil shale fracking poses substantial risks (Figure 132), including:

- Threats of pollution to water systems and supplies
- Leaking methane
- Health impacts on local communities
- Above ground footprint; and
- Related seismic activity.

Gas industry operators have claimed that because shale and tight gas extraction involves deeper rock layers, they are safer than gas extraction from shallower coal seams (CSG) (Appea 2010). According to a European Commission Report (Broomfield 2012) there is an overall high risk of ground and surface water contamination resulting from fracking.

U.S. studies have implicated shale gas in the contamination of groundwater with heavy metals, salts and gas (Green Peace 2013). Contamination can occur from well casing failure due to corrosion, faulty construction or repeated fracturing. Data from one US state shows that 6-7% of new shale gas wells were faulty and leaking gas (Green Peace 2013). After 20 years this failure rate may increase to 50%, as wells corrode and cement casings degrade.

Groundwater contamination can also occur if gas and toxic flowback fluids migrate from gas wells into aquifers through natural underground faults or fractures created during fracking operations. Recent research (Fontenot *et al* 2013) found higher levels of arsenic and other heavy metals, plus higher salinity, in water bores which were less than 3km from shale gas wells. Other research (Osborn *et al* 2011) has found increased methane concentrations in water bores closer to shale gas wells, creating an explosion hazard.

Surface water pollution can occur when there are accidental spills of fluids or solids at the surface, when well blow outs occur, and through discharge of insufficiently treated waste water into waterways. Work done by Duke University in the U.S. have found high levels of radioactivity in a creek used for disposal of wastewater (Warner *et al* 2013).

Fracking for shale and tight gas is an extremely water-intensive practice. Each well may require up to ten fracks over its production life (Usubiaga 2012). The Australian gas industry provides a figure of 11 million liters per shale or tight gas frack (Appea 2019). According to an alternative (outside industry), a single frack operation on a shale gas well will use between 11 and 34 million liters of water, roughly 360 – 1100 truckloads (WA Government 2019). Drilling a shale or tight gas well also requires around 1 million liters per well (Kargbo *et al* 2010).

According to industry sources, around 30% of the fracking fluid flows back to the surface (Appea 2019). However, other sources note that as little as 6 to 8% may actually be recovered (Kargbo *et al* 2010). Underground water in the drilling area can also come to the surface during gas production. For a typical shale gas well, daily 'produced' water volumes range from 300 – 4,500 liters (EPA 2016).

In the U.S., towns and pastoral properties that must compete with fracking operators for scarce water supplies have been seriously affected (Taillant *et al* 2015). In Texas, extraction of water for fracking has contributed to serious problems of ground and surface water depletion during drought conditions (Hylton 2013).

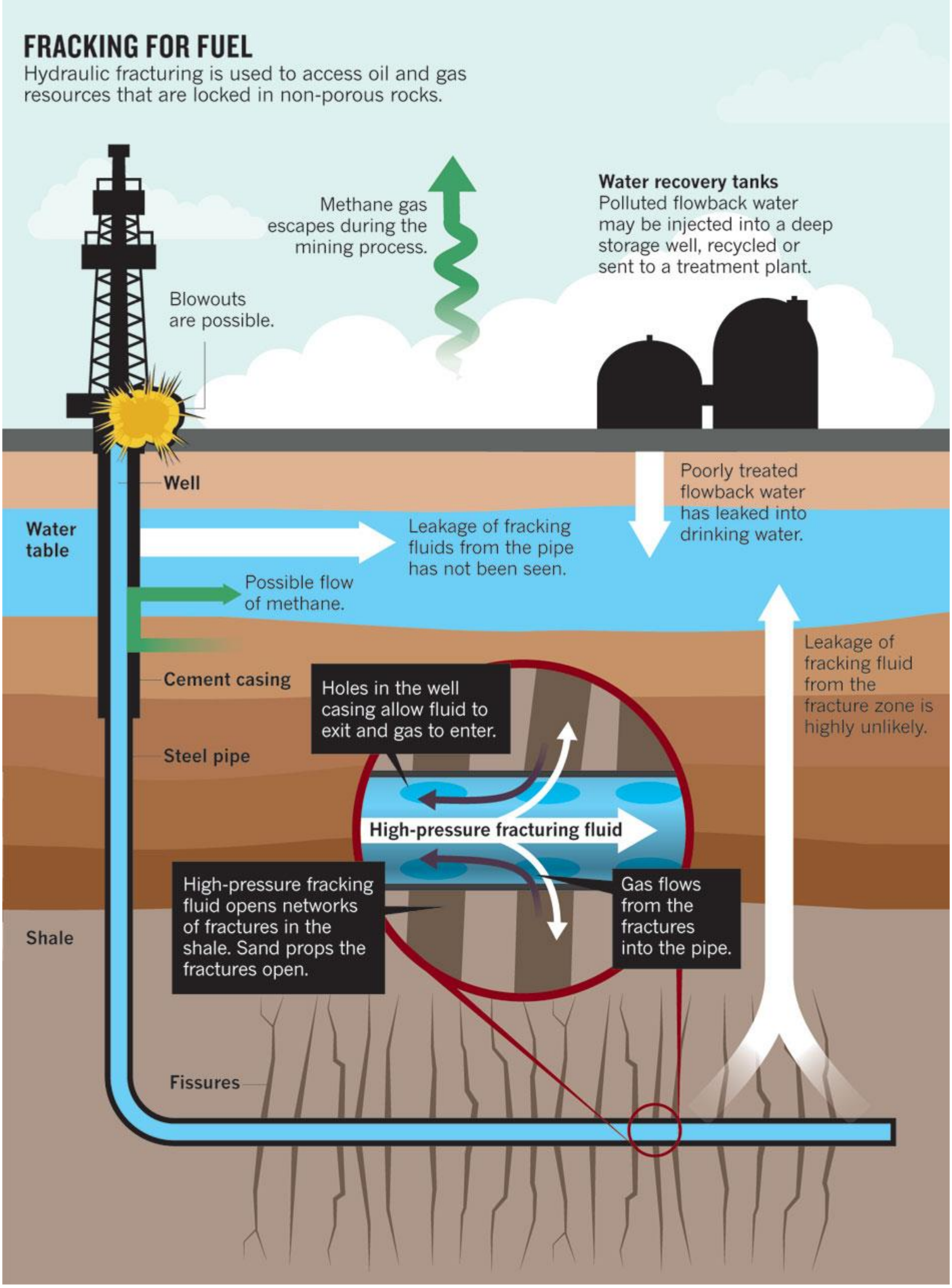

Figure 132. Environmental hazard vectors in CSG fracking operations
(Source: Lock the Gate, https://www.lockthegate.org.au/)
(Copyright License: https://creativecommons.org/licenses/by/2.0/)

Most of the fracking fluid is water (99%). The gas industry reports that chemical additives make up only a very small proportion of proppant fracking fluids- 'approximately' 0.5% (Appea 2019). In alternative studies, the amounts measured range from 0.5 to 2% and while this is a small proportion relative to the large volumes of water used, it translates to very large quantities of chemicals (Hazen & Sawyer 2009). Approximately one pound of proppant is used for each one gallon of water (Hughes 2019).

The United States EIA reports that a typical 4 million gallon (15 million liter) fracking operation uses between 80 tons and 330 tons of chemicals (EIA 2013). This is much higher than what operators have claimed. In the United States, approximately 750 compounds have been listed as additives or ingredients to manufacture the pressurized fracking fluid used in fracking. Appendix G (COMPOUNDS HAVE BEEN LISTED AS ADDITIVES FOR HYDRAULIC FRACTURING IN THE UNITED STATES) shows a referenced list of these chemicals.

The fracking Industry also reports that 'most' of these chemicals are found in household products (Appea 2019). This statement may be factual but this does not mean that the chemicals used are environmentally safe to have in the water table at such high levels of concentration (Hays & Shonkoff 2016). Fracking compounds used in Australia and the U.S. have also been shown to include many hazardous substances, including carcinogens, neurotoxins, irritants/sensitizers, reproductive toxins and endocrine disruptors. Many of the chemicals used in fracking have never been assessed for their long-term impacts on the environment and human health (CHPNY & PSR 2019, Zucker and Shah 2014, NTN Coalition 2012).

Sand or other proppants such as ceramic beads are vital to fracking. Sand (or a proppant) is a significant part of the mix that's injected into a well to fracture the rocks. Once a formation has been fracked, the sand props open the cracks in the rock allowing the gas to flow. To squeeze hydrocarbons out of shale, fracking operations need to pump large quantities of sand and other materials into the ground. In the US fracking for shale and tight gas was expected to consume more than 43 billion kg of sand just in 2014 (Taillant *et al* 2015).

Whilst the gas industry maintains that unconventional gas extraction is safe and 'clean', there is a rapidly growing body of research from overseas that highlights the impacts of shale and tight gas operations on land, water and human health (CHPNY & PSR 2019, Zucker & Shah 2014, Broomfield 2012, UNEP 2012, NTN Coalition 2012). Communities living near gasfields in the US have reported serious health effects following the commencement of unconventional gas operations. Some of the public health effects of unconventional gas development that US researchers have documented, as outlined in The Compendium of Fracking Risks (CHPNY & PSR 2019) include:

- Increased rates of hospitalization for cardiological complaints, cancer, skin conditions, and urological problems.
- Increase in frequency of health symptoms reported by residents as distance between households and gas wells decreased; with rashes and upper respiratory problems more prevalent among persons living less than one kilometre from drilling and fracking operations.
- Increase in infant deaths to six times the normal rate over three years.
- Congenital heart defects, and possibly neural tube defects in newborns, associated with the density and proximity of natural gas wells within a 10-mile radius of mothers' residences.

- Reductions in average birthweight and length of pregnancy as well as increased risk for low birthweight and premature birth associated with proximity to fracking operations.

- Residents living adjacent to coal seam gas operations around Chinchilla Queensland also report a range of health symptoms, including serious respiratory ailments, nose throat and eye irritations and neurological illnesses.

- A 2012 case study in the U.S. (NTN Coalition 2012) also found serious evidence of harm to domestic stock from shale gas drilling waste contamination, including cattle deaths, stillbirths and reproductive problems.

From a purely technical point of view, it is possible to do this method with a lower risk of environmental pollution, however to do so would require a much higher cost of operation (which could make the operation economically unviable). A critical problem is also that if an operator did not do best practice methods and caused environmental pollution, it would be impossible to prove which operator (different leases with different operators are often in the same environmental impact region). An accusation of noncompliance could be defeated in court with a simple response: 'prove it was the defendant operator'. This opens the question for whether fracking should have been allowed to be legislated in the first place.

It is the authors opinion that the hydraulic fracturing or 'fracking' is inappropriate to engage in to extract oil and gas. The application of fracking has probably pushed total peak oil production back 10-15 years. The resulting environmental devastation is most certainly not an acceptable outcome in return for this extra time for operation of the exiting energy systems. What have we done with this extra 10-15 years? Did our industrial and political leadership use this time to develop an appropriate transition plan to phase out the use of oil and petroleum products? A great deal of discussion has been had about the development of the Electric Vehicle revolution but its practical logistical applications have not been understood (Michaux 2020). There certainly has been comparatively little infrastructure development.

A case can be made that CSG and fracking might be a bubble in terms of investment viability. It is not nearly as productive as conventional gas. It is also now clear that political leadership and corporate leadership have knowingly mislead the public regarding the impact of fracking to the environment and to the societies that are local to fracking wells (Mobbs 2017, Lowe 2014, Fox 2010, Fox 2013 and Heinberg 2013). Without fracking, peak oil would have happened sometime between 2005 and 2009, which would have led to the devastation of all monetary, industrial and corporate systems. In exchange for the environmental devastation (destruction of arable land in an era of projected food shortages), pollution of underground fossilized water reserves (in an era of projected drinking water shortages), and devastated communities, the date of peak oil has been pushed back 10 years.

From a business model perspective, Shale oil is not economically viable in a challenging market environment. Oil from fracked Shale deposits cannot even be processed without the addition of a lot of conventional crude in support. It requires 3 to 5 barrels of conventional crude to refine 1 barrel of Light Tight Oil (LTO). LTO cannot be put through a refinery by itself. It takes somewhere between 70-80% of the inputs to be conventional for refineries to operate if they include shale (Fahim *et al* 2010).

6.8 Oil sands deposits (tar)

Oil sands/ Tar sands are a type of fossil fuel. These deposits are formed from organic matter which decays according to specific temperatures and pressure. The light hydrocarbons are consumed by microbe bacteria leaving behind the heavy fractions including sulfur. Oil sands are synthetic crudes and derivative products, also known as tar sands, or more technically bituminous sands, are a type of unconventional petroleum deposit. Oil sands are either loose sands or partially consolidated sandstone containing a naturally occurring mixture of sand, clay, and water, saturated with a dense and extremely viscous form of petroleum technically referred to as bitumen (or colloquially as tar due to its superficially similar appearance) (Mech 2011). There is an abundance of oil sand reserves found in Saudi Arabia and Venezuela with Canada having the world's third largest oil reserves (Shell, 2014). Canada is one of the only reservoirs to produce oil from oil sands due to the required large scale industry of oil sands.

Figure 133. Raw oil sand from Syncrude's North Mine (Syncrude Canada Flickr) (Copyright License: Authorized by Syncrude, https://www.flickr.com/help/terms)

The sand oil deposits can be found deep underground as well as on the surface. They are naturally formed over years and reside in wells. The valued product is the heavy oil also known as bitumen which contains the heavy hydrocarbons found in crude petroleum. The bitumen is coating each sand particle (quartz) over a 10 nanometer layer of water. So the bitumen needs to be removed from the surface of each particle.

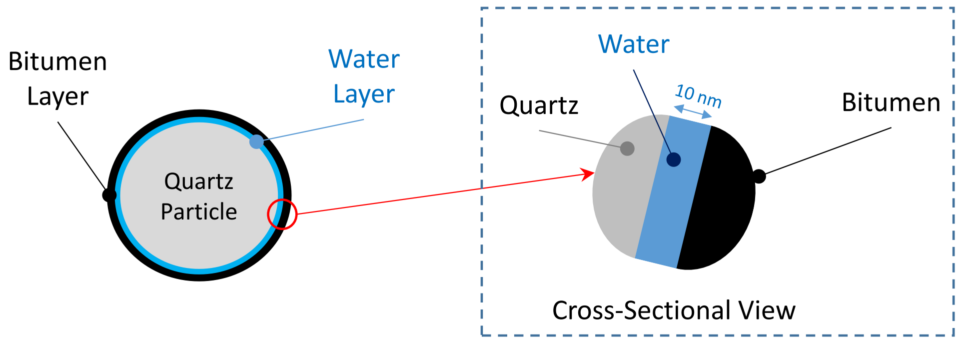

Figure 134. Bitumen coating sand particles in oil sands

The amount of bitumen contained in a well, ranges from 1% to 20% (Fuel Chemistry, 2006). The heavy oil can be described as a black to brown semi-solid at ambient temperature. The mixture is known to soften upon heating; usually steam is injected underground to liquefy the sand oils so they can be transported to the process plant.

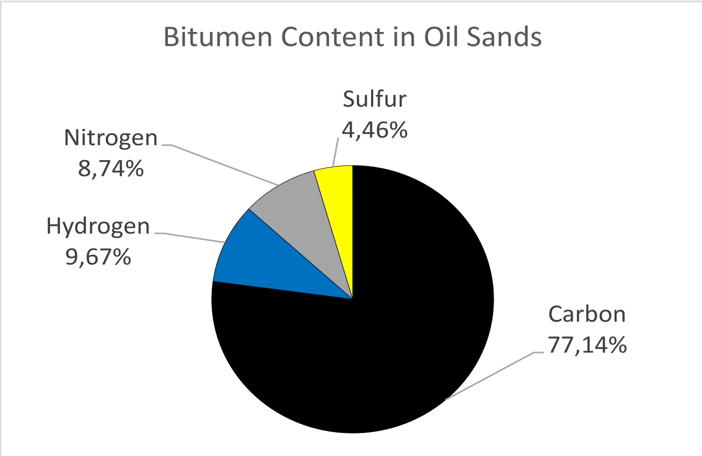

Figure 135. Bitumen content in oil sands (Source: Fuel Chemistry, 2006)

The primary producer of oil from tar sands is Canada. Figure 136 shows the production from tar sands from the 1998 to 2018. The oil sands accounted for 64% of Canada's oil production in 2018 or 2.9 million barrels per day (Canadian Association of Petroleum Producers CAPP 2019). The oil sands have an estimated $313 billion of capital investment to date, including $10.4 billion in 2018. Canadian reserves at the end of 2018 was 166.7 billion barrels of crude oil, of which 162.5 billion barrels (96% of Canadian total) was in oil sands, and 4.2 billion barrels were in conventional oil deposits (Canadian Association of Petroleum Producers CAPP 2019). Of the oil sands reserves in Canada, 31.8 billion barrels are to be extracted with the mining method, and 131.7 billion barrels are to be extracted *insitu*.

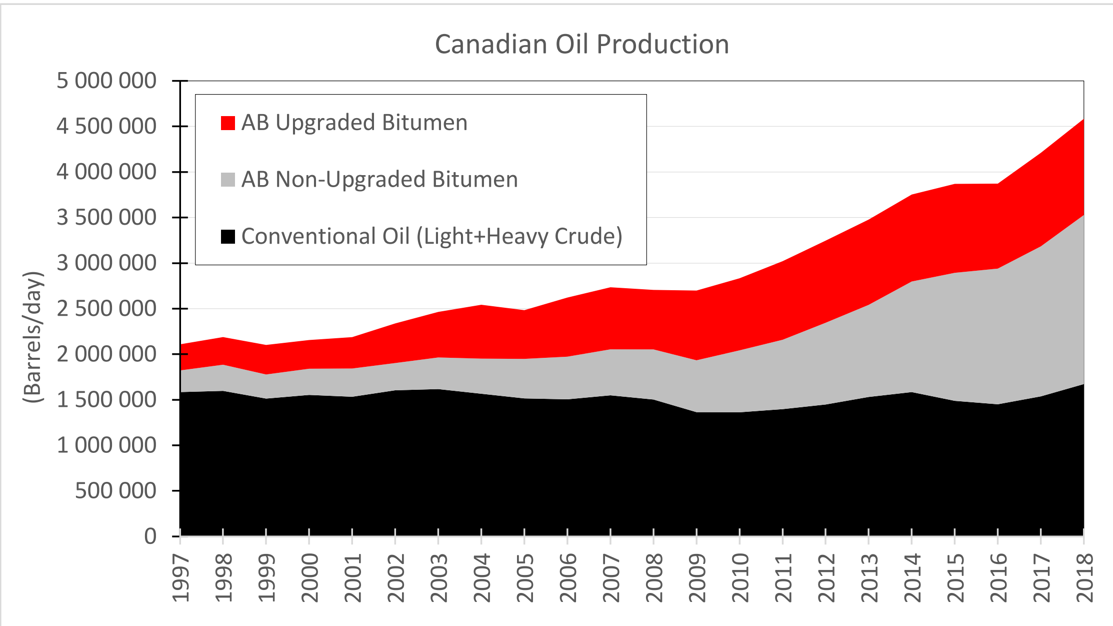

Figure 136. Canadian tar sands oil production 1998 to 2019
(Source: Canadian Association of Petroleum Producers CAPP 2019)

The oil sands underlie 140,800km^2, or 21% of the province of Alberta in Canada. Data from the Alberta government's Department of Energy show that the mining portion of this land base will be approximately 4,750km^2, and that 99% of the mineable area has already been leased (Mech 2011).

The *insitu* operation makes use of steam that is pumped underground to heat the bitumen liquefying it, so it can be pumped to the surface. The disadvantage of drilling is that the process is energy intensive however this process has a smaller footprint on the environment. The *insitu* method of extraction accounts for 53% of 2018 Canadian production and 81% of Canadian resources (Natural Resources Canada 2019). More than 20 projects are *insitu* extraction in Alberta – the largest in 2018 were:

- Christina Lake (Cenovus) at 201 Mb/d
- Firebag and MacKay River (Suncor) at 242 Mb/d
- Foster Creek (Cenovus) at 162 Mb/d
- Cold Lake (Imperial Oil) at 148 Mb/d.

Most of the oil sands in available reserves are to be recovered using the in-situ drilling technique (approximately 80%). The *insitu* technique is more complex and requires drilling into the ground. The amalgam of the in-situ oil sand is still the same as the oil sand which is obtained through surface-mining. The difference is most *insitu* deposits are buried more than 350-600 meters below the ground.

Steam assisted gravity drainage (SAGD) begins with a pair of horizontal wells that are drilled into the formation in order for the bitumen to be extracted from the ground (Figure 137). Typically these wells are situated at least 5m apart and 300 to 600m in depth. The horizontal length of the wells stems about 1000 to 1500m. The minimum stem temperature is 200^{0}C with a pressure greater than 3000kPa.

Once heated to a temperature of approximately 200^{0}C, the bitumen has a viscosity similar to water and can therefore be pumped easily.

Within these horizontal wells are 2 parallel horizontal pipes with one of them located 4-6 meters above the other. The upper pipe is referred to as a steam injection well whereas the bottom pipe is referred to as the production well. The water is converted into steam at a nearby boiler plant and is transferred (in a pipe) to the place where the drilling is taking place. Steam is passed through the upper well and into the reservoir which consists of the oil sand. The steam then leaves the upper well whilst extend outwards into the formation in all directions. The heat from the steam is then conveyed to the bitumen.

Warming of bitumen results in the reduction of its viscosity to allow it to flow more easily. Since the viscosity was decreased significantly, it is now able to flow freely downward under the force of gravity into the production well. This process of draining of the bitumen is referred to as gravity drainage. From the production well, the fluid bitumen is pumped to the surface. The steps consisting of steam injection and bitumen production happen simultaneously and continuously. The final bitumen product and condensed steam emulsion is transferred via pipelines to the plant where it is distilled and treated. The excess water from this process is recycled for generating more steam.

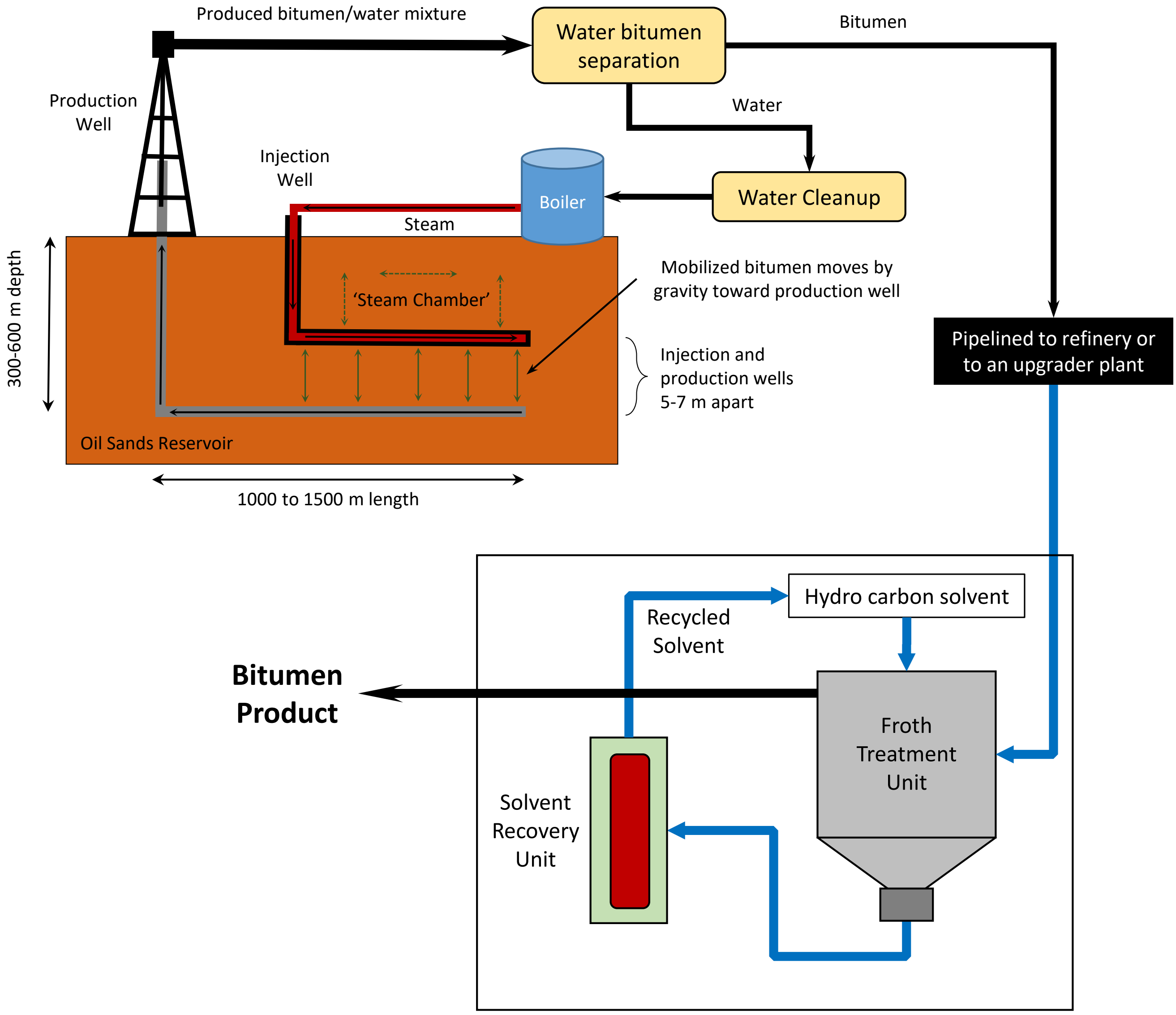

Figure 137. *Insitu* extraction and processing of oil sands
(Source: data from Mech 2011)

Figure 138 shows Suncor's in-situ project is located on leases known as "Firebag".

Figure 138. *Insitu* oil sands operation Firebag well pad using Steam Assisted Gravity Drainage (SAGD) technology SAGD (Image: Suncor Media Release)

Oil sands that are at a depth of 70m or less are mined in open pit fashion and then process extraction is used to produce oil (Figure 139). The sand 'ore' is mined, transported, and then crushed. Then the crushed fragments are fed into rotary drum unit to fragment apart the feed into separate sand grains. This makes accessible the surface of each particle to separate the bitumen.

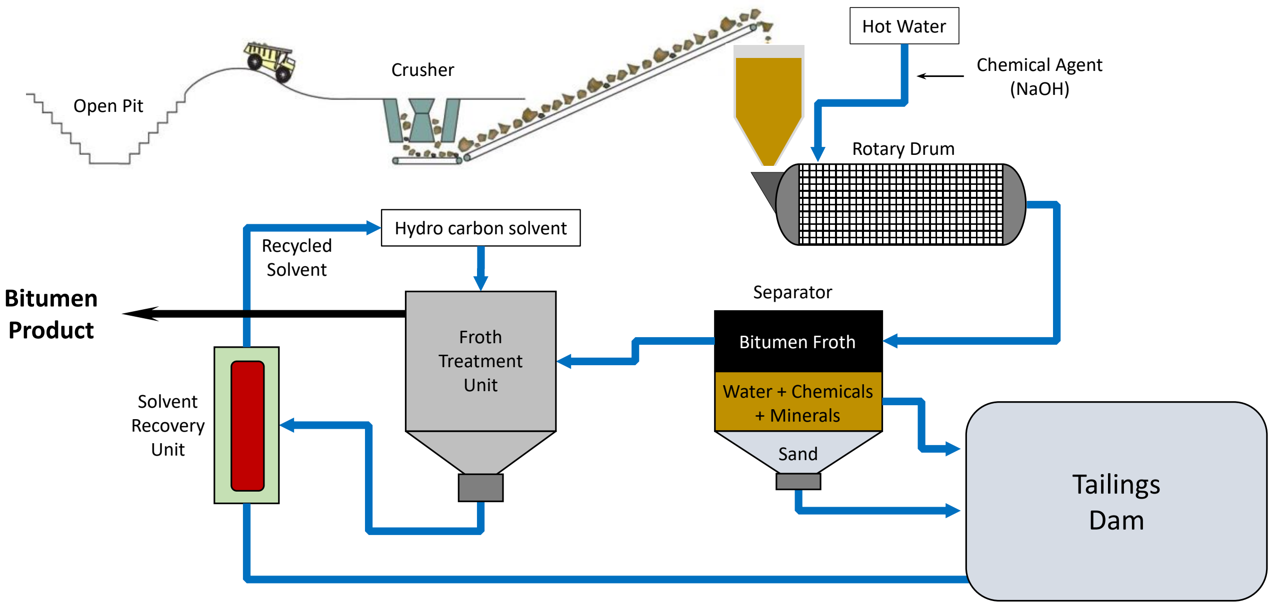

Figure 139. Open pit mining and processing of oil sands (Source: data from Mech 2011)

Figure 140. Truck and shovel in Oil Sands open pit mining (Image: Suncor media release)

The oil sands mining method accounts for 47% of 2018 Canadian production and 19% of Canadian oil sands reserves (Natural Resources Canada 2019). In 2018, seven mining projects in Alberta produced approximately 1.47 million barrels a day:

- Syncrude Mining Project (302 Mb/d)
- Suncor Base Mine (259 Mb/d)
- CNRL Horizon Mine (264 Mb/d)
- Athabasca Oil Sands Project – Muskeg River (163 Mb/d) and Jackpine Mine (132 Mb/d)
- Imperial's Kearl Mine (223 Mb/d)
- Fort Hills (125 Mb/d)

The processing of oil sands can be divided into 3 parts. The first part is extraction which involves the removal of sand, water and fine clay from the bitumen, the second part is improving the quality of the bitumen and the final step is refining of the crude oil to products.

The basic processing steps are:

1. **Conditioning**. The breaking down the large pieces of oil sand after which the oil sand is mixed with water. Hydro-transport pipelines agitate the mixture and transfer it to the extraction processing plant facility. This results in the breaking of bonds which are holding the bitumen, water, and sand together. This can be done in a rotary drum.

2. **Separation** - Mixing hot water and the water-oil sand mix (from the open pit) into a vessel where the three components separated (oil, sand and water). Within this vessel, there is a diluting chemical which is present to assist this process. Bitumen is considered to be hydrophobic (surface chemistry repels water), this property allows for the bitumen to attach itself to air bubbles that are liberated to the surface. The clay, free bitumen and other particles are suspended in the middle with the larger density sand particles sinking to the bottom as tailings. Three layers form with bitumen froth that floats on top, sand sinking to the bottom and an amalgamation of bitumen, sand, clay, and water in the middle. This process takes about 20 minutes and removes the thick bitumen from the sand. The component that does not consist of bitumen which remains is composed of sand, water, fine clays, and minerals. This remaining component is referred to as tailings and is thereafter sent to tailings ponds which allows the sand to settle out. This mixture is then sent to tailings ponds.

3. **Froth treatment** where the solids and water are removed from the bitumen froth. The bitumen is then diluted with naphtha and sent to a series of settlers and centrifuges to allow particles to settle and be removed completely. This material is sent to tailings ponds. At this point in time, the bitumen has a low water content and consists of few solids and the extraction is complete. The bitumen can now be upgraded and reduced in sulfur content.

The refining of oil sands derived oil to a lighter hydrocarbon and more desired products, make use of bifunctional catalyst in hydrocracking units and metal catalysts in catalytic cracking units. Each plant maybe set up differently due to different compositions of bitumen extracted. In total, 2 tonnes of oil sand must be received and processed with 2-4 barrels of water (as an estimate) to produce one barrel of crude oil in its synthetic form (Alberta Government Services, 2019).

The bitumen is heavy and can therefore not flow or be pumped without being heated or diluted. Bitumen is comprised of mainly different hydrocarbons. Bitumen can be broken down into four main components:

- asphaltenes,
- resinous components (polar aromatics)
- naphtene aromatics (non-polar aromatics)
- saturates

At ambient temperatures bitumen exists as a thermoplastic solid or semi-solid, upon heating the viscosity of the bitumen reduces. The lighter fractions of bitumen can be refined into liquid petroleum gas, petrol and diesel from heavy crude oil. Majority bitumen is used in construction as a binder for roads and paving. The various products from refined bitumen make sand oil process valuable.

Figure 141 shows the Syncrude bitumen upgrading plant. Upgrading transforms bitumen into a high quality light, sweet synthetic crude oil. Syncrude uses three fluid cokers and a hydrocracker to thermally crack the long carbon molecule chains into hydrocarbon gases, naphtha and gas oils.

Figure 141. Bitumen upgrading plant, (Syncrude Canada Flickr)
(Copyright License: Authorized by Syncrude, https://www.flickr.com/help/terms)

Bitumen as produced from an oil sands upgrade plant is not mobile and is not pipeline transportable due to its viscosity. The frequent method that is used for the transportation of bitumen is to add diluents so that its viscosity is reduced and so that it becomes mobile. A pipeline specification has to be adhered to before the industry will accept the bitumen and its blend (Banerjee, 2012). This is often achieved through blending (Figure 142). In the country of Canada, this specification is established by the Canadian Association of Petroleum Producers (CAPP) (Banerjee, 2012).

It is absolutely necessary to change the bitumen into a substance of higher API gravity and lower viscosity in order to meet the pipeline requirements. The American Petroleum Institute gravity, or API gravity, is a measure of how heavy or light a petroleum liquid is compared to water: if its API gravity is greater than 10, it is lighter and floats on water; if less than 10, it is heavier and sinks.

The commonly used technique is the addition of condensate derived from natural gas. Condensates consists of lighter hydrocarbons (in the range of C5–C12), and above 55°API (Banerjee 2012). A substantial amount of condensate is needed in order to meet the pipeline specification.

Because of the rising production of bitumen in Canada, the demand for condensate is increasing significantly resulting in the industry facing many serious challenges (Banerjee, 2012):

- The cost of condensate is dependent on the market price of natural gas.
- The cost of condensate is more than 25% higher than the cost of light crude oil.
- With the increasing demand for condensate, there will be a shortage of availability of the diluent, and that drives the cost high.
- Condensates are not acceptable by refineries.
- A return pipeline is needed to recycle the condensate.

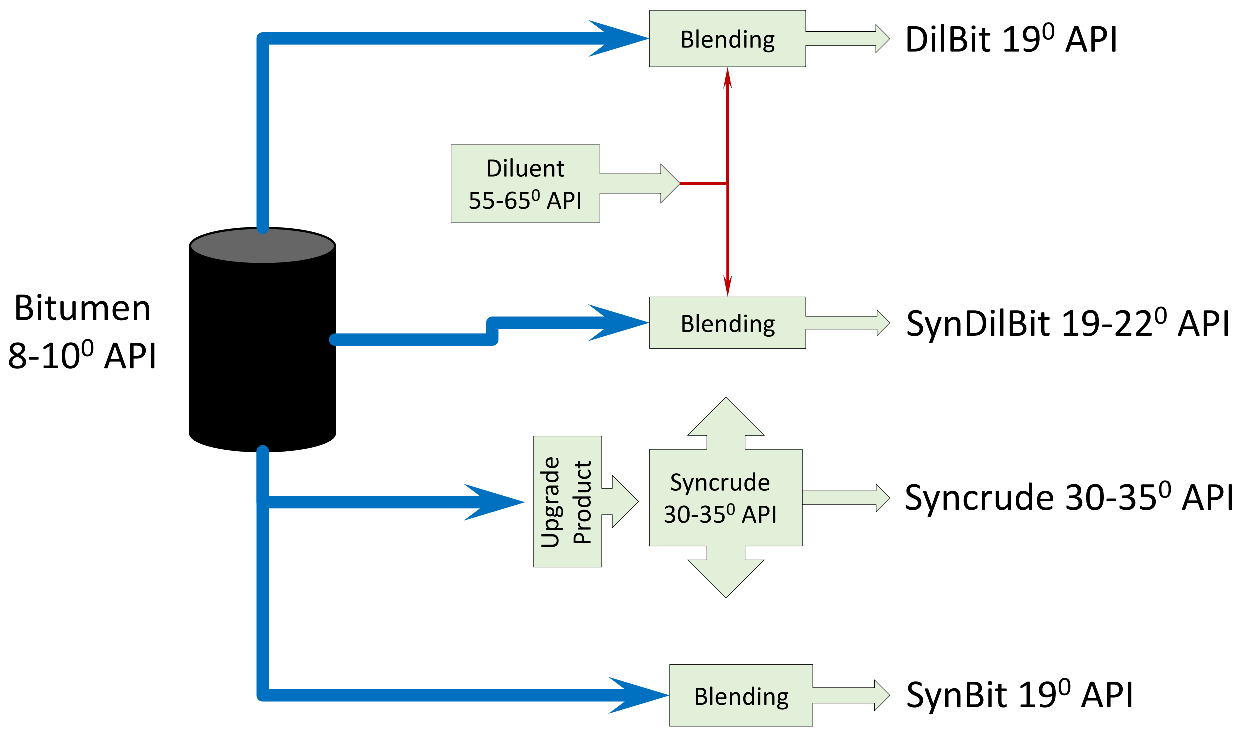

Figure 142. Types of bitumen blends for pipeline transportation
(Source: Based on image from Banerjee 2012)

The tailings of the process (consisting of water, sand, clay and residual oil) are stored in a tailing dam where settling occurs and water near the top is reused for future mining recovery (CAPP 2019 b). Figure 143 shows Syncrude's $1.9 billion centrifuge plant, currently under construction, which will spin water out of tailings to allow for accelerated land reclamation. Suncor is the first Alberta oil sands company to convert a tailings pond to a stable surface solid enough to be re-vegetated (Figure 144).

Mine land rehabilitation is conducted after water has been settled out of the tailing dams. The rehabilitation process involves reestablishing the natural flora, fauna and land drainage of the site prior to industrial activity. Syncrude for example, is attempting to restore old tailing dams by planting a variety of trees and shrubs indigenous to the region and climate, as part of its reclamation process (Figure 145).

Figure 143. Water reclamation and recycling plant, (Syncrude Canada Flickr)
(Copyright License: Authorized by Syncrude, https://www.flickr.com/help/terms)

Figure 144. Wapisiw reclamation site in the oil sands (Image: Suncor)

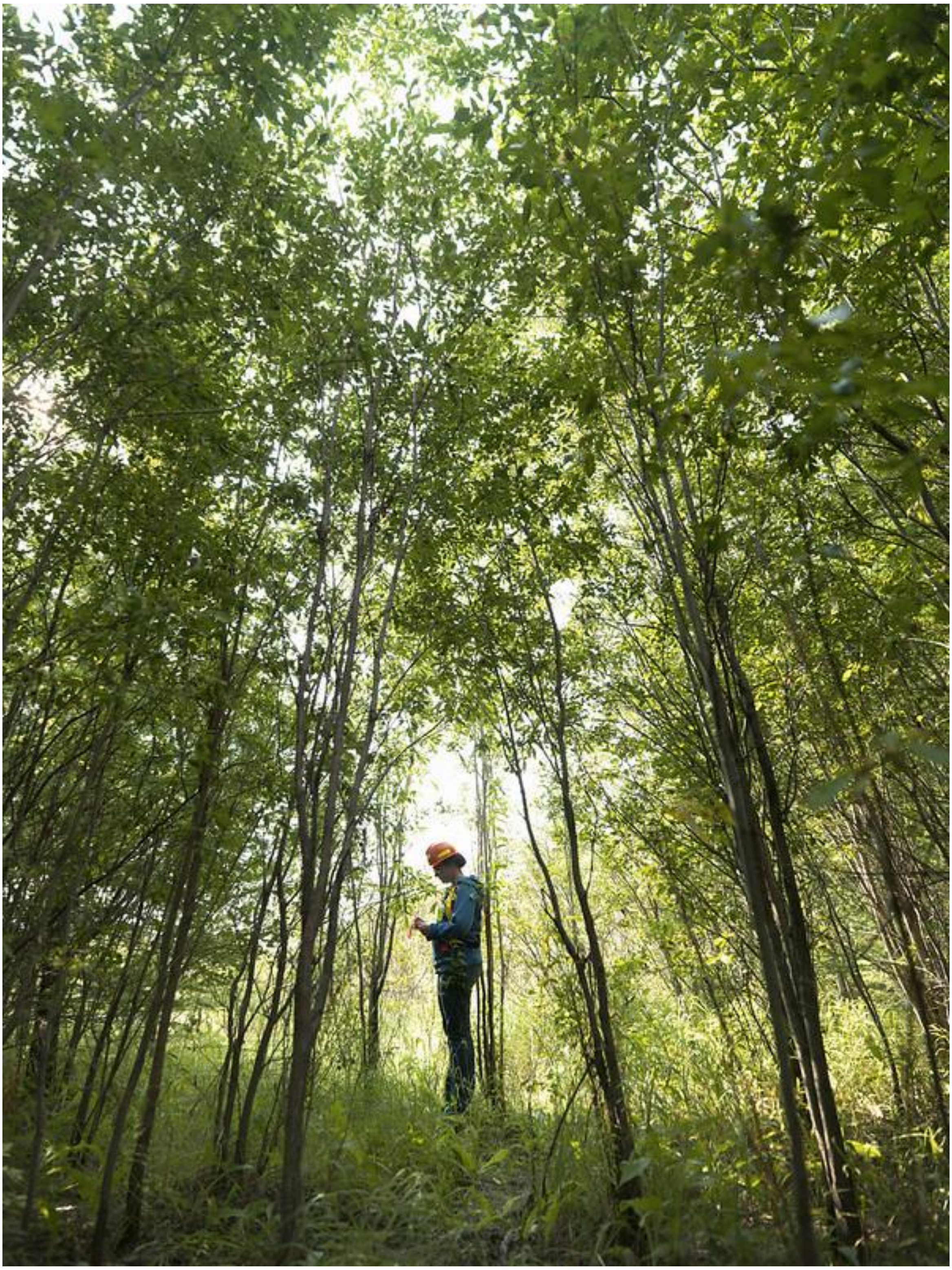

Figure 145. Land rehabilitation with indigenous flora and fauna. Suncrude
(Source: Flickr, Photographer: Roth & Ramberg Photography)

6.9 Environmental Impact of Oil Sands Production

As the rate and scale of oil sands development increases, concerns about the associated environmental impacts have grown. The Pembina Institute has been reporting on these concerns and providing factual information on the environmental impacts since the release of its Oil Sands Fever report in 2005.

In situ development could occur in an area approximately 30 times greater than the mining area. This type of development creates significant linear disturbance to the boreal forest. These linear disturbances, from seismic and core hole exploration, production well pads, roads and pipelines, can negatively impact species of wildlife that avoid linear features, such as the endangered woodland caribou (Dyer 2009).

Reclamation of boreal forest lands after development is quite a challenge for the industry, and the boreal ecosystem will never be fully restored. While wetlands occupy about 40-50% of the landscape before development, reclamation projects are returning the landscape to a predominantly upland, forested ecosystem. Reclamation of peat land (a type of wetland) ecosystems is still undemonstrated.

As of 2017, these ponds hold approximately 1 trillion liters of sludge that is unlike any other industrial byproduct in the world. They contain a unique cocktail of toxic chemicals and hydrocarbons that will remain in molasses-like suspension for centuries if left alone.

These open, unlined ponds currently cover 220km^2, an area of land equivalent to 73 New York Central Parks. A single tailings pond – the Mildred Lake Settling Basin – has been identified by the US Department of the Interior as the world's largest dam (Berman 2017).

In addition, government data shows that these tailing ponds are leaking and indigenous leaders have repeatedly called for health studies and noted that the expansion of the tars and is violating their Treaty rights (Berman 2017).

The environmental problems associated with the tar sands operations been largely ignored, with the hope that a technology might be developed to rehabilitate these dam sites.

7 THE UNITED STATES TIGHT OIL FRONTIER

Since 2008, the American shale oil boom has grown domestic crude production some 150% to 12.4 million barrels a day in 2019. It has been a huge investing bonanza between 2008 and 2012 especially led by U.S. states North Dakota and Texas (those investment gains are not so strong in 2019). The Bakken in North Dakota, and the Permian and Eagle Ford shale plays in Texas account for some 60% of U.S. crude oil production and 85% of U.S. shale oil production. The Permian is now the largest oil field in the world, surpassing Saudi Arabia's elephant field Ghawar (Figure 146).

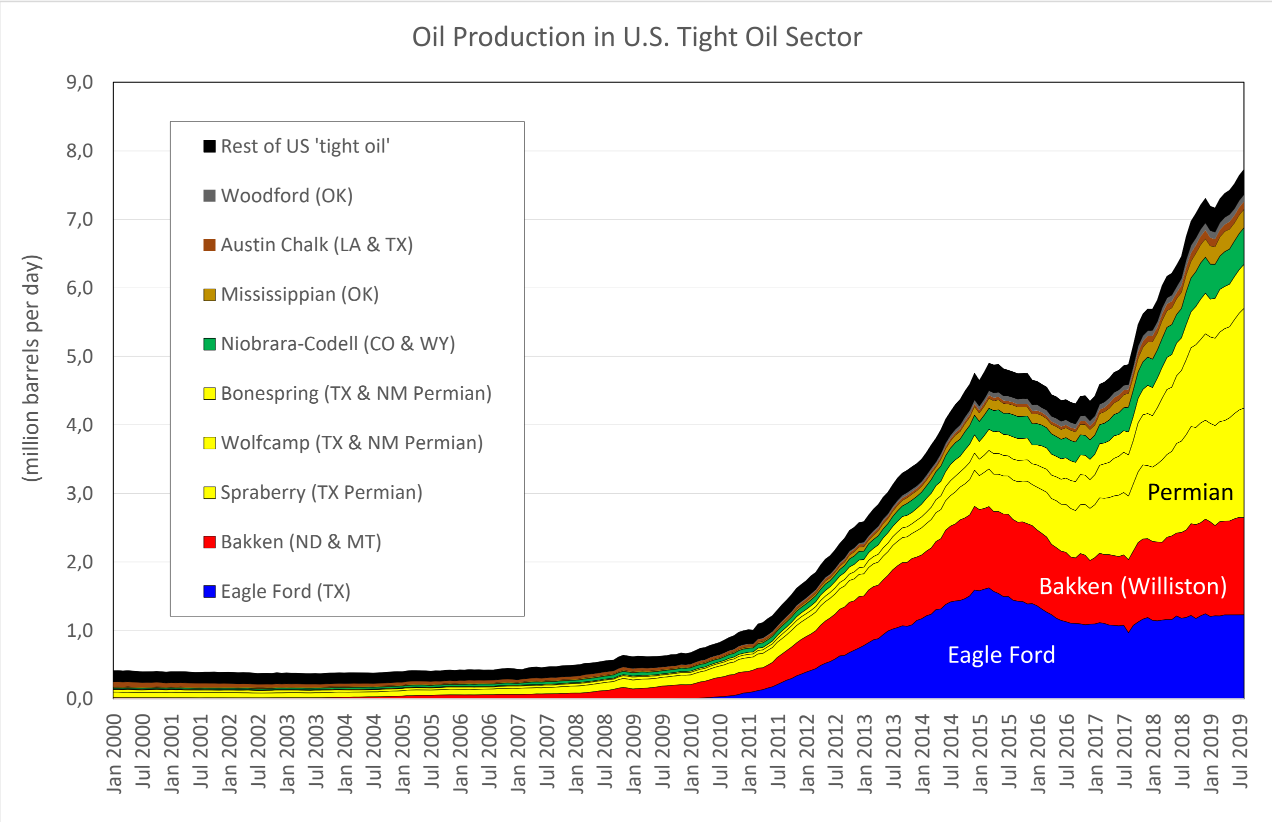

Figure 146. Oil production of the United States tight oil sector by Basin
(Source: EIA Tight Oil estimates, Shaleprofile.com)

In the 1970s, Americans faced long lines at gasoline pumps and the country depended heavily on oil imports from the Middle East. In 2019, the United States is the world’s largest crude oil producer, surpassing Russia and Saudi Arabia in 2018 (EIA 2019).

The combination of new technology (horizontal drilling techniques applied with hydraulic fracturing) and rising oil prices have made the exploration and exploitation of large volumes of shale oil possible. More generally, from a global perspective, the fast-rising shale oil production has been a major factor supporting non-OPEC supply growth which, together with moderating global oil demand, explains the relative stability of Brent oil prices until mid-2014 (European Central Bank 2015).

There has been great enthusiasm and investment of hope recently for the renaissance in the production of oil and natural gas in the United States. Starting with calls in the 2008 Obama presidential election to “drill, baby, drill!,” politicians and industry leaders alike now hail “one hundred years of gas" and anticipate the U.S. regaining its crown as the world's foremost oil producer (Hughes 2011). Much of this optimism is based on the application of technologies like hydraulic fracturing ("fracking") and horizontal drilling to previously inaccessible shale reservoirs, and the development of unconventional sources such as tar sands and oil shale (Hughes 2018).

The significance of this is that this extra oil production capacity stabilized global demand for crude oil, as conventional oil production plateaued in 2005 (see Section 14.3 and Figure 147). U.S. shale (tight oil, fracking with horizontal drilling) contributed 71.4% of new oil supply since 2005. By contrast, OPEC has added 20% of total supply, barely enough to cover losses from countries whose production has been declining (Figure 147).

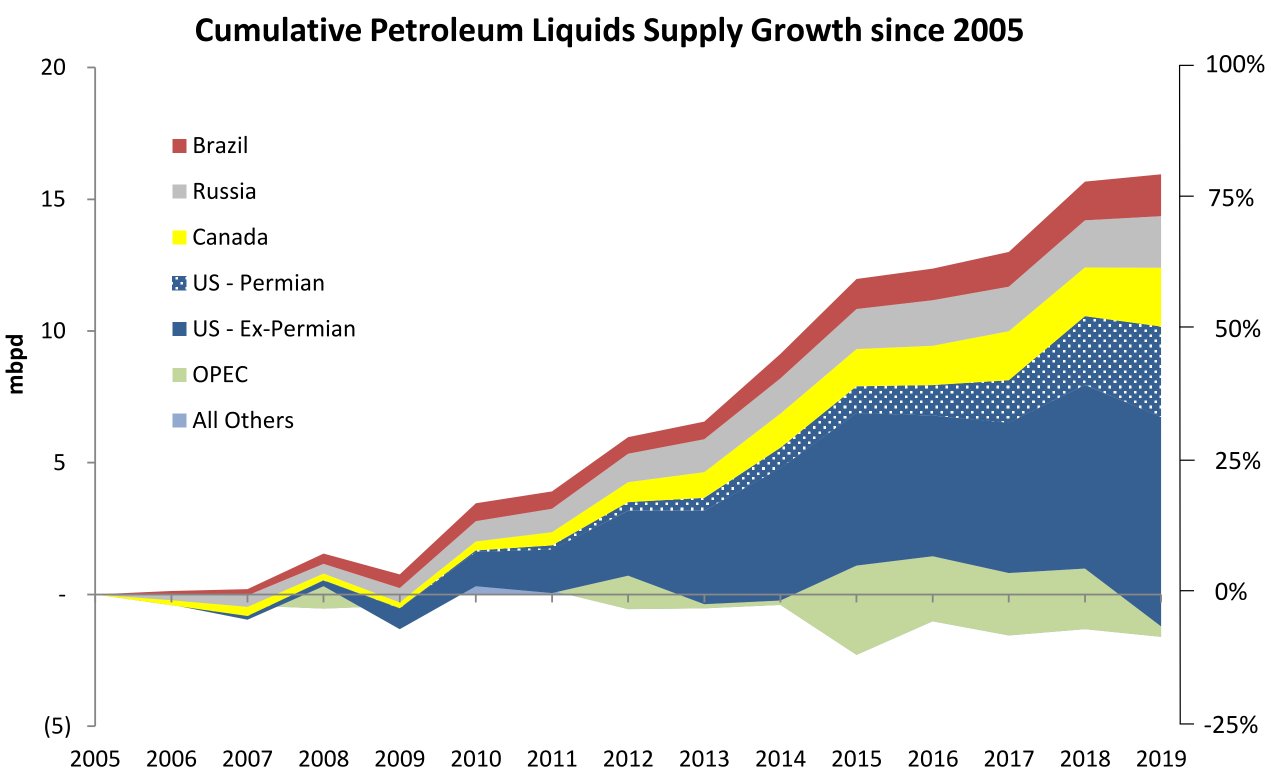

Figure 147. Cumulative Petroleum Liquids Supply Growth since 2005
(Source: Stephen Kopits – Princeton Energy Advisors, http://www.prienga.com/)

7.1 Tight Oil Basins in United States

The shale oil and tight oil deposits in the United States are much larger and are able to produce more oil than other tight oil fields around the world discovered, as of 2018 (EIA 2018). Figure 148 shows the volumes produced across the United States. Appendix F shows a more complete description of the individual major tight oil basin plays in the United States.

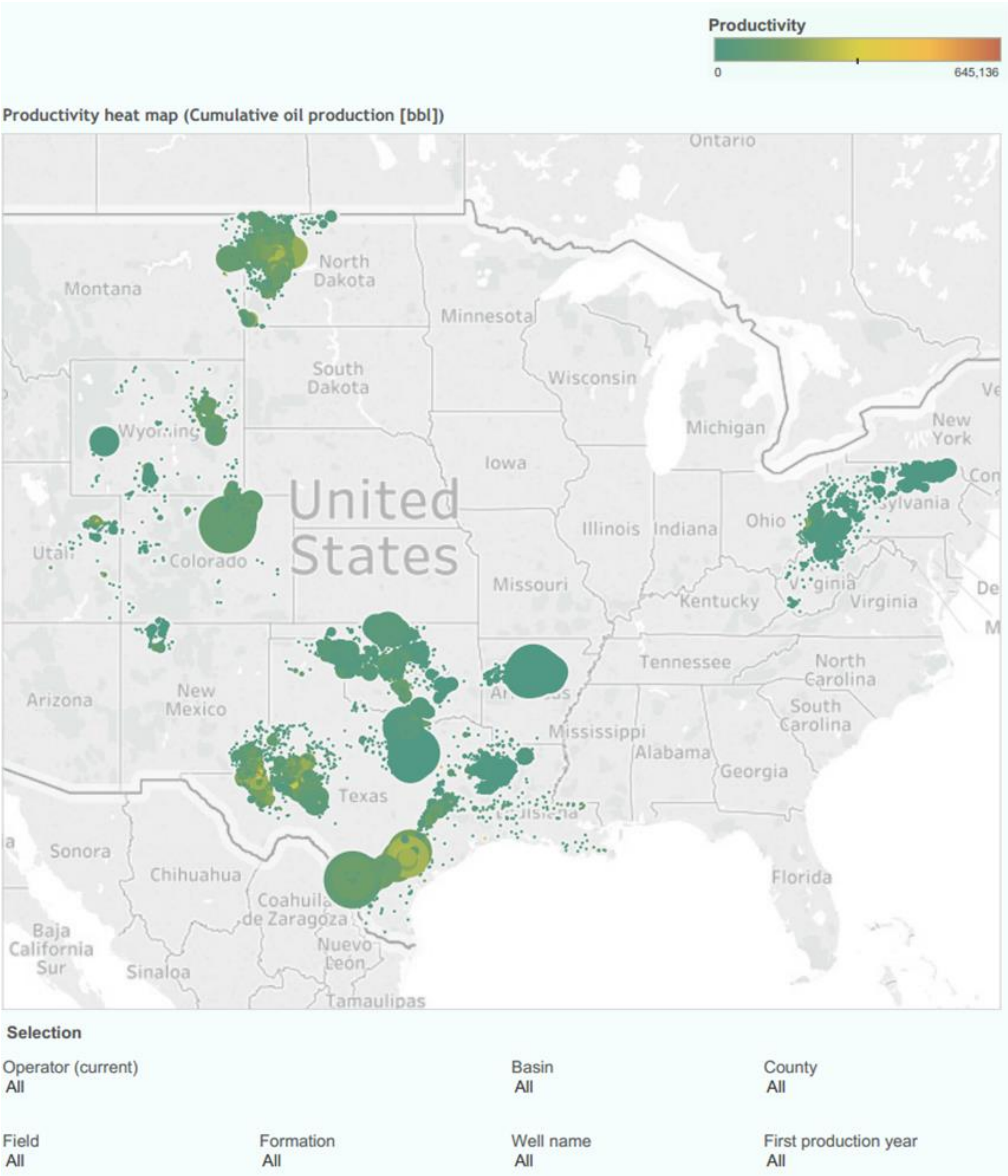

Figure 148. A productivity heat map of oil production in the Tight Oil Sector in the United States (Source: Enno Peter, Shale Profile Analytics, https://shaleprofile.com/)

These oil producing volumes are separated into individual operations, each managed in separate counties and states. The fracking operations are administered by tight oil play. Figure 149 shows a map of the major tight oil plays in the United States. 85% of production in 2018 came from just three plays:

- Permian Basin
- Eagle Ford Basin
- Bakken Basin (also called Williston)

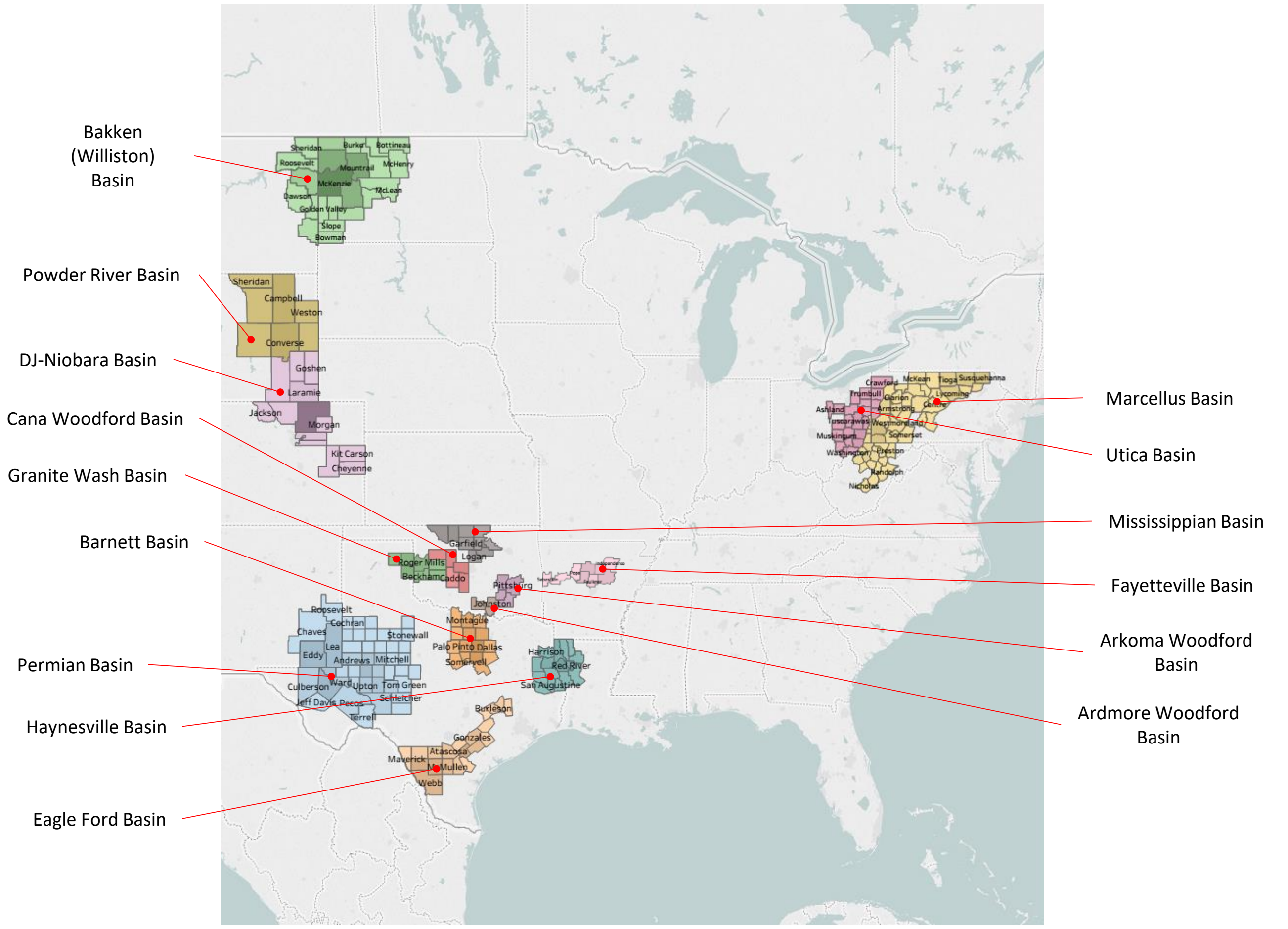

Figure 149. The geography of tight oil basins in the Tight Oil Sector in the United States (Source: Enno Peter, Shale Profile Analytics, https://shaleprofile.com/)

7.2 Drilling rates and maintenance drilling in Tight Oil basins

Due to the production depletion rates of fracked wells, large numbers of wells need to be drilled to maintain production at a consistent level. Figure 150 shows the wells drilled in the U.S. tight oil sector by year. Total U.S. shale oil production is shown to be a little bit more than 7 million barrels per day. Each color in the chart represents a year's worth of oil production. What is interesting about the chart above, is the huge decline rate of domestic shale oil production from each well. And as each year passes, the degree of decline steepens. It can be observed that depletion rates can be seen to be increasing in each passing year. That is, the 2017 rate of decrease is much steeper than the rate of decrease in 2012. This is the cumulative effect of all other wells depleting, where there is more wells depleting in 2017 than there was in 2012.

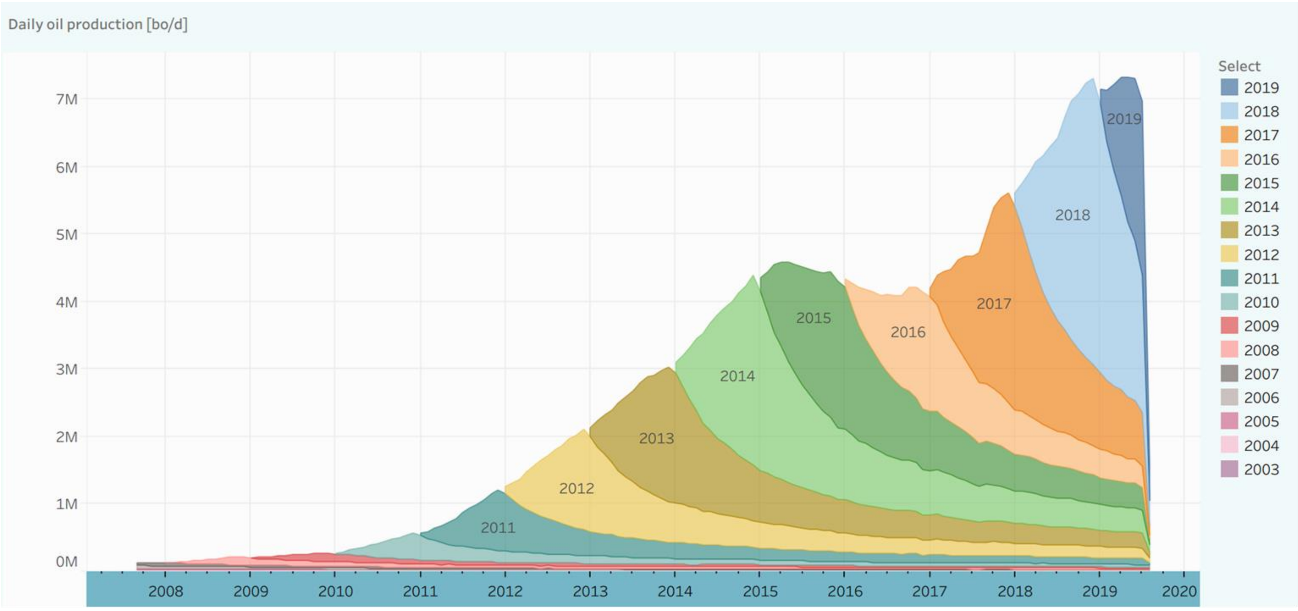

Figure 150. Daily oil production [bo/d], shown by 'Year of first flow' for the total US shale oil market 2010 to 2018 (Source: Enno Peter, Shale Profile Analytics, https://shaleprofile.com/)

Figure 151 shows the number of new wells being drilled by tight oil basin play between 2011 and July 2018.

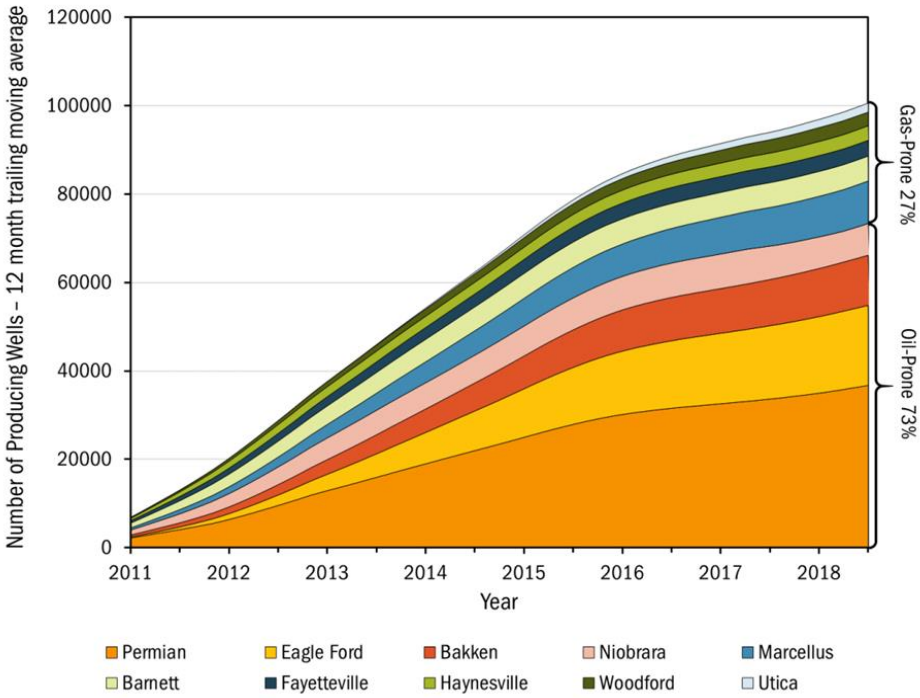

Figure 151. Number of producing wells by play drilled since 2010. Data have been smoothed with a 12 month trailing average. As of July 2018, there was 104 150 producing wells, of which 73% targeted oil prone plays (Source: Hughes 2019)

Figure 152 shows similar data to Figure 151 but with the drill rate in January 2016 set to 100. So for each tight oil play basin play, the relative increase over a 30 month time frame can be seen. Also in Figure 152 is the life cycle classification developed in Hughes 2019 (described in Section 6.6). This shows that the majority of tight oil production by volume is in the mature stage or late stage.

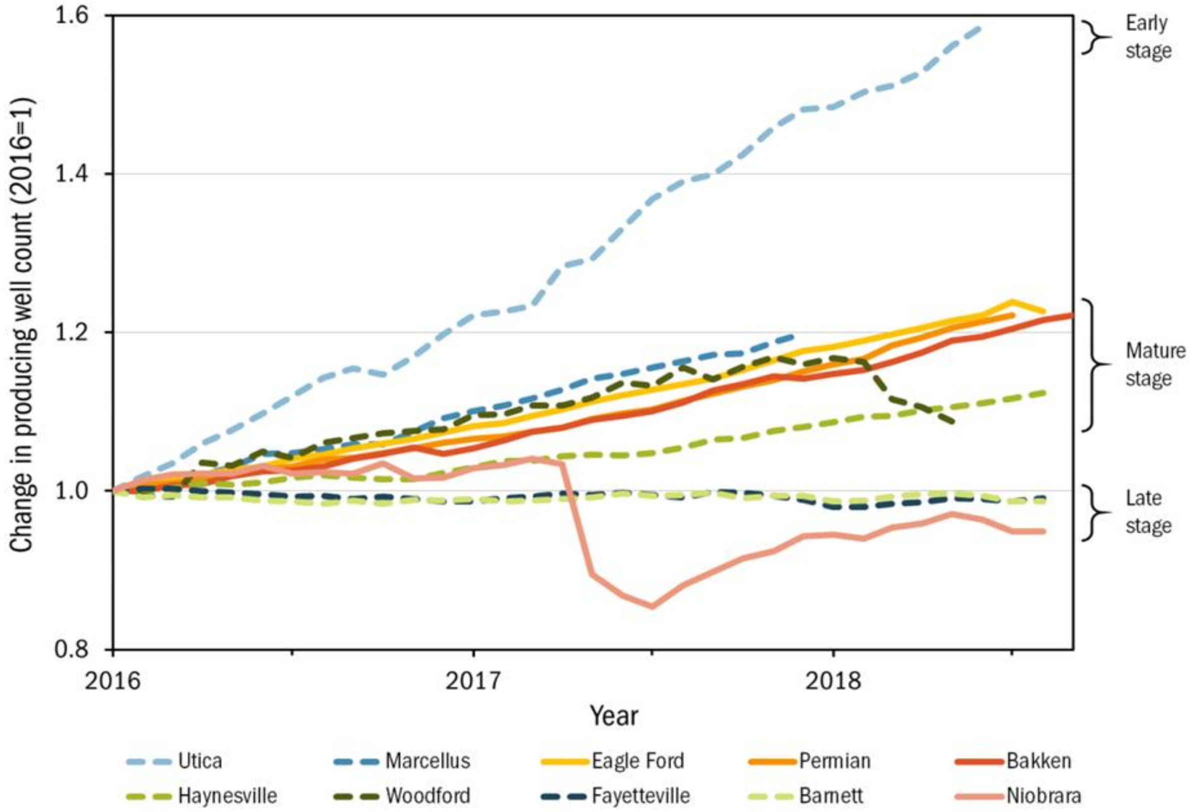

Figure 152. Change in number of post-2009 producing wells by play since the beginning of 2016 (Source: Hughes 2019)

Late stage plays have very low or negative rates of producing by well additions (Barnett, Fayette and Niobrara), whereas early stage plays have very high rates (Utica). Mature stage plays have strong growth rates to offset field decline and increase production. Oil-prone plays are shown with solid lines and gas plays are shown with dashed lines (Hughes 2019).

7.3 Horizontal drilling

In 2008, the technology to reliably do precise horizontal drilling was developed. This was applied to the tight oil fracking sector, where previously vertical drilling was used. This facilitated a boom in oil production from the hydraulic fracking operations. Collectively this contributed to the Oil Shale Revolution, which transformed the declining United States oil production into the world's largest oil producing nation that almost on its own stabilized global demand. In 2004, horizontal wells accounted for about 15% of U.S. crude oil production in tight oil formations. By the end of 2018, that percentage had increased to 96% (EIA).

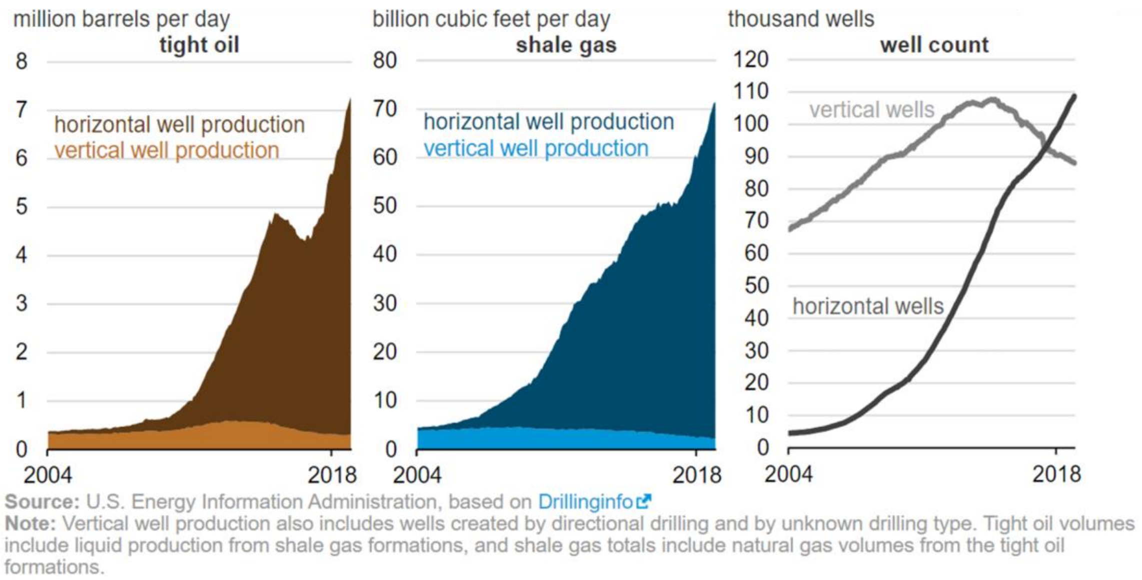

Figure 153. U.S. tight oil and shale gas production and well counts
(Source: EIA, https://www.eia.gov/todayinenergy/detail.php?id=39752)
(Copyright License: https://www.eia.gov/about/copyrights_reuse.php)

Figure 153, 154 and 155 show the increase in horizontal drilling. Percentage increases by play are also indicated. The overall average and the average for gas-prone and oil-prone plays are weighted by the number of wells each play. Gas-prone plays are shown with dashed lines and oil-prone plays are shown by solid lines (Hughes 2019).

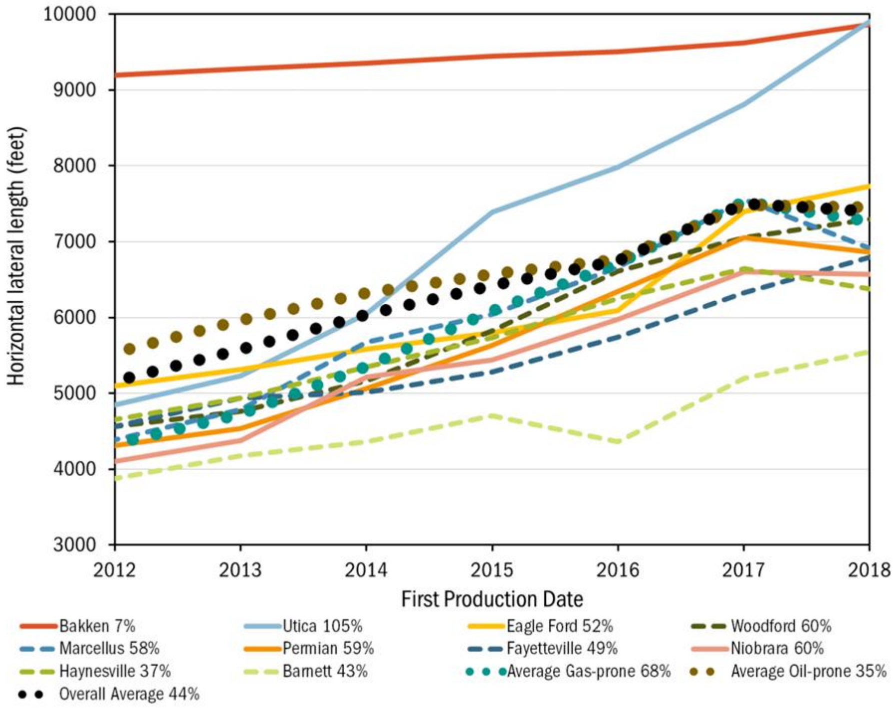

Figure 154. Average horizontal lateral length by play, 2012 to 2018
(Source: Hughes 2019)

Figure 155 shows similar data to Figure 154 but with the drill rate in January 2012 set to 100. This shows the relative increase in this technology. The implication is that costs of production have increased per well.

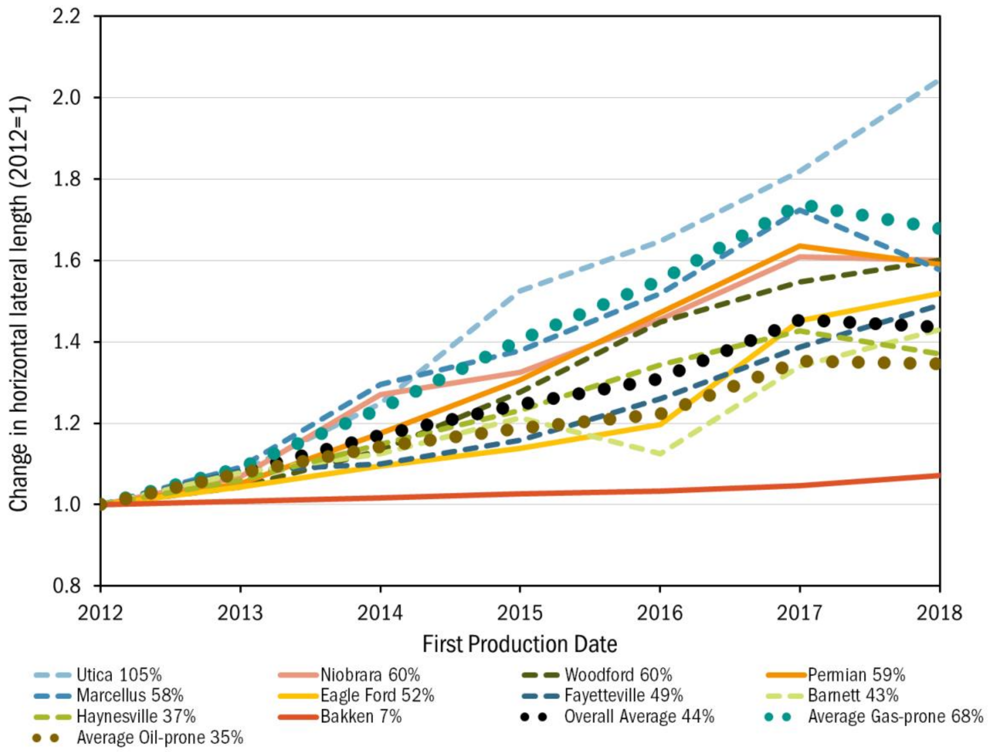

Figure 155. Rate of increase in average horizontal lateral length by play, 2012 to 2018
(Source: Hughes 2019)

7.4 Water injection in tight oil operations

Another change to increase productivity has been to increase the use of water. The process of hydraulic fracturing uses large volumes of water mixed with chemicals and proppant (sand) to fracture and hold open fractures in low-permeability shale and tight oil rocks to allow extraction of hydrocarbons. The water use for hydraulic fracturing and wastewater production in major shale gas and oil production regions has increased; from 2011 to 2016, the water use per well increased up to 770%, while flowback and produced water volumes generated within the first year of production increased up to 1440% (Kondash *et al* 2018).

The water-use per lateral length of drilling, has increased ubiquitously in all U.S. shale basins since 2008 till the present. The steady increase of the water footprint of hydraulic fracturing with time implies that future unconventional oil and gas operations will require larger volumes of water for hydraulic fracturing, which will result in larger produced oil and gas wastewater volumes (Kondash *et al* 2018).

The higher water use of the fracking industry has been shown that the overall water withdrawal for hydraulic fracturing is negligible compared to other industrial water uses on a national level (Vengosh *et al* 2014, Jackson *et al* 2014, Kondash *et al* 2017, Kondash &Vengosh 2015). On a local scale, however, water use for hydraulic fracturing can cause conflicts over water availability, especially in arid regions such as western United States, where water supplies are limited (Scanlon *et al* 2014, Scanlon *et al* 2017).

Figure 156 shows the increase in horizontal drilling, water injection volume and injection volume per lateral foot. Figures 157 to 160 shows the water use by tight oil basin.

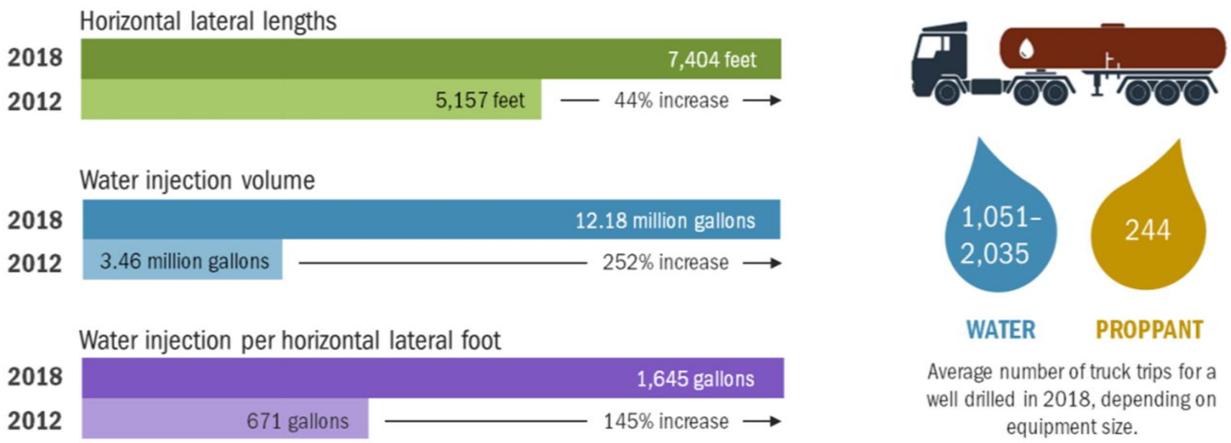

Figure 156. Increase in water use in horizontal drilling wells, comparing 2012 to 2018 (Source: Hughes 2019)

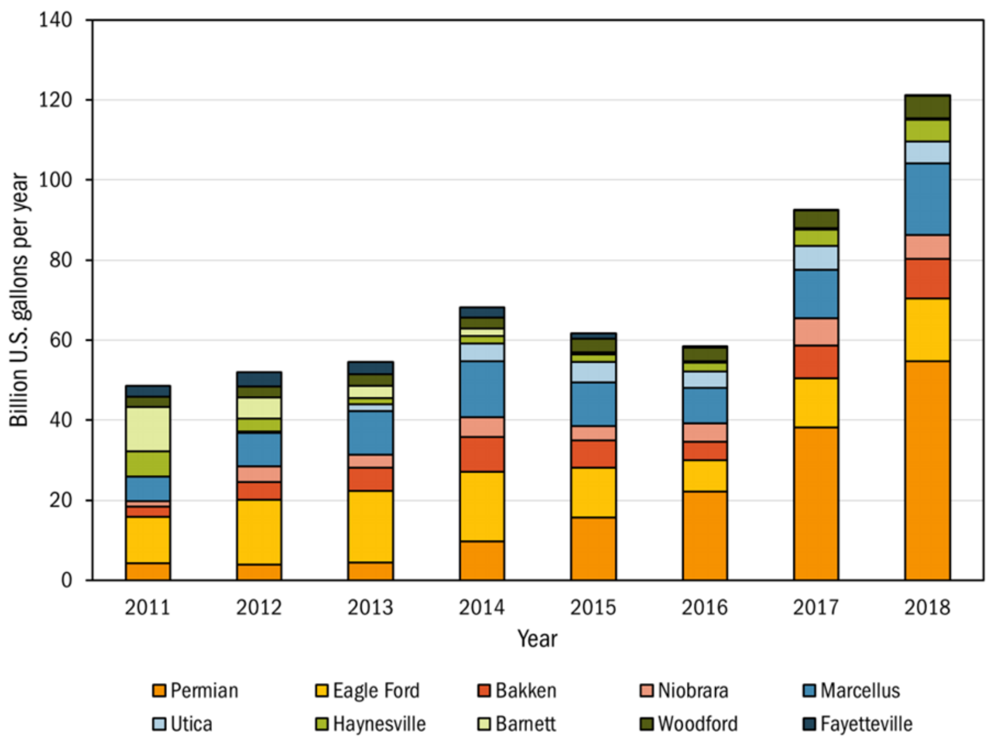

Figure 157. Overall water consumption by play, 2011 through 2018, 2018 estimated assuming drilling rates will be maintained through yearend. (Source: Hughes 2019)

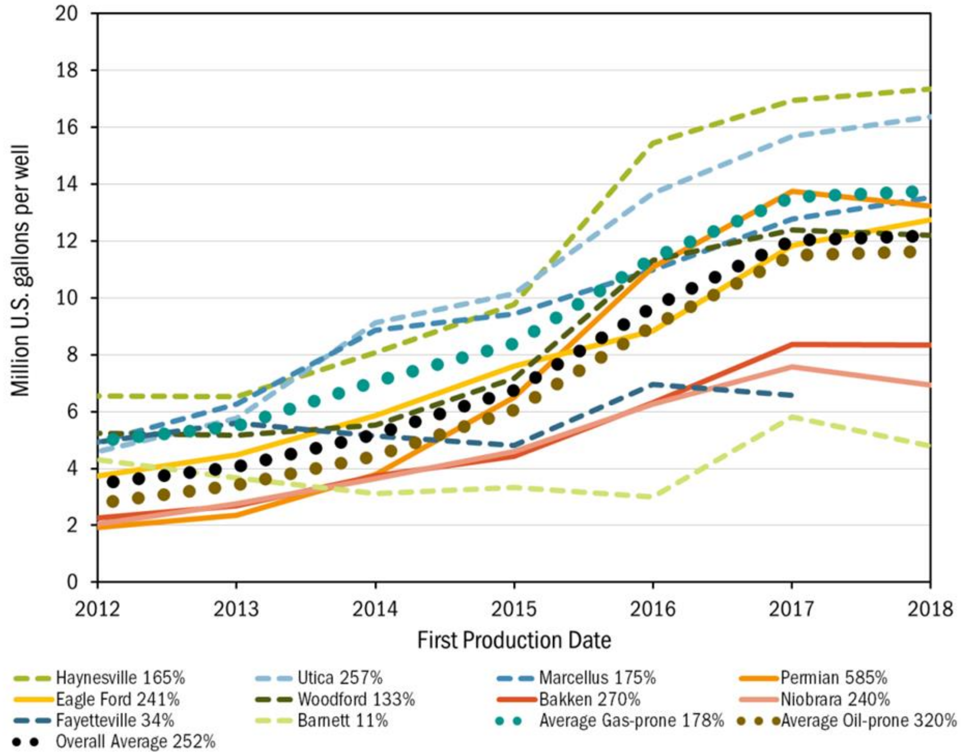

Figure 158. Total volume of water injected by play, 2012 to 2018. Percentage increases by play are also indicated. (Source: Hughes 2019)

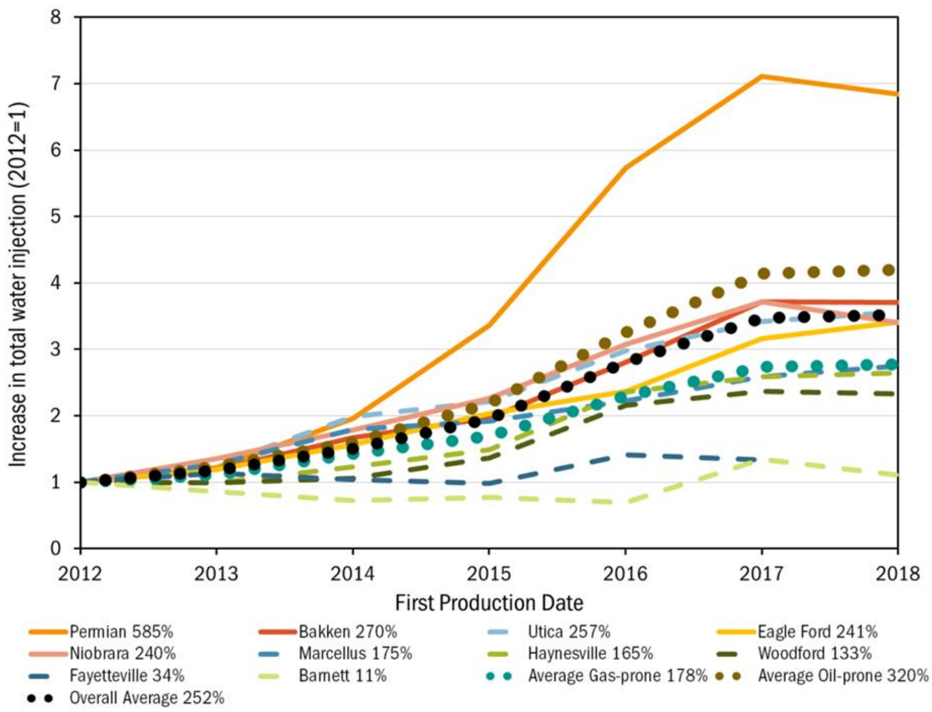

Figure 159. Rate of increase in average injection per well by play, 2012 to 2018. (Source: Hughes 2019)

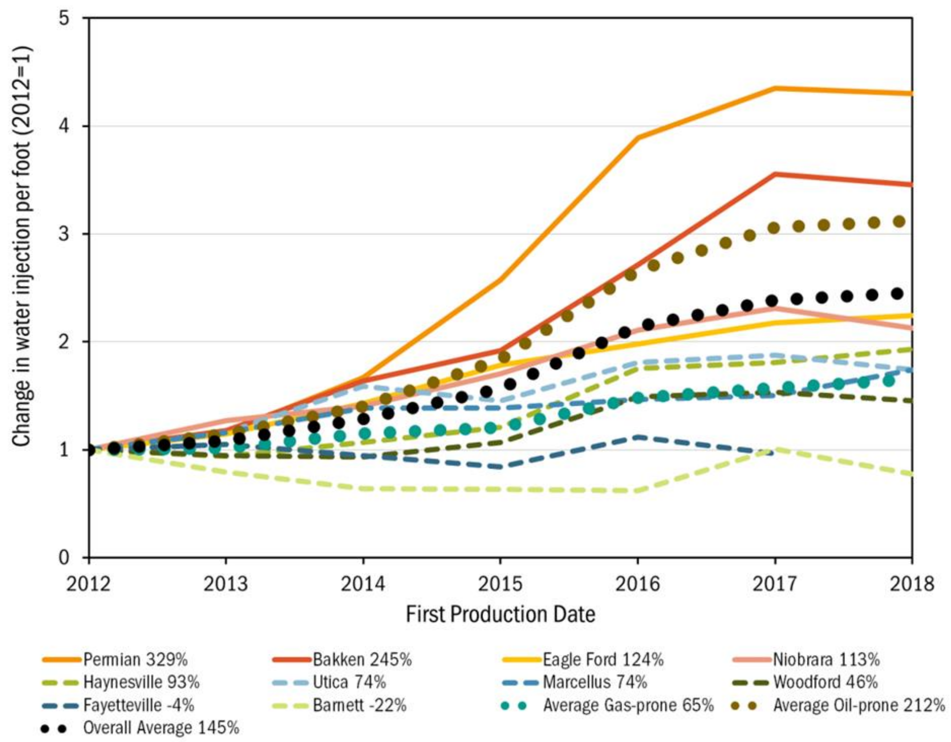

Figure 160. Rate of change in the total volume of water injected per horizontal lateral foot by play, 2012 to 2018. (Source: Hughes 2019)

7.5 Well productivity

In a report done by the Wall Street Journal (Olson and Matthews 2019) compared well productivity estimates that were disclosed to investors versus public data of how these wells have performed to date (the end of 2018); after analyzing 16,000 wells operated by 29 producers in places like North Dakota and the Permian basin, it was found that about 66% of projections made by companies between 2014 and 2017 are reportedly "overly optimistic". Only the Permian Basin and Niobrara plays were still increasing in production.

Despite considerably lower costs per well, the wells decline much faster and thus the costs per produced barrel are spiraling accordingly. In a study done on one of the successful American oil shale deposits, the wells in the Eagle Ford shale play show a production pattern of peaking within a few months after initial production and declining steeply after the peak is reached (Lund 2014). During the first year of production the decline is 75% and after two years production has decreased with 87% compared to the peak production, using the average decline curve. When taking the average of the individual decline curves the figures are similar, 75% decline the first year and 86% over the first two years.

The current oil and gas markets are quite challenging for producers. The advent of shale oil and gas production, which created the vision of ‘US energy independence’, has brought renewed interest in the economics of oil and gas production.

The key parameters for productivity and costs in an oil field is the cost per produced barrel and not the absolute cost per individual well. This is often misreported in the media and in feasibility studies done to raise capital investment.

To illustrate how this is a valid concept, the example of a standard oil well is used. A standard well which costs $10 million to drill and produces initially 200 barrels per day. The costs of $10 million tell very little as the most important fact is how much this well can produce over its lifetime. Assuming a 10 year life span and implying a 5-10% yearly decline rate (which is the standard for a conventional well), the well produces roughly 500,000 barrels during its life cycle (Figure 161).

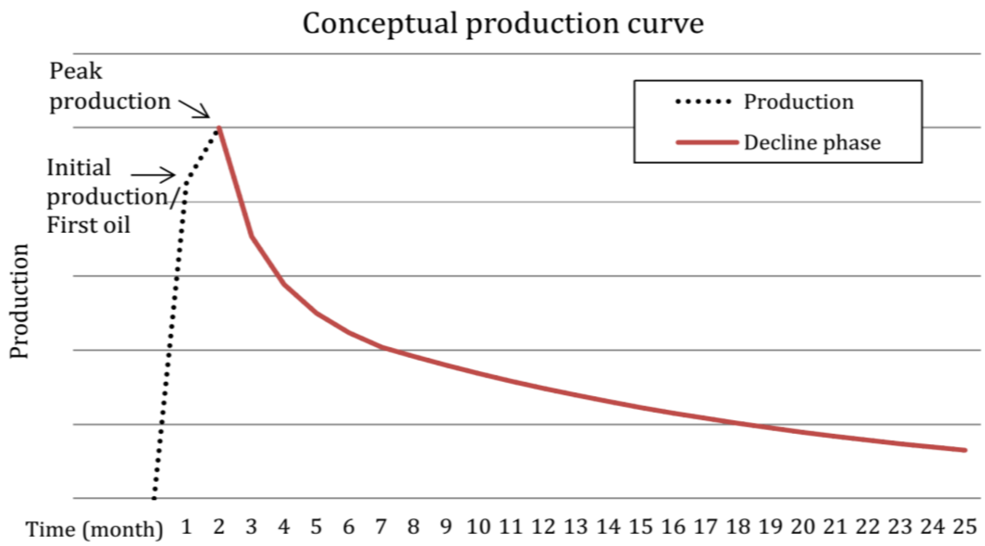

Figure 161. Conceptual decline curve of a standard well, showing the points of initial production/first and peak production and the decline phase. (Source: Lund 2014)

This gives then the drilling cost of $20 per produced barrel. Maintenance, taxes, license to operate, and transportation (etc.) have to be added and divided by the amount of produced barrels. This gives then a production cost of roughly $40 per barrel. This is the standard model of a conventional oil well. In theory, the true cost can only be determined when a well is shut down and the actual amount of produced barrels is known. Therefore, all of the studies for production cost are guesstimates as they are based on an estimate about future oil production of the wells.

If now the life span of a well is much shorter than the above standard well. For the sake of simplicity, a life span of just five years is selected, implying a yearly decline rate of 10-20 %, the amount of produced barrels sinks to 250,000 barrels and the drilling cost increases to $40 per barrel and the total cost surges towards $80 per barrel. This comes despite the drilling cost as well as the maintenance, overhead, are the same as in the above example.

As a conclusion, the true costs are strongly dependent on the life span (or the yearly decline rate – referred to very often as 'legacy' rate) of the well. So, if a company reports it has decreased its drilling costs from $10 million per well to $8 million per well, it is just part of the true cost as the well may decline much faster and thus produce less oil over its life span and the drilling cost per barrel could be actually much higher, despite the reduction in costs per well.

This concept is highly relevant to examining the productivity of oil shale extraction. The average shale oil (fracked) well declines in productivity much faster than a conventional oil well (Hughes 2018). This means that to maintain production (or grow production rate) in a shale oil field, new holes have to be drilled a much faster rate.

Figure 162 shows the rate of change in production per foot and water injection (for the 10 largest tight oil basin plays, accounting for 93% of the U.S. Tight Oil frontier). Figure 162 shows that average production increased between 2010 and 2018 by 28%, but also water injection (and therefore chemical and proppant use) increased by 118% (Hughes 2019). The 118% increase is an average across the whole U.S. tight oil frontier. There was comparatively much less water, chemical and proppant use in the gas prone wells compared to the oil prone wells in the same time period (Hughes 2019). Examining just the oil prone plays, there was a 230% increase in water injection between 2010 and 2018.

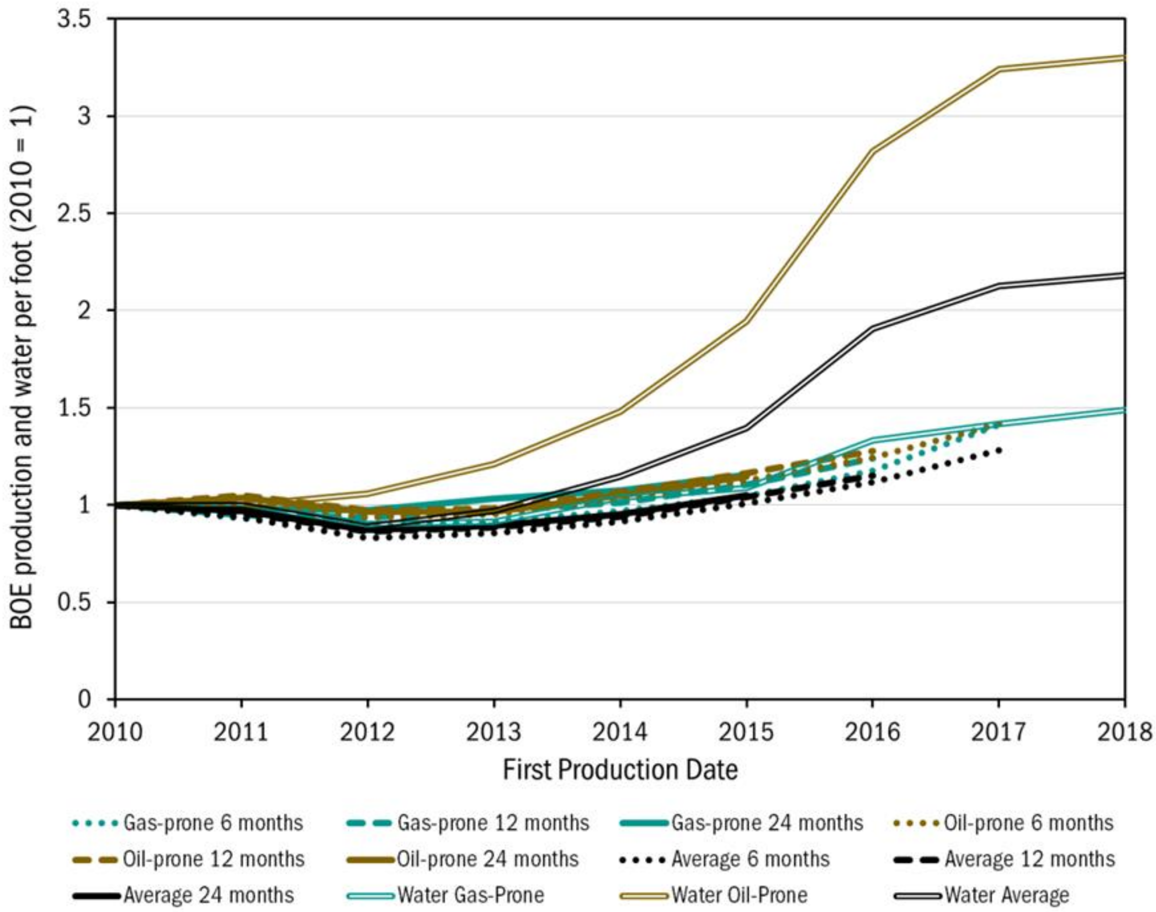

Figure 162. Rate of change in production per foot and water injection for the ten largest plays, 2010 to 2018. 2010=1 (Source: Hughes 2019)

7.6 Tight Oil cash flows

IEEFA, (Institute for Energy Economics and Financial Analysis), in partnership with the Sightline Institute published a market report (Williams-Derry *et al* 2019) examining the viability of the U.S. fracking industry.

This report studied 29 North American shale companies and found a combined $2.5 billion in negative free cash flow in the first quarter. That was a deterioration from the $2.1 billion in negative cash flow from the fourth quarter of 2018. The report concluded that the consistent failure for the sector as a whole to generate positive free cash flow amounts to an indictment of the entire business model. A few companies are performing well, but most are not. The 29 companies examined consumed a combined $184 billion more capital than they generated between 2010 and 2019. The phrase used in the report: “hemorrhaging cash every single year.”

Rystad studied 40 U.S. shale companies and found that only four had positive cash flow in the first quarter (Rystad Energy 2019). In fact, the numbers were particularly bad in the first three months of 2019, with the companies posting a combined $4.7 billion in negative cash flow.

How this state of affairs came to be has been the subject of analysis. One possible cause is that some of the oil producing companies have so called Negative Operating Losses (NOL) which can be carried forward (indefinitely), and this is quite normal in many economies. Also, booked proven reserves (SEC rules) and estimates based on actual data suggests PDP (Proven Developed Producing) are overstated perhaps as much as 30% - 70%. This may cause balance sheets to be inflated and may have allowed those companies to take on more debt than what would normally be considered appropriate (Likvern 2019). Primarily it is the investors’ money (equity, owners’ capital) that are at risk for shale companies then follows creditors money (bonds, bank credit). Unsecured credit and light covenant bond/credit is first at risk after investors equity. This suggests a market sharp downturn for investors if fracking oil is really just a bubble that is likely to burst without higher oil prices.

That 9 out of 10 fracking companies in the U.S. tight oil sector are losing money is most unfortunate, as global production for oil is now dependent on this sector for growth (Rapier 2019 and BP 2019 Statistical Review Energy of World Energy).

The BP 2019 Statistical Review Energy of World Energy reported a new global oil production record in 2018 of 94.7 million barrels per day, an increase of 2.22 million barrels per day over the previous year. The U.S. extended its lead as the world's top oil producer to a record 15.3 million barrels per day. In addition, the U.S. led all countries in increasing production over the previous year, with a gain of 2.18 million BPD (equal to 98% of the total of global additions).

7.7 Tight Oil prognosis

A great deal of hope has been placed on the productivity of the United States tight oil and shale oil producing fields. The main regions of tight oil production in the United States are not producing at rates hoped for when they were first commissioned (Art Berman). The future of the US tight oil frontier rests almost entirely on the productivity of the Permian Basin (Hughes 2018 and 2019).

The United States Energy Information Agency conducted a study to predict energy production and consumption, the Annual Energy Outlook 2019, with projections to 2050 (EIA 2019 Jan). Figure 163 shows three scenarios of future crude oil production in the United States. The AEO2019 Reference case represents EIA’s best assessment of how U.S. and world energy markets will operate through 2050, based on many key assumptions. For instance, the Reference case projection assumes improvement in known energy production, delivery, and consumption technology trends.

The low oil price scenario is based on lower than expected oil and gas prices. The high oil price scenario is based on higher than expected oil and gas prices. Additional AEO2019 side cases are the High and Low Oil and Gas Resource and Technology cases, where production costs and resource availability within the United States are varied, allowing for more or less production at given world oil and natural gas prices. That is, the potential increase in the productivity and capacity of tight oil basins.

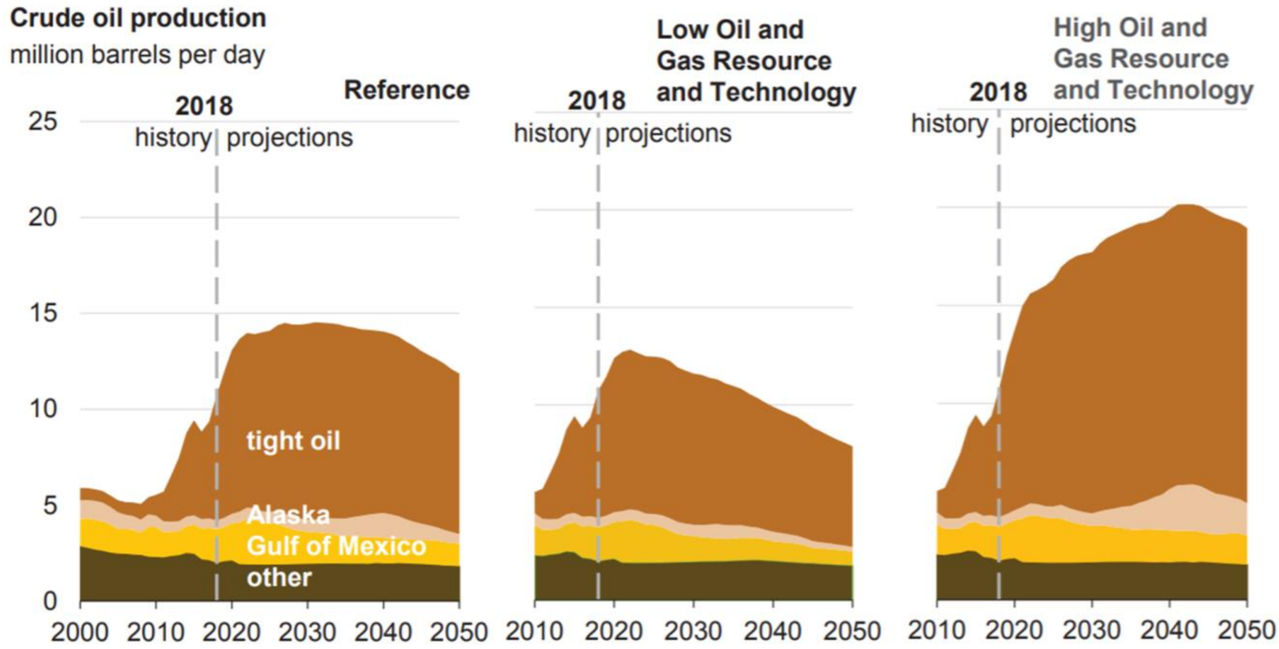

Figure 163. Three scenarios of crude oil production the United States
(Source: EIA 2019 Jan) (Copyright License: https://www.eia.gov/about/copyrights_reuse.php)

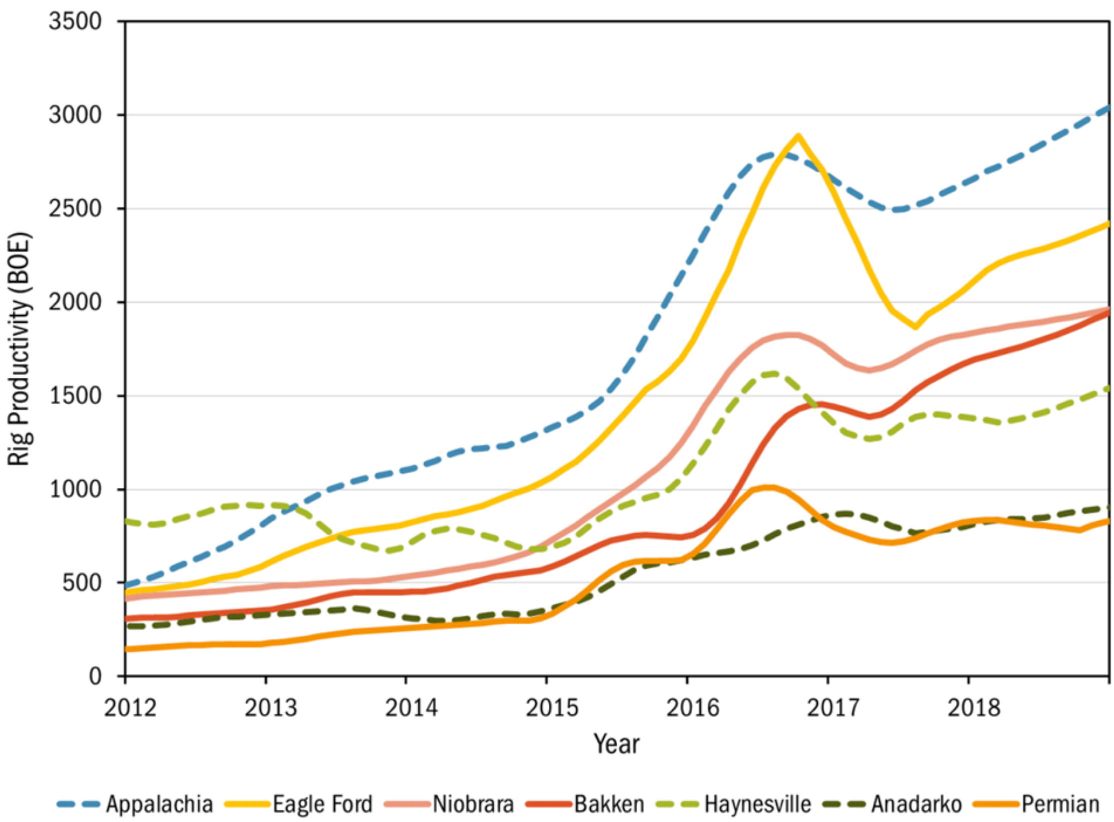

Figure 164. Energy Information Administration (EIA) 'producing per rig' metric by region, 2012 to 2018. Appalachia includes the Utica and Marcellus plays and Anadarko includes the Woodford Play.
(Source: Hughes 2019)

This assessment is highly optimistic. It does not account for observable decreases in real productivity. Yes well productivity has increased, but it has come at a cost of increased lateral drilling per hole and the increase of water, chemical and proppant. Figure 164 shows an EIA assessment of rig productivity shown by tight oil basin play. The gradients of each line between January 2015 and September 2016, are much steeper than the gradients of the same lines between June 2017 to August 2019. This in conjunction with the increased drilling lateral lengths and increased water injection per meter, suggests that productivity these tight oil basins are nearing their collective peak.

Well productivity is a function of technology and geological potential. There is an above ground influence that is proving to be also relevant. Due to well depletion rates being much higher in a fracked well compared to a conventional oil and gas well requires new wells to be drilled constantly. To illustrate this point, Figure 165 shows the crude oil production in the U.S. Tight Oil frontier (this is the same data and presentation as Figure 150), but any production after December 2017 was excluded. This shows what the collective production of the U.S. Tight Oil frontier would be if drill had stopped at the end of 2017.

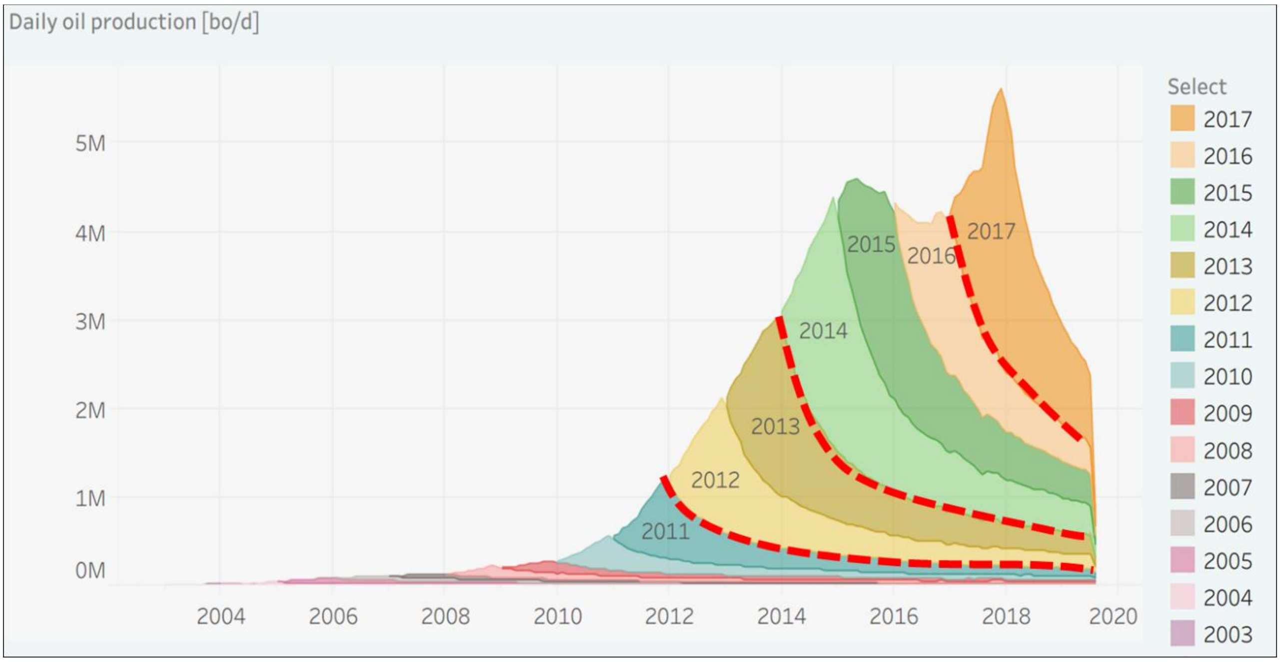

Figure 165. All drilling in the U.S. Tight Oil sector, up to December 2017.
(Source: Enno Peter, Shale Profile Analytics, https://shaleprofile.com/)

Figure 165 also shows the cumulative well decline in the whole U.S. Tight Oil sector. With each passing year, the decline of previous years continues to happen. This produces increasingly steep declines of wells drilled in the first 12 months of production (as shown the red dotted lines in Figure 165). This suggests that soon well depletion will be almost vertical.

It requires capital to conduct this drilling. Section 10 shows that the tight oil sector is struggling to produce positive cash flows. This in turn would make it more difficult to justify capital investment to sustain drilling to support production.

Table 14 shows the results of a study (Hughes 2019) across the oil and gas production of the largest basins. The average well production decline of 86.8%, and an average field decline was 26.3% (with the application of maintenance drilling) and a required 5399 wells needed to be drilled to offset field decline. This shows the rate of decline that needs to be offset if production is to remain consistent.

Table 14. Decline rates, wells needed, drilling costs, play stage and play production prognosis (Source: Hughes 2019)

Play	3-year well decline	Field decline 2017	Production OCT-18 (oil, mbd; gas, bcfd)	Wells/ year to offset decline	Wells drilled 2018	Wells to offset decline %	Well cost ($million)	Drilling cost to offset decline ($million)	2018 drilling cost ($million)	Play stage	Prognosis
Tight Oil											
Bakken	87.5%	28.8%	1.30	1018	1177	86.5%	$7.80	$7,940	$9,181	Mature	Growth
Eagle Ford	86.2%	19.3%	1.28	1017	1239	82.1%	$7.50	$7,625	$9,293	Mature	Growth
Niobrara	90.5%	50.5%	0.47	1243	868	143.2%	$5.00	$6,215	$4,340	Late	Decline
Permian post 2009 horizontal	86.2%	24.4%	3.03	2121	4133	51.3%	$7.50	$15,907	$30,994	Mature	Growth
Production weighted total	86.8%	26.3%	6.08	5399	7417	72.8%	$7.37	$37,687	$53,807		Growth
Shale gas											
Barnett	72.5%	9.5%	2.58	142	101	141.0%	$5.00	$712	$505	Late	Decline
Fayetteville	80.5%	16.6%	1.37	113	3	3760.1%	$5.00	$564	$15	Late	Decline
Haynesville	89.1%	29.4%	7.27	197	306	64.2%	$6.40	$1,258	$1,958	Mature	Growth
Marcellus	72.1%	29.2%	21.04	1251	1320	94.8%	$6.40	$8,008	$8,448	Mature	Growth
Utica gas	83.1%	43.4%	7.33	337	369	91.2%	$6.40	$2,154	$2,362	Early	Growth
Woodford	78.2%	28.5%	2.96	295	459	64.3%	$6.40	$1,889	$2,938	Mature	Growth
Production weighted total	77.6%	30.0%	42.54	2335	2558	91.3%	$6.27	$14,585	$16,226		Growth

The question then becomes at what point does the negative cash flows impact the funding of new drilling, which in turn impacts oil production? Figure 166 shows a decline in the rate increase of oil production in the U.S. in the first half of 2019. It could be argued that the combination of the negative cash flow and the reduction of drilling has already had an effect on the volume of oil produced here.

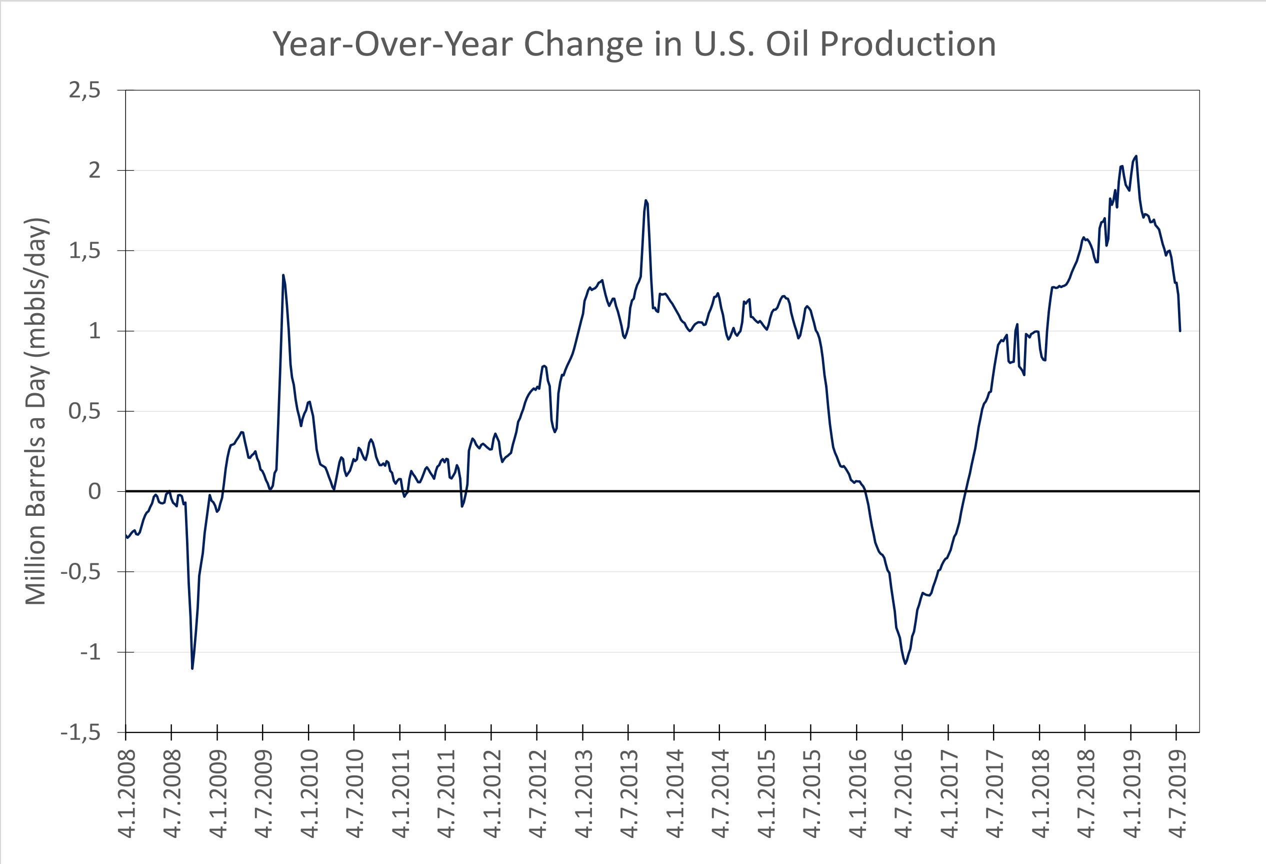

Figure 166. Year over Year change in U.S. oil production
(Source: Energy Information Agency and Rapier July 28 2019)

This suggests that the tight oil frontier is struggling to maintain consistent production, let alone continued growth. This is probably due to a lack of capital investment required to mainatin drilling rather than geological limits.

The recent boom in US tight oil (considered to be a market bubble by many analysts, is fuelled by low interest rates and record oil industry debt) has been responsible for most additional supply since the peak in conventional oil in 2005.

The date of peak oil production in the tight oil sector is very difficult to estimate due to the nature of modelling life cycles of shale oil deposits, it is likely to be in terminal decline within the next 5 to 10 years, with the possibility that it has already peaked due to contraction of upstream capital investment.

This means that Tight Oil while a short term investment bonanza, is not a long term solution to maintaining oil supply to meet global demand. Underneath Tight Oil supply, conventional oil still declines. Tight Oil does not invalidate peak oil, it merely postpones it for a few years.

Shale oil companies may be having difficulties with cash flow (many are in negative cash flows), but the economic reality is this: The global economy cannot continue to expand at a normal pace without a commensurate increase in the oil supply. The only sector that is expanding at all, is shale oil fields, where conventional field volumes are declining. Regardless of the environmental problems with fracking, it is the lifeblood of the global economy and absolutely essential to the world's prosperity.

8 OIL REFINING

After crude oil is removed from the ground, it is sent to a refinery where different parts of the crude oil are separated into useable petroleum products (Figure 167). These petroleum products include gasoline, distillates such as diesel fuel and heating oil, jet fuel, petrochemical feedstocks, waxes, lubricating oils, and asphalt. On average, 44.4% of petroleum becomes gasoline (Source: EIA 2006). There really are no waste products from petroleum. The lighter chemicals are natural gas, liquefied petroleum gas (LPG), jet fuel, and kerosene. The heavier products are used for the manufacture of lubricants, plastics, and asphalt. In addition, many less valuable products can be chemically converted into more saleable compounds.

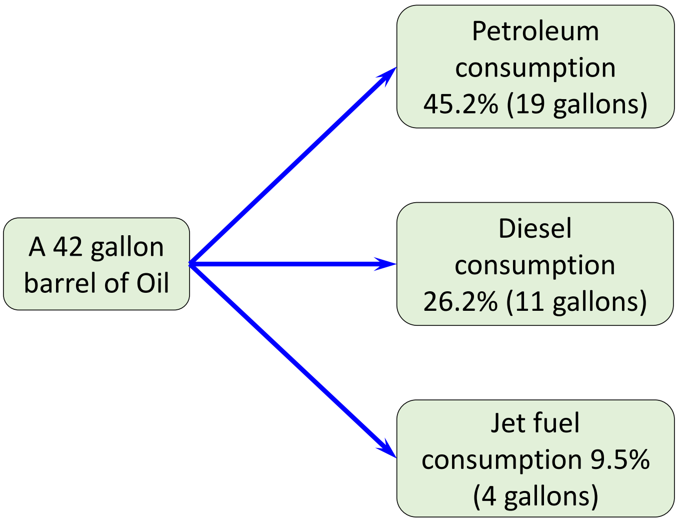

Figure 167. Refining oil into industrially useful products (Source: data from EIA 2006 –Refining of crude oil)

Light, sweet crudes have a higher proportion of the light molecules used to make premium fuels like gasoline, naphtha, and – to some extent – diesel. Heavy crudes have a higher proportion of molecules that can only be used to make diesel fuel or residual fuels oils that are sold at a discount to ships or power producers. Heavy crudes are also more difficult to refine, requiring intensive processing using catalytic cracking and coking units.

Heavy crude oils (and bitumen) are cheaper for the refiner to buy, but they require more processing to yield lower-value products. Modern complex refineries, however, can convert and upgrade the heavy residuals left over from distillation into lighter and more valuable molecules by processes called cracking and coking. The end products are premium products such as gasoline, naphtha, jet fuel, and road diesel.

The quality of crude oils are highly variable, not only differing from one source to the next but even within individual sources. Shale oils for example can be high in solids, including high-melting point waxes, which can accumulate and cause equipment blockages. Other issues that can affect shale oil processing include the presence of hydrogen sulfide (which produces that “rotten egg” smell) and the potential for corrosive salt build-up. For example, oil supplied from the U.S. Tight Oil Bakken and Eagle

Ford plays are too light: while they yield liquid petroleum gas (LPG), gasoline, and diesel, they don't have enough "gas oil" and residue to keep the gasoline-making heart of refineries running properly (EIA 2018).

Table 15, Figures 168 to 171 show the refinery throughput on a global scale. As can be observed, the United States and China dominate the global market, where between them, they account for 34% of refining capacity and 35% of refinery throughput.

Global refining capability has approximately 11% extra capacity, should crude oil supply should increase. This means that as of 2018, the global oil market is not refinery limited.

Table 15. Global refinery capacity, throughput and spare capacity (Source: BP Statistical review of World Energy 2019)

Country	Refinery Capacity (kbbls/day)	Refinery Capacity Global Rank	Refinery Throughput (kbbls/day)	Refinery Throughput Global Rank	Extra Refining Capacity (kbbls/day)	Spare Refining Capacity (%)
United States	18 762	1	16 962	1	1 800	9,59 %
China	15 655	2	12 441	2	3 214	20,53 %
Russian Federation	6 596	3	5 833	3	763	11,57 %
India	4 972	4	5 154	4		
South Korea	3 346	5	3 030	6	316	9,44 %
Japan	3 343	6	3 059	5	284	8,50 %
Saudi Arabia	2 835	7	2 770	7	65	2,29 %
Brazil	2 285	8	1 733	10	552	24,16 %
Iran	2 225	9	2 026	8	199	8,94 %
Germany	2 085	10	1 775	9	310	14,87 %
Canada	2 025	11	1 656	11	369	18,22 %
Italy	1 900	12	1 346	13	554	29,16 %
Spain	1 564	13	1 365	12	199	12,72 %
Mexico	1 546	14				
Singapore	1 514	15	1 047	17	467	30,85 %
Venezuela	1 303	16				
Netherlands	1 294	17				
France	1 245	18	1 086	15	159	12,77 %
Thailand	1 235	19	1 131	14	104	8,42 %
UAE	1 229	20	1 044	18	185	15,05 %
United Kingdom	1 227	21	1 054	16	173	14,10 %
Indonesia	1 116	22				
Taiwan	1 083	23				
Rest of World	19 664		18 441		1 223	6,22 %
Global Capacity	100 049		82 953		10 936	10,93 %

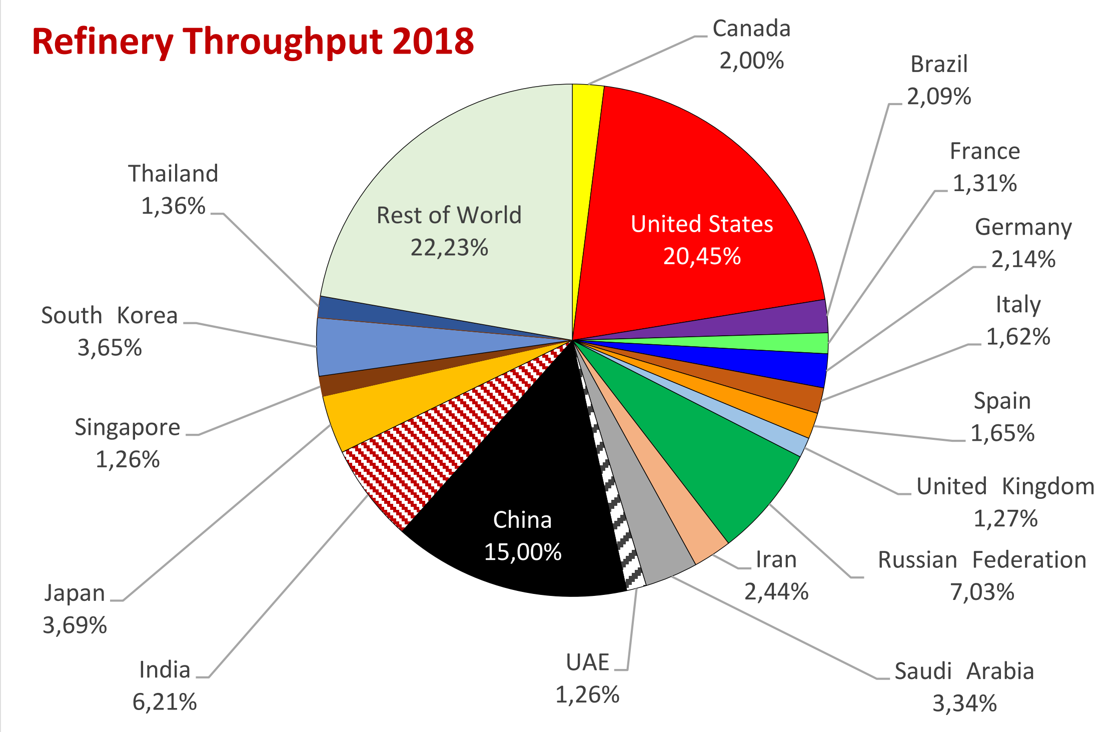

Figure 168. Global Oil Refinery Throughput in 2018
(Source: BP Statistical review of World Energy 2019)

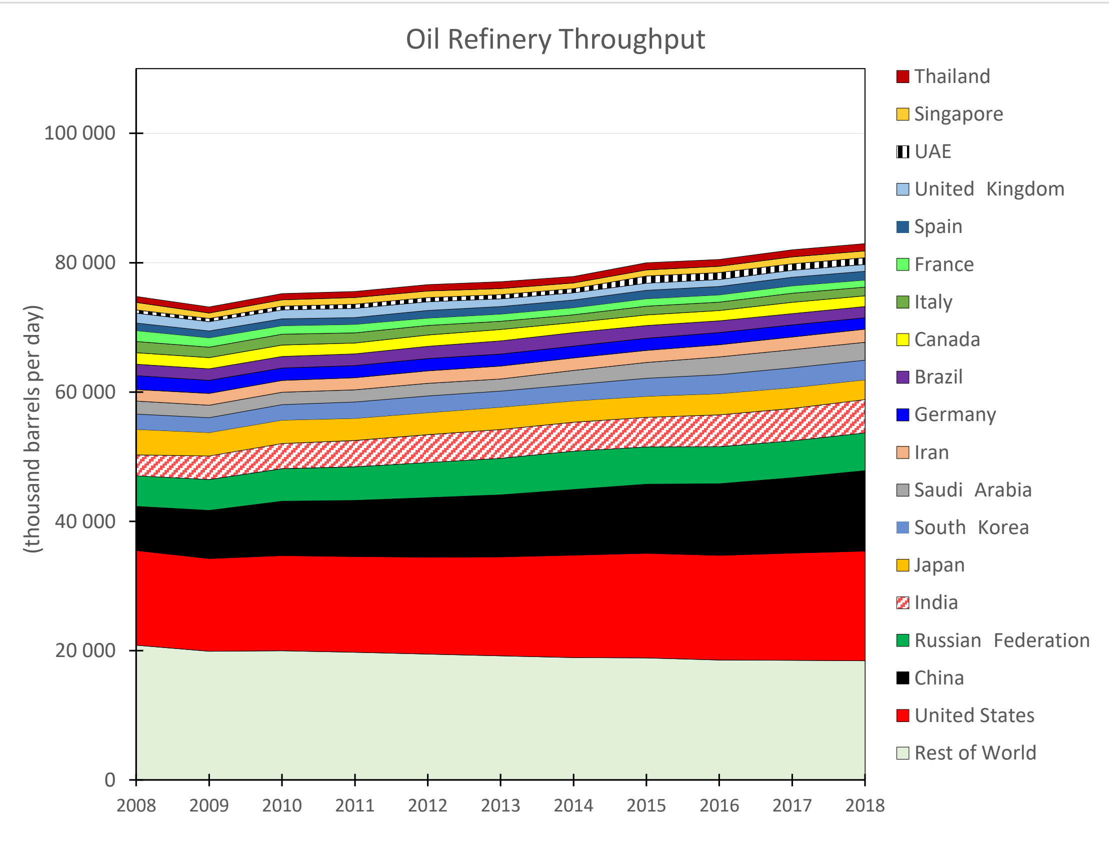

Figure 169. Global Oil Refinery Throughput in 2008 to 2018
(Source: BP Statistical review of World Energy 2019)

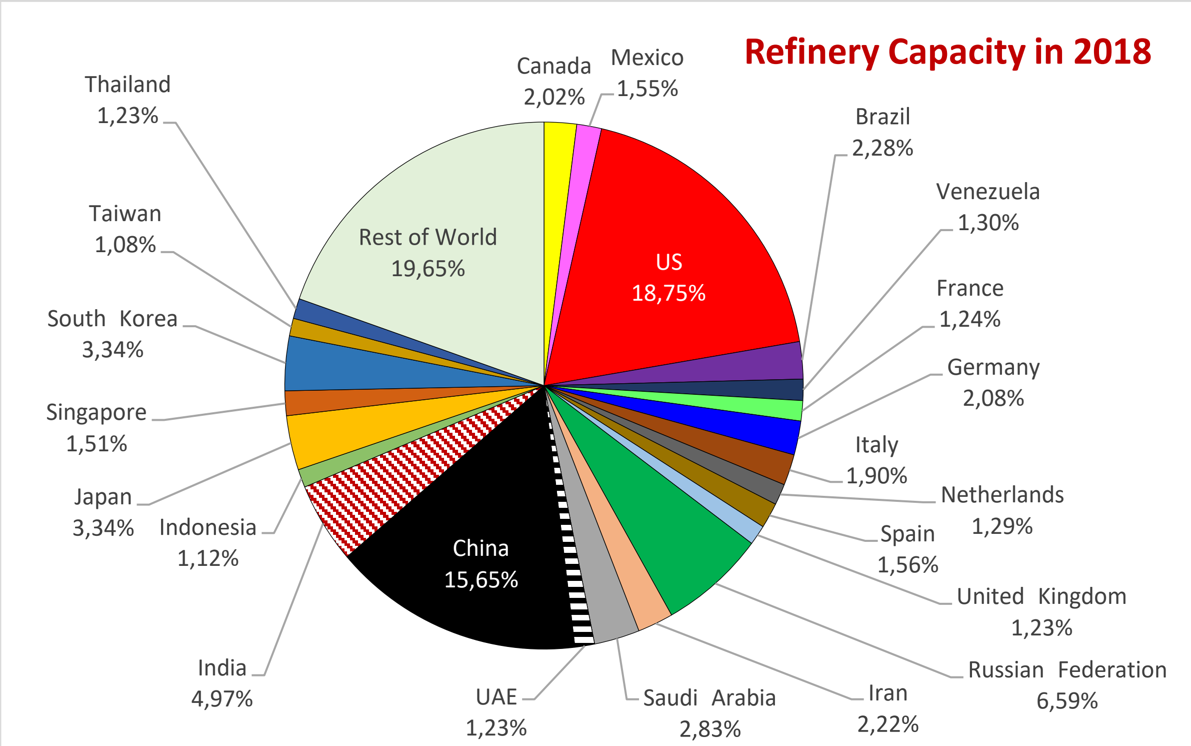

Figure 170. Global Oil Refinery Throughput in 2018
(Source: BP Statistical review of World Energy 2019)

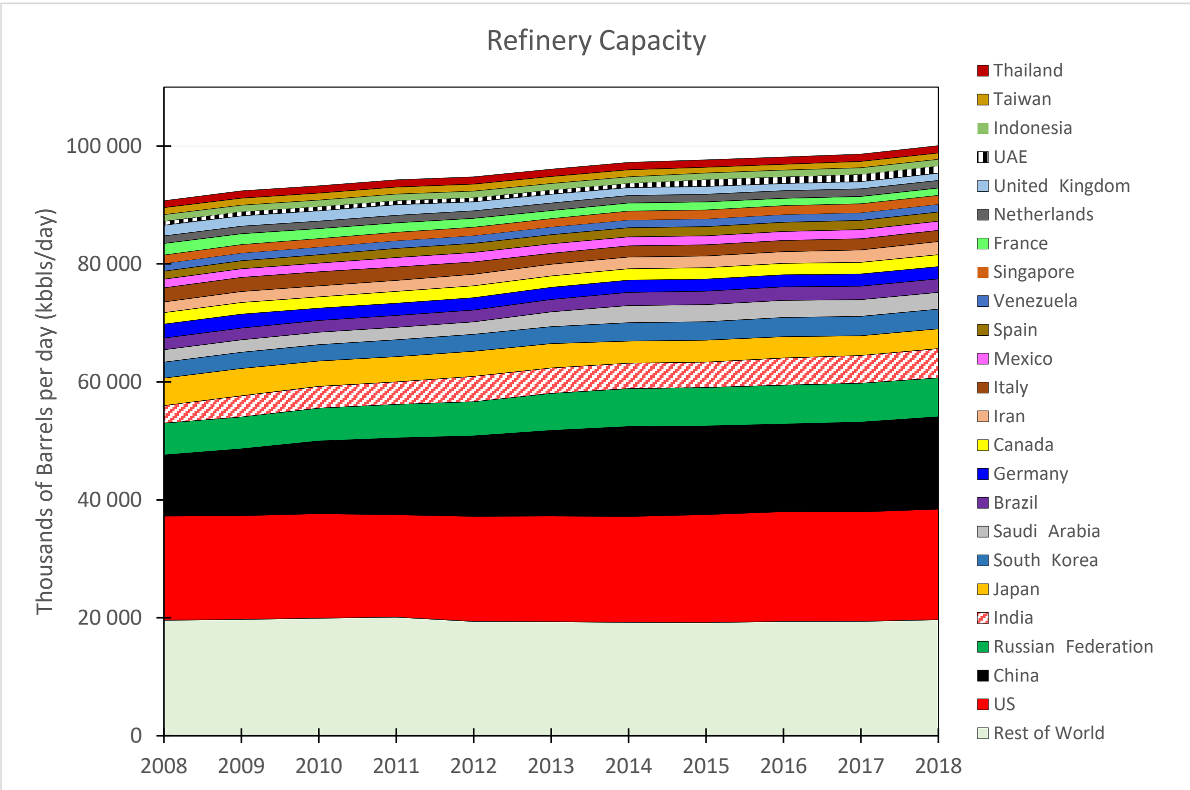

Figure 171. Global Oil Refinery Throughput in 2008 to 2018
(Source: BP Statistical review of World Energy 2019)

Petroleum refining begins with the distillation, or fractionation, of crude oils into separate hydrocarbon groups. The resultant products are directly related to the characteristics of the crude oil being processed. Most of these products of distillation are further converted into more useable products by changing their physical and molecular structures through cracking, reforming and other conversion processes. These products are subsequently subjected to various treatment and separation processes, such as extraction, hydrotreating and sweetening, in order to produce finished products. Whereas the simplest refineries are usually limited to atmospheric and vacuum distillation, integrated refineries incorporate fractionation, conversion, treatment and blending with lubricant, heavy fuels and asphalt manufacturing; they may also include petrochemical processing. Most refineries, regardless of complexity, perform a few basic steps in the refining process (Fahim et al 2010 and Jones 2008):

- Distillation
- Cracking
- Treating
- Reforming

These processes are often grouped into the following main operating areas (using example of the Chevron operation Pascagoula Refinery – Jones 2008).

- Crude/Aromatics
- Cracking I
- RDS/Coker
- Cracking II
- Sulfur Recovery Unit

8.1 Distillation

Modern distillation involves pumping oil through pipes in hot furnaces and separating light hydrocarbon molecules from heavy ones in downstream distillation towers – the tall, narrow columns that give refineries their distinctive skylines. Using a generic example, refining process begins when crude oil is distilled in two large Crude Units that each have three distillation columns, one that operates at near atmospheric pressure, and two others that operate at less than atmospheric pressure, (for example a low vacuum) (Fahim et al 2010 and Jones 2008).

During this process, the lightest materials, like propane and butane, vaporize and rise to the top of the first atmospheric column. Medium weight materials, including gasoline, jet and diesel fuels, condense in the middle. Heavy materials (usually termed gas oils) condense in the lower portion of the atmospheric column. The heaviest tar-like material, called residuum, is referred to as the “bottom of the barrel” because it never really rises.

In some cases, distillation columns are operated at less than atmospheric pressure (low vacuum) to lower the temperature at which a hydrocarbon mixture boils. This “vacuum distillation” (VDU) reduces the chance of thermal decomposition (cracking) due to overheating the mixture. Using the process control systems, refinery operators control the temperatures in the distillation columns which are designed with pipes to withdraw the various types of products where they condense. Products from the top, middle and bottom of the column travel through these pipes to different plants for further refining.

This distillation process is repeated in multiple other plants in a series step process as the oil is further refined to make various products.

8.2 Catalytic Cracking

The middle distillate, gas oil and residuum is converted into primarily gasoline, jet and diesel fuels by using a series of processing plants that physically “crack” large, heavy molecules into smaller, lighter ones (Fahim et al 2010 and Jones 2008). This process uses heat to break up longer hydrocarbon chains into shorter hydrocarbon chains.

Heat and catalysts are used to convert the heavier oils to lighter products using three “cracking” methods: fluid catalytic cracking (FCC), hydrocracking, and coking (or thermal-cracking). In a typical unit, the Fluid Catalytic Cracker (FCC) uses high temperature and catalyst to crack 86,000 barrels (13.6 million liters) each day of heavy gas oil mostly into gasoline (Fahim et al 2010 and Jones 2008). Hydrocracking uses catalysts to react gas oil and hydrogen under high pressure and high temperature to make both jet fuel and gasoline. Also, about 58,000 barrels (9.1 million liters) of lighter gas oil is converted daily in a separate unit(s), using this hydrocracking process (in the example used by Fahim et al 2010 and Jones 2008). Usually, the products from the FCC are blended directly into transportation fuels, (i.e., gasoline, diesel and jet fuel). The lightest molecules are burned as fuel for the refinery’s furnaces, thus conserving natural gas and minimizing waste.

An example process unit could be the application of a Delayed Coking Unit (Coker), where low-value residuum is converted (using the coking, or thermal-cracking process) to high-value light products, producing petroleum coke as a by-product. The large residuum molecules are cracked into smaller molecules when the residuum is held in a coke drum at a high temperature for a period of time. Only solid coke remains.

8.3 Combining

While the cracking processes break most of the gas oil into gasoline and jet fuel, they also break off some pieces that are lighter than product termed gasoline. The most cost efficient by volume group of saleable products is transportation fuels. So the process used to valorize these really short chain hydrocarbons (that would normally be a waste product) is to recombine all of the lighter components (collected all over the refinery) in an Alkylation Unit(s). This process takes the small molecules and recombines them in the presence of sulfuric acid catalyst to convert them into high octane gasoline.

8.4 Removing Impurities with hydrotreating

The products from the distillation column(s) and the product streams from other units contain some natural impurities, such as sulfur and nitrogen. Using a process called hydrotreating (a milder version of hydrocracking), these impurities are removed to reduce air pollution when our fuels are used (Fahim et al 2010 and Jones 2008). Because most of the crude oil processed by most refineries is of the heavier oils quality that are high in sulfur and nitrogen, various treating units throughout the refinery work to remove these impurities.

In the hydrotreating reactors, sulfur and nitrogen are removed from FCC feed stream. The sulfur is converted to hydrogen sulfide and sent to the Sulfur Unit where it is converted into elemental sulfur.

Nitrogen is transformed into ammonia which is removed from the process by water-washing. Later, the water is treated to recover the ammonia as a pure product for use in the production of fertilizer. Low sulfur vacuum gas oil, is then fed to the FCC (fluid catalytic cracker) Unit which then cracks it into high value products such as gasoline and diesel.

8.5 Reforming

Octane rating is a key measurement of how well a gasoline performs in an ICE automobile engine. Much of the gasoline that comes from the Crude Units or from the Cracking Units does not have enough octane to burn well in cars (Fahim et al 2010 and Jones 2008). The reforming process actually removes hydrogen from low-octane gasoline. The hydrogen is used as a feed blending stream throughout the refinery in various cracking (hydrocracking) and treating (hydrotreating) units.

The gasoline process streams in the refinery that have a fairly low octane rating are sent to a Reforming Unit where their octane levels are boosted. These reforming units employ precious-metal catalysts – platinum and rhenium (which have the industry name “rheniformers). In the reforming process, hydrocarbon molecules are “reformed” into high octane gasoline components. For example, methyl cyclohexane is reformed into toluene.

8.6 Blending

A final and critical step is the blending of products. Gasoline, for example, is blended from treated components made in several processing units, which are then stored (Figure 172). In many refineries this task is performed in the Blending and Shipping Area, where operators precisely combine the process stream products to ensure that the final product blend has the right octane level, vapor pressure rating and other important specifications. All products are blended in a similar fashion to produce a saleable product that can be consistently pass a QA/QC characterization step.

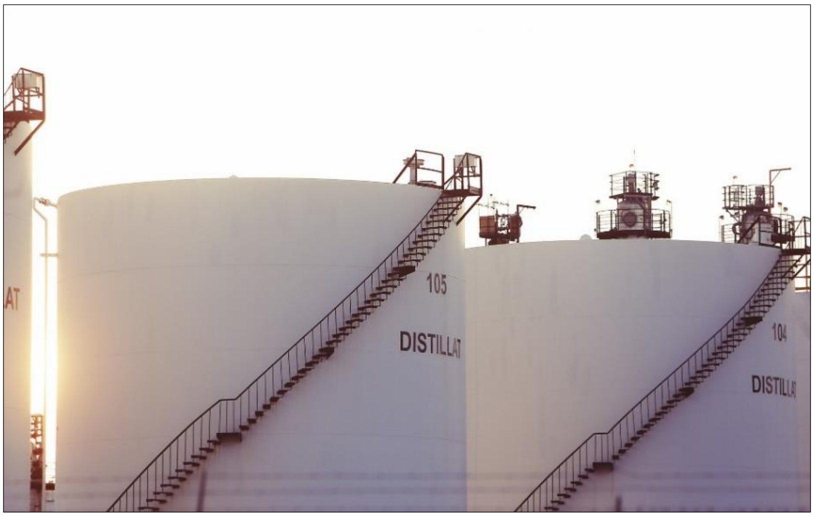

Figure 172. Refined petroleum products stored for transport to the market
(Image by LEEROY Agency from Pixabay)

Figure 173 shows a picture of a petroleum refinery in the United States. Figure 174 shows a generic process flowsheet that describes the basic steps an oil refinery.

Figure 173. Oil refinery in Indiana USA (Source: Image by jpenrose from Pixabay)

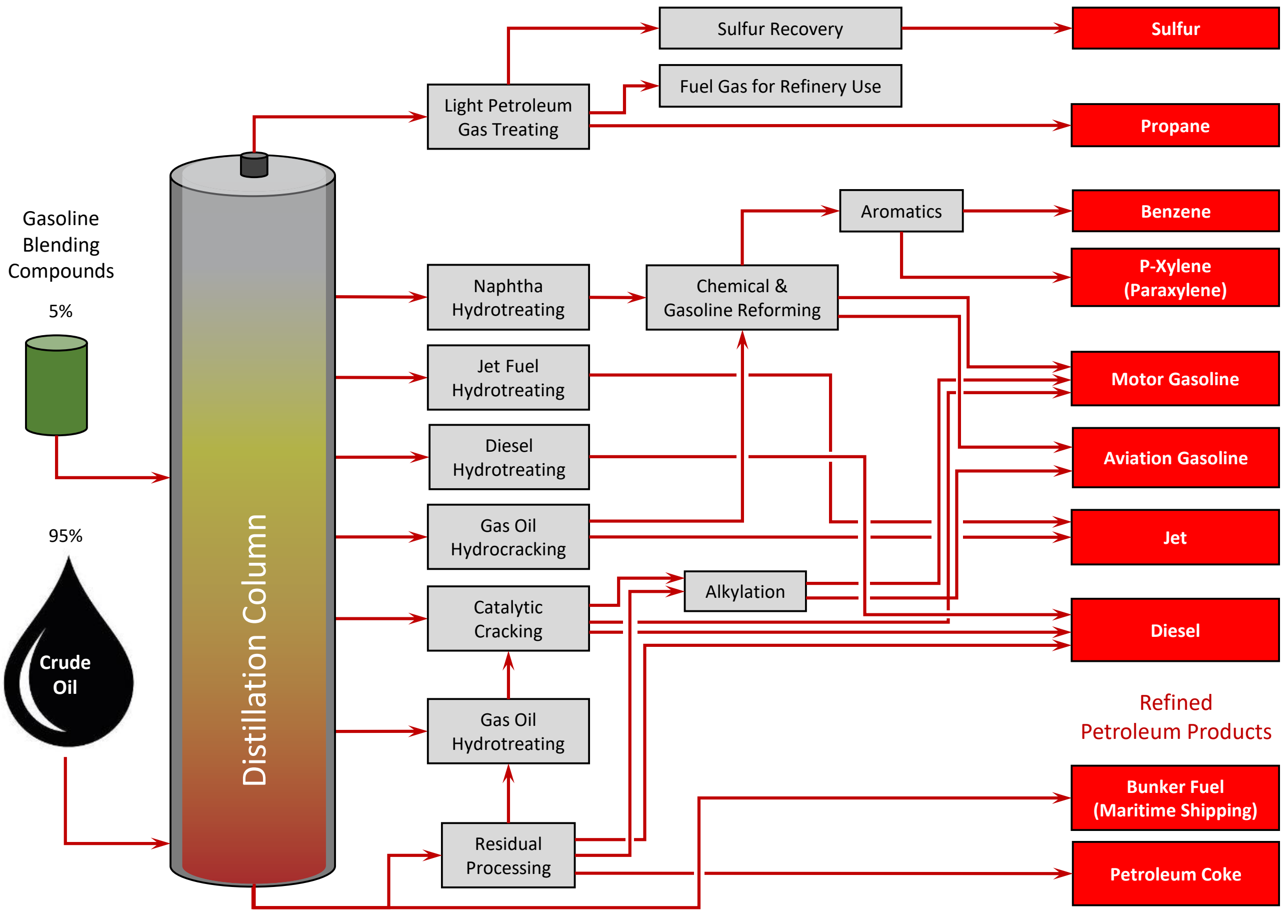

Figure 174. A generic process flow chart for an oil refinery
(Source: Concepts developed from Fahim *et al* 2010 and Jones 2008)

The United States the world's largest capacity for oil refining. It imports a lot of crude oil from all over the world. Figure 175 and 176 shows the quality of oil refined in the United States in context of imports and domestic supply. The light crude that is produced in the United States is often better quality than the imported crude oils. In 2018, 7.5 million barrels a day (97%) of imported crude oil had an API gravity of 40 or lower, compared with 4.7 million (45%) barrels a day of U.S. domestic production.

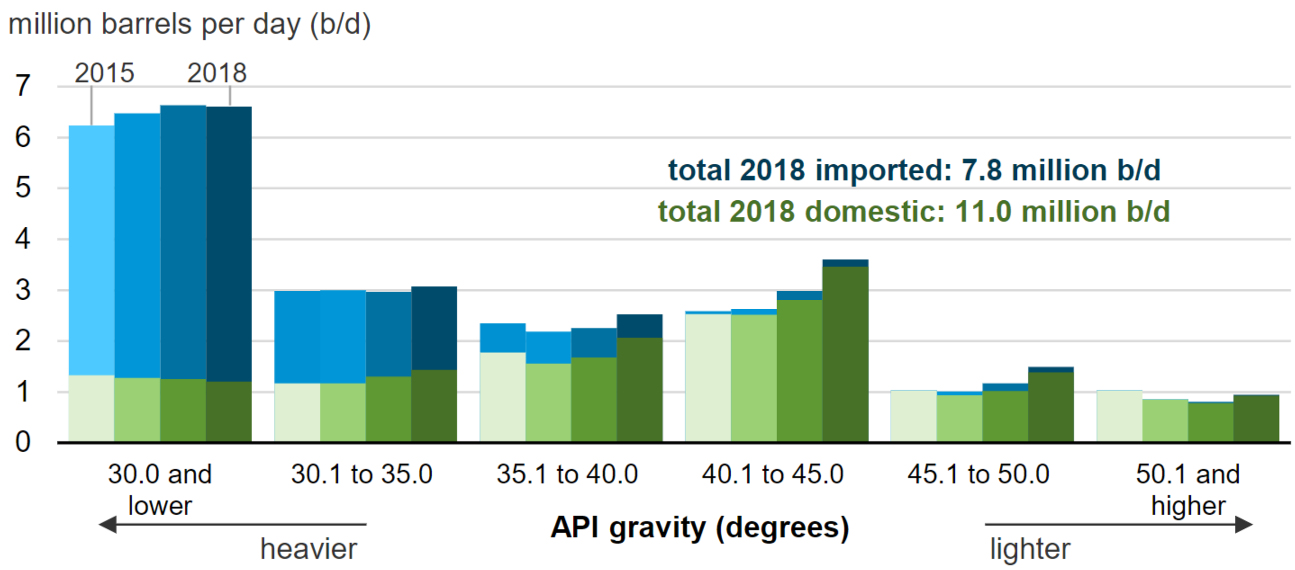

Figure 175. U.S. imported and domestic crude oil by API gravity category, 2015 to 2018
(Source: Monthly Crude Oil and Natural gas Production and Monthly Imports Report, EIA 2019 Oct a)
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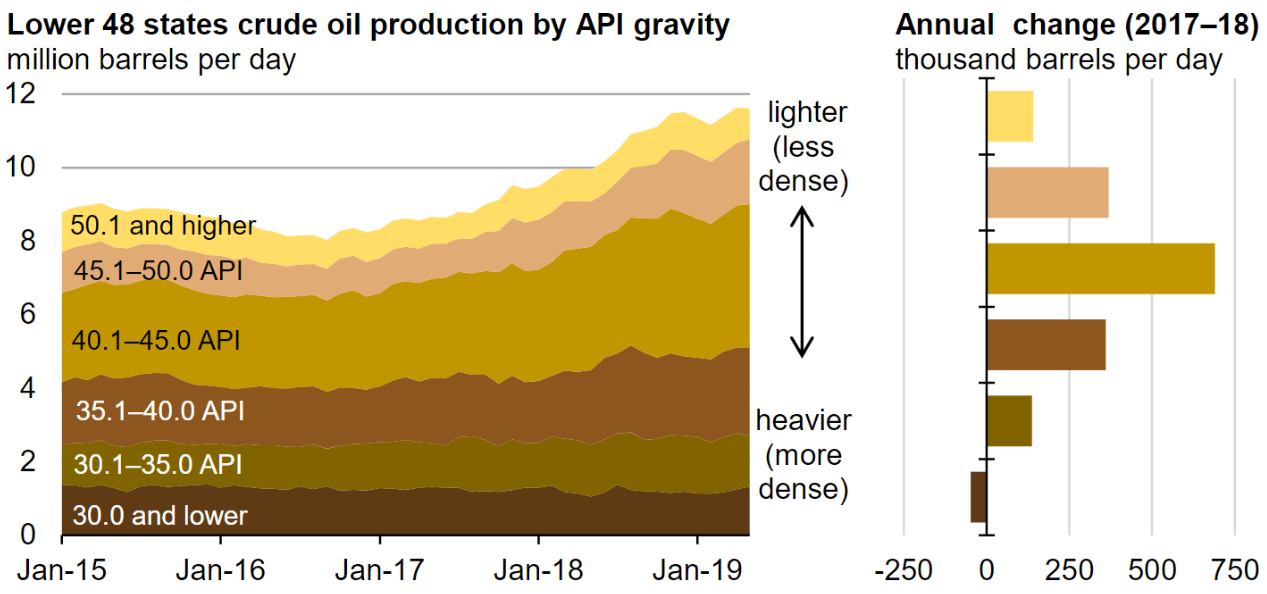

Figure 176. Quality of the crude oil produced in the United States, 2015 to 2019
(Source: Monthly Crude Oil and Natural gas Production, EIA 2019 Oct a)
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Table 16 shows the calorific properties of the refined products that are refined in the oil & gas industry.

Table 16. Higher and Lower Calorific Values of fuels
(Source: The Engineering Toolbox https://www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html)

Fuel	Density		Higher Heating Value (HHV) (Gross Calorific Value - GCV)					Lower Heating Value (LHV) (Net Calorific Value - NCV)				
	@0°C/32°F, 1 bar											
Gaseous fuels	**[kg/m³]**	**[g/ft³]**	**[kWh/kg]**	**[MJ/kg]**	**[Btu/lb]**	**[MJ/m³]**	**[Btu/ft³]**	**[kWh/kg]**	**[MJ/kg]**	**[Btu/lb]**	**[MJ/m³]**	**[Btu/ft³]**
Acetylene	1,10	31,10	13,90	49,90	21453,00	54,70	1468,00					
Ammonia				22,50	9690,00							
Hydrogen	0,09	2,55	39,40	141,70	60920,00	12,70	341,00	33,30	120,00	51591,00	10,80	290,00
Methane	0,72	20,30	15,40	55,50	23874,00	39,80	1069,00	13,90	50,00	21496,00	35,80	964,00
Natural gas (US market)*	0,78	22,00	14,50	52,20	22446,00	40,60	1090,00	13,10	47,10	20262,00	36,60	983,00
Town gas						18,00	483,00					
	@15°C/60°F, 1 bar											
Liquid fuels	**[kg/l]**	**[g/gal]**	**[kWh/kg]**	**[MJ/kg]**	**[Btu/lb]**	**[MJ/l]**	**[Btu/gal]**	**[kWh/kg]**	**[MJ/kg]**	**[Btu/lb]**	**[MJ/l]**	**[Btu/gal]**
Acetone	0,79	2,98	8,83	31,80	13671,00	25,00	89792,00	8,22	29,60	12726,00	23,30	83580,00
Butane	0,60	3,07	13,64	49,10	21109,00	29,50	105875,00	12,58	45,30	19475,00	27,20	97681,00
Butanol	0,80		10,36	37,30	16036,00	30,20	108359,00	9,56	34,40	14789,00	27,90	99934,00
Diesel fuel*	0,85	3,20	12,67	45,60	19604,00	38,60	138412,00	11,83	42,60	18315,00	36,00	129306,00
Dimethyl ether (DME)	0,67	2,52	8,81	31,70	13629,00	21,10	75655,00	8,03	28,90	12425,00	19,20	68973,00
Ethane	0,57	2,17	14,42	51,90	22313,00	29,70	106513,00	13,28	47,80	20550,00	27,30	98098,00
Ethanol (100%)	0,79	2,99	8,25	29,70	12769,00	23,40	84076,00	7,42	26,70	11479,00	21,10	75583,00
Diethyl ether (ether)	0,72	2,71	11,94	43,00	18487,00	30,80	110464,00					
Gasoline (petrol)*	0,74	2,79	12,89	46,40	19948,00	34,20	122694,00	12,06	43,40	18659,00	32,00	114761,00
Gas oil (heating oil)*	0,84	3,18	11,95	43,00	18495,00	36,10	129654,00	11,89	42,80	18401,00	36,00	128991,00
Glycerin	1,26	4,78	5,28	19,00	8169,00	24,00	86098,00					
Heavy fuel oil*	0,98	3,71	11,61	41,80	17971,00	41,00	146974,00	10,83	39,00	16767,00	38,20	137129,00
Kerosene*	0,82	3,11	12,83	46,20	19862,00	37,90	126663,00	11,94	43,00	18487,00	35,30	126663,00
Light fuel oil*	0,96	3,63	12,22	44,00	18917,00	42,20	151552,00	11,28	40,60	17455,00	39,00	139841,00
LNG*	0,43	1,62	15,33	55,20	23732,00	23,60	84810,00	13,50	48,60	20894,00	20,80	74670,00
LPG*	0,54	2,03	13,69	49,30	21195,00	26,50	94986,00	12,64	45,50	19561,00	24,40	87664,00
Marine gas oil*	0,86	3,24	12,75	445,90	19733,00	39,20	140804,00	11,89	42,80	18401,00	36,60	131295,00
Methanol	0,79	2,99	6,39	23,00	9888,00	18,20	65274,00	5,54	19,90	8568,00	15,80	56562,00
Methyl ester (biodiesel)	0,89	3,36	11,17	40,20	17283,00	35,70	128062,00	10,42	37,50	16122,00	33,30	119460,00
MTBE	0,74	2,81	10,56	38,00	16337,00	28,20	101244,00	9,75	35,10	15090,00	26,10	93517,00
Oils vegetable (biodiesel)*	0,92	3,48	11,25	40,50	17412,00	37,30	133684,00	10,50	37,80	16251,00	34,80	124772,00
Paraffin (wax)*	0,90	3,41	12,78	46,00	19776,00	41,40	148538,00	11,53	41,50	17842,00	37,40	134007,00
Pentane	0,63	2,39	13,50	48,60	20894,00	30,60	109854,00	12,60	45,40	19497,00	28,60	102507,00
Petroleum naphtha*	0,73	2,75	13,36	48,10	20679,00	34,90	125145,00	12,47	44,90	19303,00	32,60	116819,00
Propane	0,50	1,89	13,99	50,40	21647,00	25,10	89963,00	12,88	46,40	19927,00	23,10	82816,00
Residual oil*	0,99	3,75				41,80	150072,00	10,97	39,50	16982,00	39,20	140470,00
Tar*			10,00	36,00	15477,00							
Turpentine	0,87	3,27	12,22	44,00	18917,00	38,10	136555,00					
Solid fuels*			**[kWh/kg]**	**[MJ/kg]**	**[Btu/lb]**			**[kWh/kg]**	**[MJ/kg]**	**[Btu/lb]**		
Anthracite coal			9,06	32,60	14015,00							
Bituminous coal			8,39	30,20	12984,00			8,06	29,00	12468,00		
Carbon			9,11	32,80	14101,00							
Charcoal			8,22	29,60	12726,00			7,89	28,40	12210,00		
Coke			7,22	26,00	11178,00							
Lignite (brown coal)			3,89	14,00	6019,00							
Peat			4,72	17,00	7309,00							
Petroleum coke			8,69	31,30	13457,00			8,19	29,50	12683,00		
Semi anthracite			8,19	29,50	12683,00							
Sub-Bituminous coal			6,78	24,40	10490,00							
Sulfur (s)			2,56	9,20	3955,00			2,55	9,20	3939,00		
Wood (dry)	0,701		4,50	16,20	6965,00			4,28	15,40	6621,00		

* Fuels which consist of a mixture of several different compounds may vary in quality between seasons and markets. The given values are for fuels with the given density. The variation in quality may give heating values within a range 5 -10% higher and lower than the given value. Also the solid fuels will have a similar quality variation for the different classes of fuel.

9 RISING COST OF OIL PRODUCTION

As oil deposits get harder to access in deeper water and require more processing steps to produce a saleable product, the cost of extraction and production goes up. This rise in production cost is not just related to where the deposit is, but the infrastructure needed to extract it, then the processing steps required to make a saleable product. This combination of logistical limitations is what has resulted in a steady rise in the cost of oil production. When all of the historical oil deposits that have low cost profiles deplete, most of the industry will have a high cost curve, which will through necessity, push the price up. Production cost increases are related to the following:

- General inflation
- Specific inflation on components necessary in a well, such as steel for casing etc,
- New equipment in wells to increase recovery
- The cost of increased safety (HES costs).

Technology has been developing in complexity as well as cost. This is how oil has been able to be extracted reliably in such extreme circumstances (compared to the beginning of the oil industry in the late 1800's).

Currently society requires a stable oil market and does not cope well with price spikes. There is a high risk that peak oil production will happen when the cost of oil production sharply increases. Figure 177 shows conceptually this concept.

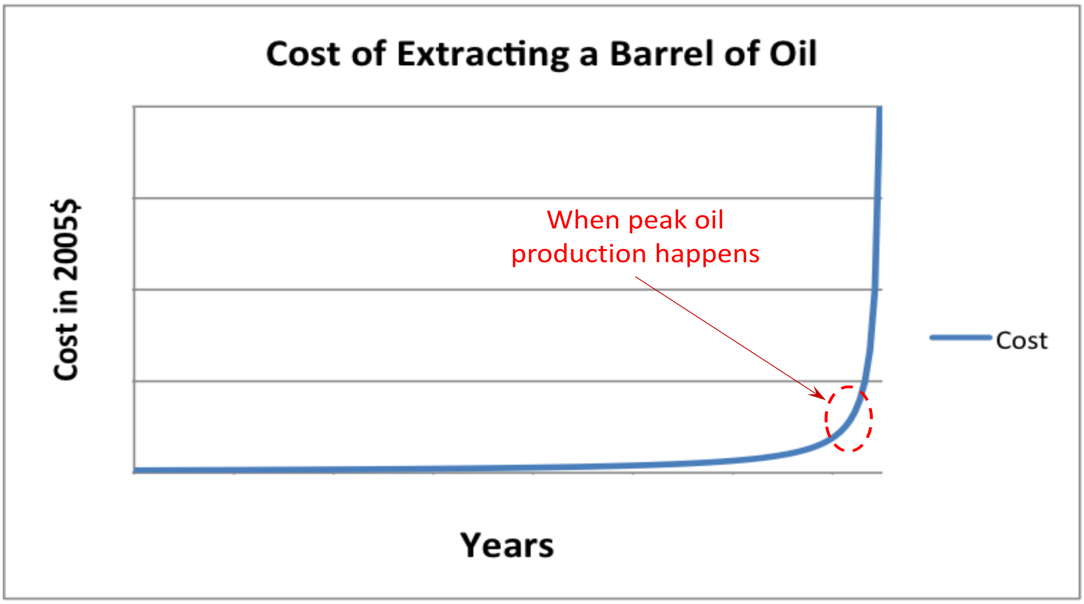


Figure 177. Reaching limits eventually leads to sharp cost of production increases

9.1 Rising cost of oil exploration

The cost of oil exploration has been increasing (Figure 178). To find new deposits, exploration has to be done in logistically increasigly more difficult cicumstances. Exploration wells are more expensive because they are often required to be deeper, and are often in deeper water (in the case of offshore explroation). The oil deposits are also smaller in volume, thus require more exploration wells to get a a reasonable strike rate. Figure 178 shows an increase in the cost of oil exploration, peaking in 2008, followed by a reduction. In 2008, the Global Finacial Crisis (GFC) had the rippled effect of all activity that did not directly generate revenue was discontinued. After the GFC, investment in epxloration was able to be justified again. In spite of the extra capital spent in exploration, the rates of discovery for new oil deposits continued to fall (see Section 13).

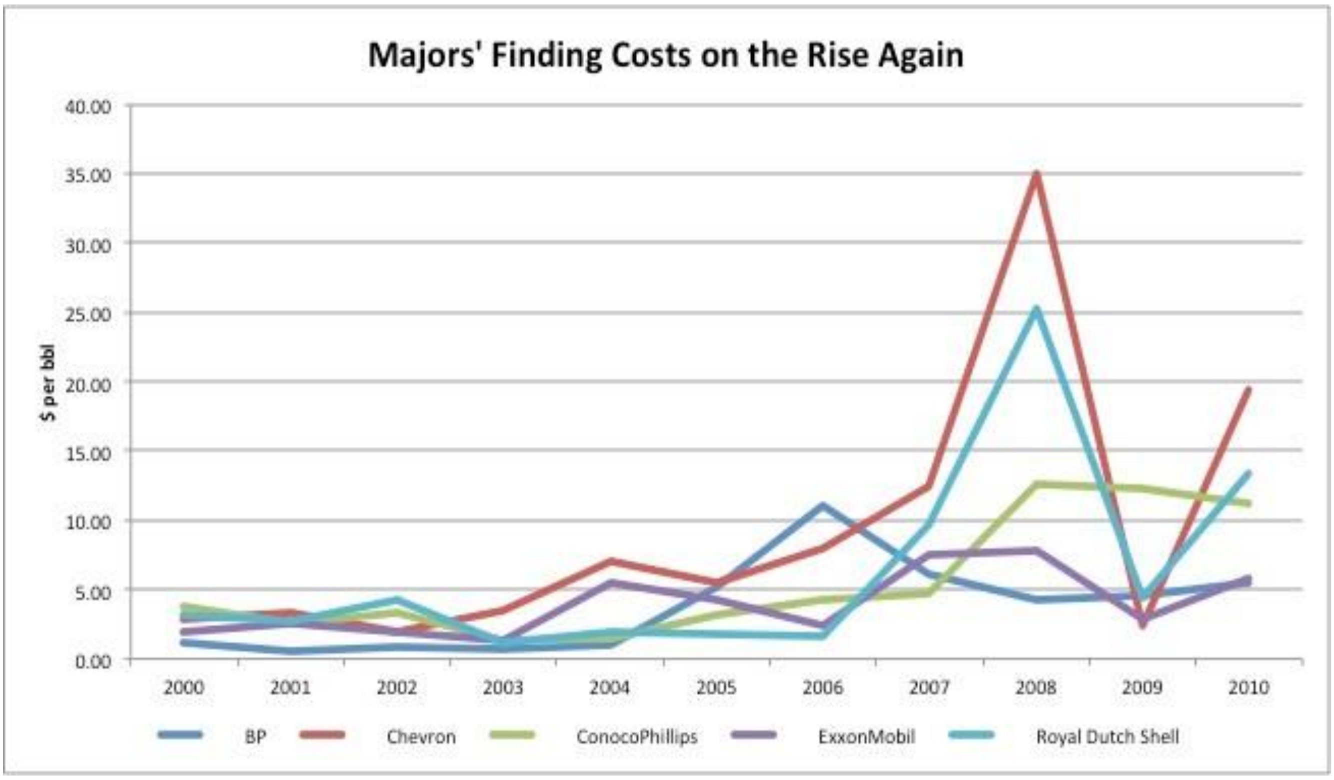


Figure 178. Cost of oil and gas exploration is increasing (IOC majors)
(Source: Evaluateenergy.com)

9.2 Rising oil operation CAPEX

In 2018, much more effort is required to get the same unit of oil compared to 1900 in Texas. Processing and refining steps are now much more complex. The startup CAPEX (capital expediture) costs of of commissoning an oil extraction well have been steadily increasing.

Figure 179 shows upstream CAPEX investment for the oil and gas industry. From 2000 to 2014, CAPEX steadily increased. This increase was consistent through the year 2005, when oil production plateaued. From 2014 to 2016, there was a 24% decrease in investment each year, which is an indication that the investment community has lost confidence in oil (EIA 2016).

The present oil price range ($55 - $70 a barrel ($USD) [Brent Spot]), combined with leverage and balance sheet constraints makes it harder for many shale companies to obtain more outside financing. Several will cut their CAPEX considerable during 2019 according to their SEC filings. At the present oil price range, it is not possible to sustain present production/extraction levels from operating cash flow. This while the investors/owners want to see money returned to them as dividend (Likvern 2019). Figure 179 shows that this process may have started in 2014.

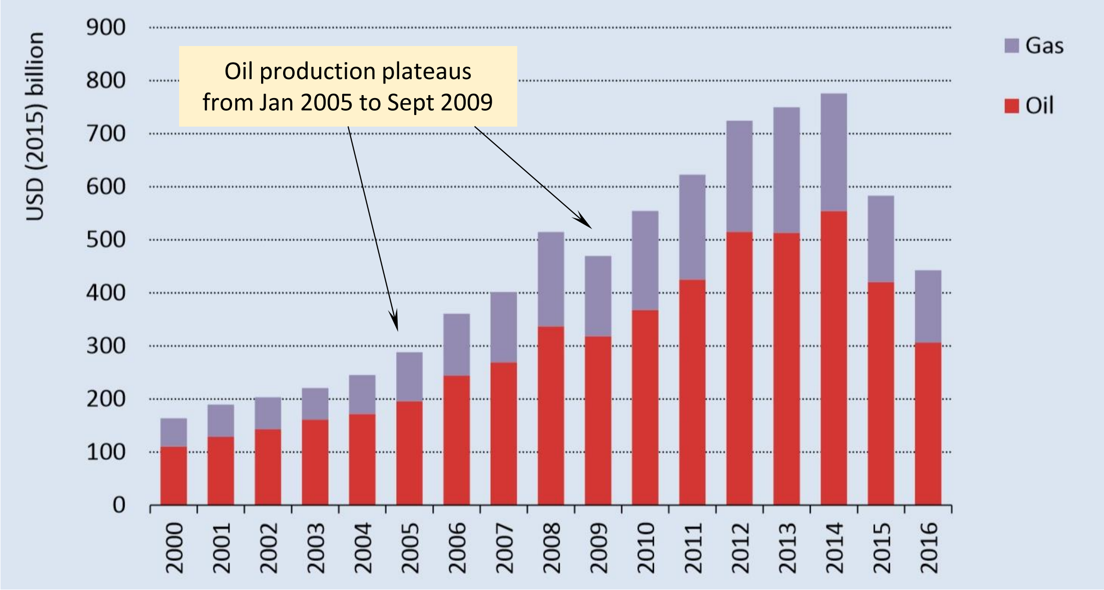


Figure 179. International Oil Companies (IOC) crude oil upstream Capital Investment CAPEX (Source: EIA (crude production), IEA WEO 2003, 2010 and 2016 (CAPEX)) (Copyright License: https://www.eia.gov/about/copyrights_reuse.php)

9.3 Rising oil operation OPEX

The cost of operation (OPEX) is also rising for the oil industry. Figure 180 shows the global liquid supply cost curve in context of the kind of oil deposit (what the oil production price is at the point of cost neutral break even return). As the conventional producing fields decommission, and the more expensive unconventional fields take their place, the rising oil production costs require an ever increasing sale oil price. Figure 180 in conjunction with Figure 233 shows that the cost curve is sliding into the region of the red ellipse in Figure 177. It is about at this point where peak oil production is projected to happen (with the understanding that a number of complex factors collectively influence exactly when this is).

This has resulted in a shortfall in capital investment in the development of new operations. The current oil industry requires constant capital investment to maintain steady supply (his is an artifact of the fracking sector, which requires constant new drilling). This will result in a shortfall in future oil producing capacity, where supply may not be as smooth and reliable as it is now.

As can be seen most of the oil industry needs a higher oil price with each passing year to be economically viable (Kleinberg et al 2018). If the price was to drop below the cost of production, then most operations would become unsustainable in the medium term and would be shut down. Low prices could be sustained for a short time by cutting back on exploration and cancelling future investments to maintain revenue cash flow (much like what is being done now by the major IOC producers).

In summary, the costs of exploration for new oil deposits, the CAPEX required to establish a producing oil well, and the operating costs OPEX are all increasing. All of this is happening in an investment environment where investment confidence in the viability of return is deteriorating. Either the sale price of oil goes up in a sustainable fashion, or the oil industry production stalls.

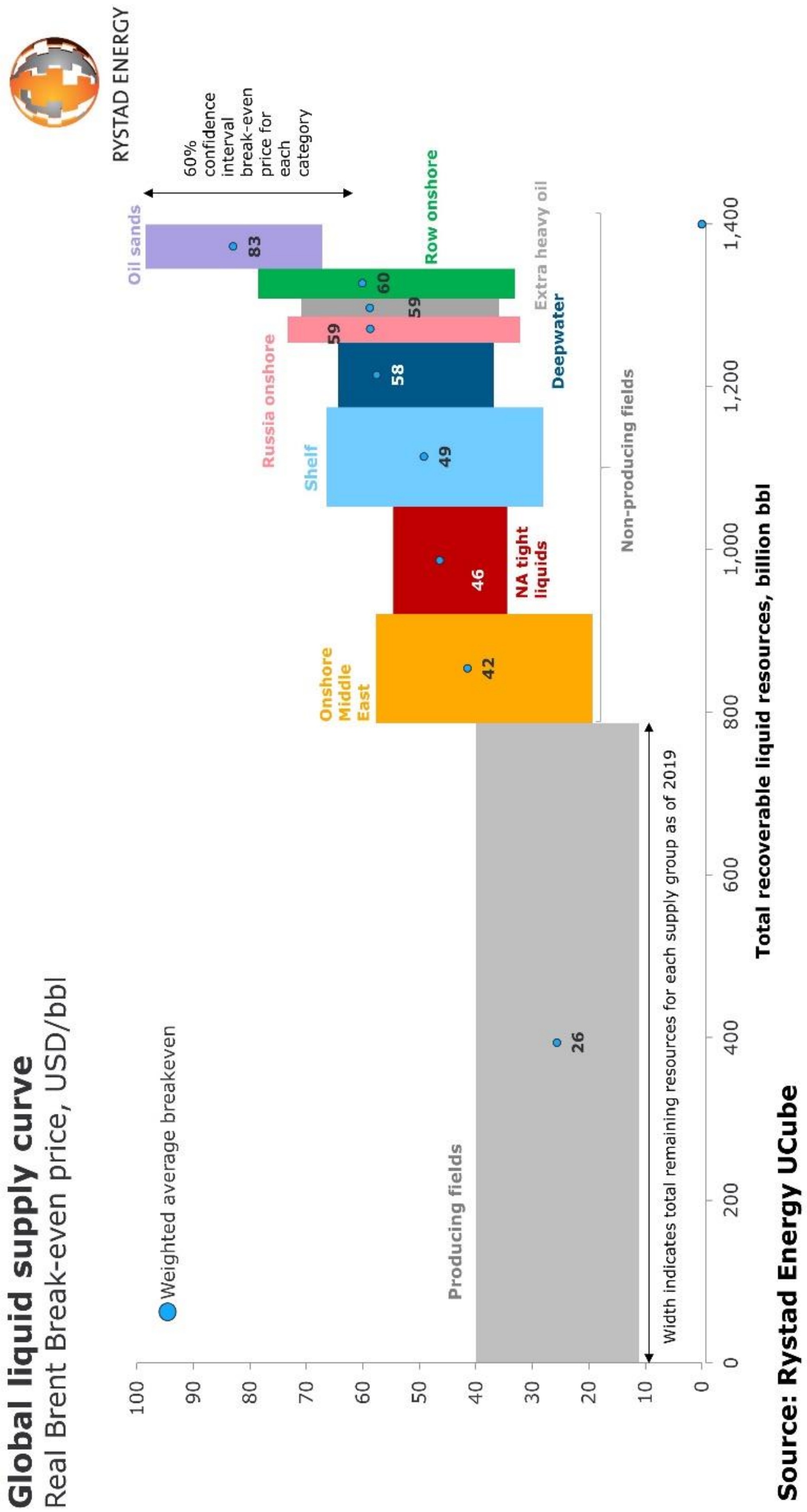


Figure 180. Global liquid supply curve, the break even production price for different oil producing regions (Source: Rystad Energy UCube Research & Analysis 2019)

10 OIL INDUSTRY INVESTMENT

To maintain capital investment at the required rate, it is clear that government will be required to demonstrate leadership. Approximately 70% of the $2 trillion required each year in energy supply investment either comes from state-directed entities or receives a full or partial revenue guarantee (Figure 181).

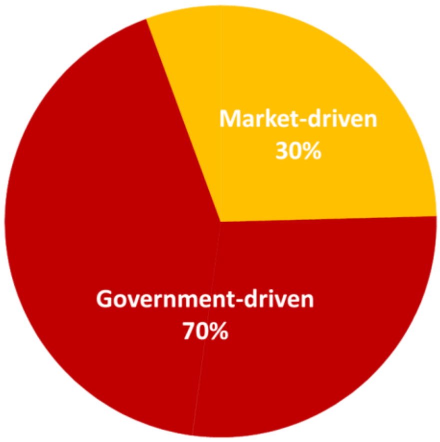


Figure 181. Total investment in energy supply
(Source: World Energy Outlook 2018)
(Copyright License: https://www.iea.org/media/copyright/Termsandconditions_2019update_FINAL.docx.pdf)

"Over 70% of global energy investments will be government-driven and as such the message is clear – the world's energy destiny lies with decisions and policies made by governments."
- Dr Fatih Birol, Executive Director, IEA WEO 2018

To date, oil industry analysts have used a traditional demand constrained prediction model, where the only limits to oil supply are available CAPEX capital to start new projects (Figure 182).

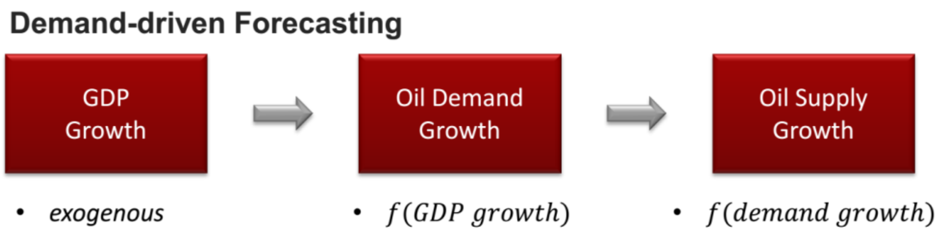


Figure 182. The traditional fossil fuel supply and demand forecasting model (demand constrained)
(Source: Kopits 2014 b)

Virtually all forecasters (investment banks, oil companies, and industry analysts, the US and other nation state governments) use demand-constrained models like in Figure 182 (Kopits 2014 a & b). Supply growth is a function of non-OPEC supply and OPEC supply. One of the purposes of OPEC is to stabilize prices with increased production or production cuts. Figure 183 shows the difficulties demand constraint models have had over the last 10-15 years.

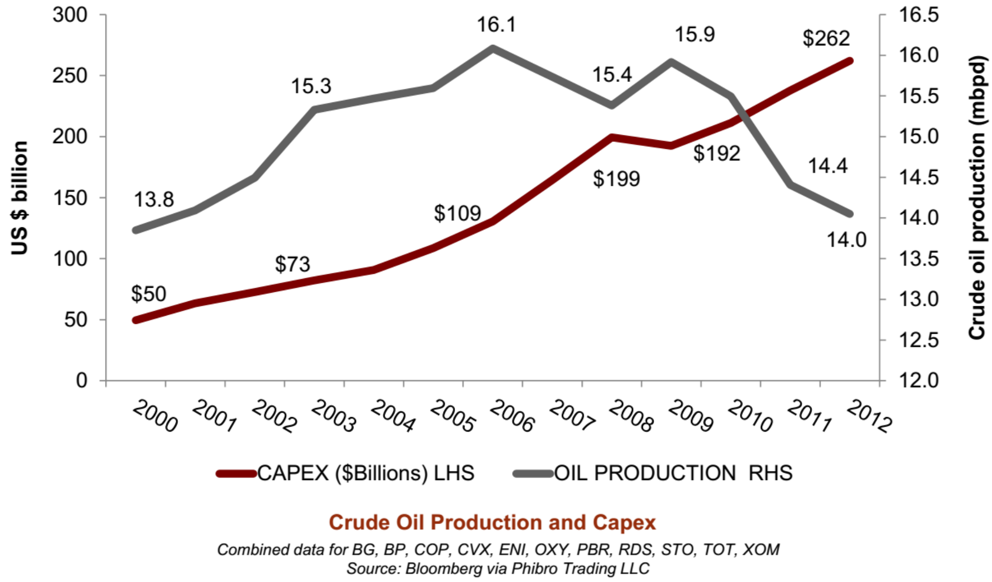


Figure 183. International Oil Companies (IOC) crude oil upstream Capital Investment CAPEX and oil production (Source: Douglas Westwood Analyst – Stephen Kopits)

Figure 183 shows a very important temporal marker. CAPEX investment in constructing new projects steadily increased from 2000 to 2014. Between 2000 and 2012, $USD 212 billion was invested, yet only 1.4% increase in oil production was returned (this includes US tight oil plays). CAPEX productivity has fallen by a factor of five since 2000, with an observed decline trend now approaching 5% per year.

Costs in CAPEX and OPEX for the oil industry are now rising quickly in an unprecedented fashion. In the year 2000, there was a change in CAGR (compound annual growth rate) for oil production costs (upstream + downstream) (Figure 184).

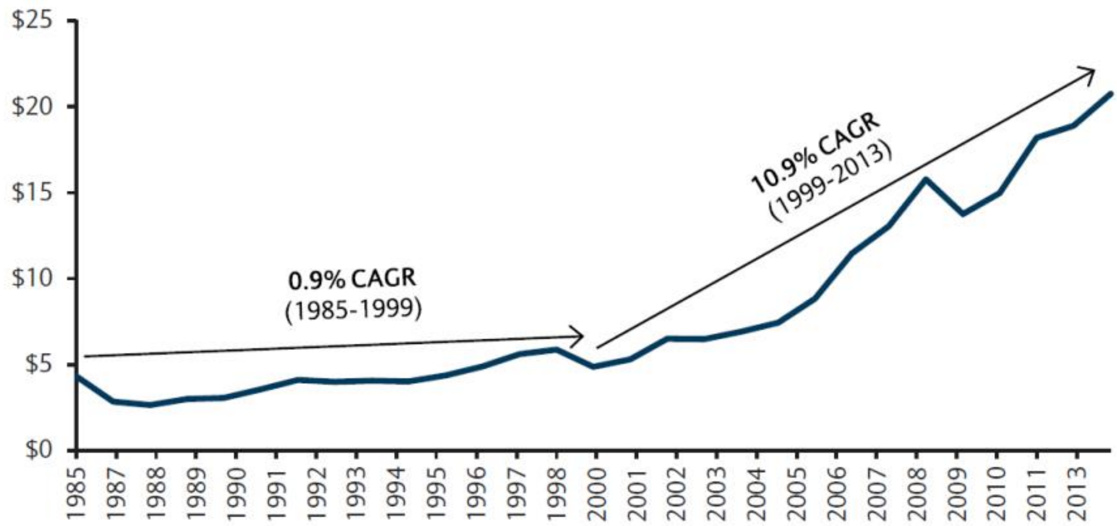


Figure 184. Oil exploration and production (E&P) CAPEX per barrel (Source: IEA, Barclays Research and Kopits 2014b)

This change suggests an evolution from a demand constrained system to a supply constrained system. Profits have stagnated because production costs have risen (and still do so) faster than revenues returned. Exploration and production CAPEX has been rising by a consistent 11% per year since 2000.

As a direct consequence, a number of projects have consequently been deferred, cancelled or returned for re-evaluation. This implies that the business model supporting the oil industry is about to evolve from a demand constrained profile (Figure 182) to a supply constrained profile (Figure 185) (Kopits 2014 a & b).

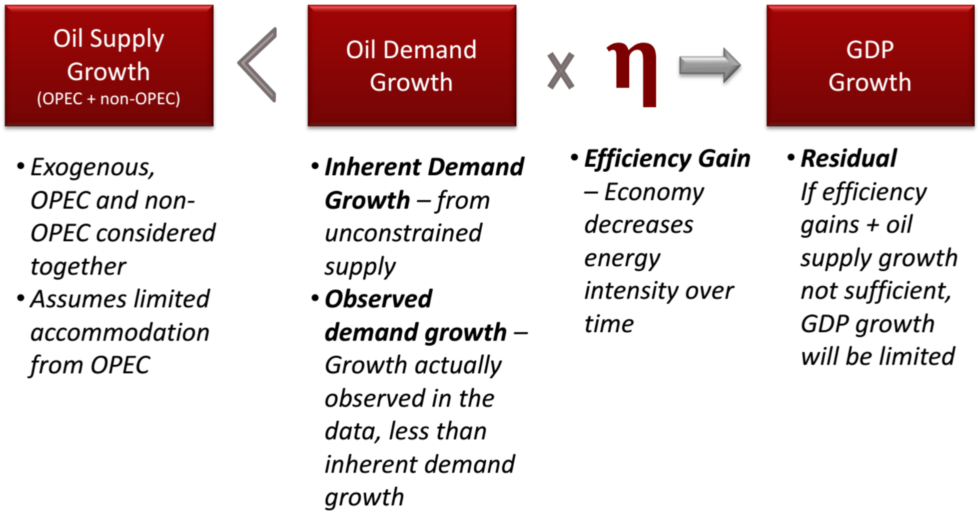


Figure 185. The unconventional fossil fuel supply and demand forecasting model (supply constrained) (Source: Kopits 2014 b)

So a supply constrained global system for the oil is not constrained by the volume of oil deposits in the ground, but *by the number of economically viable projects available to be developed at a low enough production cost*. The supply constrained forecasting model applies a “binding constraint” paradigm of economic growth. When oil supply growth is insufficient, reducing GDP growth. This has yet to be accepted by the oil industry, as Figure 184 shows, the oil industry may have been operating like this since the year 2000.

Another school of thought for the data shown in Figure 184, is that the true breakout point was actually 2004 (Årsnes 2020). The explanation for the increase in the investment cost was due to a "payback" period where the supply industry to the oil and gas industry broke out from the old pricing model of keeping production costs down as much as possible and adding a restrained margin, and started to price their products based on a mark-to-market planning.

This effectively linked the pricing of the supply industry products and services, to the oil price curve. As the oil price increased, the supply industry were able to increase their support prices accordingly, and the oil and gas operators continued to buy because they got their gain back from the increase in the oil price, thus the business was still viable (Årsnes 2020).

The implications of this is that the logistical support and supply companies, not the oil and gas operator companies, are the forces of change that are driving up the oil price.

What is clear though that as time has gone on, exploration and extraction has had to have happened in increasingly more difficult to access sites. Oil deposits have been at an increasingly deep depth, often under deep water in the ocean. Exploration holes are more expensive in this circumstance. Multiple holes are often drilled, where most do not produce oil, before a producing well is established (cost of exploration increases). Once the deposits have been found, the cost of extraction is often higher (cost of off shore platform, etc.). Once the oil is stored on the surface, the cost of refining is often more expensive as the quality of the oil is 'heavier' and more 'sour'. All of this has been driving the costs of production up and is highly unlikely to decrease.

11 ENERGY RETURNED ON ENERGY INVESTED (EROEI RATIO) FOR OIL

Oil when it was first discovered was the most concentrated source of energy the world had ever seen. it did not require much in the way of processing. It could be stored easily and transported easily. It is now understood is that as time has progressed, the quality of energy has deteriorated in in practical terms. The ERoEI ratio for energy sources in general but in particular for oil have all sharply reduced since their first discovery (Hall 2014).

The steps in producing the crude oil have become more expensive. This includes having to construct deep water wells, extract bitumen from oil sands, and then upgrade to crude oil, or extensive drilling required in tight oil fields. The quality of oil being refined has also been declining. Most (not all) of the light sweet crude is now been extracted and used. Now most refineries have to be upgraded to refine heavy sour crude with higher sulfur content. The net energetic value of oil produced in 2019 is much less than what was produced in the early 1900's (graphically described in Figure 186).

What is challenging to consider, is to phase out petroleum products (and fossil fuels in general), the entire global industrial ecosystem will need to be reengineered, retooled and fundamentally rebuilt. This will be perhaps the greatest industrial challenge the world has ever faced historically. To do this, the energy resources available are much poorer in quality and quantity than when the current ecosystem was built in the golden age of industrialization (1900 to 1960).

Resource depletion can be modelled with Hubbert Curve analysis to predict peak production. This does not cater for some aspects of demand, nor economic viability of price. It also does not allow for the impact of credit money creation (printing of money) to make unviable projects viable. As finite non-renewable natural resources deplete, cost of ERoEI ratio declines and cost of extraction increases. As cost of extraction increases, the sale price of the commodity also increases. There comes a point where the real economy cannot function smoothly as the fundamental raw materials that allow it to function are too expensive. This leads to a price crash. In the last few years, there were low commodity prices in conjunction with persistent stagnation of the real economy. This has been punctuated by severe economic downturns as the fiat economy has been printing money to continue to grow at its needed 2% per annum (to service existing debts) in this business environment. There is a serious risk that a significant drop off in oil production as the market sustainable oil price drop too low to make production viable.

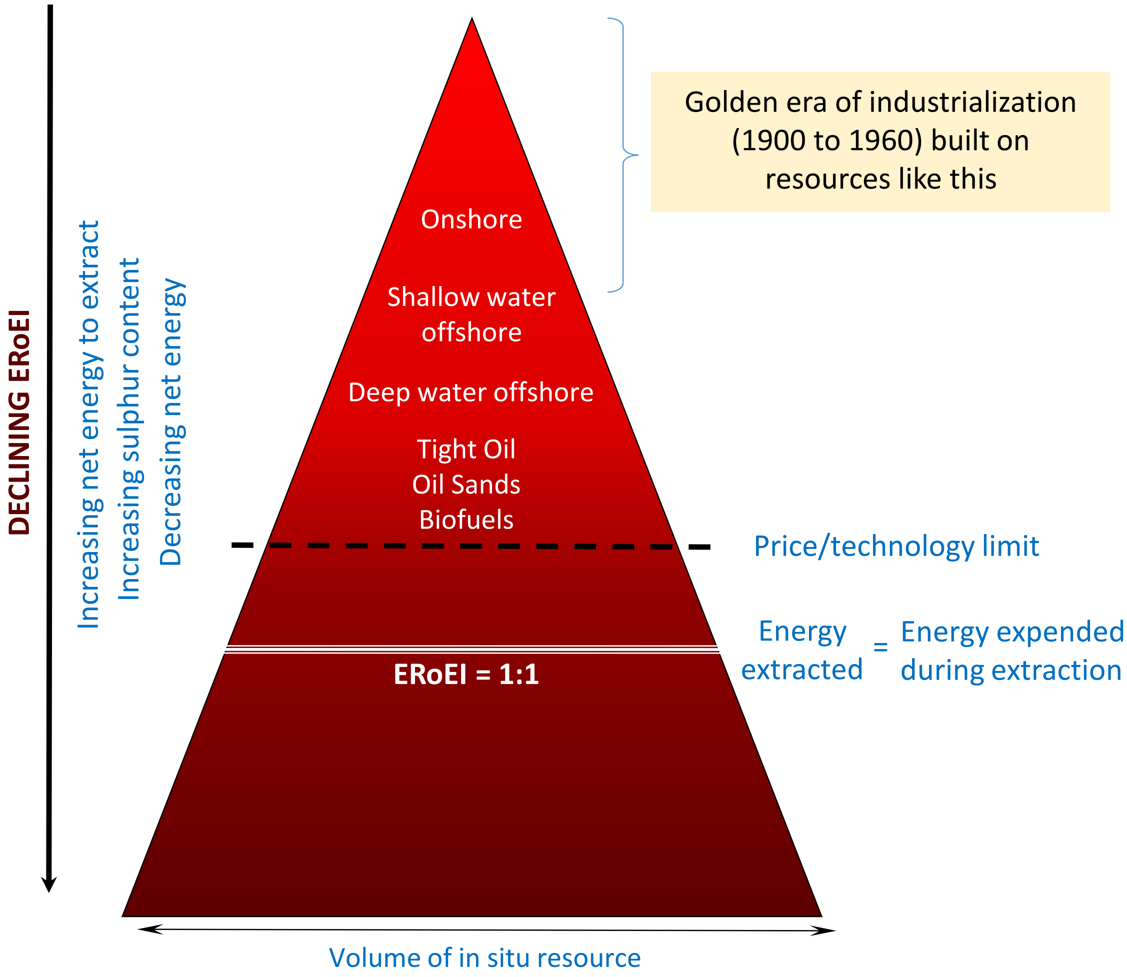


Figure 186. The pyramid of oil and gas resource volume versus resource quality

In addition to this, the effort and complexity in extracting useful energy out of each of these resources has been degrading over time. The golden era of the last century when much of our industrialization technology was developed and constructed, energy resources had a much higher return. A method of analysis that describes this deterioration is the Energy Returned on Energy Invested (ERoEI). The ratio of energy extracted to the energy expended in the process is often referred to as the Energy Return on Energy Investment (ERoEI or EROI). Should the ERoEI drops to one, or equivalently the Net energy gain falls to zero, the oil production is no longer a net energy source. The basic ERoEI ratio is defined in Equation 3.

$$\text{ERoEI} = \frac{\textbf{\textit{E}}\text{nergy }\textbf{\textit{R}}\text{eturned to do useful physical work from resource}}{\textbf{\textit{E}}\text{nergy }\textbf{\textit{I}}\text{nvested through consumption of energy to gather resource}} \qquad \text{(Equation 3)}$$

There are a number of excellent references that examine ERoEI analysis more completely than shown in this report (Mearns 2016, Hall *et al*. 2012, Hall *et al*. 2014, Hu *et al*. 2011, Ferroni & Hopkirk 2016, Fizaine & Court 2016, and Murphy et al. 2011). In doing so, an attempt is made to directly compare all energy sources into the same analysis, where the effort expended to operate at different time periods is also compared. This is not to be confused with the Economic Cost of Energy (Equation 4) (Hall and Klitgaard, 2012). Much of the modern economic development has been assumed that Equation 4 matches reality.

$$\text{Economic Cost of Energy} = \frac{\textit{Dollars to buy energy}}{\textit{GDP}} \qquad \text{(Equation 4)}$$

Actually conducting these studies is not straight forward. It is not clear what should and should not be included. The straight energy consumption from the relevant resource to power equipment in extraction is just the beginning. The energy consumed in extracting the raw materials to make the equipment also needs to be considered. As does refining and transportation from source to point of application, in all forms. Where matters get unclear is how to include human labor, efficiency of extraction at different geographies and climates, the development and application of new technologies, maintenance and replacement cycles, depreciation and deterioration of assets and how to include all of this in the same analysis where the outcome makes logical sense. It is for this reason that many ERoEI studies differ in their conclusions.

There is much disagreement on how to approach this topic. There are many methodological discrepancies related with the functional units used in analysis. For example joules of heat energy versus joules of grid electricity. For a difference in boundaries used where the analysis starts and stops. For example, the well head versus the end use or energy technology versus energy system. Boundaries used in the literature for ERoEI analysis can be summarized as:

Standard ERoEI calculation is applied to fuel at the point where it leaves the extraction or production facility (well head for oil & gas, or Run of Mine for coal, farm gate for biofuels). Standard ERoEI includes the on-site and offsite (energy needed to make the products used on site) energy requirements to get energy. For example to build, operate and maintain a power plant.

Point of use ERoEI includes the energy costs to get and deliver the fuel to the point of use for society. For example refinement and transportation.

Extended ERoEI includes the energy required to get, deliver and use a unit of energy. For example the energy required to produce the machinery and devices used to build, operate and maintain a power plant or a transport facility as well as the energy required for exploration, investment, communication, labor, etc. in the energy system.

Calculating these terms can get complex and impractical. If they are done appropriately though, they relate as follows:

$$\text{Standard ERoEI} > \text{Point of use ERoEI} > \text{Extended ERoEI} \qquad \text{(Equation 5)}$$

To produce a useful results, dynamic ERoEI analysis should be used where possible, where the net energy sued by society is examined, accounting for operating consumption of a given energy system, where Equation 6 is applied to each box in Figure 187, then summed together.

$$Net\ Energy = energy\ returned \times \left(1 - \frac{1}{ERoEI}\right) \qquad \text{(Equation 6)}$$

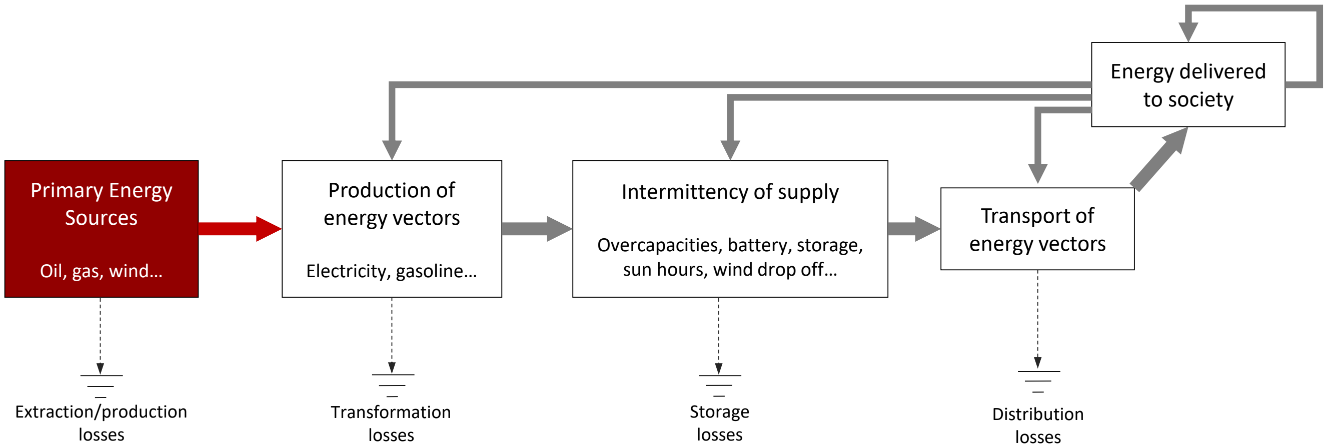


Figure 187. An approach for the analysis of energetic metabolism of a society (Source. Developed from Capellán-Pérez *et al* 2019)

A graphical method to describe the relevance of ERoEI has been developed by a number of analysts on the internet blog The Oil Drum (http://www.theoildrum.com/) (Mearns 2016) called the Net Energy Cliff (Figure 188). The dark grey section is the net energy available for society to use. The pale grey section is proportion of energy consumed in collecting that energy to make it useable. Declining ERoEI will exacerbate the problem of peak fossil fuels.

There are two ERoEI thresholds below which the modern western society will struggle to function at (Hall et al 2014):

- ERoEI 11:1 The minimum to maintain complex technology and information based structures like the internet, credit banking finance transfer system, just in time supply grid, integrated electronics manufacture, regional continuous grid supplied smooth sinusoidal wave quality electrical power supply, tertiary level hospitals, etc.

- ERoEI 7:1 The minimum to maintain the bare necessities of public utility services like potable drinking water supply, sewerage sanitation, localized intermittent supply poor quality rough wave electrical power supply, intermittent goods supply grid with 6 month lag times, etc.

Capellán-Pérez et al 2019 calculates that the thresholds are lower again, but this may be appropriate as society transitions out of fossil fuels.

Current Western society is comparatively fragile compared to historical societies. Once current society falls below one of these thresholds for a relatively short time (estimated 3 - 6 months), and/or does not receive aid from an external source, transformation and evolution of that society will be desired/required/forced (Smil 2008).

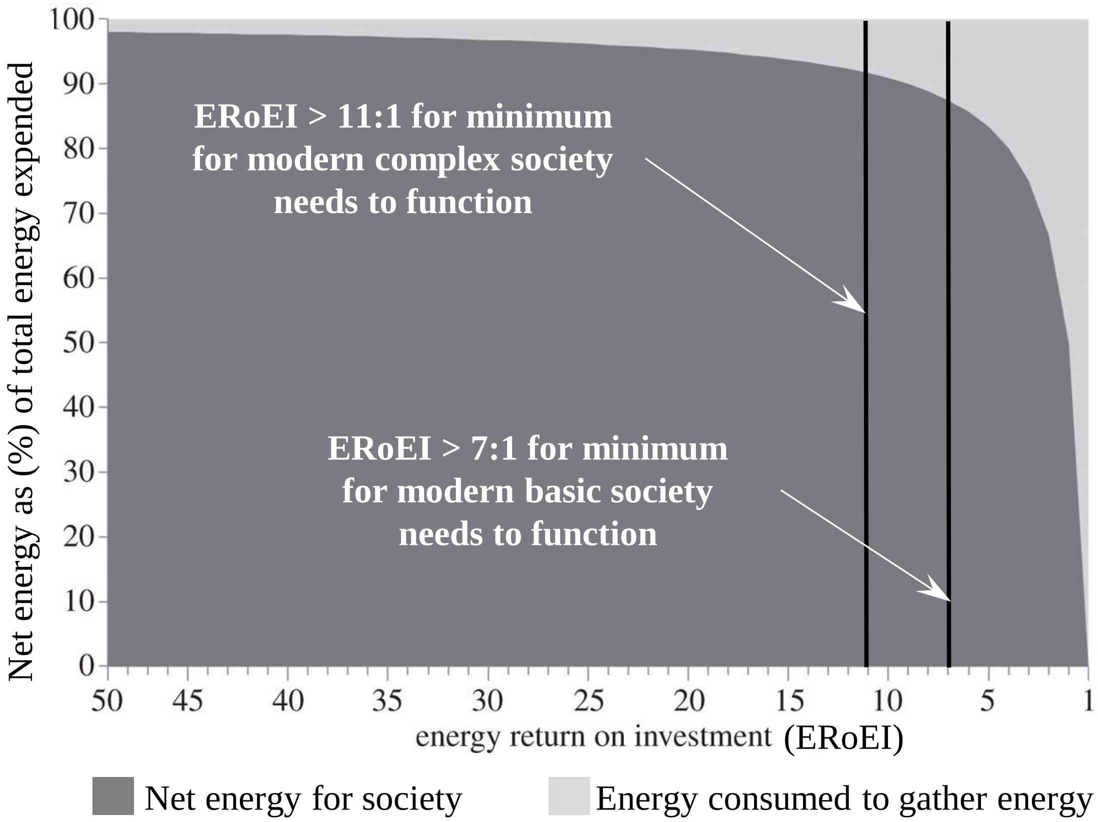


Figure 188. The Net Energy Cliff

Conventional oil and gas are considered together as they are often extracted together and processed in the same refinery. There is great variation on the ERoEI of different fields and operations. Does the study include:

- Is the operation on land or offshore?
- If it's offshore, in how deep water out in the ocean?
- How deep is the drill depth?
- What is the quality of the oil? (For example sulphur content)
- What steps in refining are required to make a saleable product?

When oil extraction first started and 'oil gushers' were observed, ERoEI for oil was an extraordinary 500:1. In the 1900-1930 era, ERoEI for oil was still 100:1. In 1970, ERoEI for oil was approximately 30:1.

What a decline in ERoEI means in context of an oil resource is a decline in quality. The deposit is harder to get to (deeper in drilling depth) or under the ocean floor (more expensive in terms of CAPEX and OPEX). Once the oil has been extracted, the quality of the oil itself is heavier and sourer in sulfur content. This requires more refining steps, which decreases the net value of the oil.

11.1 Conventional Oil & gas ERoEI

An excellent example of what a change in ERoEI over time looks like has been the conventional oil industry. ERoEI is a method to compare the required physical work done between different extraction methods for the same final product (per unit/quantity and quality).

When oil was discovered in the Pennsylvania oil rush from 1859 to the early 1870s, the first oil boom in the United States began. Oil quickly became one of the most valuable commodities in the United States and railroads expanded into Western Pennsylvania to ship petroleum to the rest of the country. By the mid-1870s, the oil industry was well established, and the "rush" to drill wells and control production was over. Pennsylvania oil production peaked in 1891, and was later surpassed by western states such as Texas and California.

In this early period of oil exploration and extraction, oil was comparatively easy to gain energy from. Crude oil would often bubble to the surface in small springs, which still occur in small examples today.

Most of the oil found in the 1860 to 1920 time period would today be classified light sweet crude, containing small amounts of hydrogen sulfide and carbon dioxide (less than 0.42%). This kind of oil requires very little (and in some case none at all) processing steps before use as a saleable commodity (Burrough 2010)

Drilling depths were very shallow by current standards. During this time period, a drill depth of 1,300ft (400m) was considered standard (Burrough 2010), with some producing wells as shallow as 200ft (60m). Also, some of these early reserves had extraordinary oil pressure. There are many examples where oil would blowout and fountain high into the air (Figure 189 and 190). There were initially all kinds of logistical problems in managing these gusher blowouts as a single spark could cause an uncontrollable fire.

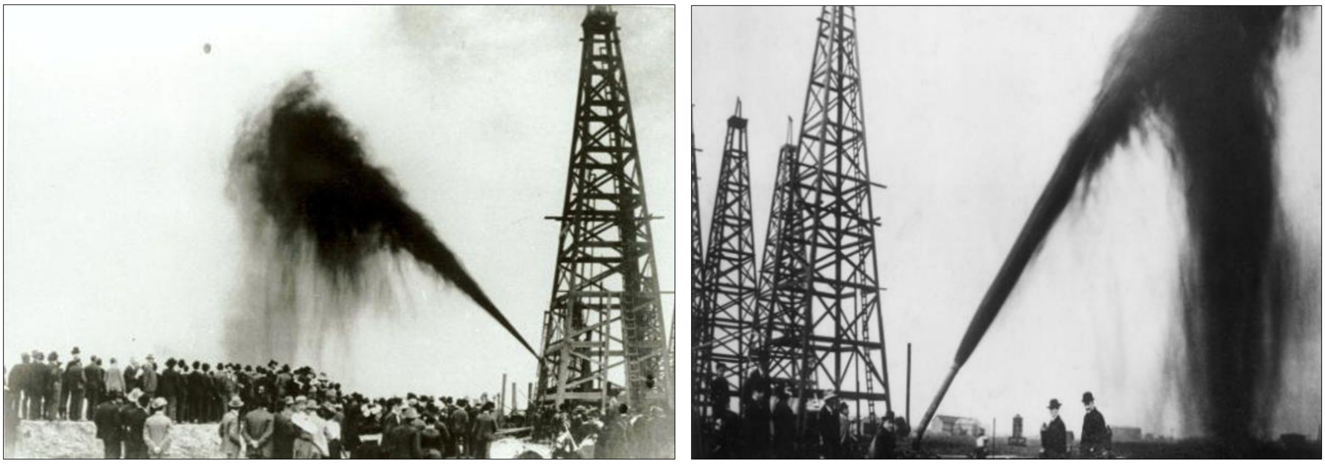


Figure 189. The Lucas gusher at Spindletop 1902 (LHS) and Gusher in Port Arthur, Texas Oil Well in 1901 (RHS)

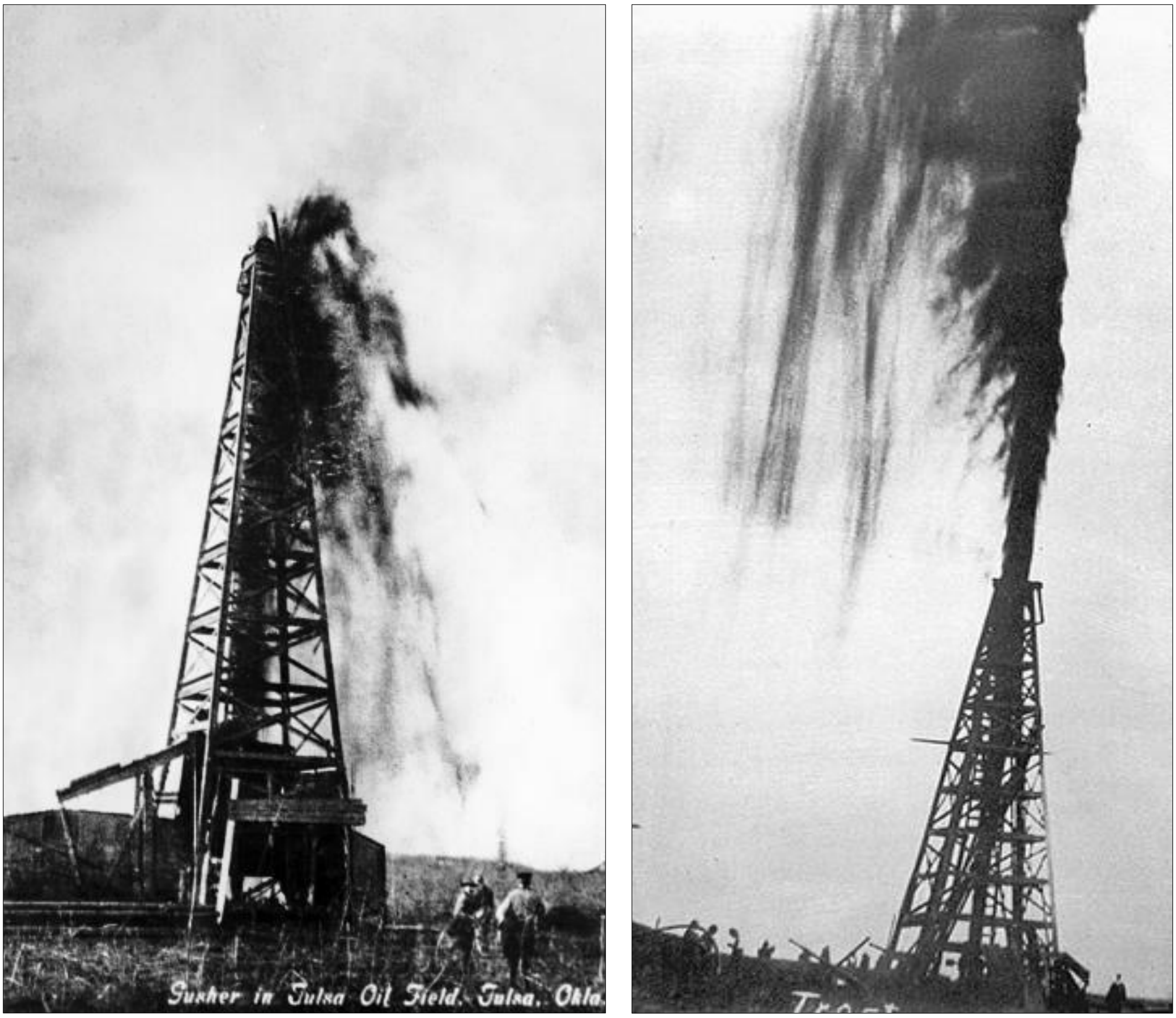


Figure 190. The Pennsylvania oil rush in northwestern Pennsylvania from 1859 to the early 1870s (LHS) The Tulsa gusher at Oaklahoma and (RHS)

Very quickly the oil boom took hold and oil became the foundation master resource for the industrial economy (Burrough 2010). In this era of oil extraction, ERoEI was approximately 100:1 with examples of even higher values. What is interesting to note that investment culture at the time also saw oil in terms of 100:1 for return on investment (with some examples up to 500:1 in 1880). As in, for every dollar you invest, you would get a return of 100 dollars. So in 1900, the difference between Equation 1 and Equation 2 would be very little compared to the same comparison in 2019. Coal and steam power was made obsolete by the internal combustion engine. Extensive infrastructure was constructed to exploit vast oil fields in the United States as quickly as possible (Figure 191 and 192).

Figure 191. A forest of oil derricks sprouts up on the Signal Hill oil field, Long Beach, California, in 1934

Figure 192. A forest of oil derricks sprouts up on the Signal Hill oil field, Long Beach, California, in 1937

In 2017 however, much more effort is required to get the same unit of oil compared to 1900 in Texas. Processing and refining steps are now much more complex. The startup CAPEX capital expenditure costs of commissioning an oil extraction well have been steadily increasing.

In terms of oil extraction infrastructure, offshore drill platforms are now accounting for 1/3 of global oil production. These structure are quite large in size and scale (Figure 193). In addition to this, these large scale industrial structures are required to operate in increasingly deep areas of ocean and drill to increasingly deep drill depths starting from the ocean floor (Figure 122).

Figure 193. Deep water oil & gas drilling platform
(Image by PublicDomainPictures from Pixabay)

Also, as most oil extracted now is classified as sour crude, the stages of oil refining have become more complex. The size and scope of an oil refinery have become much more complex than oil refining in 1900 (Figure 194 and 195). The energy cost of refining is also getting more difficult.

Figure 194. Oil refinery in Indiana USA
(Image by Markus Naujoks from Pixabay)

Figure 195. Oil refinery in Indiana USA
(Image by David Mark from Pixabay)

Figure 196 shows the global energy-return-on-investment (EROI) of oil, from the beginning of reported production in 1860 (Court and Fizaine 2017). The EROI is the ratio of the quantity of energy delivered by a given process to the quantity of energy consumed in this same process. Hence, the EROI is a measure of the accessibility of a resource, meaning that the higher the EROI, the greater the amount of net energy delivered to society in order to support economic growth (Hall et al. 2014).

As can be observed in Figure 196, the EROI of global oil production reached its maximum values in the 1930s–40s, around 50:1, and have declined subsequently. This means that the best industrially useful returns from oil as an energy source is decades in the past. Figure 197 shows the same analysis for all fossil fuel energy (oil, gas and coal). This figure shows that the usefulness of fossil fuels is also in the past, with a collective peak at around 1960.

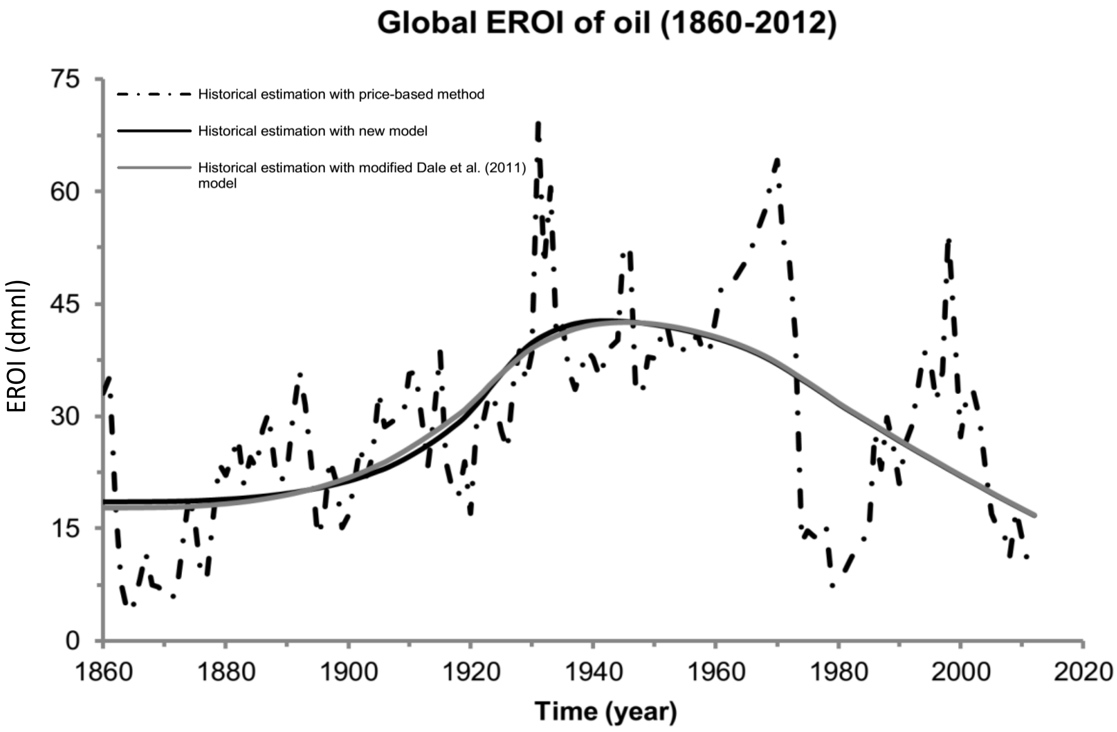


Figure 196. Global EROI of oil 1860 to 2012
(Source: Court and Fizaine 2017)

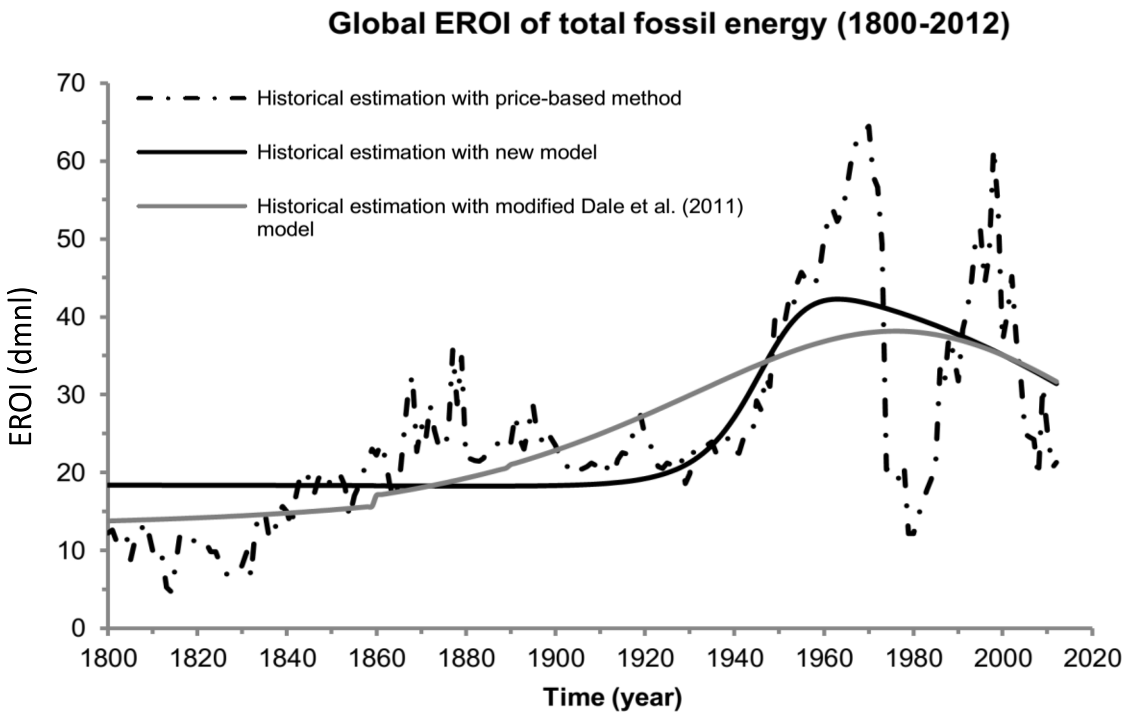


Figure 197. Global EROI of total fossil energy 1800 to 2012
(Source: Court and Fizaine 2017)

Figure 189 to 197 show how more physical work and infrastructure has gone into producing a given unit volume of oil saleable oil in 2013 compared to 1900. More energy has been invested than ever before for the same return. Thus the ERoEI and EROI for oil in has degraded and reduced.

11.2 Unconventional Oil & gas ERoEI

Sources like shale oil and shale gas or Coal Seam Gas (CSG) have ERoEI ratios of around 29:1 depending on circumstance. What this does not account for at is the environmental impact these methods have. Fracking methods have a history of destroying fossilized drinking water reserves that communities depend on for their livelihood. Also, fracking often results in large quantities of saline water deposited on the surface, which can lead to sterilization of arable land previously used for agriculture. To date the fracking industry has not been held accountable for any of these environmental problems, so including them in an ERoEI is difficult. If they were included, it is possible that the fracking of shale oil or shale gas would result in an ERoEI less than 1.

11.3 ERoEI Comparison

Table 17 shows a summary of the ERoEI calculations from the literature (not exhaustive) for fossil fuels. These have been quoted separately from renewable energy's sources. The products of these energy systems is a physical fuel which is then burnt to convert it to energy. Note the range of ERoEI by country. Not all fossil fuel sources are the same in effective source of energy.

Table 17. Energy Returned on Energy Invested for fossil fuel sources (References taken from several sources, as quoted)

Energy Source	Year	Country	ERoEI	Reference
Conventional Oil & Gas production	1999	Global	35:1	Gagnon 2009
Conventional Oil & Gas production	2006	Global	18:1	Gagnon 2009
Conventional Oil & Gas (Domestic)	1970	United States	30:1	Cleveland et al 1984, Hall et al 1986
Discoveries	1970	United States	8:1	Cleveland et al 1984, Hall et al 1986
Production	1970	United States	20:1	Cleveland et al 1984, Hall et al 1986
Conventional Oil & Gas (Domestic)	2007	United States	11:1	Guilford et al 2011
Conventional Oil & Gas (Imported)	2007	United States	12:1	Guilford et al 2011
Conventional Oil & Gas production	1970	Canada	65:1	Freise 2011
Oil & Gas production	2010	Canada	15:1	Freise 2011
Conventional Oil & Gas production	2008	Norway	40:1	Grandell 2011
Conventional Oil production	2008	Norway	21:1	Grandell 2011
Conventional Oil & Gas production	2009	Mexico	45:1	Ramirez 2013
Conventional Oil & Gas production	2010	China	10:1	Hu et al 2011
Hydraulic Fracking oil	2015	United States	29:1	Brandt et al 2015
Oil tar sands	2010	Canada	11:1	Poisson & Hall 2013
Hydraulic Fracking Natural Gas	2005	United States	67:1	Sell et al 2011
Natural Gas	1993	Canada	38:1	Freise 2011
Natural Gas	2000	Canada	26:1	Freise 2011
Natural Gas	2009	Canada	20:1	Freise 2011
Coal (Run of Mine)	1950	United States	80:1	Cleveland et al 1984
Coal (Run of Mine)	2000	United States	80:1	Hall et al 2011
Coal (Run of Mine)	2007	United States	60:1	Hall et al 2014 and Balogh et al 2012
Coal (Run of Mine)	1995	China	35:1	Hu et al 2013
Coal (Run of Mine)	2010	China	27:1	Hu et al 2013

Table 18 shows a summary of the ERoEI calculations for the non-fossil fuel energy systems. These systems are used to generate electricity. Table 19 shows the calorific density energy content of the fossil fuel products and the relative efficiency of energy conversion in the Internal Combustion Engine (ICE) technologies. In comparison, Table 20 shows the calorific density energy content of the non-fossil fuel systems and their relative efficiencies in electrical power generation.

Table 18. Energy Returned on Energy Invested for non-fossil fuel sources

Energy Source	ERoEI	Reference
Nuclear	15:1	Hall et al 2011
Nuclear (incuding U mining & enrichment)	5:1	Lenzen 2008
Hydroelectricity	50:1	Capellán-Pérez et al 2019
Geothermal	7:1	Capellán-Pérez et al 2017
Oceanic wave	3.25:1	Capellán-Pérez et al 2017
Wind Turbine	18:1	Kubiszewski et al 2010
Solar Thermal	2.4:1	de Castro & Capellán-Pérez 2018
Solar PV (conventional EROEI analaysis)	9 to 10:1	Raugei et al 2017
Solar PV (dynamic EROEI analaysis)	7 to 8:1	Raugei et al 2017
Ethanol (sugarcane)	0.8 to 10:1	Yuan et al 2008 and Pimental et al 2005
Corn based ethanol	0.8 to 1.6:1	Pimental et al 2005 and Farrell et al 2006
Biodiesel	1.3 to 1.5:1	Capellán-Pérez et al 2017, and Pimental et al 2005

Table 19. Refined Petroleum Products (Source: OECD Data Statistics Database and Table 16)

Fuel	Energy Content of Fuel	ICE Technology	Energy Efficiency of ICE Technology	Reference
Crude Oil	41.87 MJ/kg	N/A		
Diesel Fuel Oil	45.6 MJ/kg	Diesel Engine	35-42%	Kiameh 2013
Heavy Fuel Oil	41.8 MJ/kg	Diesel Engine	35-42%	Kiameh 2013
Petrol (Gasoline)	46.4 MJ/kg	Petrol Engine	25-50%	Kiameh 2013
Jet Fuel	43.0 MJ/kg	Jet Turbine	36-48%	Griggs et al 2014

Table 20. Efficiency of electric power generation by fuel source (Referenced from Table 16)

Power Generation System	Fuel	Energy Content of Fuel	Efficiency of Power Generation from Fuel	Reference
Coal	Coal	8.06 MJ/kg	32-42%	Kiameh 2013
Gas	Gas	40.6 MJ/m^3	32-38%	Kiameh 2013
Nuclear	Enriched Uranium	2000 MJ/Kg	0.27%	Kiameh 2013
Hydroelectric	Moving water	-	85-90%	Abu-Rub et al 2014
Wind	Moving air	-	35-45%	Abu-Rub et al 2014
Solar PV	Sunlight	-	15-20%	Abu-Rub et al 2014
Solar Thermal	Sunlight	-	20 %	Abu-Rub et al 2014
Geothermal	Geological heat	-	10-35%	Abu-Rub et al 2014
Biowaste to energy	Biowaste	12-35 MJ/kg	13 %	Biswas 2009
Fuel Oil Diesel	Crude Oil	46.6 MJ/kg	38 %	Kiameh 2013

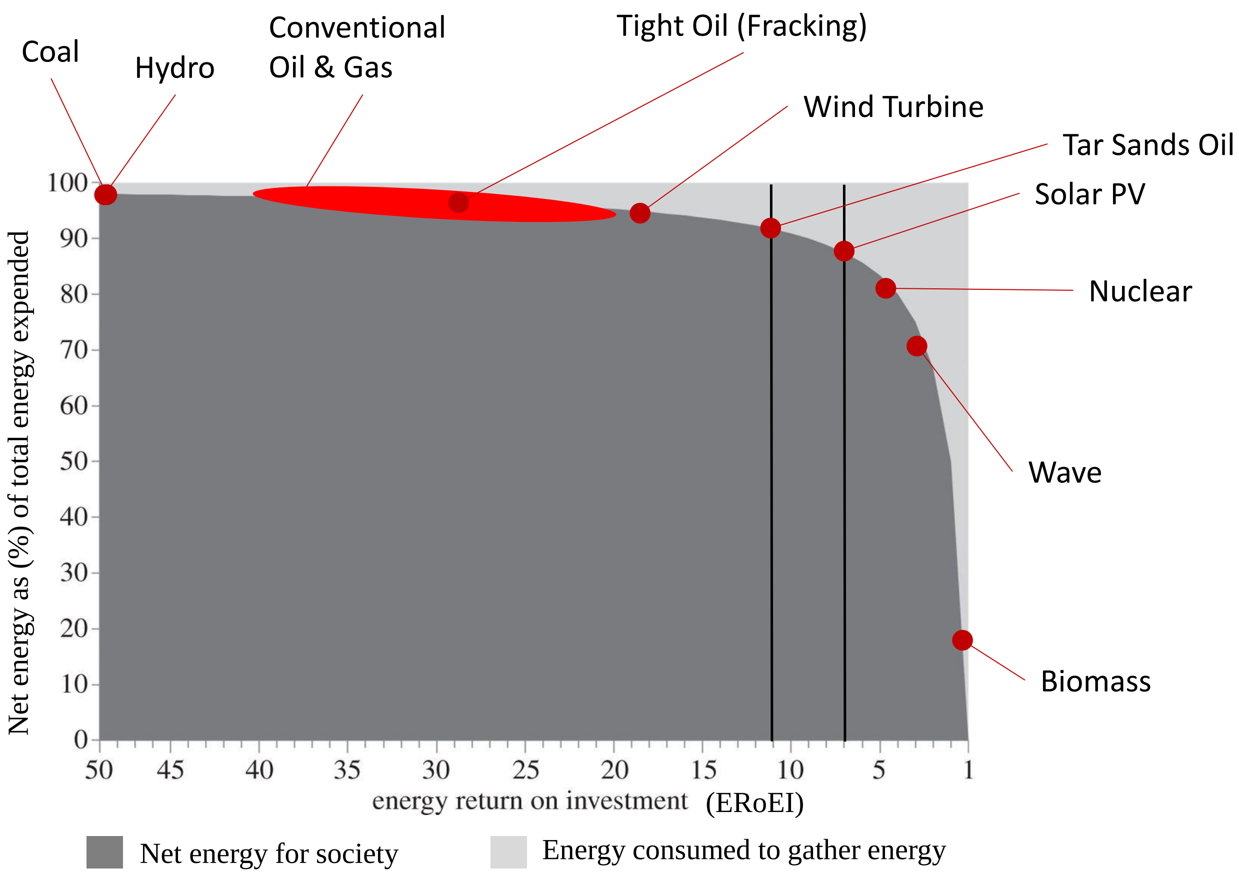


Figure 198. The net energy cliff with published numbers of ERoEI from Tables 17 and 18

To appropriately compare Table 17 and Table 18 together a consistent and comprehensive dynamic ERoEI needs to be applied to the same macro scale industrial ecosystem, where each of these sources supply energy in some form. Each one of these studies have been done to a separate paradigm, using different input assumptions and boundaries and often have inconsistent material units. Most of these studies may have been done with a static or standard ERoEI paradigm using just Equation 3. This means that the results shown in Figure 198 should be treated as rough guide, not a precise calculation. As such comparing sources in this context is not that useful beyond a few very blunt statements:

- The fossil fuels (oil, gas and coal) being extracted now are much lower in ERoEI than what was extracted 80 to 100 years ago.
- The non-fossil fuel systems being examined to replace fossil fuels, are generally lower in ERoEI.
- This trend of decline in ERoEI is likely to continue as most non-fossil fuel systems depend on fossil fuels in some form to function.

12 STATUS OF EXISTING OIL RESERVES

The proved oil reserves as stated at the end of 2018 is shown in Figure 199. To show how this has changed over time, compare the 2018 proven reserves to the 1990 proven reserves (Figure 200). Note the changes between 1990 and 2018.

- Saudi Arabia reduced in global share – from 24.6% to 16.2%
- Venezuela increased in global share – from 5.7% to 16.5%
- Canada increased in global share – from 1.1% to 9.1%

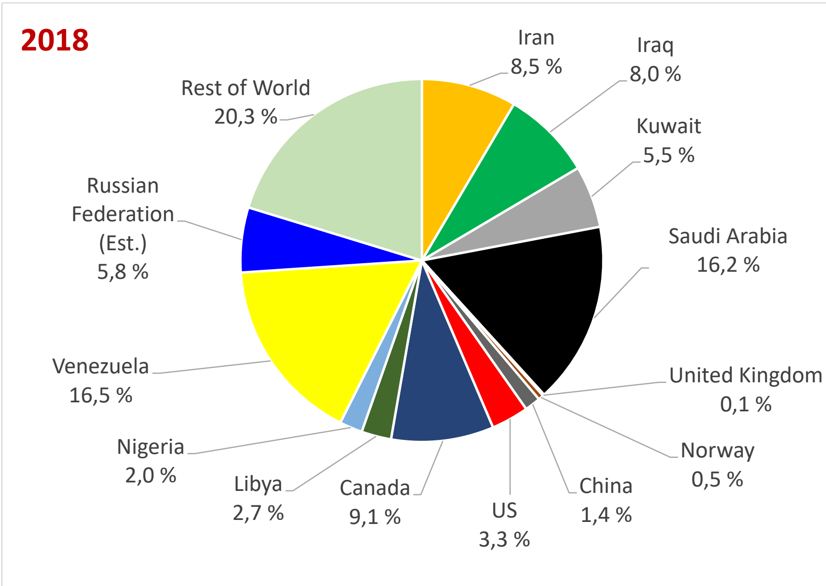


Figure 199. Proved oil reserves in 2018
(Source: BP Statistical World Energy Review 2019)

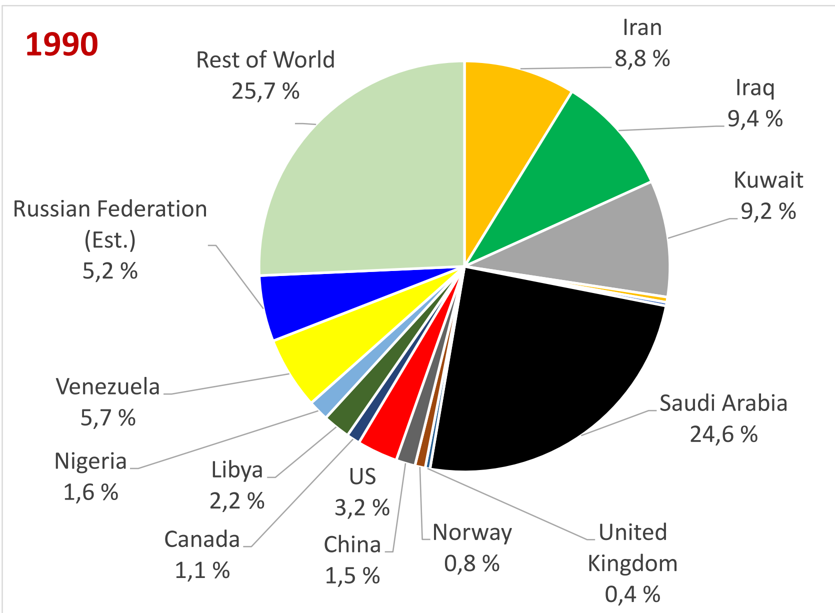


Figure 200. Proved oil reserves in 1990
(Source: BP Statistical World Energy Review 2011)

Table 21 shows the total global proved reserves of oil at the end of 2018 in thousand million barrels.

Table 21. Proved oil reserves (Source: BP Statistical World Energy Review 2019)

	At end 1998 Thousand million barrels	At end 2008 Thousand million barrels	At end 2017 Thousand million barrels	At end 2018 Thousand million barrels	At end 2018 Thousand million tonnes	At end 2018 Share of total	At end 2018 R/P ratio
Canada	49.8	176.3	168.9	**167.8**	**27.1**	9.7%	88.3
Mexico	21.6	11.9	7.7	**7.7**	**1.1**	0.4%	10.2
US	28.6	28.4	61.2	**61.2**	**7.3**	3.5%	11.0
Total North America	100.0	216.6	237.8	**236.7**	**35.4**	13.7%	28.7
Argentina	2.8	2.5	2.0	**2.0**	**0.3**	0.1%	9.3
Brazil	7.4	12.8	12.8	**13.4**	**2.0**	0.8%	13.7
Colombia	2.5	1.4	1.7	**1.8**	**0.3**	0.1%	5.6
Ecuador	4.1	4.3	3.0	**2.8**	**0.4**	0.2%	14.8
Peru	0.9	1.1	1.0	**1.0**	**0.1**	0.1%	17.6
Trinidad & Tobago	0.7	0.8	0.2	**0.2**	**†**	♦	7.6
Venezuela	76.1	172.3	302.8	**303.3**	**48.0**	17.5%	*
Other S. & Cent. America	1.1	0.8	0.5	**0.5**	**0.1**	♦	11.5
Total S. & Cent. America	95.6	196.0	324.0	**325.1**	**51.1**	18.8%	136.2
Denmark	0.9	0.8	0.4	**0.4**	**0.1**	♦	10.1
Italy	0.6	0.5	0.6	**0.6**	**0.1**	♦	16.2
Norway	11.7	7.5	7.9	**8.6**	**1.1**	0.5%	12.8
Romania	1.2	0.5	0.6	**0.6**	**0.1**	♦	22.2
United Kingdom	5.1	3.1	2.5	**2.5**	**0.3**	0.1%	6.3
Other Europe	1.9	1.9	1.6	**1.6**	**0.2**	0.1%	14.1
Total Europe	21.4	14.2	13.7	**14.3**	**1.9**	0.8%	11.1
Azerbaijan	1.2	7.0	7.0	**7.0**	**1.0**	0.4%	24.1
Kazakhstan	5.4	30.0	30.0	**30.0**	**3.9**	1.7%	42.7
Russian Federation	113.1	106.4	106.3	**106.2**	**14.6**	6.1%	25.4
Turkmenistan	0.5	0.6	0.6	**0.6**	**0.1**	♦	7.4
Uzbekistan	0.6	0.6	0.6	**0.6**	**0.1**	♦	25.4
Other CIS	0.3	0.3	0.3	**0.3**	**†**	♦	18.1
Total CIS	121.1	144.8	144.7	**144.7**	**19.6**	8.4%	27.4
Iran	93.7	137.6	155.6	**155.6**	**21.4**	9.0%	90.4
Iraq	112.5	115.0	147.2	**147.2**	**19.9**	8.5%	87.4
Kuwait	96.5	101.5	101.5	**101.5**	**14.0**	5.9%	91.2
Oman	5.4	5.6	5.4	**5.4**	**0.7**	0.3%	15.0
Qatar	13.5	26.8	25.2	**25.2**	**2.6**	1.5%	36.8
Saudi Arabia	261.5	264.1	296.0	**297.7**	**40.9**	17.2%	66.4
Syria	2.3	2.5	2.5	**2.5**	**0.3**	0.1%	284.8
United Arab Emirates	97.8	97.8	97.8	**97.8**	**13.0**	5.7%	68.0
Yemen	1.9	2.7	3.0	**3.0**	**0.4**	0.2%	121.4
Other Middle East	0.2	0.1	0.1	**0.2**	**†**	♦	2.1
Total Middle East	685.2	753.7	834.3	**836.1**	**113.2**	48.3%	72.1
Algeria	11.3	12.2	12.2	**12.2**	**1.5**	0.7%	22.1
Angola	4.0	9.5	8.4	**8.4**	**1.1**	0.5%	15.0
Chad	–	1.5	1.5	**1.5**	**0.2**	0.1%	40.9
Republic of Congo	1.7	1.6	1.6	**1.6**	**0.2**	0.1%	13.2
Egypt	3.8	4.2	3.3	**3.3**	**0.4**	0.2%	13.6
Equatorial Guinea	0.6	1.7	1.1	**1.1**	**0.1**	0.1%	15.8
Gabon	2.6	2.0	2.0	**2.0**	**0.3**	0.1%	28.2
Libya	29.5	44.3	48.4	**48.4**	**6.3**	2.8%	131.3
Nigeria	22.5	37.2	37.5	**37.5**	**5.1**	2.2%	50.0
South Sudan	n/a	n/a	3.5	**3.5**	**0.5**	0.2%	73.4
Sudan	0.3	5.0	1.5	**1.5**	**0.2**	0.1%	41.1
Tunisia	0.3	0.6	0.4	**0.4**	**0.1**	♦	23.2
Other Africa	0.7	0.7	3.9	**3.9**	**0.5**	0.2%	33.7
Total Africa	77.2	120.4	125.3	**125.3**	**16.6**	7.2%	41.9
Australia	4.8	4.2	4.0	**4.0**	**0.4**	0.2%	30.8
Brunei	1.0	1.1	1.1	**1.1**	**0.1**	0.1%	27.0
China	17.4	21.2	25.9	**25.9**	**3.5**	1.5%	18.7
India	5.4	5.8	4.5	**4.5**	**0.6**	0.3%	14.1
Indonesia	5.1	3.7	3.2	**3.2**	**0.4**	0.2%	10.7
Malaysia	3.4	5.5	3.0	**3.0**	**0.4**	0.2%	12.1
Thailand	0.4	0.5	0.3	**0.3**	**†**	♦	1.8
Vietnam	1.9	4.7	4.4	**4.4**	**0.6**	0.3%	43.9
Other Asia Pacific	1.3	1.3	1.2	**1.2**	**0.2**	0.1%	12.9
Total Asia Pacific	40.8	48.0	47.7	**47.6**	**6.3**	2.8%	17.1
Total World	**1141.2**	**1493.8**	**1727.5**	**1729.7**	**244.1**	**100.0%**	**50.0**
of which: OECD	124.5	234.0	254.4	**254.0**	**37.6**	14.7%	26.4
Non-OECD	1016.7	1259.8	1473.1	**1475.8**	**206.6**	85.3%	59.1
OPEC	827.9	1027.9	1240.2	**1242.2**	**174.8**	71.8%	86.5
Non-OPEC	313.3	465.9	487.3	**487.5**	**69.4**	28.2%	24.1
European Union	8.7	5.7	4.9	**4.8**	**0.6**	0.3%	8.6
Canadian oil sands: Total	43.1	170.3	163.4	**162.3**	**26.4**	9.4%	
of which: Under active development	8.4	27.0	22.0	**20.9**	**3.4**	1.2%	
Venezuela: Orinoco Belt	–	94.2	260.9	**261.4**	**41.9**	15.1%	

†Less than 0.05.
♦Less than 0.05%.
n/a not available.
*More than 500 years.

Notes: Total proved reserves of oil – Generally taken to be those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known reservoirs under existing economic and operating conditions. The data series for total proved oil reserves does not necessarily meet the definitions, guidelines and practices used for determining proved reserves at company level, for instance as published by the US Securities and Exchange Commission, nor does it necessarily represent BP's view of proved reserves by country.
Reserves-to-production (R/P) ratio – If the reserves remaining at the end of any year are divided by the production in that year, the result is the length of time that those remaining reserves would last if production were to continue at that rate.
Source of data – The estimates in this table have been compiled using a combination of primary official sources, third-party data from the OPEC Secretariat, World Oil, Oil & Gas Journal and Chinese reserves based on official data and information in the public domain.
Canadian oil sands 'under active development' are an official estimate. Venezuelan Orinoco Belt reserves are based on the OPEC Secretariat and government announcements.
Reserves include gas condensate and natural gas liquids (NGLs) as well as crude oil. Saudi Arabia's oil reserves include NGLs from 2017.
Shares of total and R/P ratios are calculated using thousand million barrels figures.

Table 22 shows the only 6 nations still expanding production (Also Figure 201). The U.S. relies on Tight Oil fracking and Canada relies on oil sands to expand production. This represents 46.3% of reserves and 45.7% of 2018 global production.

Table 22. Oil producing countries still growing capacity
(Source: BP Statistical World Energy Review 2019)

Country	Reserves (billion barrels)	Peak Year	Production in 2010 (kbbls/day)	Production in 2018 (kbbls/day)
United States	61,2	still growing	7 552	15 311
Saudi Arabia	297,7	still growing	9 865	12 287
Canada	167,8	still growing	3 332	5 208
Iraq	147,2	still growing	2 469	4 614
UAE	97,8	still growing	2 937	3 942
Kazakhstan	30,0	still growing	1 676	1 927

Reserves of countries still with growing production capacity	801,7	Production of countries still growing (Including U.S. Conventional Oil)	43 289
Reserves of countries still with growing production capacity	46,3 %	Production of countries still growing (Including U.S. Conventional Oil)	45,7 %

Table 23. Table #. Oil producing countries that have peaked production
(Source: BP Statistical World Energy Review 2019)

Country	Reserves (billion barrels)	Peak Year	Production At Peak (kbbls/day)	Production in 2018 (kbbls/day)
Russian Federation	106,2	1987	11 484	11 438
Iran	155,6	1974	6 060	4 715
China	25,9	2015	4 309	3 798
Kuwait	101,5	1972	3 339	3 049
Brazil	13,4	2017	2 721	2 683
Nigeria	37,5	2005	2 499	2 051
Mexico	7,7	2004	3 824	2 068
Qatar	25,2	2013	1 991	1 879
Venezuela	303,3	1970	3 754	1 514
Libya	48,7	1970	3 357	1 010
United Kingdom	2,5	1999	2 909	1 085
Norway	8,6	2001	3 418	1 844
Rest of World	91,90	2008	16 647	14 295
United States (Conventional Oil)		1972	11 185	8 807

Reserves of countiries past peak production (Excluding U.S. Conventional Oil)	928,00	Production of countries past peak (Excluding U.S. Conventional Oil)	51 429
Reserves of countiries past peak production (Excluding U.S. Conventional Oil)	53,7 %	Production of countries past peak (Excluding U.S. Conventional Oil)	54,3 %
Global Reserves	1729,7	Global 2018 Crude Oil Production	94 718

Table 23 and Figure 202 show the countries that have now peaked crude oil production. This represents 53.7% of global reserves and 54.3% of global production in 2018. This means that more than half of all reserves and production is now declining in capacity. Just so, prognosis to grow the oil sector for the future while human population is actually increasing is grim.

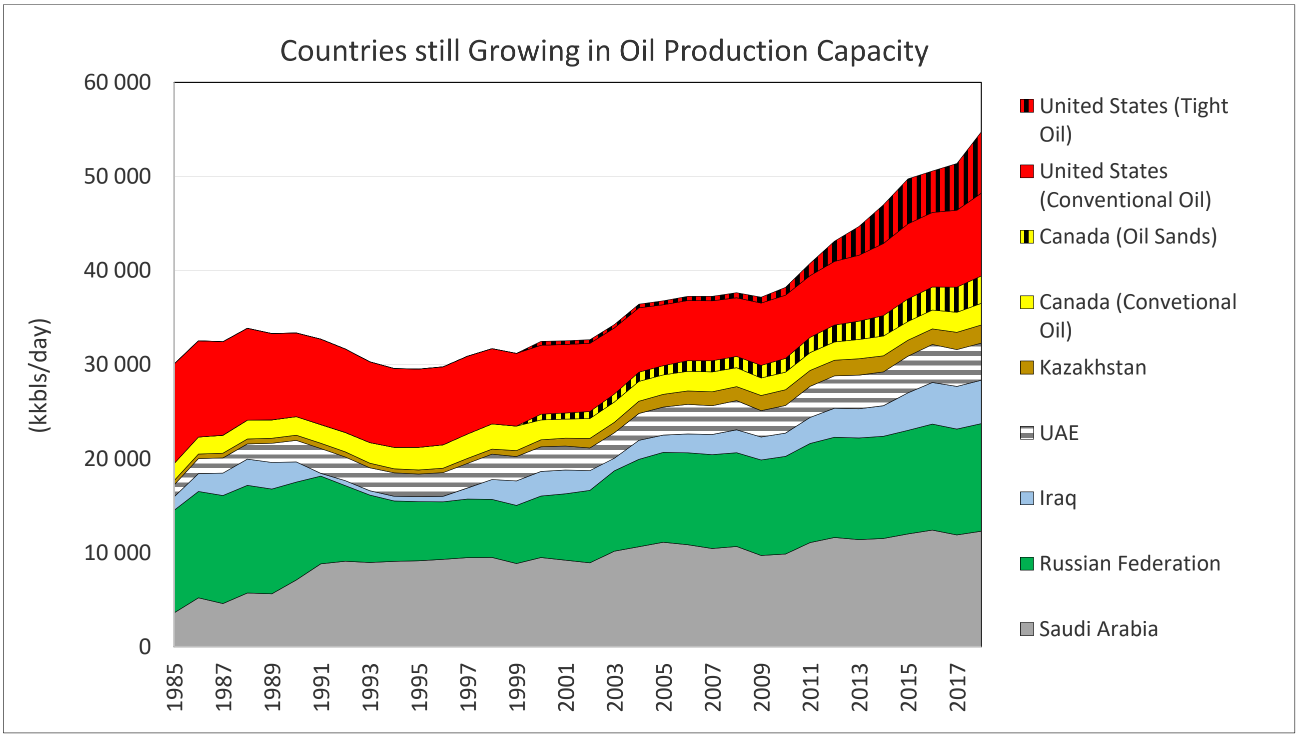


Figure 201. Oil producing countries still growing capacity
(Source: BP Statistical World Energy Review 2019)

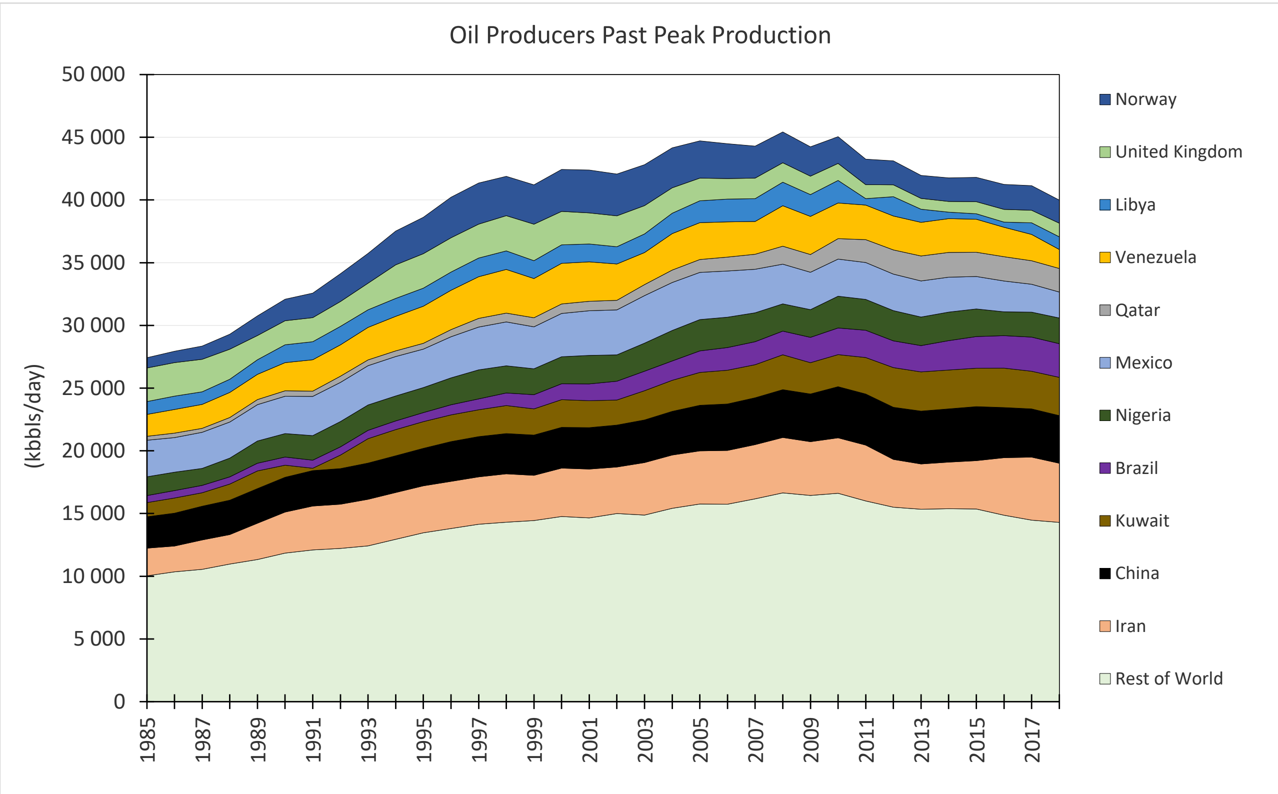


Figure 202. Oil producing countries that have peaked production
(Source: BP Statistical World Energy Review 2019)

Of the 193 countries in the United Nations assembly (all of which consume oil as a critical necessity), only 7 of them have the capacity to grow oil production capacity while all other producing nations are declining. These countries are: Saudi Arabia, Russia, Iraq, UAE, Kazakhstan, Canada and the United States.

However, this statistic is by nation state. If one was to consider each crude oil producing operation, it is estimated that 81% of world liquids production is already in decline (excluding future redevelopments) (Ahmed 2017). The HSBC study (Fustier *et al* 2016) quoted a projected probable range for average decline rate on post-peak production is 5-7%, equivalent to around 3-4.5mb/d of lost production every year from 2016 forward. Small oilfields typically decline twice as fast as large fields.

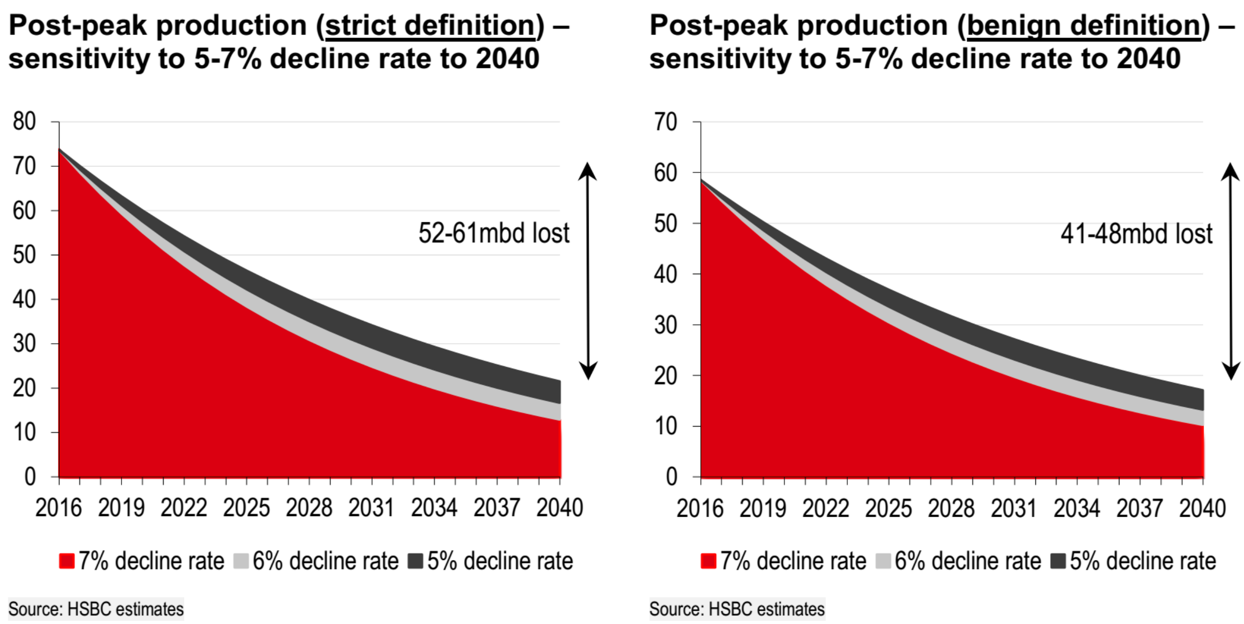


Figure 203. Post peak oil production decline rates
(Source: HSBC Global Research, Fustier et al. 2016)

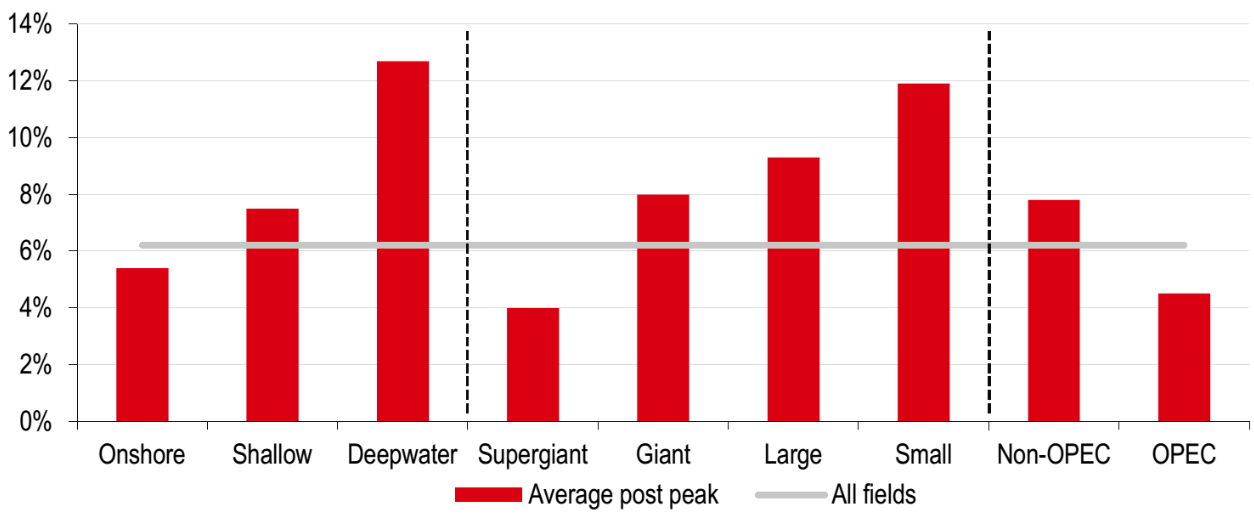


Figure 204. Annual decline rates for various filed types and sizes (Source: Fustier et al 2016, IEA data)

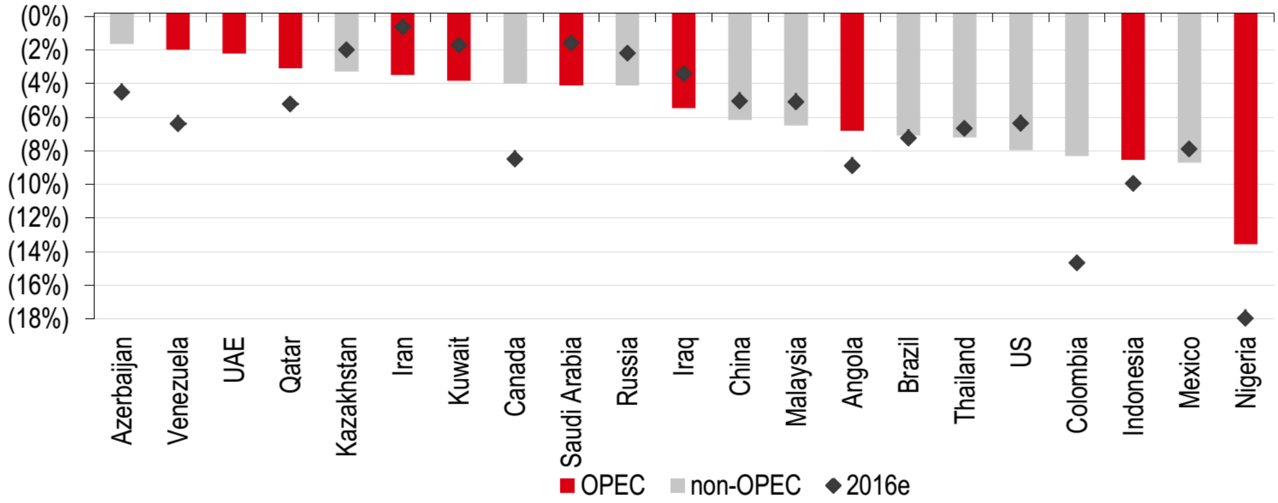


Figure 205. Compound-average underlying decline rate by country, last 20 years. Excludes NGLs and unconventional shale production in the US and Canada.
(Source: Fustier et al 2016, Wood Mackenzie)

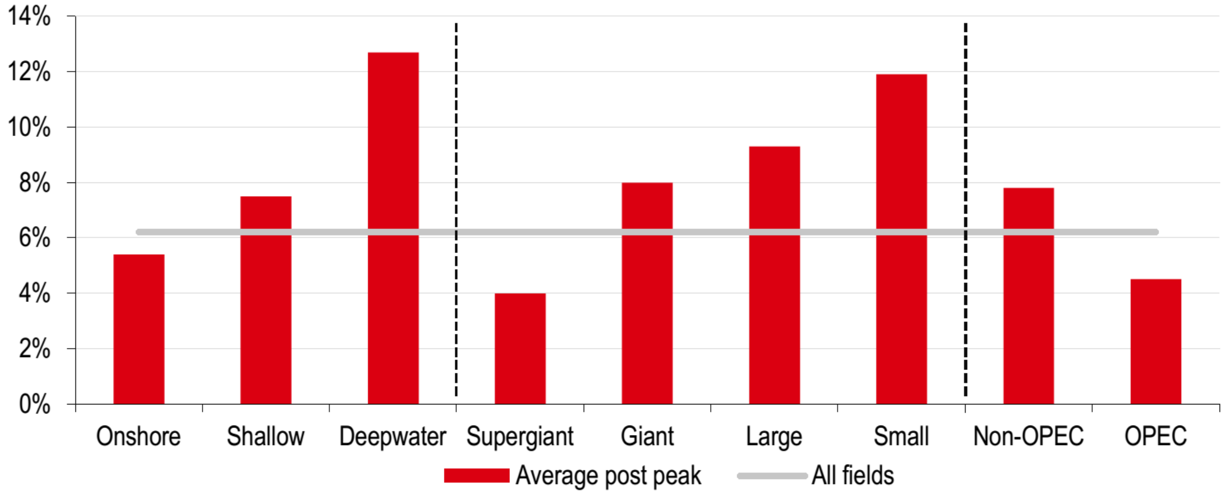


Figure 206. Annual decline rates for various filed types and sizes (Source: Fustier et al 2016, IEA data)

The global oil reserves are concentrated in one region of the planet. The primarily geographical concentration of the oil deposits and transport infrastructures can be described as the "Strategic Ellipse" (shown in Figure 207). Inside the red ellipse in Figure 207, is approximately 74% of the global conventional oil reserves and approximately 70% of the global gas reserves. As oil is so important to our current industrial society, this makes this region the focus of a lot of geopolitical tension of all kinds.

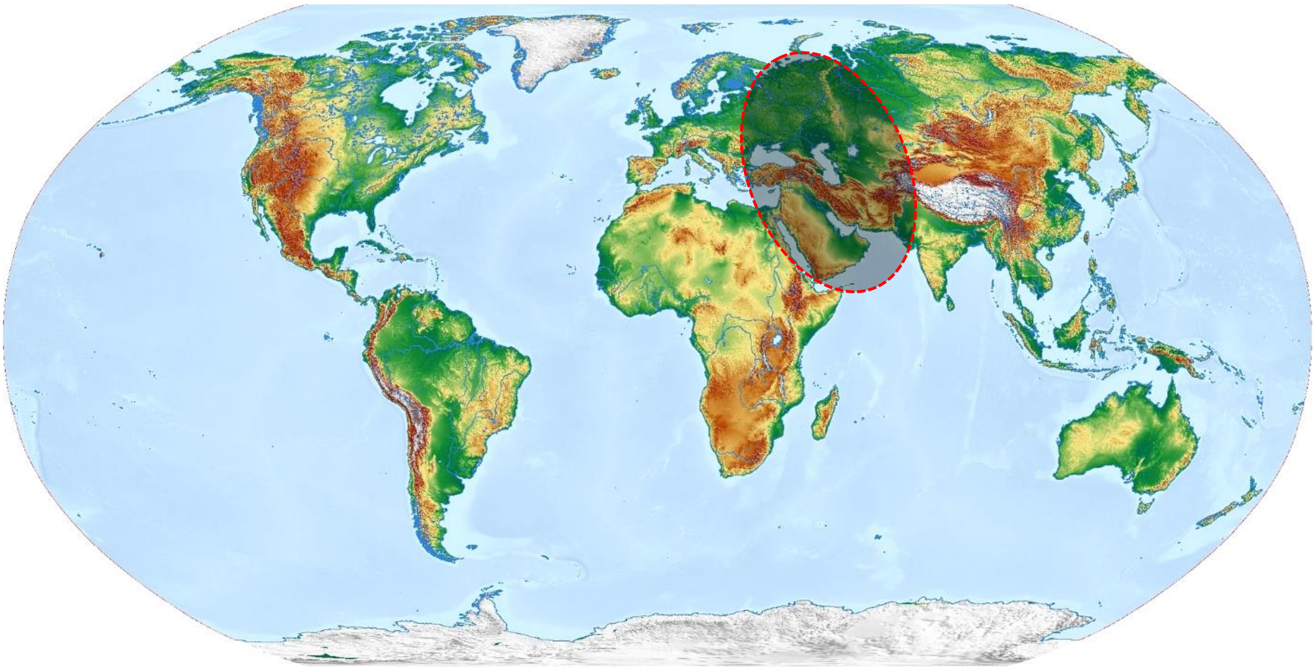


Figure 207 The strategic ellipse (Source: Redrawn from BTC 2010, Federal Institute for Geosciences and Natural Resources BGR, Map Image by Mapswire from Pixabay, https://pixabay.com/)

For some time now Saudi Arabia has dominated the oil market. They were able to supply more high quality oil than any other producer for decades. So much so that when the US dollar was coupled with oil production, by pricing all oil contracts in $USD (forming the Petrodollar), Saudi Arabia became the global dominant oil producer. Since then, Saudi Arabia has aggressively protected its true capacities as a state secret by using its global dominance in the market (Emerson 1985).

For years now, peak oil analysts have believed that when Saudi Arabia peaks in oil production, the rest of the world will also peak in production. In doing so, peak oil has been linked to the Saudi net position. Saudi oil capacity has been tied to the production of their largest producing deposit, the Ghawar field (Simmons 2002), which accounts for about half of the Saudi production.

12.1 The Ghawar elephant field

The largest producing field in the world, Ghawar (in Saudi Arabia), was discovered in 1948 (Figures 208 and 209). Measuring 280 by 30km, it is by far the largest conventional oil field in the world. Cumulative production until April 2010 exceeded 65 billion barrels. In 2002, Ghawar was estimated to produce over 5 million barrels of oil a day (6.25% of global production), as stated by the United States EIA. That's the equivalent of around 250,000 large sperm whales, every day in context of whale oil as it used to be produced (Simmons 2002).

> *"Ghawar is the greatest oil-bearing structure the world has ever known. Its superlative qualities cannot be overstated. It is unlikely that any new oilfield will ever rival the bounteous production Ghawar has delivered to Saudi Arabia and the international petroleum markets"*
>
> - Matthew Simmons, Oil investment banker (Simmons 2005)

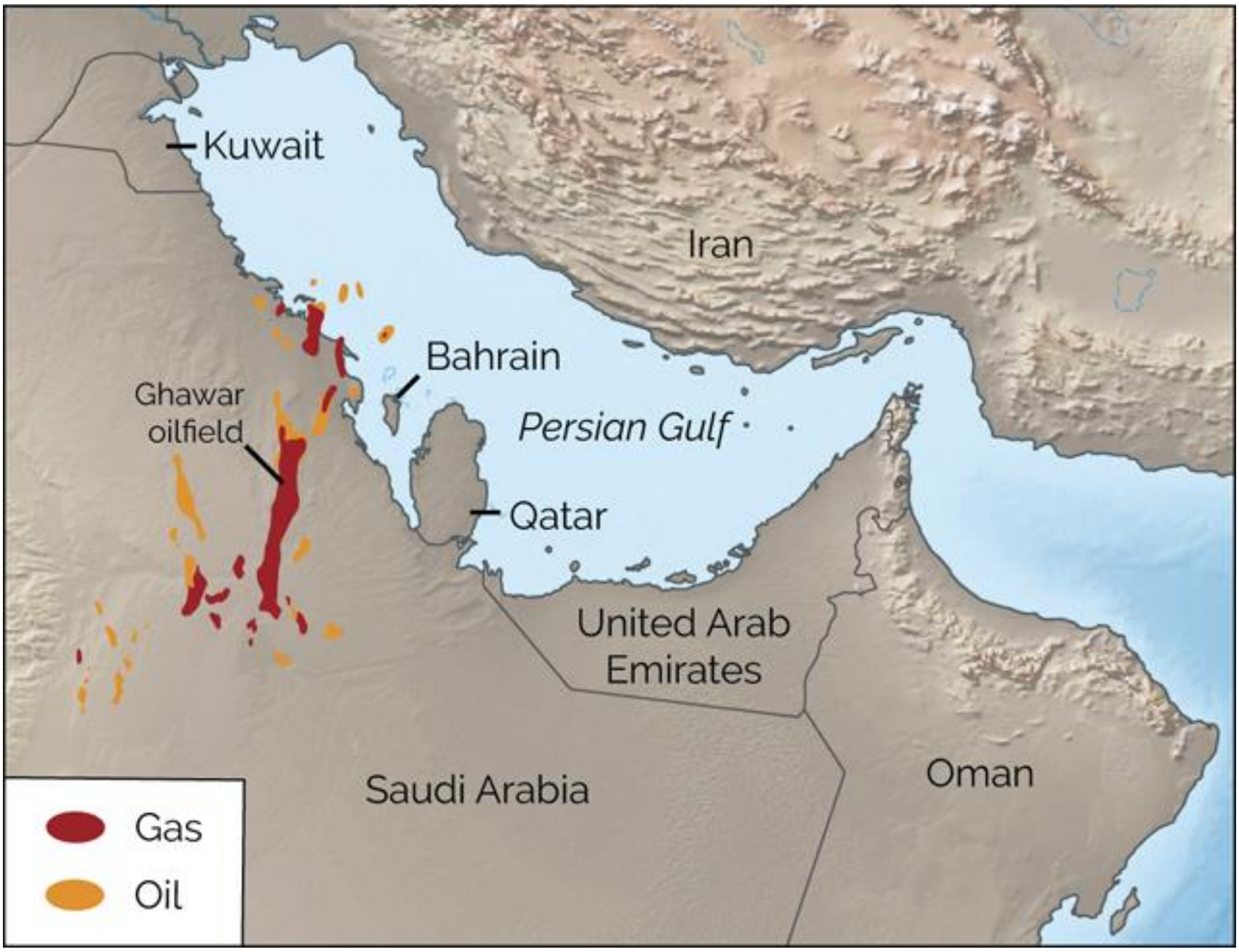


Figure 208. Geographical location of the Ghawar field (Source: Earth Magazine)

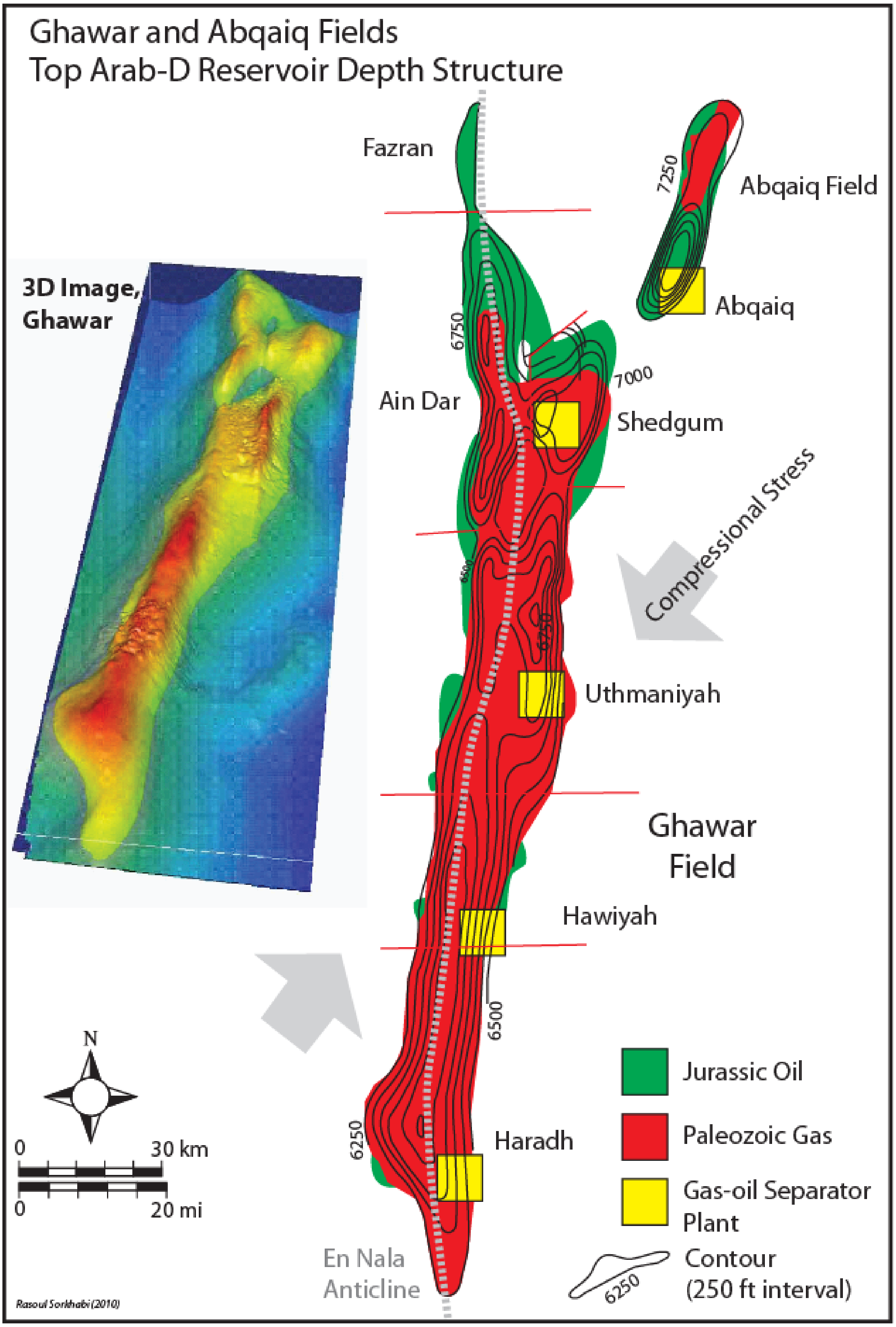


Figure 209. The geologic structure of the Ghawar and Abqaiq oil fields (Source: R. Sorkhabi, GEO ExPro, Vol. 7, no 4, pp. 24-29, https://www.geoexpro.com/articles/2010/04/the-king-of-giant-fields)

The true size of the Ghawar field was a state secret and the source of a Saudi kingdom's riches. It was so important that U.S. military planners once debated how to seize it by force. For oil traders, it was a source of endless speculation.

The actual size and production capacity is a jealously guarded state secret by the government of Saudi Arabia. What is known is that water pumping is now used in this reserve to maintain oil pressure (a signature of age of deposit).

Saudi Aramco published its first ever profit figures since its nationalization nearly 40 years ago, it also lifted the confidentiality around its mega oil fields (Blas April 4th 2019, and Blas et al April 1st 2019). The company's bond prospectus revealed that Ghawar is able to pump a maximum of 3.8 million barrels a day. This is approximately 1.2 million below the more than 5 million that had become conventional wisdom in the market (Figure 210). Prior to the Armco IPO, the true status of depletion for Ghawar is a Saudi Arabian state secret and is not public knowledge. Many analysts believe that this field has peak production as water is being used to pressurize it to increase extraction efficiency.

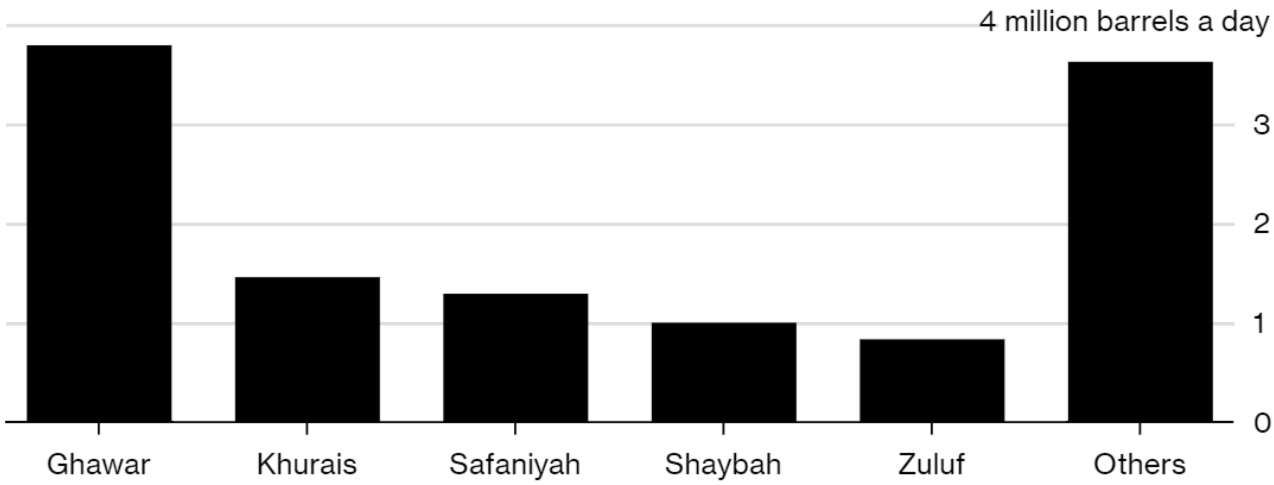


Figure 210. Saudi Aramco published oil field production rates
(Source: Saudi Armaco bond prospectus, Blas April 2nd 2019)

The nation state of Saudi Arabia has a serious cash flow shortfall, where a case can be made that the Kingdom only has 3-5 years of cash reserves left (Mauldin 2016).

Aramco is the world's most valuable company. It's also one of the most important sources of geopolitical power for Saudi Arabia. Selling of such a high cash revenue asset would be strategically shortsighted, if it truly was so profitable in future revenue production. It could be speculated that the 'alpha' of the true value of the Aramco asset has been exhausted and it is considered good business sense to sell to the public. This could be done for example because the revenue produced is projected to be less lucrative in the future.

Alpha is used in the finance sector as a measure of performance, indicating when a strategy, trader, or portfolio manager has managed to beat the market return over some period. Alpha, often considered the active return on an investment, gauges the performance of an investment against a market index or benchmark that is considered to represent the market's movement as a whole. The excess return of an investment relative to the return of a benchmark index is the investment's alpha.

As the primary revenue producing field for Aramco is the Ghawar field and most others have reached maturity and are now declining in production), this suggests that the Ghawar field is past its peak production. This also could mean that Saudi Arabia is past its peak production capacity. Today, the giant field produces about 5 million barrels per day — about 6.25% of the world's total oil production.

This field is only one of four able to produce over a million barrels per day. (Cantarell in Mexico, produces nearly 2 million barrels per day, Burgan in Kuwait produces 1.7 million barrels per day and Da Qing in China which produces 1 million barrels per day.) Ghawar is, therefore, extremely important to the world's economy.

Figure 211 shows the number of Baker Hughes drill rigs brought on line and oil production in Saudi Arabia from January 1997 to August 2019. During the years 2004 to 2008, the price of oil spiked from $USD50/bbl to $USD147/bbl.

Saudi Arabia expanded its rig count from 31.35 (average from October 2000 to October 2004) to 76.52 (average from September 2006 to September 2008), or a 144% increase. In the same time frames, Saudi Arabian oil production went from 8.41 million barrels a day to 8.99 barrels a day (or a 6.5% increase). *In that time when profit presumably was at an all-time high, Saudi Arabia brought on line 144% extra capacity of operating drill rigs to produce oil, yet oil production in that time increased comparatively little.*

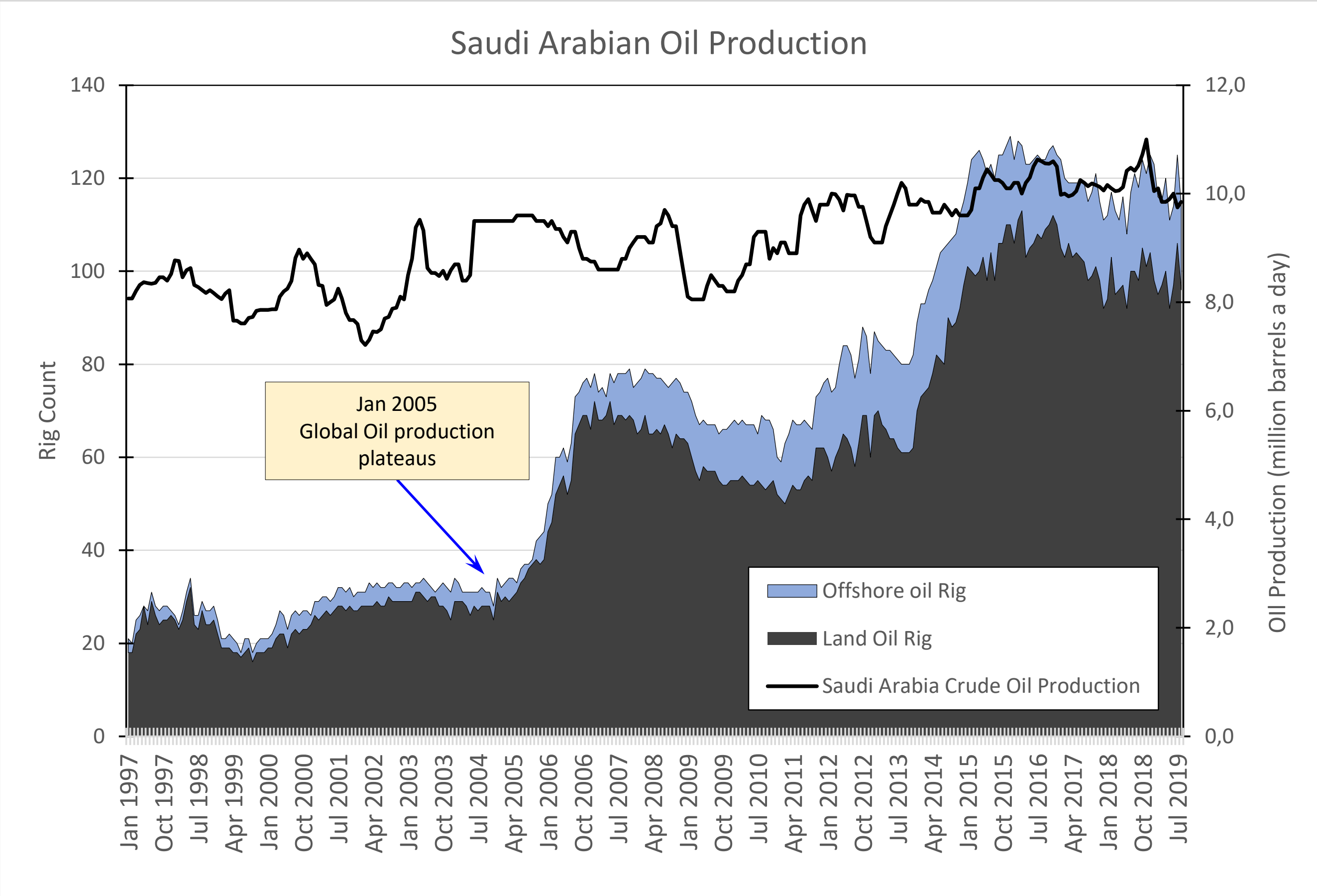


Figure 211. Saudi Arabian rig count and crude oil production, January 1997 to August 2019 (Source. Baker Hughes Rig Count data, EIA monthly production data)

A second sharp expansion of Saudi Arabian oil production capacity from April 2014 to January 2015. Saudi Arabia expanded its rig count from a 76.5 (average from September 2006 to September 2008), to 124.3 (average from January 2015 to September 2016). This is a 62% expansion between years 2006 to 2016. In the same time frames, Saudi Arabian oil production went from 8.99 million barrels a day to 10.22 barrels a day (or a 13.7% increase). This second expansion happened while the U.S. Tight Oil sector was meeting extra global oil demand (see Section 7). As such this did not correlate with a global scale signature. In late 2013, conventional oil did start to increase production and break out of its rough plateau that started in January 2005 (Figure 113 in Section 6).

The Saudi Arabian increases in operating drilling rigs with a disproportionally low corresponding increase in oil production is another example of the Red Queen problem. The Red Queen (or Queen of Hearts) quote:

> *"My dear, here we must run as fast as we can, just to stay in place. And if you wish to go anywhere you must run twice as fast as that."*

Lewis Carroll 1865, Alice's Adventures in Wonderland

Figure 212 shows the Saudi Arabian oil productivity in context of the monthly oil production (EIA monthly production) divided by the monthly rig count (onshore + offshore). This shows a permanent decrease in productivity starting in January 2005.

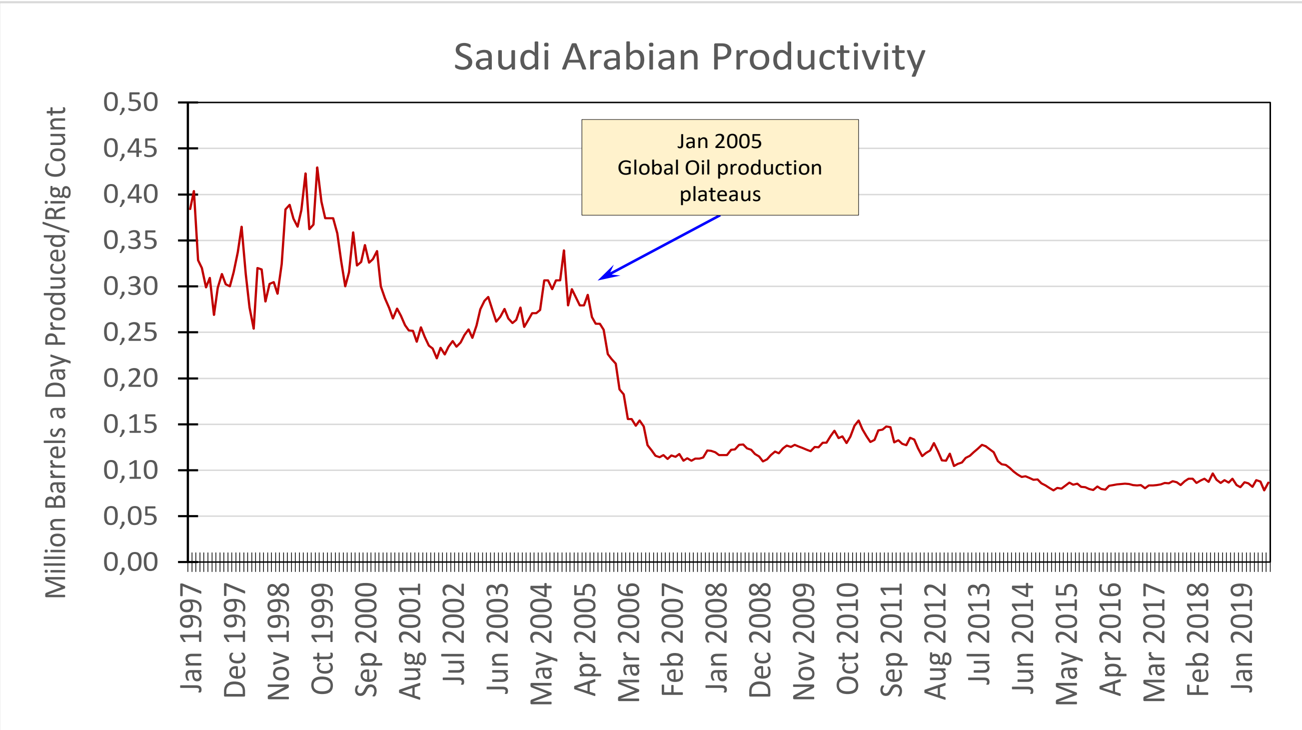


Figure 212. Saudi Arabia oil production productivity, oil production/rig count
(Source. Baker Hughes Rig Count data, EIA monthly production data)

Between the year 2000 and the year 2016, Saudi rig count expanded 296% to achieve a 21% increase in production. This implies that extra effort was needed just to maintain oil production. Which in turn suggests that the Saudi Arabian supply of oil is becoming less effective in oil extraction and is approaching peak oil production.

The above few paragraphs and figures suggest that Saudi Arabia may well be close its peak oil production rate and certainly has passed its peak ERoEI. Historically, Saudi Arabia has supported the global oil industry post WWII, in the same way the United States did prior to WWII. This means that the global oil production now is supported by the unconventional Tight Oil sector in the United States. So Figure 212 shows the transition point between Saudi Arabia to the United States as the global 'swing' producer. The oil production plateau in January 2005, was resolved in September 2009, as the U.S. Tight Oil sector rolled out its Shale Oil revolution.

Figure 213 shows the oil deposits, oil infrastructure of the Saudi Arabian oil industrial ecosystem, with the geographical position of the different ethnical groups in the region. What is curious is that the oil deposits themselves are in areas controlled by the Shia ethic group, while the Saudi Arabian administration and oil processing infrastructure is centralized around the Wahhabi ethic group. The Ghawar oil field is also partly controlled by the Shia ethnic group.

Figure 213 also puts the Iran/Saudi Arabian diplomatic conflict into perspective. Iran is mostly a Shia ethnic group, while Saudi Arabian political leadership is dominated mostly by the Wahhabi ethic group and the Saudi Arabian population is mostly dominated by the Sunni ethnic group. That being stated, most of the oil reserves are controlled by the Shia ethic group. Just so, the diplomatic conflict between Iran and Saudi Arabia, may not be driven by a religious difference as commonly suggested (Marcus 2019) but by who controls the oil reserves and infrastructure.

As it also can be shown in Figure 213, that the oil processing infrastructure is centralized round the Ghawar field. In particular, there is only one oil processing plant (Abqaiq), at the northern region of the Ghawar field.

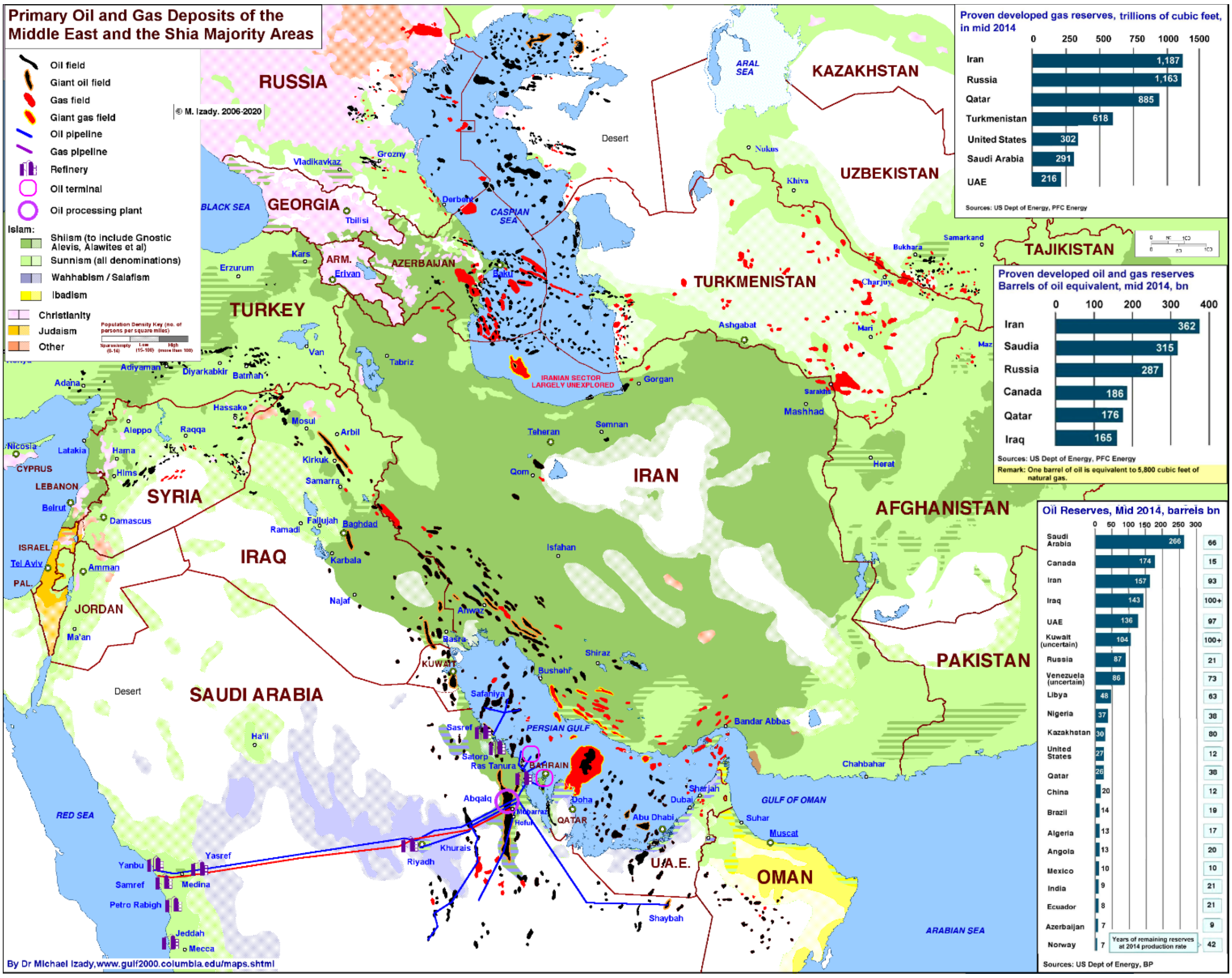


Figure 213. The ethnic groups in the Middle East, and location of oil deposits and oil infrastructure (Source: Dr. Michael Izady http://gulf2000.columbia.edu/images/maps/Saudi_Oil_Ethnicity_lg.png) (Copyright license granted)

12.2 Reliability of proved reserves

The stated oil reserves for the Middle East are not a 'bankable' number though. OPEC made an agreement to allow members to produce only a proportion of their stated reserves each year in a bid to make these resources last as long as possible.

To combat falling revenue from oil sales, in 1982 Saudi Arabia pressed OPEC for audited national production quotas in an attempt to limit output and boost prices (OPEC 2019). When other OPEC nations failed to comply, Saudi Arabia first slashed its own production from 10 million barrels daily in 1979–1981 to just one-third of that level in 1985. When even this proved ineffective, Saudi Arabia reversed course and flooded the market with cheap oil, causing prices to fall below US$10/bbl and higher-cost producers to become unprofitable.

Faced with increasing economic hardship, the oil exporters that had previously failed to comply with OPEC agreements finally began to limit production to shore up prices, based on painstakingly negotiated national quotas that sought to balance oil-related and economic criteria since 1986. Within their sovereign-controlled territories, the national governments of OPEC members are able to impose production limits on both government-owned and private oil companies. This means that generally when OPEC production targets are reduced, oil prices increase.

Since then, at one time or another, each of the OPEC members have announced massive oil finds, which in turn allows them to produce more oil and still stay within the OPEC rules (Figure 214). For each of these countries however, the data to support these claims are kept as state secrets and a matter of national security. As such, the data to support these claims is inaccessible (Simmons 2005).

Figure 214 has a series of kinks in the chart that correspond with these changes to the rules. As these oil reserves are often a state secret and are not subject to external audit, their true size and quality has been debated with many differences in opinion in conclusion.

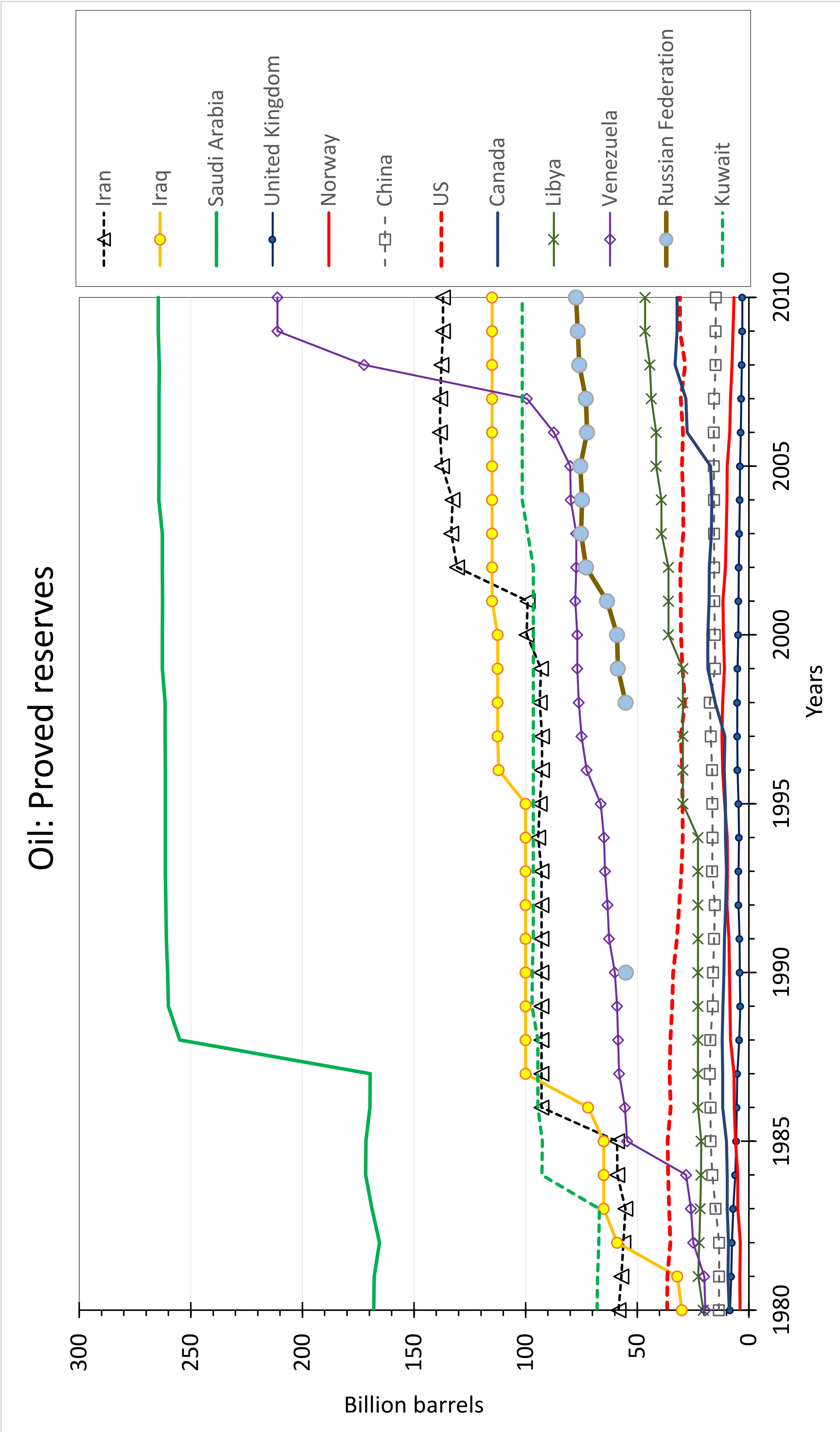


Figure 214. Declared oil reserves of OPEC 1980–2010
(Source: BP Statistical Review of the World Energy 2011)

13 OIL RESOURCE DISCOVERY

The geology of organic rich rocks (hydrocarbon source rocks) is well understood. The petroleum system resides inside a sedimentary basin, often trapped between geological structures (Figure 215). The basic elements of a petroleum system consists of a source rock, a porous and permeable reservoir rock and a tight cap rock. These systems are found on dry land (onshore) and under the ocean (offshore).

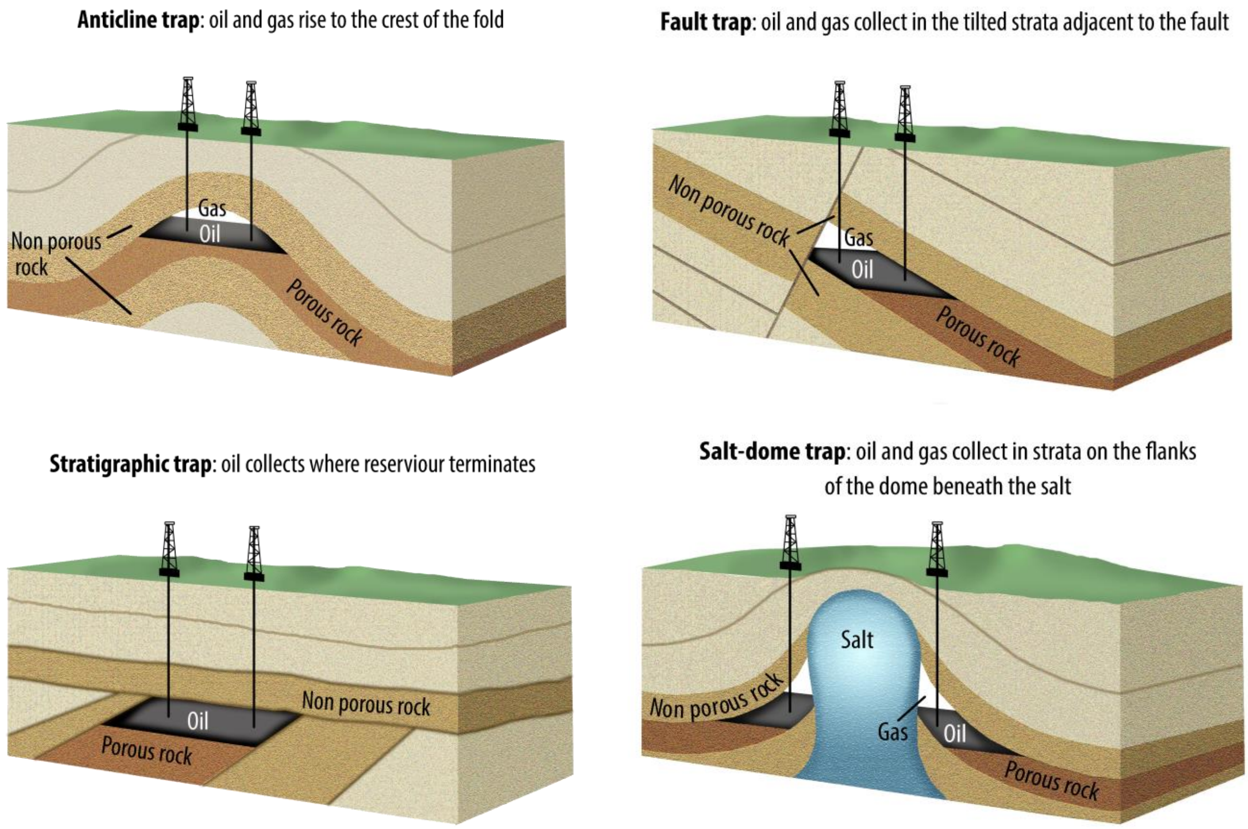


Figure 215. The four kind's geology formations that oil and gas are trapped in (Image: Tania Michaux)

13.1 Resource to Reserve Definition

Oil deposits are classified as resources and reserves. Petroleum resources are the quantities of hydrocarbons naturally occurring on or within the Earth's crust, where resources assessments estimate quantities in known and yet-to-be-discovered accumulations. Resources evaluations are focused on those quantities that can potentially be recovered and marketed by economically viable projects (SPE 2018). This classification is to quantify a given oil deposit project in context of range of uncertainty and economic viability (chance of a commercial enterprise being formed to extract this oil for market sale).

The following definitions apply to the major subdivisions within the resources classification (shown in Figures 216 and 217):

- Total Petroleum Initially-In-Place (PIIP) is all quantities of petroleum that are estimated to exist originally in naturally occurring accumulations, discovered and undiscovered, before production.
- Discovered PIIP is the quantity of petroleum that is estimated, as of a given date, to be contained in known accumulations before production.
- Production is the cumulative quantities of petroleum that have been recovered at a given date. While all recoverable resources are estimated, and production is measured in terms of the sales product specifications, raw production (sales plus non-sales) quantities are also measured and required to support engineering analyses based on reservoir voidage.

The outcome would be a forecast to for a project to recover an estimated portion of the initially-in-place quantities. The projects are to be subdivided into commercial, sub-commercial, and undiscovered. A further sub-classification is the estimated recoverable quantities being classified as Reserves, Contingent Resources, or Prospective Resources respectively (SPE 2018).

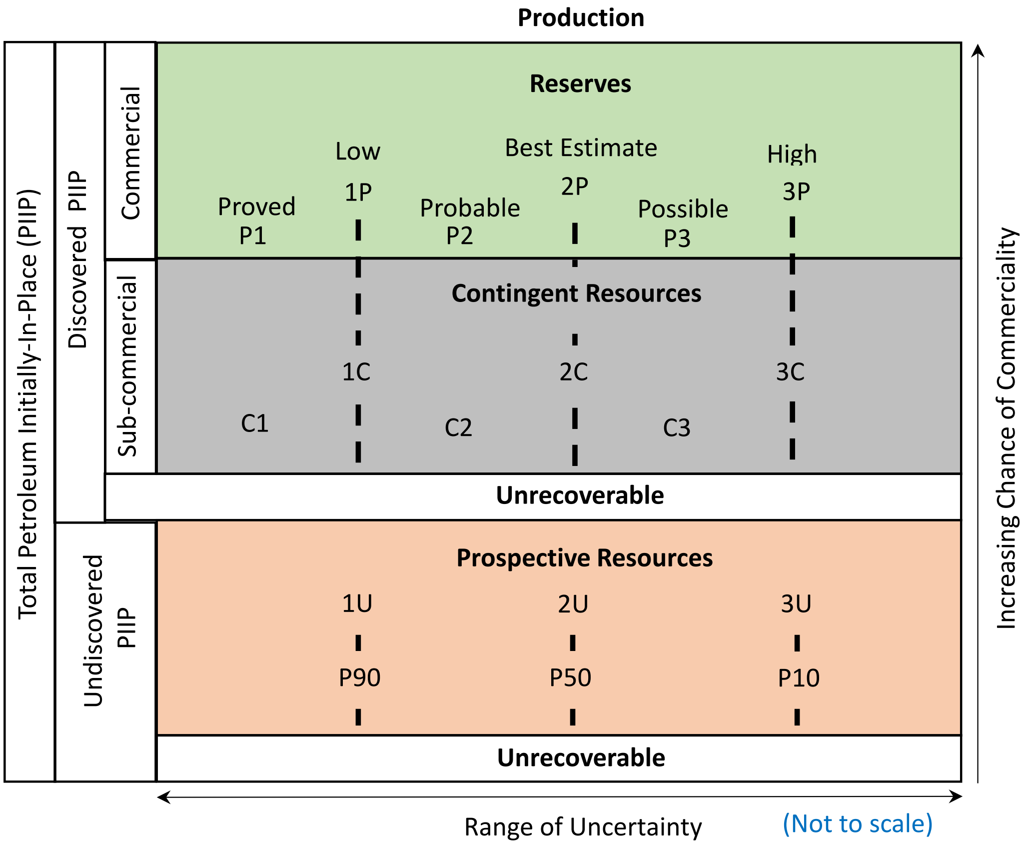


Figure 216. Resources classification framework
(Source: Re-drawn from a figure in SPE 2018)

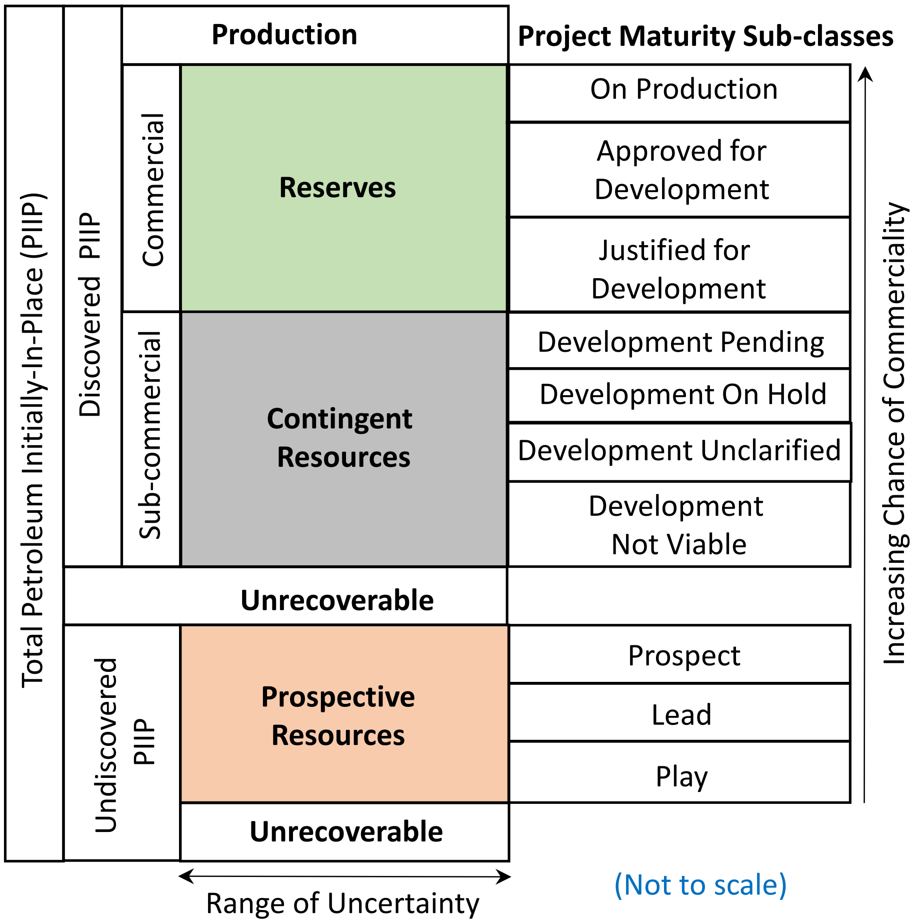


Figure 217. Sub-classes based on project maturity
(Source: Re-drawn from a figure in SPE 2018)

13.1.1 Reserves

Reserves are those quantities of petroleum anticipated to be commercially recoverable by application of development projects to known accumulations from a given date forward under defined conditions. Reserves must satisfy four criteria (SPE 2018):

- discovered
- recoverable
- commercial, and
- remaining (as of the evaluation's effective date) based on the development project(s) applied.

Reserves are recommended as sales quantities as metered at the reference point. Where the project development also recognizes quantities consumed in operations (CiO), as Reserves these quantities must be recorded separately. Non-hydrocarbon quantities are recognized as reserves only when sold together with hydrocarbons or CiO associated with petroleum production. If the non-hydrocarbon is separated before sales, it is excluded from reserves. Figure 218 shows a graphical comparison in volume of the global oil reserves.

Reserves are further categorized in accordance with the range of uncertainty and should be sub-classified based on project maturity and/or characterized by development and production status.

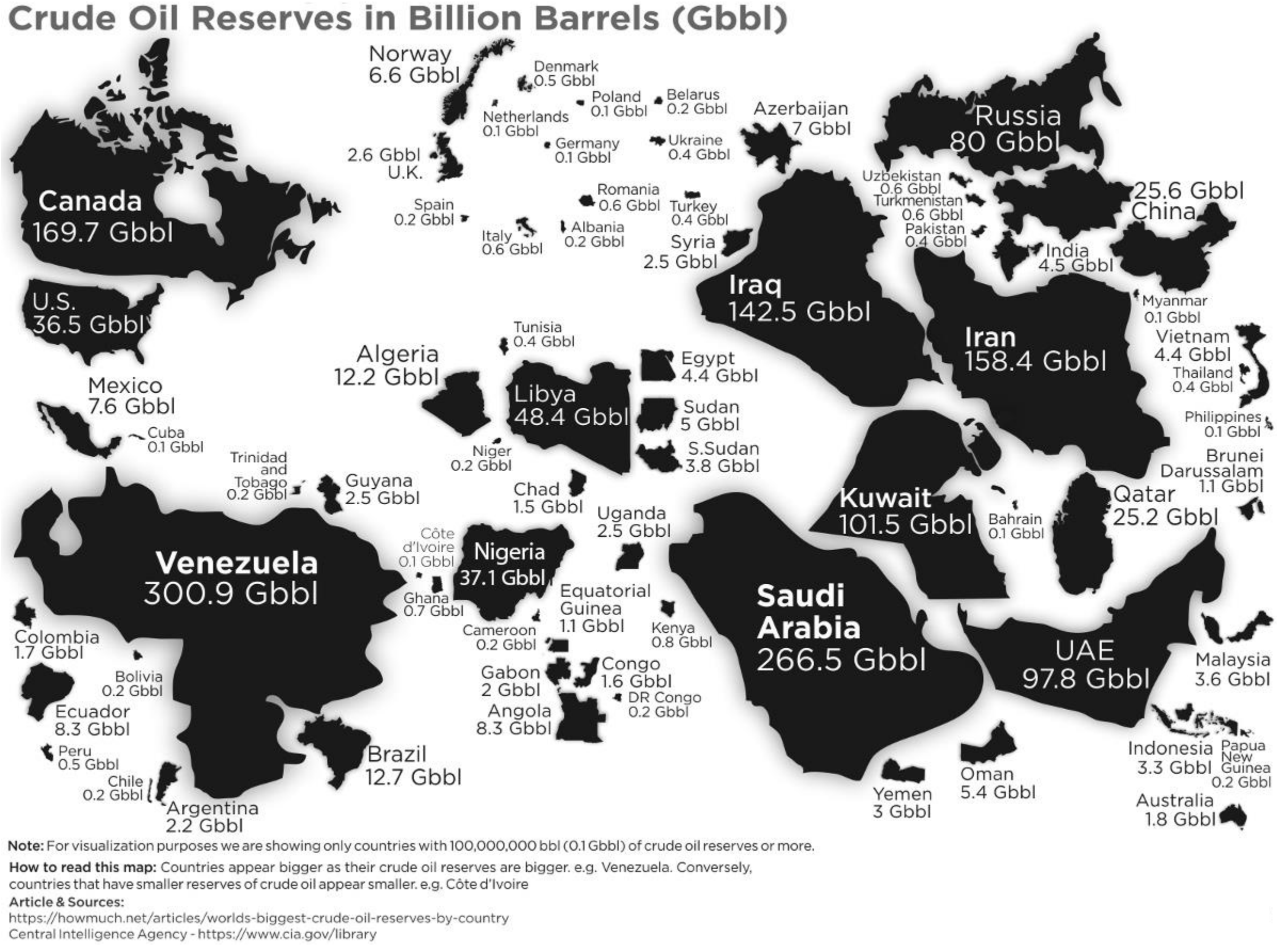


Figure 218. Oil reserves shown by country and relative volume
(Source: Visual Capitalist, https://www.visualcapitalist.com/map-countries-most-oil-reserves/)

13.1.2 Contingent Resources

Contingent resources are those quantities of petroleum estimated, as of a given date, to be potentially recoverable from known accumulations, by the application of development project(s) not currently considered to be commercial owing to one or more contingencies (SPE 2018).

Contingent resources have an associated chance of development. Contingent resources may include, for example, projects for which there are currently no viable markets, or where commercial recovery is dependent on technology under development, or where evaluation of the accumulation is insufficient to clearly assess commerciality. Contingent resources are further categorized in accordance with the range of uncertainty associated with the estimates and should be sub-classified based on project maturity and/or economic status.

13.1.3 Undiscovered PIIP

Undiscovered PIIP is that quantity of petroleum estimated, as of a given date, to be contained within accumulations yet to be discovered (SPE 2018).

13.1.4 Prospective Resources

Prospective resources are those quantities of petroleum estimated, as of a given date, to be potentially recoverable from undiscovered accumulations by application of future development projects. Prospective Resources have both an associated chance of geologic discovery and a chance of development. Prospective Resources are further categorized in accordance with the range of uncertainty associated with recoverable estimates, assuming discovery and development, and may be sub-classified based on project maturity (SPE 2018).

13.1.5 Unrecoverable Resources

Unrecoverable resources are that portion of either discovered or undiscovered PIIP evaluated, as of a given date, to be unrecoverable by the currently defined project(s). A portion of these quantities may become recoverable in the future as commercial circumstances change, technology is developed, or additional data are acquired. The remaining portion may never be recovered because of physical/chemical constraints represented by subsurface interaction of fluids and reservoir rocks (SPE 2018).

13.2 Historical Discovery of Conventional Resources

Figure 219 shows historical oil discovery. Most oil was discovered in the 1960's with a persistent decline since a peak in 1962. The largest producing field in the world, Ghawar, Saudi Arabia, was discovered in 1948 (see Section 12.1). Figure 220 shows the global oil and gas deposit discovery between 2013 and 2018, which fits inside the blue box in Figure 219.

New conventional oil deposit discoveries in 2017 were at the lowest since 1947. Explorers replacing just 6% of resources they drill (Rsytad 2018, Davis 2017). Explorers in 2015 discovered only about a tenth as much oil as they did annually on average since 1960 (Davis 2017).

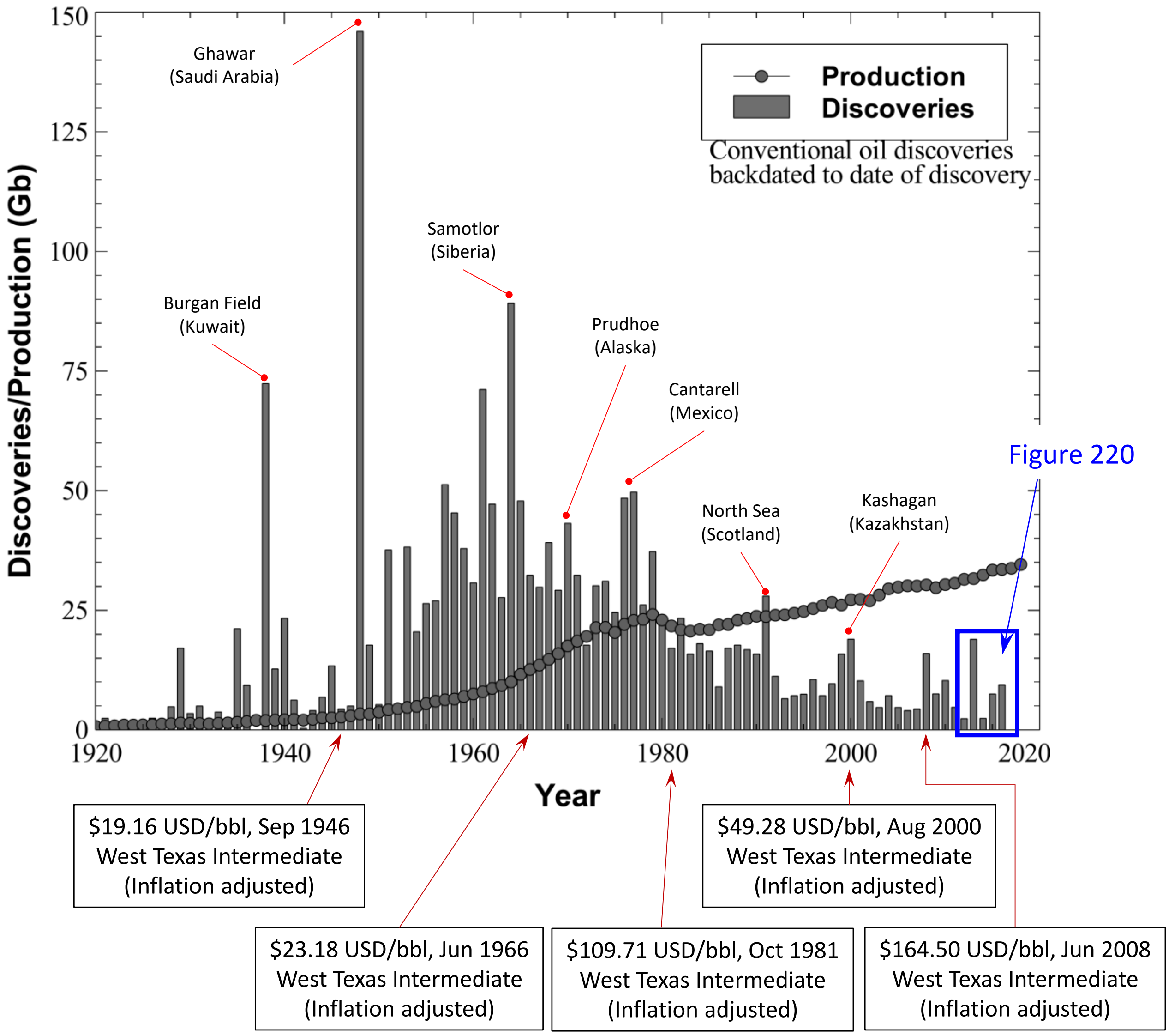


Figure 219. Conventional oil resource discovery 1920-2018
(Source: Analyst – John Peach, data from ASPO 2019, Wood and Mackenzie, Oil Price 2017, Rsytad Energy 2018, Our World in Data 2019, BP Energy Statistics 2019 CNBC 2017)

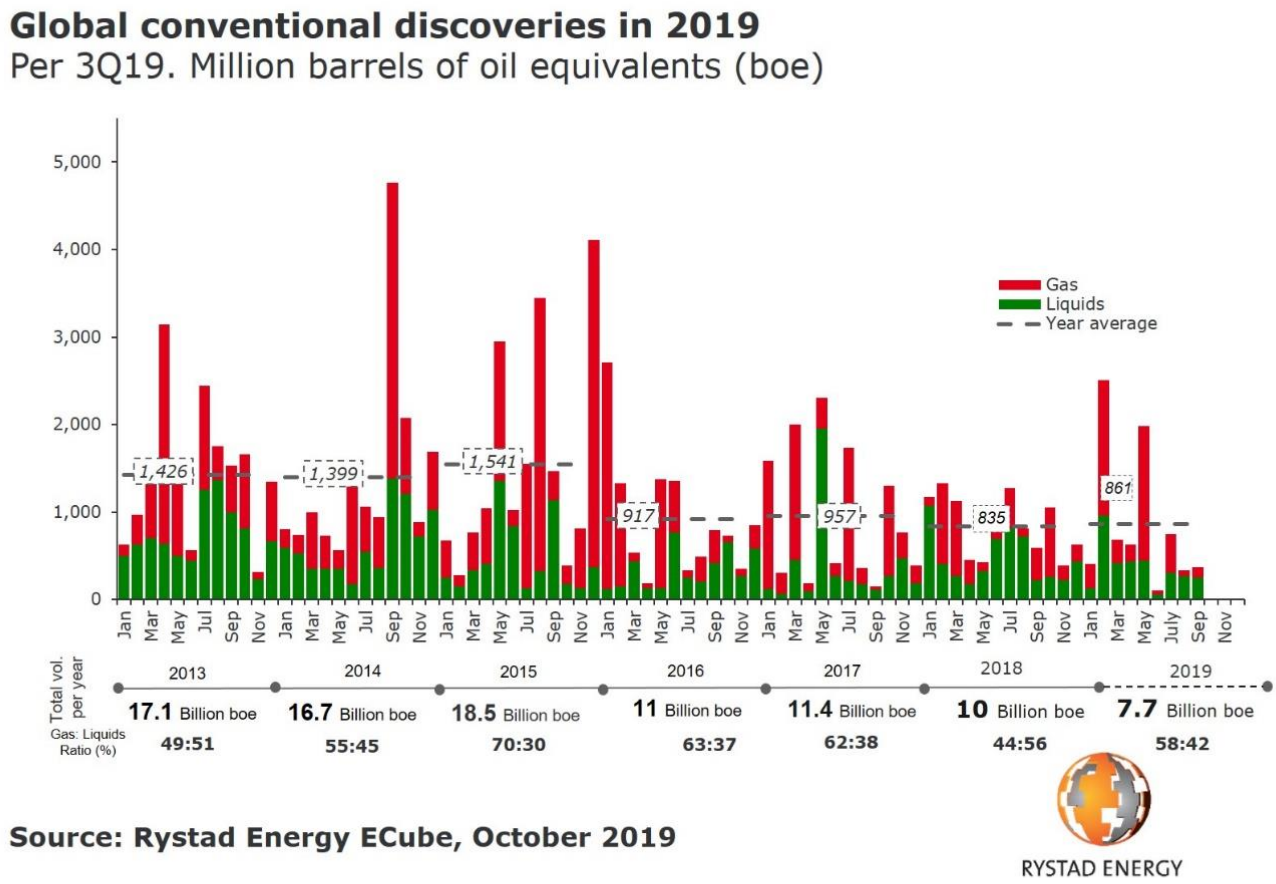


Figure 220. Global resource discoveries for conventional oil and gas in 2019 (Source: Rsytad Energy ECube Oct 2019)

It is to be remembered that this is new volumes discovered. This does not mean that these deposits are extractable with current technology, or economically viable to be exploited commercially. Many of these are small and the Norwegian Petroleum Directorate (NPD) gives likelihood for developments of each of these discoveries on the Norwegian Continental Shelf (NCS). No this cannot be extrapolated to the whole world but suggests that commercial discoveries are somewhat less than total discoveries (Likvern 2019).

The Hirsch report (Hirsch 2005 & 2010) showed, new oil discoveries have been in long term decline — lately reaching record lows notwithstanding record investments between 2001–2014. New discoveries are invariably smaller fields with more rapid peak and decline rates (Fustier *et al* 2016).

If the 2018 stated global reserves of oil is 1730 billion barrels (Appendix E), and the 2018 global consumption of oil was 36.4 billion barrels (99 843 kbbls/day) (Appendix C), then current reserve will last 47.5 years before depletion.

This number assumes that all of that oil is extractable. Also the rate of global oil production will peak and decline well before 47 years, creating a demand to supply gap (see Section 17 and Section 11)

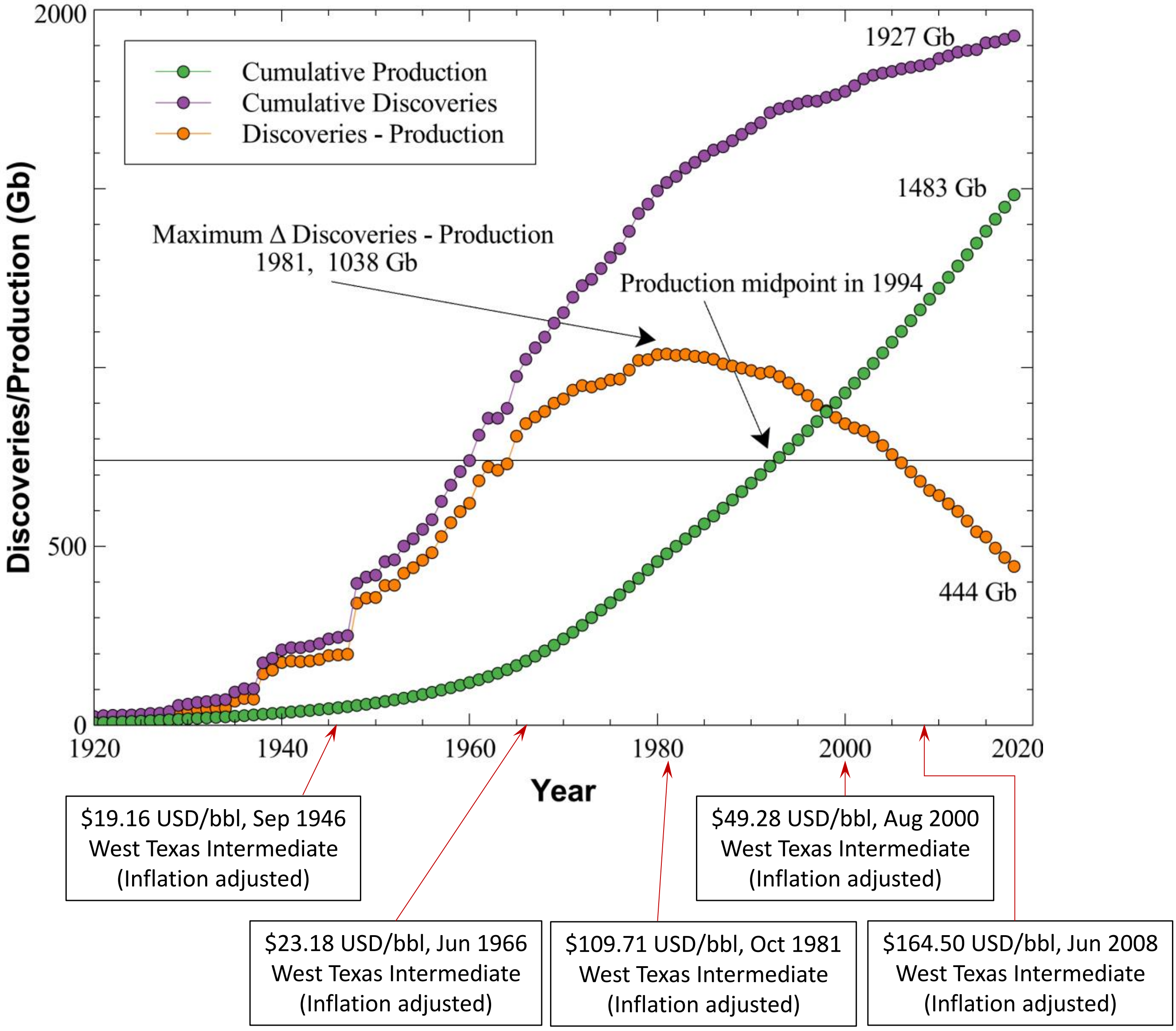


Figure 221. Cumulative global oil resource discoveries and global oil production, and net difference (Source: Analyst – John Peach, data from ASPO 2019, Wood and Mackenzie, Oil Price 2017, Rsytad Energy 2018, Our World in Data 2019, BP Energy Statistics 2019 CNBC 2017)

Figure 221 shows the cumulative global oil discovery and global oil production, and the difference between the two. The midpoint of production occurred in 1994, meaning the global industrial system has consumed 50% of all oil produced in the last 25 years (Peach 2019). The peak of net contribution of oil discovery was in 1981. That is, since 1981, production outpaced discovery additions to the global oil deposit inventory. Figure 222 shows the net contribution to annual world oil reserves. Again, since 1981, net contribution has declined. The oil price did rise between 1981 and 2008, but reserves continued to decline. Oil price does not correlate with oil deposit discovery.

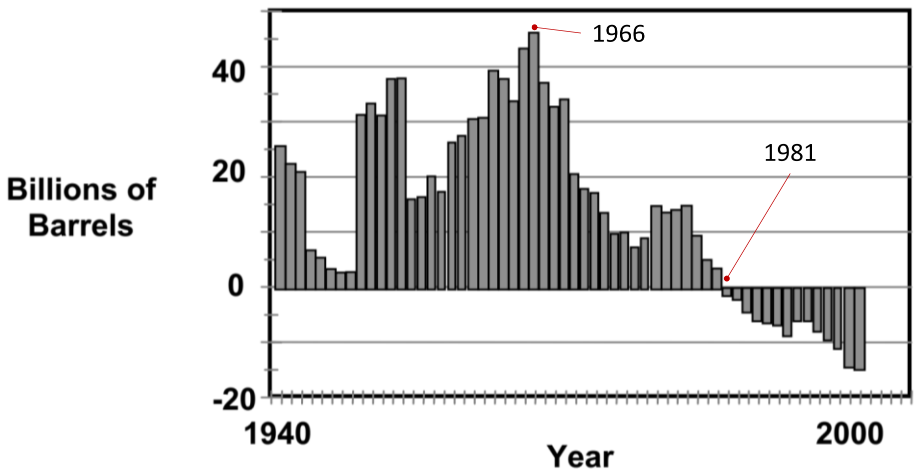


Figure 222. Net difference between annual world oil reserves additions and annual consumption (Source: Hirsch et al. 2005 report commissioned by US DOE)

Figures 219 to 222 show an interesting signature in context of oil price. Conventional thinking often uses the following logic to debunk the concept of peak oil:

- Oil reserves decrease through production of oil
- The supply of oil based products becomes inelastic
- The oil price increases, making it more worthwhile to explore for and exploit lower grade resources.
- Lower grade resources are declared reserves and overall reserves increase. Thus the previously perceived peak production from finite depleting reserves is deferred into the future.

This logic chain has been used in the past to discredit the concept that not only oil might one day peak production, but the net addition to reserves may well be years in the past. Figure 221 show the net oil reserve addition peaking in 1981, with half of all oil ever extracted, has been produced since 1994. Discovery volumes have been falling consistently since the mid 1960's.

Yet the West Texas Intermediate oil spot price in August 2000 was $49.28 USD a barrel (inflation adjusted), and eight years later, in June 2008, it was $164.50 USD a barrel (an increase of 333%). Yet in that time, when the rate of production is considered, net addition to reserves continued to decline (Figure 221).

This means that conventional thinking out of step with the reality of the net addition to conventional oil reserves.

13.3 Historical Discovery of Unconventional Resources

The discovery of unconventional oil resources has changed the supply capability of the oil industry. The history of the oil shale industry in the United States goes back to the 1850s; it dates back farther as a major enterprise than the petroleum industry. But although the United States contains the world's largest known resource of oil shale, the US has not been a significant producer of shale oil since 1861.

There were three major past attempts to establish an American oil shale industry: the 1850s; in the years during and after World War I; and in the 1970s and early 1980s. Each time, the oil shale industry failed because of competition from cheaper petroleum.

Shale oil became viable in small scale operations with the application of vertical well fracking technology (first applied in 1948 (EIA 2013). In 2008, the innovation of precision horizontal well drilling (in conjunction with higher oil price) made viable fracking operations on a much larger scale of operation (See Section 6).

Since then a number of unconventional oil resource discoveries have been made (US EPA 2015). The volume of some of these discoveries were impressive. A new study released in 2018 (USGS 2018) presents a possible extension of the Permian play. The USGS estimates that over 46 billion barrels of oil, 280 trillion cubic feet of gas, and 20 billion barrels of natural gas liquids are trapped in these low-permeability shale formations. To put this in perspective, at the end of 2017, total U.S. proven reserves of crude oil was approximately 40 billion barrels. The new upward revision of Permian resources represents a more than 100% increase (or more) in U.S. oil reserves, <u>if they can be extracted economically</u>. The key take away from this report however was while this discovery was indeed impressive, it is not known if it is viable.

Many unconventional deposit discoveries were not economically viable. Many of these new deposits were reported with incomplete or inappropriate feasibility studies. Much of the oil discovered was not able to be extracted with the technology available at the time, thus was not viable.

An example of this is the Monterey Shale play. In 2011, the EIA published a report that stated the Monterey Shale in California had 15.4 billion barrels of recoverable oil, or two-thirds of the then estimated recoverable tight oil in the US. The EIA subsequently downgraded its estimate to 13.7 billion barrels in 2013. Further analytical work done by the Post Carbon Institute resulted in a further EIA downgrade of the Monterey shale deposit to 600 million barrels (Hughes 2013). This represents a 96% reduction in resource size. A further study done by the US Geological Survey revised, the most oil-rich portion of the giant shale formation holds just 21 million barrels of oil that can be recovered by intensive methods, such as hydraulic fracturing (Associated Press 2015). This was a further serious reduction in recoverable oil for the play.

The Canadian oil sands deposit in Alberta were discovered by Europeans first in 1717, and their economic significance was first understood in 1908 (CAPP 2019). The first commercial development of the oil sands didn’t happen until 1967 with the opening of the Great Canadian Oil Sands project – now Suncor (CAPP 2019).

Just so, the volumes discovered in unconventional deposits need to be considered to different metrics to conventional oil and gas plays. Required CAPEX and OPEX in addition to ERoEI ratios tend to change the outcome classification.

Both conventional and unconventional reserves are often quoted together (BP Statistical Review of World Energy 2019), which can make it difficult to quantify. How they are judged to be viable can also be unclear.

14 THE THREE OIL SHOCKS AND THE MINOR STALL

It has been demonstrated that oil is vital to the functioning of the global industrial ecosystem and the economy it supports. Due to the critical contribution oil makes to our industrial society, even a short term disruption in supply will have measureable consequences across the whole ecosystem. There are four examples of a shock to the global system, which can be mapped in oil consumption. Three out of four of these oil shocks were created by above ground limitations.

To map this effectively, two metrics were chosen. Oil consumption (not production) and Vehicle Miles travelled in the region of oil consumption. Vehicle Miles travelled is a useful proxy for actual activity in the real economy at the application end of the value chain. The United States was chosen to show these patterns because it was the largest crude oil consumer for decades and it is has once again become the largest crude oil producer. The United States also has been the world reserve currency, and as a consequence of the Petrodollar agreement, all oil trades are transacted in $USD. The United States Department of Transport also collects the appropriate data (Vehicle Miles Travelled).

Figure 223 shows the US miles driven vs. US oil consumption. Shown in Figure 223 is the clear peaks around the first two oil shocks (1973 Oil Crisis or First Oil Shock, 1979 Oil Crisis or Second Oil Shock), and the plateauing of crude oil production in 2005. In 2005, oil supply stalled in what could be termed as the third oil shock. In 2010, there was a comparatively smaller stall termed the fourth oil shock. Each of these three oil shocks and the fourth minor stall will examined separately in due course.

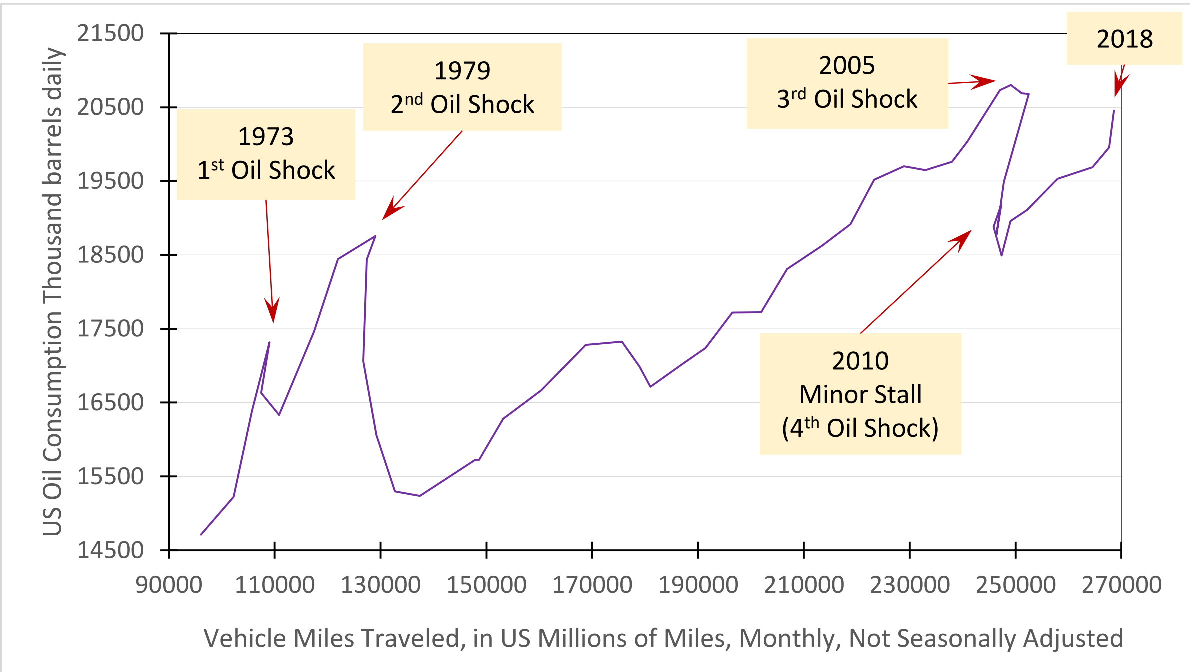


Figure 223. Index of U.S. vehicle miles driven and U.S. oil consumption (1970-2018)
(Source: US Department of Transportation, BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011)

These are clear signatures that something fundamental has changed at each of these points. Previously in this report, the correlation of oil consumption and many other physical measures of human society.

Also in this report (and supporting appendices) is presented data showing that the capacity and capability to supply energy to society is deteriorating.

It is to be remembered that each economic shock is often subject to a speculative fuelled bubble. The concept of oil being a market indicator to economic downturns is complex and mostly due to 'above ground' influences. The commodities market is subject to speculation, where the perception of a supply shortage can drive up the market price. The price can often exceed the level justified by the market fundamentals. For example the rise of the oil price between 2005 and 2008, where the price of oil reached $147/barrel.

> *"The boom and bust dynamic in finance is a big 'above ground factor' when it comes to oil prices. Prices rarely reflect the fundamentals accurately for this reason. When supply and demand get tight, the result in the financial world is price volatility - an exaggerated boom and bust cycle - rather than a straight moonshot. This is very destabilizing for the industry."*

Nicole Foss – Industrial Ecologist

The four examples of oil shocks shown here all had elements of the above present in the market place, which has the net effect of masking the difference between causality of the different events.

14.1 The 1st oil shock. Case study – 1973 Oil Embargo

An example of how vulnerable our industrially complex society is to a supply shortfall of oil is the 1973 oil embargo, when the Organization of the Petroleum Exporting Countries (OPEC) oil cartel decided to stop exporting oil to the United States. On October 19, 1973, the twelve OPEC members agreed to the embargo. Over the following six months, oil prices quadrupled (Amadeo 2018, Oil & Gas Journal 2005).

This price increase had a dramatic effect on oil exporting nations, for the countries of the Middle East who had long been dominated by the industrial powers seen to have taken control of a vital commodity. The oil-exporting nations began to accumulate vast wealth.

Some of the income was dispensed in the form of aid to other underdeveloped nations whose economies had been caught between higher oil prices and lower prices for their own export commodities, amid shrinking Western demand.

The embargo had a negative influence on the US economy by causing immediate demands to address the threats to U.S. energy security. On an international level, the price increases changed competitive positions in many industries, such as automobiles. Macroeconomic problems consisted of both inflationary and deflationary impacts.

Figure 224. Petrol shortages in the United States during the 1973 oil embargo

The oil embargo aggravated inflation, already at 10% for some commodities, by raising oil prices. It came at a vulnerable time for the U.S. economy. Domestic oil producers were running at full capacity. They were unable to produce more oil to make up the supply gap. Furthermore, U.S. oil production had declined as a percentage of world output.

It also worsened the US economic recession that was in progress in the early 1970's. First, higher gas prices meant consumers had less money to spend on other goods and services. This lowered demand. It also weakened consumer confidence. Supply of petroleum products became scarce and subject to rationing (Figure 224 and 225). This had a ripple effect through the whole global economy.

Figure 225. Petrol shortages in the United States during the 1973 oil embargo

For example, drivers were forced to wait in lines that often extended around the block. Paying customers woke up before dawn or waited until dusk to avoid the lines. Gas stations posted color-coded signs: green when gas was available, yellow when it was rationed, and red when it was gone. States introduced odd-even rationing: drivers with license plates ending with odd numbers could get gas on odd-numbered days.

A few months later, the crisis eased. The embargo was lifted in March 1974 after negotiations at the Washington Oil Summit, but the effects lingered throughout the 1970s. The dollar price of energy increased again the following year, amid the weakening competitive position of the dollar in world markets. Control of oil became known as the "oil weapon." It came in the form of an embargo and production cutbacks from the Arabian states.

Figure 226 shows the U.S. oil consumption and Vehicle Miles Travelled in the U.S. between 1970 and 1976. A clear peak can be seen in 1973. By 1974, the oil shock was resolved and recovery was in progress. Figure 227 shows global oil production between 1965 and 1977. A peak can be seen in this figure but it is not as sharp as seen in Figure 226.

This peak was clearly created by above ground influences where OPEC oil producers reduced supply to the United States.

This peak was visible in data structures:

- Oil consumption vs. Vehicle Miles Travelled
- Oil production
- Oil price as an immediate lagging indicator

This peak was not limited by geological restraints or financial industry instability.

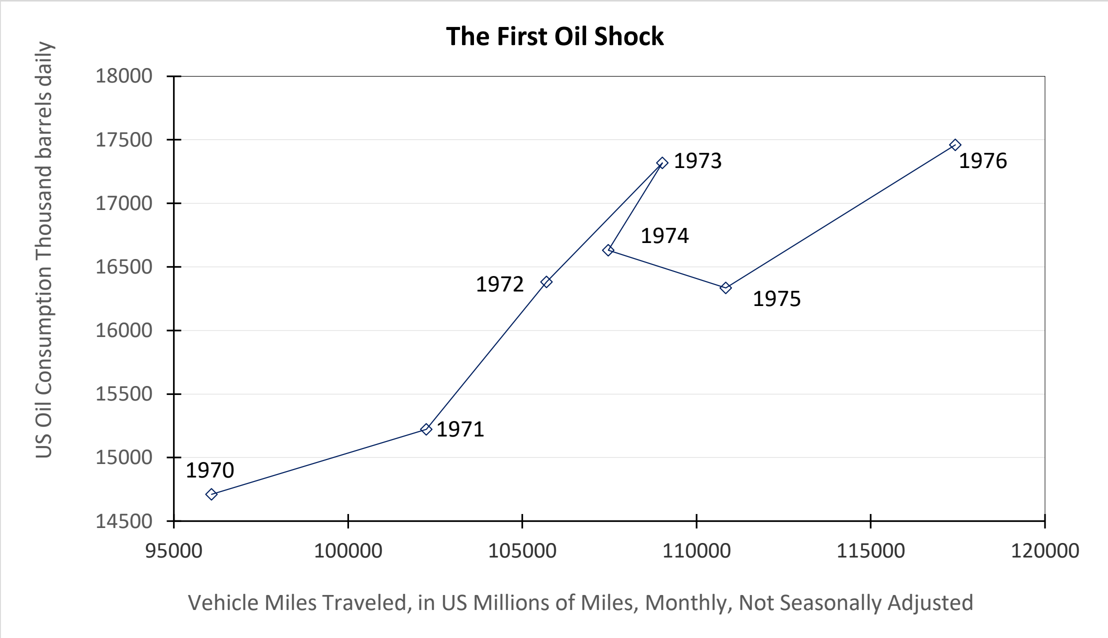


Figure 226. The 1st oil shock - 1973
(Source: U.S. Federal Reserve Economic Data, BP Statistical Review of World Energy 2011)

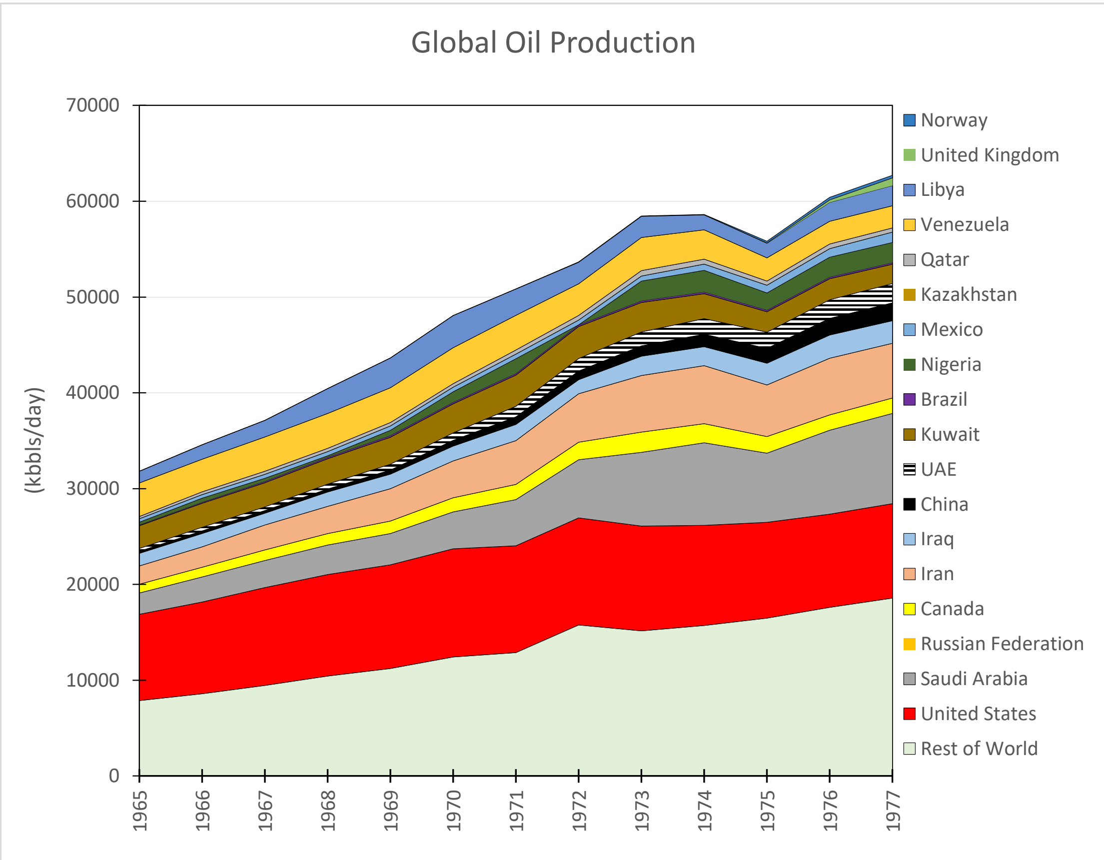


Figure 227. Global oil production 1965 to 1977. (Includes crude oil, shale oil, oil sands, condensates (both lease condensate and gas plant condensate) and NGLs (natural gas liquids – ethane, LPG and naphtha separated from the production of natural gas). Excludes liquid fuels from other sources such as biomass and derivatives of coal and natural gas.)
(Source: data from BP Statistical Review of World Energy 2019 and BP Statistical Review of World Energy 2011)

14.2 The 2nd oil shock. Case study – 1979 Iranian Revolution

The 1979 (or second) oil crisis or oil shock occurred in the world due to decreased oil output in the wake of the Iranian Revolution. Despite the fact that global oil supply decreased by only about 4%, widespread panic resulted, driving the price far higher. The price of crude oil more than doubled to $39.50 USD per barrel over the next 12 months, and long lines once again appeared at gas stations, as they had in the 1973 oil crisis.

In 1980, following the outbreak of the Iran–Iraq War, oil production in Iran nearly stopped, and Iraq's oil production was severely cut as well (see Figures 93 and 94). Iran oil production was already declining in 1978. Economic recessions were triggered in the United States and other countries. Oil prices did not subside to pre-crisis levels until the mid-1980s.

After 1980, oil prices began a 20-year decline, except for a brief rebound during the Gulf War, eventually reaching a 60 percent fall-off during the 1990s. As with the 1973 crisis, global politics and power balance were impacted. Oil exporters such as Mexico, Nigeria, and Venezuela expanded production; the Soviet Union became the top world producer; North Sea and Alaskan oil flooded the market. It seemed that the United States of America and Norway had much more oil reserves than forecasted in the 1970s. OPEC lost influence as consequence of these actions.

Figure 228 shows the U.S. oil consumption and Vehicle Miles Travelled in the U.S. between 1975 and 1982. A clear peak can be seen in 1978, with the shock unfolding from 1979 to 1982. Figure 229 shows global oil production between 1975 and 1985, showing a clear peak in 1979.

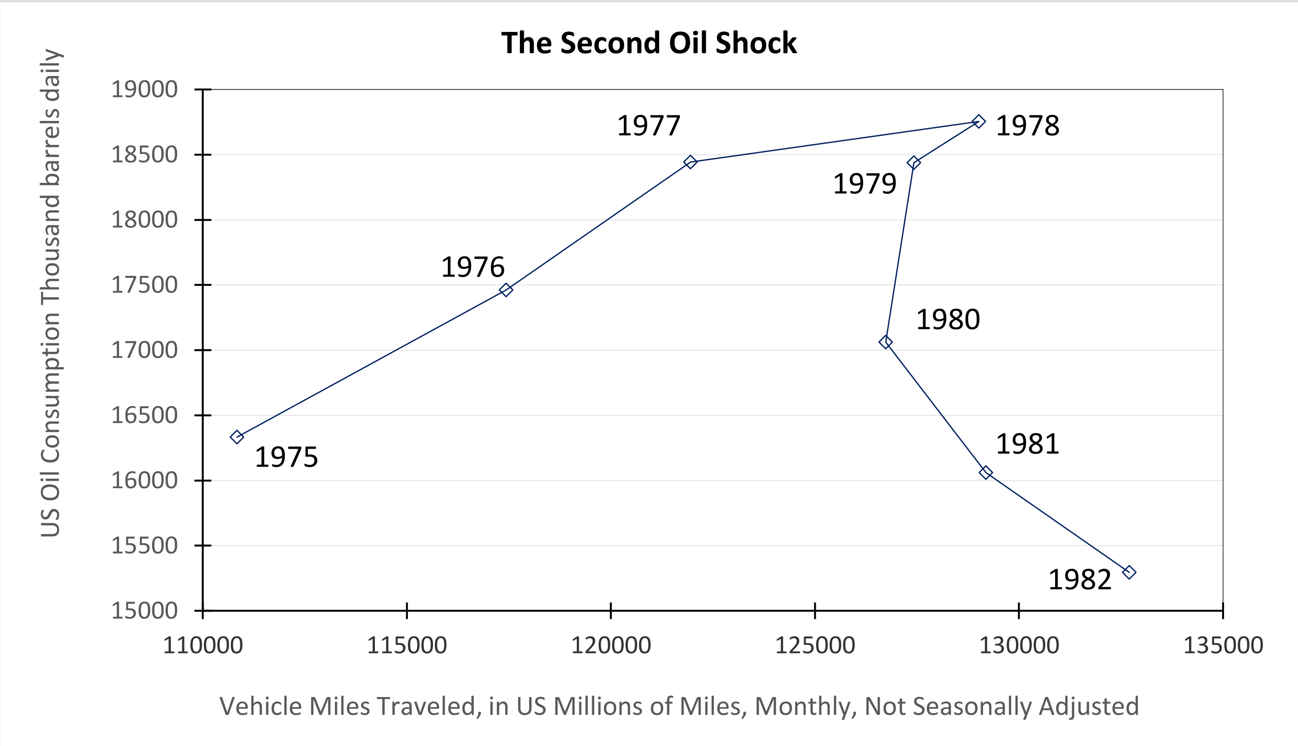


Figure 228. The 2nd oil shock - 1979
(Source: U.S. Federal Reserve Economic Data, BP Statistical Review of World Energy 2011)

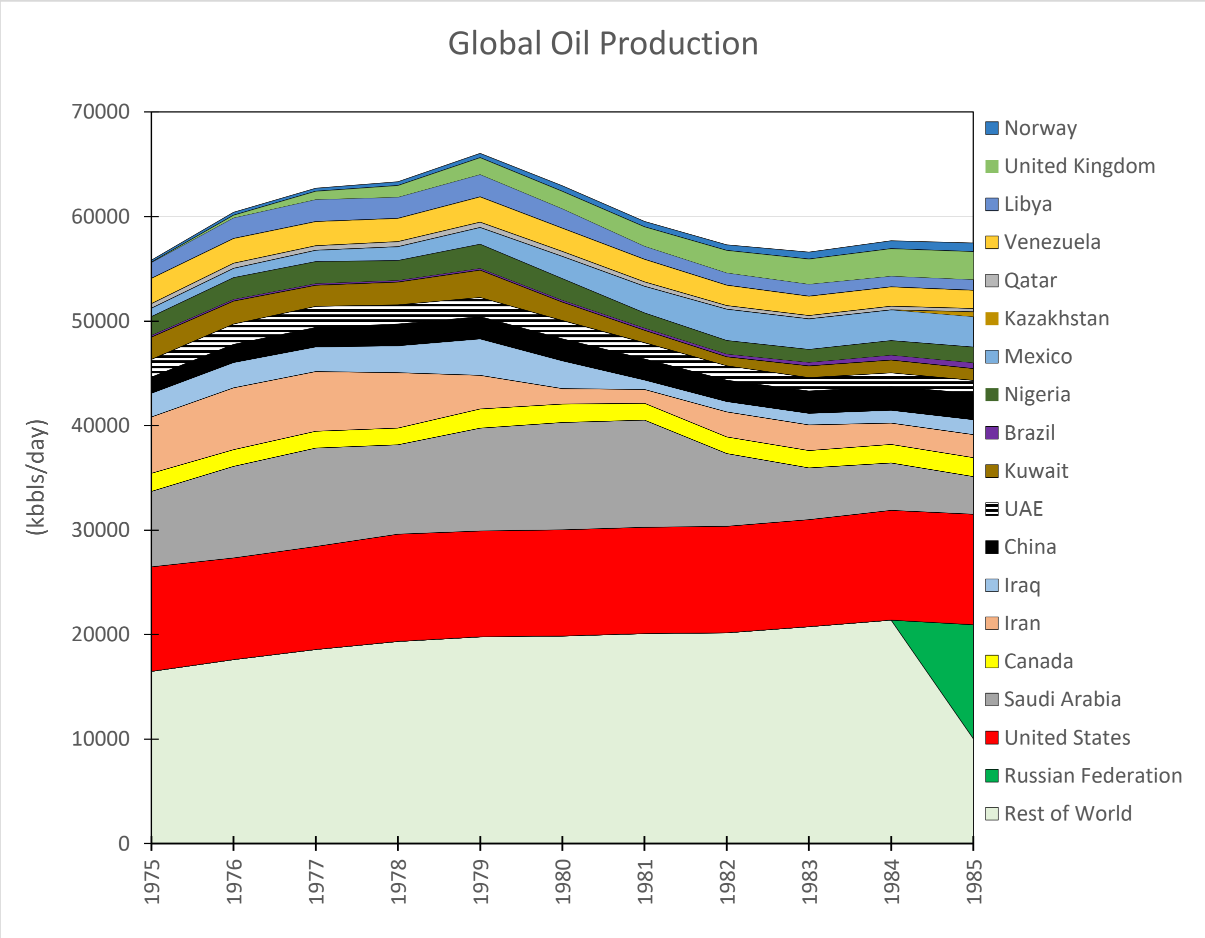


Figure 229. Global oil production 1975 to 1985. (Includes crude oil, shale oil, oil sands, condensates (both lease condensate and gas plant condensate) and NGLs (natural gas liquids – ethane, LPG and naphtha separated from the production of natural gas). Excludes liquid fuels from other sources such as biomass and derivatives of coal and natural gas.)
(Source: data from BP Statistical Review of World Energy 2019 and BP Statistical Review of World Energy 2011)

This peak was clearly created by above ground influences where first the Iranian Revolution created volatility in the oil market, followed by a step reduction in crude oil production in Iran and Iraq. This was caused by the Iran/Iraq war, which was triggered by perceived weakens in Iran and Iraqi desire to replace Iran as a dominant nation in the Arabian Peninsula. At the same time, global economic stagnation and reduction in oil demand (driven by energy conservation inspired by the 1973 oil embargo) created a glut in the global oil market. In response to this oil supply glut, oil price crashed. To address this situation, Saudi Arabia cut production in 1981, which further reduced global oil production.

This peak was visible in data structures:

- Oil consumption vs. Vehicle Miles Travelled
- Oil production
- Oil price as an immediate lagging indicator

This peak was not limited by geological restraints or financial industry instability.

14.3 The 3rd oil shock, Case study – 2005

Global conventional liquids production plateaued in January 2005 (Figure 230). Demand continued to grow (see Figure 64) as human population was also growing.

Unconventional liquids (tight oil, shale gas, etc.) started to make up the gap in global oil demand (oil supply and demand separated between 2005 and 2009. Increases in oil production since have all come from unconventional sources like Tight Oil and oil sands (see Sections 6 and 7 and Figure 113).

An excellent study to discuss and examine why the year 2005 was decisively important for supply of crude oil is the presentation: (Kopits 2014a) & associated multi-media presentation on YouTube: (Kopits 2014b).

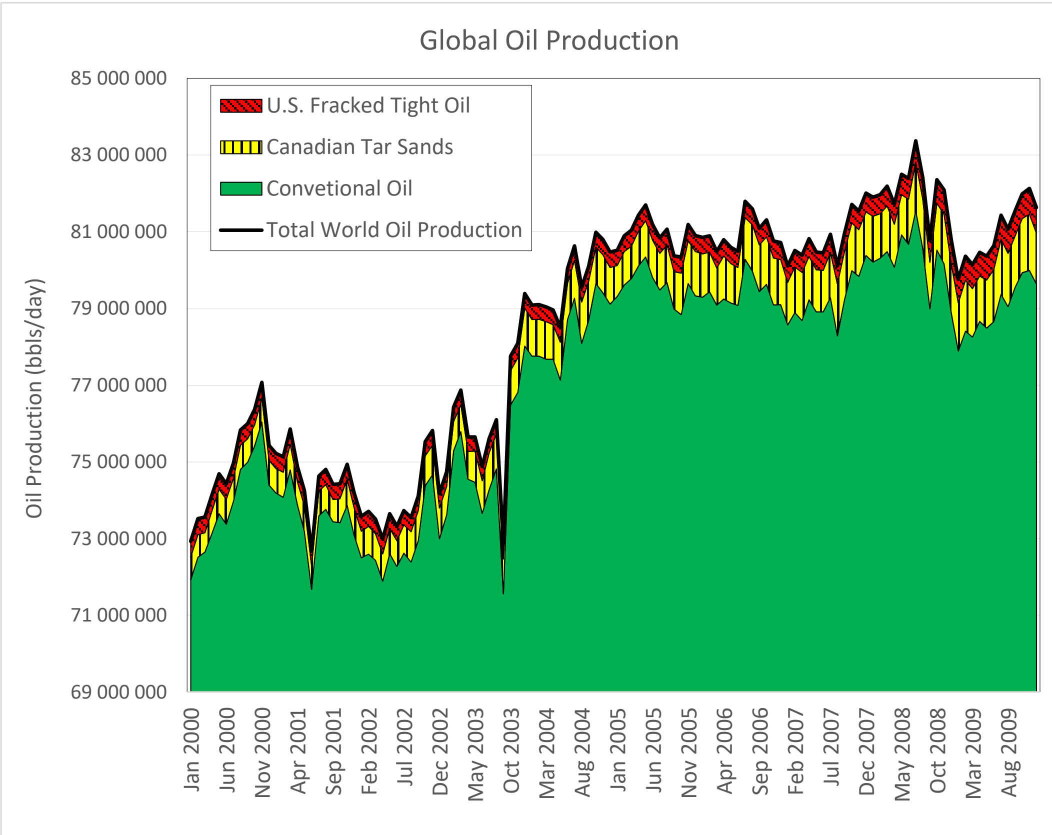


Figure 230. Global oil production 2000 to 2009. (Includes crude oil, shale oil, oil sands, condensates (both lease condensate and gas plant condensate) and NGLs (natural gas liquids – ethane, LPG and naphtha separated from the production of natural gas). Excludes liquid fuels from other sources such as biomass and derivatives of coal and natural gas.)
(Source: data from BP Statistical Review of World Energy 2019 and BP Statistical Review of World Energy 2011)

Figure 231 shows the U.S. oil consumption and Vehicle Miles Travelled in the U.S. between 1994 and 2010. A plateau can be seen from 2005 to 2007, with an actual peak in 2005. So the market responded holding a plateau for 34 months, before clear oil shock unfolding from October 2007 until the decent was arrested in 2009 and a recovery started.

The 3rd Oil Shock (correlating with the Global Financial Crisis (GFC)) started with the 2007 decent in oil price in Figure 231. The arrest of the crashing economy correlates with the start of quantitative easing program QE1 in November 2008.

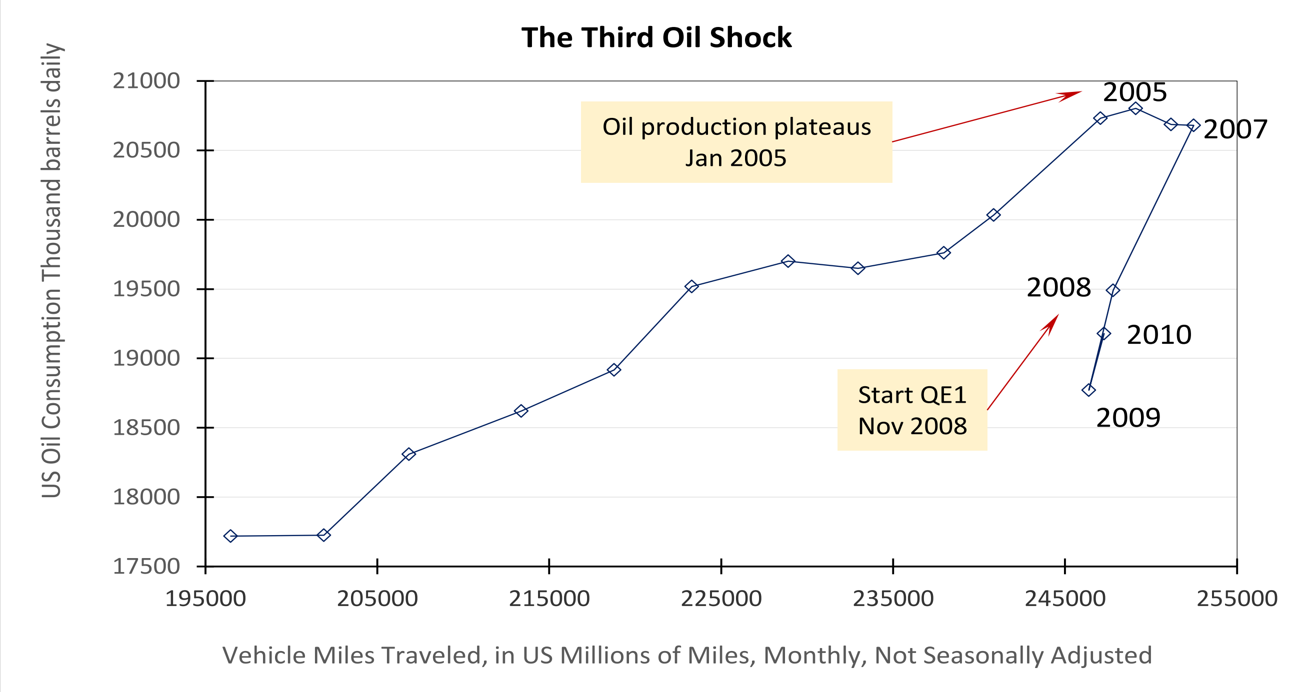


Figure 231. The 3rd oil shock - 2005
(Source: U.S. Federal Reserve Economic Data, BP Statistical Review of World Energy 2011)

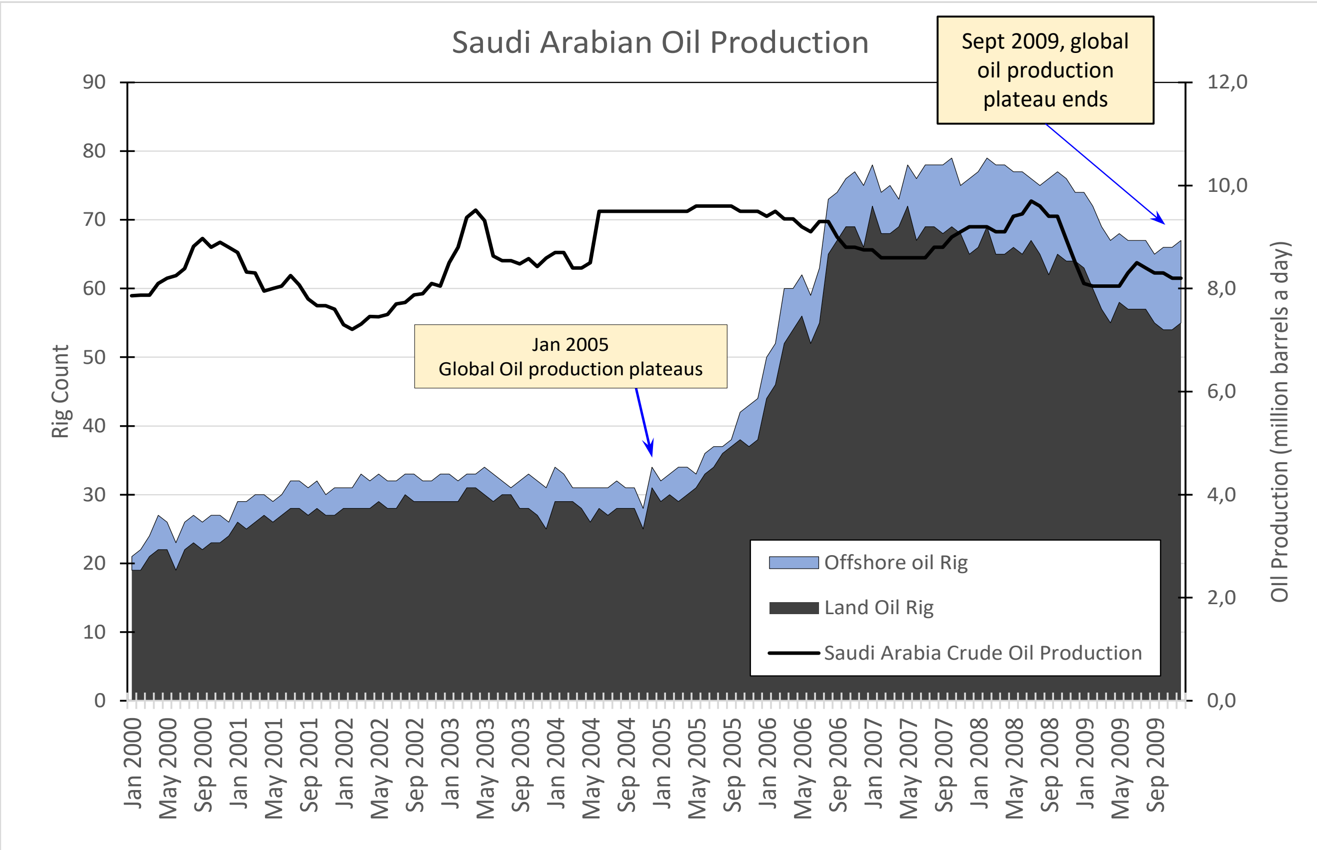


Figure 232. Saudi Arabian rig count and crude oil production, January 2000 to December 2009
(Source. Baker Hughes Rig Count data, EIA monthly production data)

Figure 232 shows the number of Baker Hughes drill rigs brought on line and oil production in Saudi Arabia from January 2000 to December 2009. During the years 2004 to 2008, the price of oil spiked from $USD50/bbl to $USD147/bbl. In that time when profit presumably was at an all-time high, Saudi Arabia brought on line more than twice the number of operating drill rigs to produce oil, yet oil production in that time remained stable. This implies that extra effort was needed just to maintain oil production. Which in turn suggests that the Saudi Arabian supply of oil is becoming less effective in oil extraction and is approaching peak oil production.

For decades, Saudi Arabia was the major oil supplier to the global industrial ecosystem. It was able to raise and lower crude oil production at will, and was often referred to as the 'Swing Producer of oil'. While it probably did this to secure its own long term profit margins, it had the effect of stabilizing the global demand for oil.

Figure 232 shows at a time when global oil production plateaued (Figure 230), the market stabilizing force was not able to raise production. Saudi Arabia expanded its rig count from 31.35 (average from October 2000 to October 2004) to 76.52 (average from September 2006 to September 2008), or a 144% increase. In that time, Saudi Arabian oil production decreased slightly. The logistics of the task of increasing such a large number of operating rigs would have taken time. The increase happened between January 2005 and September 2006. In this 19 month window, the oil market was inelastic and it put pressure on the rest of the system.

This created the conditions for a speculative bubble in oil price. Figure 233 shows the oil price from the month January 2000 to August 2009. There is no clear signature in the oil price chart that correlates with the start of the plateau in January 2005. The start of the speculative bubble was approximately February 2007, which was six months after Saudi Arabia had brought on line extra production capacity (which supports the concept of a speculative bubble). The price peak in July 2008 lags behind the start of the oil shock in October 2007 in Figure 231.

The sharp rise in oil price, put the entire global industrial ecosystem under unprecedented stress. It has been shown that oil is critically important for all other industrial (ergo economic) activities somewhere in their respective value chains. Oil was (and still is) the non-negotiable requirement for most physical work done. This persistent strain on the ecosystem of unprecedented high prices, after a short period of an inelastic supply market, pushed the whole system to breaking point. The weakest link to break under stain was the financial systems. Thus, the Global Financial Crisis was first seen in the sub-prime mortgage markets, and the New York Stock Exchange. The start of QE1 correlates with the arrest in decent of oil price in November 2008.

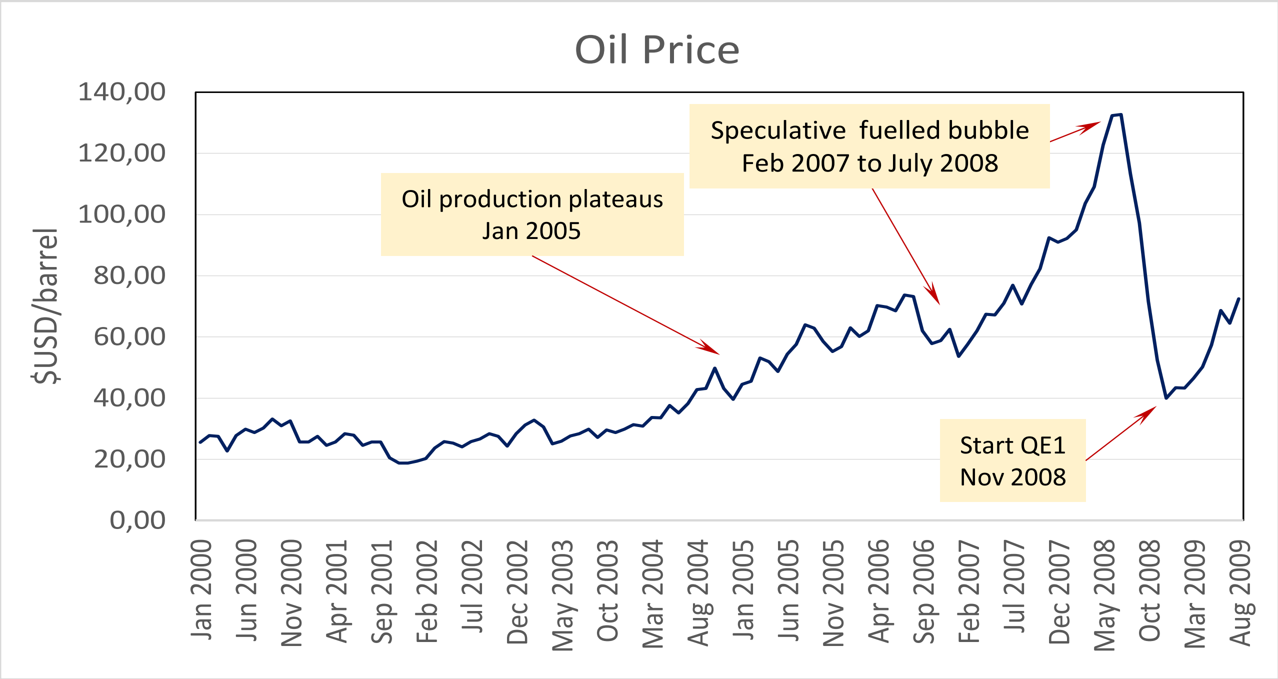


Figure 233. Oil price, Jan 2000 to Aug 2009
(Source: Brent Exchange, Europe Brent Spot Price FOB (Dollars per Barrel))

This peak was visible in data structures:

- Oil consumption vs. Vehicle Miles Travelled – January 2005 for the peak
- Oil consumption vs. Vehicle Miles Travelled – October 2007 for the actual oil shock
- Saudi Arabian rig count – January 2005
- As the start oil production of the plateau

This peak was not visible in:

- Oil price (Brent)

This peak was created geological restraints in context of the conventional oil market was not able to bring on more production. That this situation persisted for 34 months suggests this was not simply oil producers were not able to fully develop the resources they had available. This peak was not created limited by financial industry instability, but it did create conditions for a destructive speculative bubble between months February 2007 to July 2008.

This time period is critical to understand as events happened here set off a chain reaction that will define what is possible in the industrial ecosystem for the next few decades. What is vital to understand is what happened in the oil industry supply between the years 2005 and 2008, and what happened in the financial industry with the initiation of quantitative easing in November 2008. These actions in conjunction with the outcomes of strategic decisions made decades previously has placed the global industrial ecosystem in a very difficult net position.

14.4 The minor stall, the 4th oil shock. Case study – 2010

In 2010 there was a comparatively small peak and crash in the Vehicle Miles Travelled vs Oil Consumption chart (Figure 234). This peak in 2010 is much smaller when compared to the previous three oil shocks.

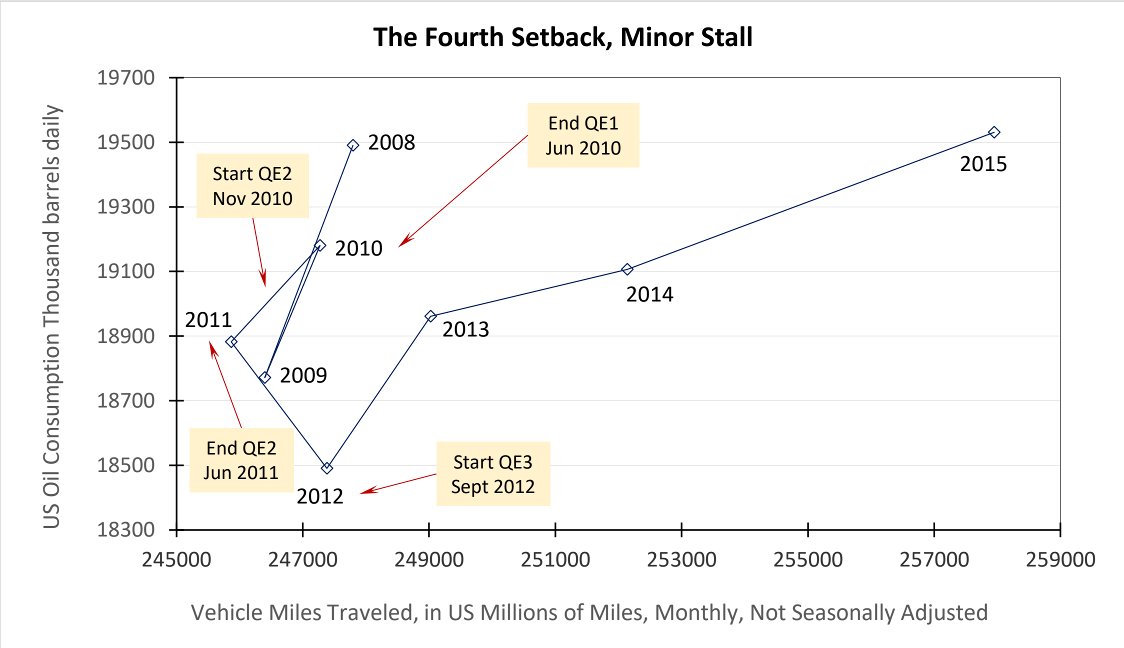


Figure 234. The 4th oil shock – 2010, the minor stall
(Source: U.S. Federal Reserve Economic Data, BP Statistical Review of World Energy 2011)

Two events of note correlate with this peak. The Arab Spring uprisings across the Middle East in 2010 to 2011, and the end of quantitative easing program QE1 on one side of the peak and the stat of QE2 on the other side of the peak.

The Arab Spring was a series of anti-government protests, uprisings, and armed rebellions that spread across North Africa and the Middle East in the early 2010s. It began in response to oppressive regimes and a low standard of living, starting with protests in Tunisia (Skinner, 2011; Maleki, 2011).

The effects of the Tunisian Revolution spread to five other countries: Libya, Egypt, Yemen, Syria and Bahrain, where either the regime was toppled or major uprisings or social violence occurred, including riots, civil wars or insurgencies. Sustained street demonstrations took place in Morocco, Iraq, Algeria, Iranian Khuzestan, Lebanon, Jordan, Kuwait, Oman and Sudan. Minor protests occurred in Djibouti, Mauritania, the Palestinian National Authority, Saudi Arabia, and the Moroccan-occupied Western Sahara.

Quantitative easing (QE) is an unconventional monetary policy in which a central bank purchases government securities or other securities from the market in order to increase the money supply and encourage lending and investment. There were several QE programs (See Section 16).

The peak seen in Figure 234 is seen in oil production (Figure 235) but as a very minor dip that is difficult to distinguish from normal data variability. The drop in production is mainly associated with a decline in conventional oil production. The peak does not correlate with oil price at all (Figure 236).

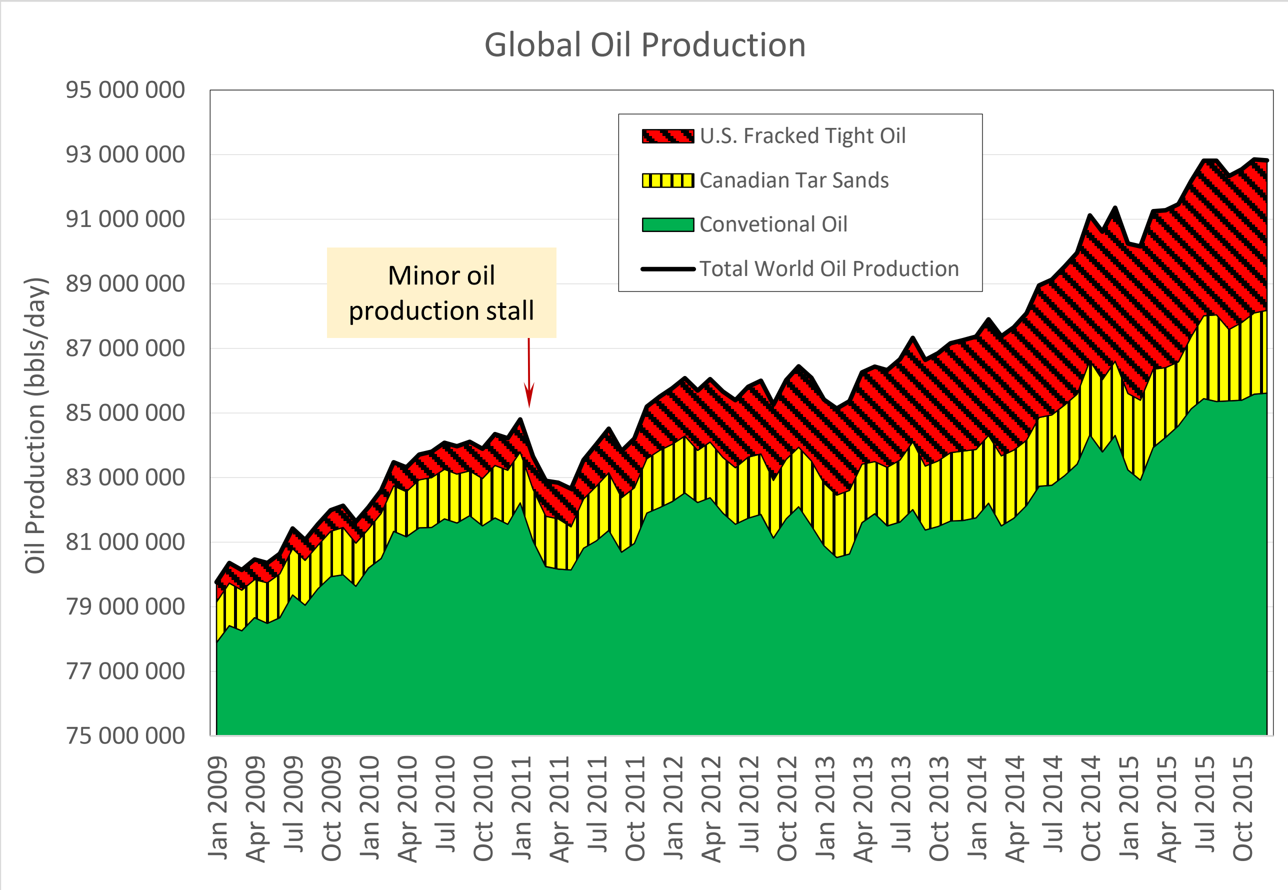


Figure 235. Global oil production Jan 2009 to Dec 2015. (Includes crude oil, shale oil, oil sands, condensates (both lease condensate and gas plant condensate) and NGLs (natural gas liquids – ethane, LPG and naphtha separated from the production of natural gas). Excludes liquid fuels from other sources such as biomass and derivatives of coal and natural gas.) (Source: data from EIA monthly global crude oil production statistics)

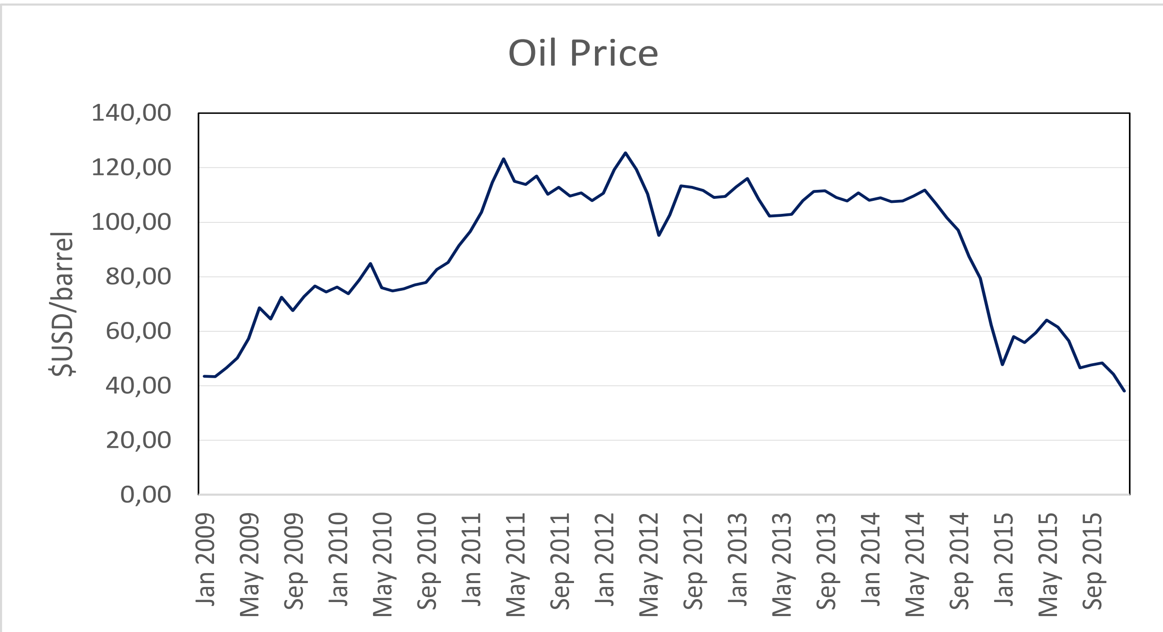


Figure 236. Oil price, Jan 2009 to Sep 2015
(Source: Brent Exchange, Europe Brent Spot Price FOB (Dollars per Barrel))

So what created the peak in Figure 234? The 3rd oil shock (peak in 2005, actual shock in 2007) triggered the Global Financial Crisis (GFC). The GFC crash was stopped in 2009 with the start of QE1 in November 2008. The oil consumption vs vehicle miles travelled signature starts to recover, but peaks in 2010. The QE1 program stopped in June 2010. Soon after the oil consumption vs vehicle miles travelled signature starts to crash again. QE2 starts in November 2010 but ends in June 2011. This did not stop the decline. It would appear that the GFC that was arrested with the application of QE1 was about to progress once more, as QE2 was not enough. The crash bottomed out on 2012, with the start of QE3 in September 2012. From that point the oil consumption vs. vehicle miles travelled signature recovers and has continued to increase consistently until present (October 2019).

So this peak was created by an economic crash that was resolved with the application of Quantitative Easing. The success of QE1 and the failure of QE2, followed by the success of QE3, suggests that the economic crash had systemic influence on a fragile system. This time frame also correlates with the Arab Spring (Skinner, 2011; Maleki, 2011). It is possible that the Arab Spring did influence the creation and severity of the peak shown in Figure 234, but the corresponding drop in global oil production does not seem large enough to support the thesis that the Arab Spring was the driving cause. The theory that QE1, while successful, was not sustainable. QE2 was successful and the decline kept happening. Once QE3 was started, the results of QE1 became a bit more sustainable.

This peak was visible in data structures:

- Oil consumption vs. Vehicle Miles Travelled – 2010
- Only visible as a minor signature in oil production

This peak was not visible in:

- Oil price

Of the four oil shocks, two were a consequence of above ground geopolitical maneuvering by oil suppliers. The third oil shock was created by a geological limit in the conventional oil production, which was addressed by the application of tight oil and oil sands production. The fourth oil shock was created by a systemic economic correction.

15 POLITICAL AND BIG BUSINESS KNOWLEDGE OF PEAK OIL

The following are the outcomes of studies done by establishment authority parts of nation state governments (not an exhaustive list).

15.1 United States Military

The United States Joint Forces Command (USJFCOM) regularly (about every two years) issues it's "perspective on future trends, shocks, contexts and implications for… the national security field." (Munroe 2010).

Amid the multitude of security threats, energy has moved rapidly to the forefront, and it is the oil supply issue which is the focus of this review. The main oil supply vulnerabilities which were cited in 2008 are reiterated, thus indicating that there has been no amelioration. It restates that:

> *"oil and coal will continue to drive the energy train" until 2030, though it warns that in order to do so, "the world would need to add roughly the equivalent of Saudi Arabia's current production every seven years".*
>
> *"By 2012, surplus oil production capacity could entirely disappear, and as early as 2015, the shortfall in output could reach nearly 10 MBD" (p. 29).*

This warning is consistent with others which have been issued (eg. the repeated verbal statements made by IEA chief economist Fatih Birol, the 2008 WEO, Paul Stevens of Chatham House, ITPOES, etc.). The Shale Revolution in the U.S. tight oil sector prevented this prediction from coming true.

The US Joint Forces Command does not exist anymore. It was dismantled many years ago and folded into a new command structure. As directed by the U.S. President to identify opportunities to cut costs and rebalance priorities, U.S. Defense Secretary Robert Gates recommended that USJFCOM be disestablished and its essential functions reassigned to other unified combatant commands. Formal disestablishment occurred on August 4, 2011.

15.2 German Government, Military

A study by a military think tank (Future Analysis department of the Bundeswehr Transformation Center for the German Military) has analyzed how "peak oil" might change the global economy (Schultz 2010). The internal draft document shows for the first time how carefully the German government has considered a potential energy crisis.

The team of authors, led by Lieutenant Colonel Thomas Will, uses sometimes-dramatic language to depict the consequences of an irreversible depletion of raw materials. It warns of shifts in the global balance of power, of the formation of new relationships based on interdependency, of a decline in importance of the western industrial nations, of the "total collapse of the markets" and of serious political and economic crises.

The report was declared classified and not for public consumption. In 2016, a copy of the report was leaked (in German). Later an English translation of this report was released (BTC 2010).

15.3 British Government

British Department of Energy, in concert with the Bank of England and the British Department of Defense, has ordered similar-and equally secret-studies on its impact (Rubin 2010). The Department of Energy and Climate Change (DECC) is also refusing to hand over policy documents about "peak oil" under the Freedom of Information (FOIA) Act requests from journalists (Guardian 2010).

15.4 British Private Industry

On 10 February 2010 at the Royal Society, six UK companies – Arup, Foster + Partners, Scottish and Southern Energy, Solar Century, Stagecoach Group and Virgin – joined together to launch the second report of the UK Industry Task-Force on Peak Oil and Energy Security (ITPOES) (Whitehorn 2010).

The Task-Force warns that the UK must not be caught out by the oil crunch in the same way it was with the credit crunch and states that policies to address Peak Oil must be a priority for the new government. One opinion concludes that the global peak production rate for oil is likely to occur within the next decade (maybe within 5 years).

The net flow rate data shows that increases in extraction will be slowing down in 2011-13 and dropping thereafter. Given the long lead-times involved in developing the necessary infrastructure, this trend is unlikely to be reversed within the next 5 years. There are now serious concerns that the free flow of relatively low cost oil, which has underpinned OECD countries economic growth since 1945, may not be sustainable for very much longer. It will be shown in this section that low-cost (under $25/b) oil supplies effectively ended in early 2005 and are unlikely to return.

- The industry is not discovering more giant fields at a sufficient rate.
- There are concerns about the levels of reserves quoted by the OPEC countries (which are critical to the confidence levels associated with future production capacity).

There are indications that underinvestment in the oil industry over the past decade has led to infrastructure and under-skilling problems that will make it particularly difficult to increase production capacity rapidly in the short-term.

15.5 International Energy Agency

Consistently optimistic in the past about future energy supplies, the IEA undertook its own field-by-field survey of oil reserves in 2008 and has become increasingly concerned about oil supplies. This year the agency explicitly discussed peak oil for the first time and proclaimed that conventional crude most likely peaked in 2006 (Staniford 2010). It continues to believe unconventional oil from the tar sands, the Arctic and deep-water fields along with natural gas liquids can make up for declining conventional oil and lead to increases in world oil production for two more decades. But it warns that this is no longer a foregone conclusion without the necessary and rather large investment required. In 2008 the chief economist of the IEA, Dr Fatih Birol, wrote in a guest editorial in the British newspaper The Independent that:

"we should leave oil before it leaves us."

15.6 US Dept. of Energy

The report (written for the US Dept. of Energy's National Energy Technology Laboratory (DOE, NETL)), published in February 2005, is more commonly known as the "Hirsch Report." This extraordinary document examines the time frame and implications of Peak Oil, and looks at what preparations need to be undertaken at a national level to mitigate its impacts.

The Hirsch Report notes that over the past century the US economy has been shaped by the availability of low-cost oil and that Peak Oil will present the US with economic losses that will be measured in the trillions of dollars. According to the report, peaking oil production will be abrupt, providing little time to evolve. Consequently, the repercussions will be revolutionary. And without massive mitigation, the report warns, the problem will be pervasive and long-term. Such mitigation efforts will require abundant preparation and substantial time, the report warns. Waiting until production peaks would leave the world with a liquid fuel deficit for 20 years. Initiating a crash program 10 years before peaking leaves a liquid fuels shortfall of a decade. However, initiating a crash program 20 years before peaking could avoid a world liquid fuels shortfall.

However, despite being commissioned by the DOE, the Hirsch Report was buried by the department and is generally not referred to.

15.7 Geopolitical aspects of oil

The systemic relevance and strategic significance that is ascribed to oil in particular and to secure energy supplies in general is also reflected in various strategic documents of states and international organizations. The international community as well as every single country therefore have a vital interest in secure oil supplies.

> ***The list of reports in Sections 15.1 to 15.6 and their conclusions mean that peak oil is a known quantity that has been studied by the governments, military, banking and private industry sectors of United Kingdom, Germany (EU) and the United States.***

It should be noted that all the government studies cited on this issue were published nearly a decade ago. At the time, all of these reports were made confidential, citing national security reasons. Since then, there has been an absence of recent material.

- In spite of the conclusions of the listed reports (some inferred, some read directly), the official stance of those same governments has been one of the cornucopian view that oil is in large supply.
- It implies a fundamental misreading/misunderstanding of the biophysical economics of oil, particularly of the shale oil and gas revolution.
- It is clear that public understanding of the concept of supply risk for oil and gas products has been suppressed, suggesting a deeply unpopular and unpalatable set of mitigation strategies.
- It can be noted how frequently these nation states (United Kingdom, United States, Germany, France, European Union) have been in a geopolitical event, regime change support (official or unofficial) or diplomatic sanction against or in a foreign country with large oil reserves in the last 20 years alone. The second Iraq war in 2003 in particular, which has since been admitted to be initiated on fragile intelligence.
- Prognosis for a sustainable solution that supports the long term security of the Western nations (U.S. Europe and the U.K.) remains unresolved and a practical path forward remains unclear.

The European Security Strategy (ESS) of 2003 considers the EU's foreseeable dependence on energy imports, which is expected to rise from 50% (2010 figure) to 70% by 2030, to be an issue of concern.

The debate in the US, too, clarifies the growing importance of national energy supply. In 2001, the then US Vice President stated in the document that became known as the "Cheney Report" that the daily import of crude oil into the United States would have to increase by 60% between 2001 and 2010 and declared that the Gulf Region was vital to American interests. Since then, the fracking tight oil industry in the United States has developed (National Security Strategy - White House 2010).

In its White Paper entitled "China's National Defense in 2008", the People's Republic of China also states that the global energy issue, amongst others, is gaining more importance worldwide and that deep-seated contradictions exist with regard to interests in this context (China's National Defense in 2008).

Russia, too, sees the increasing global shortage of fossil raw materials as a potential risk for the country's national security (National Security Strategy of the Russian Federation until 2020, Decree No. 537). Against this background, the country's new security strategy explicitly emphasizes, amongst other things, the need to build up strategic fuel reserves.

India has been the world's third biggest energy consumer since 2015 (BP Statistical Review of the World Energy 2019). This explains the significance of energy supply to this important threshold country and why, for several years now, India has intensified its external relations with energy-rich regions such as Africa, Latin America, and Central Asia and, last but not least, the Middle East, one of the aims being to diversify its oil imports.

Consider the data shown in Figure 237, global oil reserves in 1990 (LHS) and in 2018 (RHS).

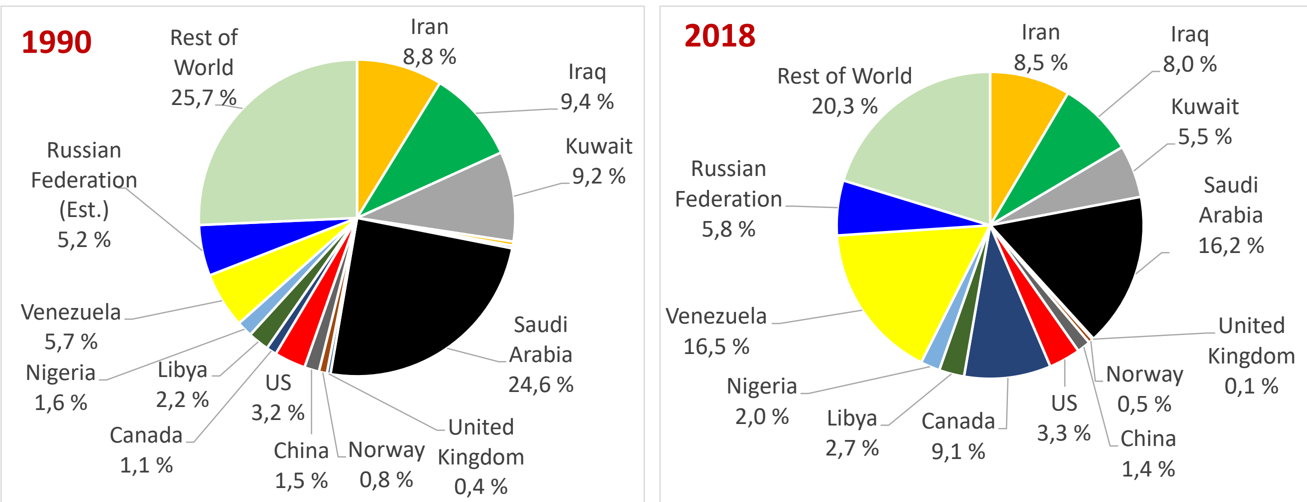


Figure 237. Stated oil reserves in 1990 (LHS), Stated oil reserves in 2018 (RHS)
(Source: BP Statistical Review of the World Energy 2011, BP Statistical Review of the World Energy 2018)

Consider the data shown in Figure 238, global oil consumption in 1990 (LHS) and in 2018 (RHS).

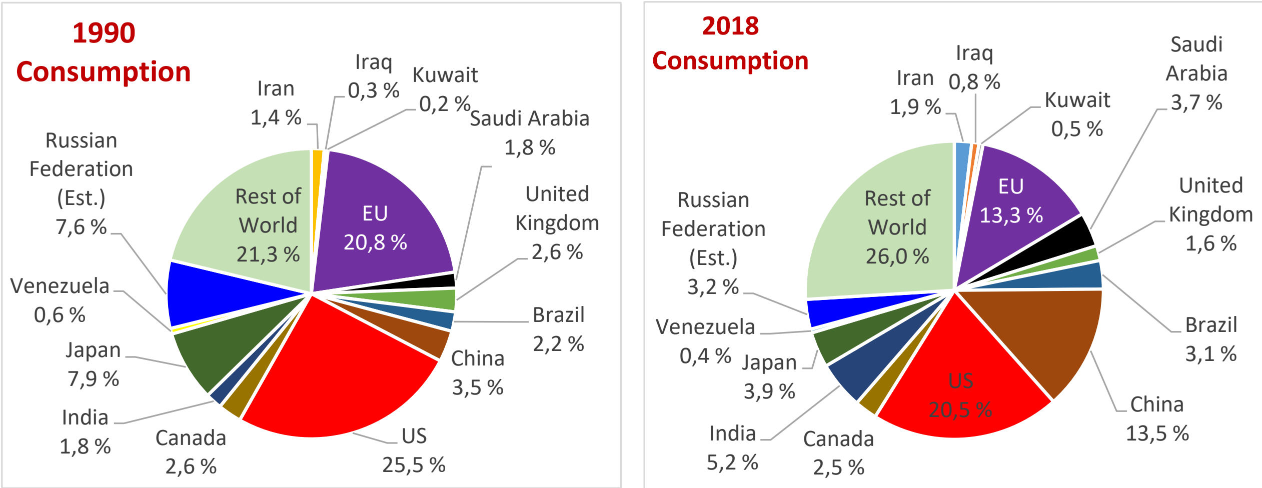


Figure 238. Oil consumption in 1990 (LHS), Stated oil reserves in 2018 (RHS)
(Includes consumption of biogasoline (such as ethanol), biodiesel and derivatives of coal and natural gas)
(Source: BP Statistical Review of the World Energy 2011, BP Statistical Review of the World Energy 2018)

Now consider the following geopolitical events (also shown in Figure 239).

- In 1980, Iraq (9.4% of 1990 global oil reserves) invaded Iran (8.8% of 1990 global oil reserves). The United States, Britain, the Soviet Union, France, and most Arab countries provided political and logistic support for Iraq.
- In 1991, Iraq (9.4% of 1990 global oil reserves) invaded Kuwait (9.2% of 1990 global oil reserves). The U.S., U.K., Canada, Australia, France, Argentina, Kuwait then invaded Iraq (with logistical support from Saudi Arabia, Egypt, Bangladesh) in the Gulf war (1990-1991).
- In 2003, U.S., U.K., Australia, Poland, and Peshmerga invaded Iraq (9.6% of 2003 global oil reserves) with logistical support from Canada, Netherlands, Italy in the Iraq War (2003-present).
- In 2011, NATO (led by France and U.S.) invaded Libya (only 2.2% of 2011 global oil reserves, but had the largest deposits of light sweet crude) with logistical support from U.S., Egypt, France, Qatar, Switzerland, Moldova.
- Since 2001, the U.S., U.K., and the E.U. has threatened Iran (8.8% of 2001 global oil reserves) with military action, surrounded Iran with military bases and has applied economic sanctions (Clark 2007).
- Since 2001, the U.S. has threatened Venezuela with military action and applied economic sanctions. In 2018, Venezuela has 16.5% of global oil reserves (Clark 2007).
- Since 2014, the U.S., U.K., and the E.U. has applied economic sanctions against the Russian Federation (In 2018, Russia has 5.8% of global oil reserves). While those sanctions are described as being for a gas pipeline in the Baltic Sea, Russia as an economy has been subject to a number of economic diplomatic actions.

Compare the list of reports examining peak oil carried out by governments in Sections 15.1 to 15.6, with the countries that have been involved in military action and/economic sanctions (see the list above) against countries that have internationally significant oil reserves (see Figure 237).

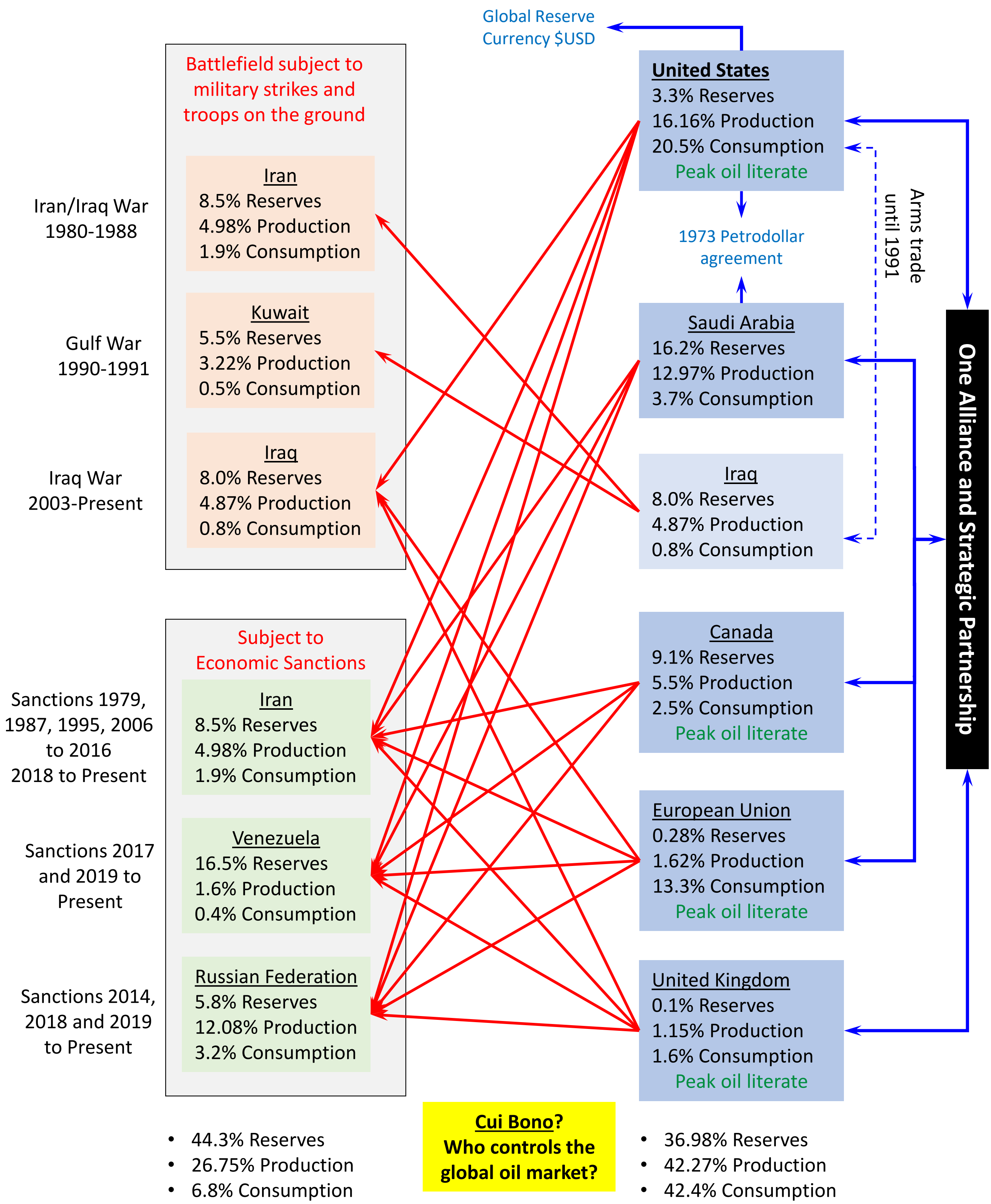


Figure 239. Countries with significant oil reserves, oil consumption and production that have been engaged in military action and the imposition of economic sanctions in the last 39 years

There are 193 countries that are members of the international United Nations Assembly, all of which use and depend on oil. The 10 countries shown in Figure 239 represent:

- 77.9% of global oil reserves
- 64.1% of global oil production
- 48.4% of global oil consumption

A case can be made that the conflicts (military and economic) shown in Figure 239 can be seen as a contest in who controls the oil market as that market approaches peak crude oil production. It is beyond the scope of this report to untangle the complexities of each of the conflicts shown in Figure 239. Needless to say, those conflicts did happen and those sanctions were applied by those nation states. There is a credible school of thought that suggests oil as a critical resource has been used as a weapon in the application of hegemonic power.

15.8 Geopolitical events of note and oil price

This report has shown that not only is the current industrial society heavily dependent on oil much of the geopolitical problem solving has involved oil at some point. The Petrodollar agreement in 1973 forced the entire global market to use and engage in the $USD fiat currency system. The petrodollar is any oil purchase or trade by an oil-exporting country is to be done in $USD. Since the dollar is a global reserve currency, all international transactions are priced in dollars. As a result, oil-exporting nations must receive dollars. Most of them own their oil industries. That makes their national income dependent on the dollar's value. If it falls, so does their revenue.

Table 24 and Figures 240 and 241 show the price of oil over a range of time periods. On each chart against the observed market price of oil are notable geopolitical events, market crashes and supply restrictions applied by the OPEC cartel.

Note the lack of large signature in Figure 240 for the collapse of the Soviet Union in December 25th, and the lack of a drop in oil prices in Figure 241 for World War II between years 1939 to 1945.

Table 24. Insights on the causes of key oil-economy events from different research communities (Source: Kallis et al 2016)

Event	Oil economics	Macro economics	Political economy	Ecological economics
Oil and economic crises 1973 & 1979	Growth and rising demand from developed economies (Kilian) vs. supply interruptions from events in Middle East (Hamilton).	Wrong policy response by the Fed which fearing inflation by oil prices precipitated recession by raising interest rates (Bernanke et al). US inflation and depreciation of the dollar to which OPEC responded by restricting production (Frankel).	End of Bretton Woods, US unable to finance Vietnam war un-pegged from gold and became a global importer of surpluses, "recycling" pet-rodollars (Varoufakis, Spiro). U.S. supported higher prices given dollar devaluation to back up Shah's regime in Iran (Anderson, Engler).	Resource limits to growth.
Low oil prices – low growth 1985–89 High oil prices – high growth 2002–2007	Tax reform and low investment in US oil industry (Edelstein & Kilian). Effect of oil prices on expenditures is cumulative and until 2007 hadn't passed the threshold where households change consumption patterns, hence no effect on growth (Hamilton). Prices increased because of economic growth and industrial demand from Asia, which more than compensated for negative effects of high oil prices – the effects of a demand-driven rise of oil price take time to show (Kilian).	– Independent monetary authorities responding to core inflation did not repeat mistakes of the 1970s (Blanchard & Gali, Nordhaus). Growth in oil-producing countries and in countries exporting to them overcompensated for negative effects from high oil prices (Rasmusen & Roitman). Asian savings and petrodollars flooding US, pushing interest rates down, keeping growth high and creating housing and commodity asset bubbles (Caballero et al)	U.S. worked with Saudis to increase oil production and damage Soviet Union (Gaidar, Schweizer) Strategic underinvestment by major producers in order to maintain high prices (Smith). Petrodollars channeled from US consumers and developing countries to oil producing nations, and from them back to US Treasury and global banks and corporations (Spiro, Sager).	Prices did not reflect real scarcity of oil. (No explanation about low growth) Resource limitations – major producers could not increase production even if they wanted Over-borrowing and credit/housing bubbles sustained household consumption and growth despite rising oil prices (Martinez-Alier)
Oil shock 2008 – Financial crisis	Rising demand from the East facing. stagnating oil production (Kilian, Hamilton). Reduced expenditures, esp. for cars and houses, from US households tilting economy to recession (Hamilton). Foreclosures in suburbs facing high commuting costs (Cortright, Kaufman et al).	With the subprime mortgage and housing bubble broken, Asian savings and petrodollars shifted to oil. Oil prices appreciated, while the economy collapsed because of the collapse of the housing bubble (Caballero et al).		Peak oil increased oil prices to unsustainable levels causing recession, which in turn led to the collapse of the credit/housing bubbles. (Daly, Martinez-Alier)
Slump of oil prices 2014c, limited recovery	Expectations for a growth slow-down and to a lesser extent higher global oil production (Baumeister & Kilian).	Negative economic effect from low oil prices on domestic US (shale) oil industry (Krugman). Expectations for tightened US interest rates in the near future (Frankel). Appreciation of the dollar (Tokic).	Saudi Arabia increasing production to drive US competitors out of the market.	Low EROI of the new supplies of unconventional oil? (Kerschner and Capellán-Pérez)

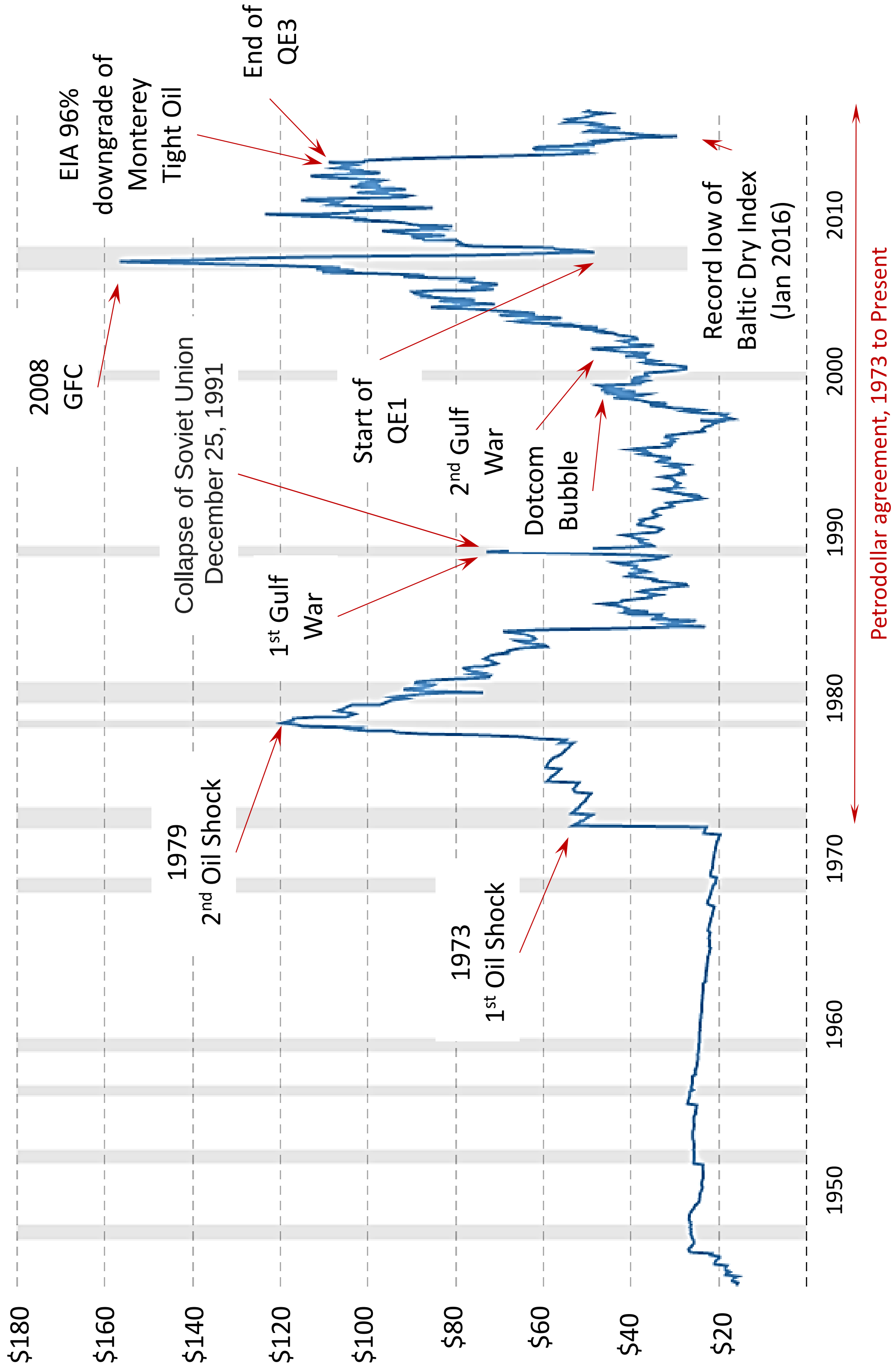


Figure 240. Crude Oil Prices - 70 Year Historical Chart 1946 - 2017
(Source: Data from Interactive charts of West Texas Intermediate (WTI or NYMEX) crude oil prices per barrel back to 1946. The price of oil shown is adjusted for inflation using the headline CPI and is shown by default on a logarithmic scale. The price of WTI crude oil as of August 03, 2017 was $49.20 per barrel.)

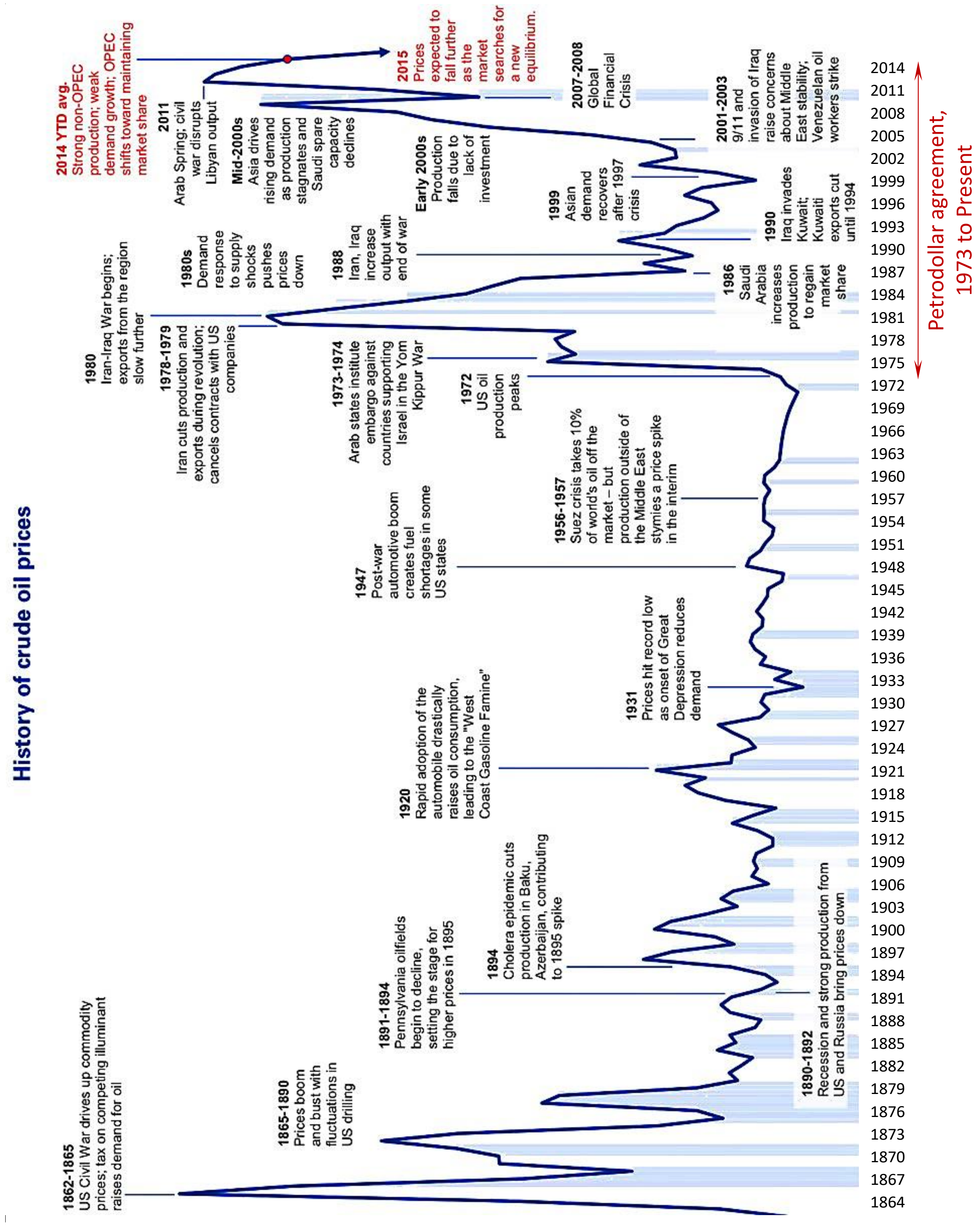


Figure 241. Oil market price (West Texas Intermediate WTI or NYMEX) in context geopolitical events, 1863 to 2014 (Source: data from Business Insider, BP Statistics, Goldman Sachs Global Investment Research, Money Morning Staff Research)

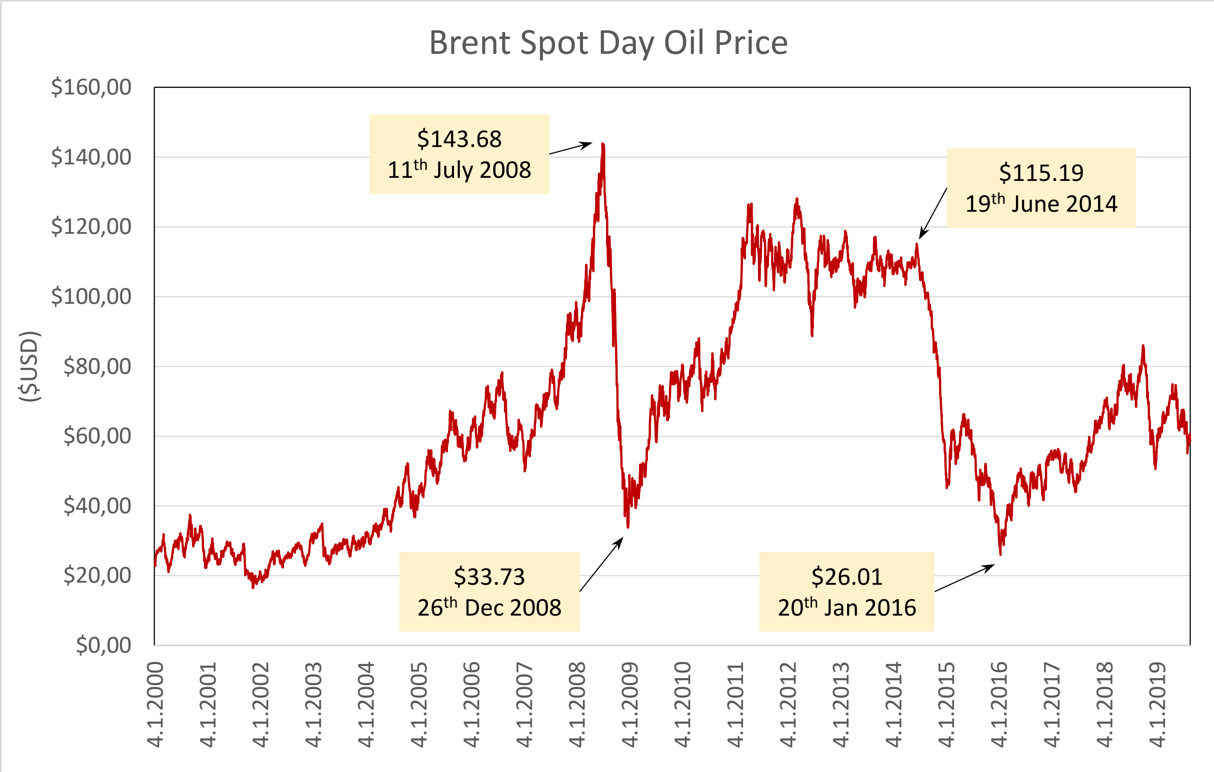


Figure 242. Brent Spot day price for oil
(Source: Brent Exchange, Europe Brent Spot Price FOB (Dollars per Barrel))

15.9 Oil price as an indicator relating to economic downturns

Over the last 160 years, it can be observed that the oil price can be related to severe economic downturns (but not exclusively so). It is also a lagging indicator in terms of geopolitical events of a certain style (examine the peaks and events of Figures 240 and 241). There is a complex discussion to be had in terms of whether oil price change is a cause or an effect of a given economic/geopolitical event.

Figure 243. The price of oil as a leading indicator and as a lagging indicator

It is postulated that the oil price is the heartbeat of our global industrial society, as our current society is a fossil fuel petroleum supported ecosystem (oil in particular is more influential than other energy resources). The supply demand dynamic is inelastic and highly susceptible to influence. Oil is so important that it has a distinct and measurable geopolitical interaction. It is for these reasons, not only should oil be part of the European Commission CRM list, <u>it should be the primary CRM</u>.

16 THE LINK BETWEEN OIL AND FINANCE

Our industrial systems also are an interdependent dynamic self-adjusting network. The raw materials we extract, manufacture, distribution, and the monetary system we use to manage the flow of materials all can be seen as one system.

16.1 Oil price - the link between oil and finance markets

A case can be made that the interaction between oil price and economy has changed. The 1973 and 1979 oil shocks did have a very inelastic impact on the economy on a global scale. Spending was affected. Demand to purchase real estate property and the sales for automobile cars were impacted.

A popular argument among macro-economists was that the U.S. recessions that followed the big oil shocks in the 1970s were not caused by the increase in oil prices per se, but by the U.S. Federal Reserve's contractionary response to them. In this view what pushed the economy into recession was the ill-founded decision by the U.S. Federal Reserve Bank to raise interest rates in order to control the supposed oil-induced inflation (Bernanke *et al* 1997). This argument was mobilized in the early 2000s to explain why high oil prices had no negative effect in the economy. The reason supposedly was that inflation policy had changed and the mistakes of the past were no longer repeated, defusing the main pathway through which oil prices affected the economy.

Oil prices, however, had increased inexorably from 2002 to 2007. Why did they not impact consumer spending earlier? Indeed, up until 2008 it was this paradox (not the means by which high prices affect the economy) that concerned economists. Why did the sharp and durable rise in oil prices between 2002 and 2007 not have the dramatic effects of the 1970s shocks (Blinder and Rudd, 2008)? The general consensus (Kallis *et al* 2016) was that the link between oil prices and the economy had been broken. Four propositions were put forward to explain this:

1. The increase in prices in the 2000s was gradual and not abrupt as in the 1970s. This was thought to have given the economy time to adjust and reallocate resources.

2. The US economy was much less dependent on energy than before and hence a rise in energy costs had much less of an impact (Nordhaus, 2007).

3. The labour markets were now more flexible, and higher costs as a result of oil prices were absorbed by lower wages (Nordhaus, 2007).

4. The structure of the car industry had changed, American companies producing fuel-efficient domestic cars, the sales of which increased as oil prices went up (Kilian, 2008).

5. A combination of points 1-4

Yet the spike in oil price can be linked to a change in supply and demand, where the price almost tripled in a 3 to 4 year period in a bubble like structure. Then in late 2008, the bubble burst and the most serious economic correction since the 1929 Great Depression was initiated (later called the GFC or the Great Recession). Since then, industrial stagnation has persisted on a global scale.

Using the ecological economic approach, it can be shown that the oil market still is at the heart of the current industrial system, but since the addition of financial instruments (like Quantitative Easing and CDS Derivatives) the interaction is not as direct. It can now be seen as a consequence of a bubble blowout.

Another perspective on why the increase in oil price did not directly impact consumer spending is how many parts of the system interact. Oil price is directly connected to the finance world. An action in the finance sector can relieve pressure in another part of the system (finance for example).

> "During a financial expansion (i.e. credit hyper-expansion), consumers can always borrow at low interest rates in order to offset higher costs. Real interest rates were negative, so people were being paid to borrow. The wealth effect from the housing boom made them overconfident and complacent about borrowing. They could always refinance their home if they needed money. The result has been a massive debt trap. The downside is going to be brutal once the negative wealth effect of the next housing bust sets in."

Nicole Foss – Industrial Ecologist

As oil is a vital part of our industrial society (see Section 1), *a sustained rise in oil price over a few years (2004-2008) will put pressure on the entire system*. As such, there will come a point where that system will be under such strain that something would blow out. The oil price spike in 2004 to 2008 preceded the largest global economic correction seen since the 1929 Great Depression. This has been labeled the Global Financial Crisis of 2008 (GFC). Just one of the outcomes was a large correction in the U.S. housing market. The stock exchange crashed and trading was stopped on several occasions. The whole finance system was with a few hours from complete paralysis (Mathiason 2008).

As a direct consequence of the GFC, quantitative easing (QE1, QE2 and QE3 programs) were deployed by the U.S. Federal Reserve Bank (Yellen 2017). Since then central banks around the world have been engaging in Quantitative Easing (colloquially referred to as the printing of money). This is dangerous as it deteriorates the integrity of the monetary system. The volumes of money being created through QE is historically unprecedented.

So the question becomes, where did this money go? Figure 243 shows the Federal Reserve total assets chart.

So it can be shown that the US Federal Reserve has been printing money through the Quantitative Easing program, then retaining the bulk of it ($2.5 trillion USD) as excess reserves, thus muting the hyperinflation outcomes (for now). With the remaining 1.75 trillion dollars, the Federal Reserve has been buying blue chip stocks and foreclosed mortgages resulting from defaulted loans. The largest landlord in the United States is the Federal Reserve Bank (Yellen 2017).

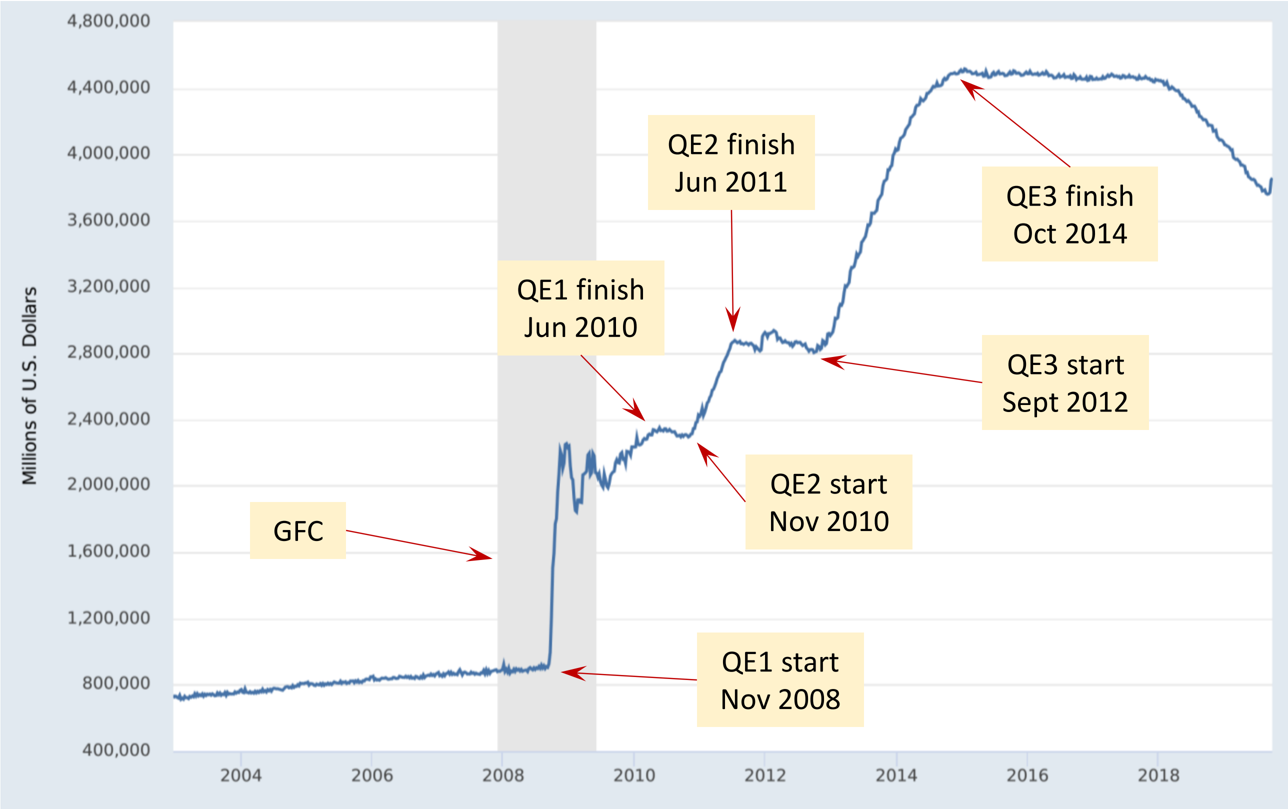


Figure 244. Total Assets (less elimination from consolidation) in the U.S. Federal Reserve Bank (Source: 2019 FRED research Excess reserves in the U.S. https://fred.stlouisfed.org/series/WALCL) (Copyright License: https://creativecommons.org/licenses/by-nc-sa/4.0/)

As can be observed, what was started in 2008 has been continued, dwarfing all historical precedents. Prior to 2008, the Federal Reserve balance sheet had $880 billon USD ($ 0.88 trillion USD). In 2017, it is a little under $4.5 trillion dollars USD. To be clear, that extra $3.62 trillion dollars debt was literally mouse clicked into existence, 97% of which only exists as numbers in an electronic ledger. *This money is not associated with any large asset or physical outcome*.

Figure 242 shows the price of oil crashed approximately 76% between 11th of July 2008 and 26th December 2008 (Brent Exchange, Europe Brent Spot Price FOB). The GFC was recognized as a fully-fledged financial crisis developed into a full-blown international banking crisis with the collapse of the U.S. investment bank Lehman Brothers on September 15th, 2008. To arrest the progress of the GFC induced Wall Street stock market crash, the U.S. Federal Reserve Bank QE1 program was started in November 2008 (Figure 244). At the same time, the price of oil rose approximately 212% across the QE1 time period. When QE3 finished on October 2014, the oil price crashed approximately 37% over the next 10 months.

To put these Quantitative Easing volumes in historical context, Figure 245 shows the volume of money printed in the United States, compared to what was the cost of major historical projects in the previous century (excludes US Civil war, WWI, and WWII).

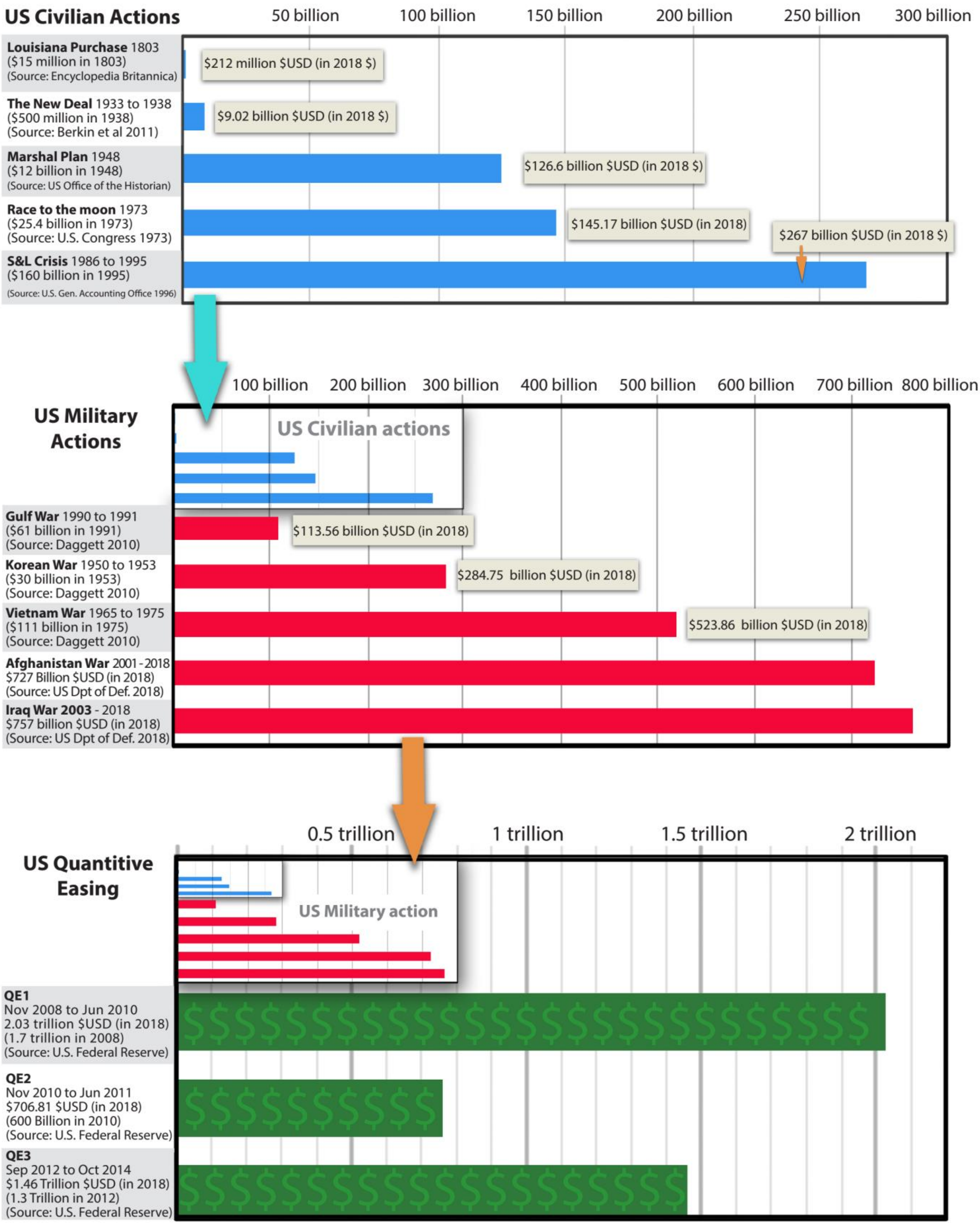


Figure 245. Scale and scope of U.S. Quantitative Easing compared to historical actions
(Inflation adjusted from the dated event to $USD in 2018)
(Source: QE data from 2019 FRED research Excess reserves in the U.S. https://fred.stlouisfed.org/series/WALCL)
(Image: Tania Michaux)

The United States is not the only nation to engage in printing money to keep economic growth positive. The European Union, Japan, China and the United Kingdom all have engaged in unprecedented quantitative easing to prop up growth in the global economy (Nelson 2018 and Guardian 2015). Since the year 2001, approximately 13 trillion dollars ($USD) has been inserted into the economy where most or all of that currency would have had to be printed (money creation from nothing). Table 25 shows a summary of Quantitative Easing since it was started in Japan in 2001.

Table 25. A summary of Quantitative Easing globally (not inflation adjusted)
(Source: U.S. Federal Reserve Research, Bank of England, World Bank, Bank of Japan)

Country	Quantitative Easing	Central Bank	Date	Added money supply to global economy
United States	QE1 US Fed	U.S. Federal Reserve (US Fed)	Nov 2008 to Jun 2010	1.7 Trillion $USD (Dollars)
United States	QE2 US Fed	U.S. Federal Reserve (US Fed)	Nov 2010 to Jun 2011	600 Billion $USD (Dollars)
United States	QE3 US Fed	U.S. Federal Reserve (US Fed)	Sept 2012 to Oct 2014	1.3 Trillion $USD (Dollars)
China	Chinese economic stimulus plan (擴大內需十項措施)	People Bank's of China (PBoC)	2008 to 2019 (debt controls started in 2014)	5.5 Trillion $USD (Dollars)
Japan	QE1 BOJ	Bank of Japan (BOJ)	Mar 2001 to Mar 2006	36 Trillion Yen ¥ (330 Billion $USD dollars)
Japan	QE2 BOJ	Bank of Japan (BOJ)	Apr 2013 to present	145 Trillion Yen ¥ (1.4 Trillion $USD Dollars)
Europe	Government bond purchase	European Central Bank (ECB)	Mar 2015 to Dec 2018	2.6 Trillion € Euros (1.7 Trillion $USD dollars)
United Kingdom	QE1 BOE	Bank of England (BOE)	Mar 2009 to Jan 2010	200 Billion £ British Pounds (320 Billion $USD dollars)
United Kingdom	QE2 BOE	Bank of England (BOE)	Oct 2011	75 Billion £ British Pounds (119 Billion $USD dollars)
United Kingdom	QE3 BOE	Bank of England (BOE)	2013 to 2014	100 Billion £ British Pounds (170 Billion $USD dollars)

Sum 13.14 Trillion $USD

The effects are remarkable however. The severe economic downturn that started in 2008 (the GFC), had the capacity to fundamentally destroy the entire monetary system and came within a few hours of permanently paralyzing the banking credit system (Mathiason 2008 and Kingsley 2012).

It was possible that if the QE program was to be stopped or even tapered, the stock markets in the US and around the world would be devastated. QE3 was stopped in October 2014. The years 2015 and 2016 were marked with economic and industrial volatility. At the time of the writing of this report, the U.S. Federal Reserve intervened in the banking sector in the Repo market (and taking great lengths to reassure the public that this is NOT quantitative Easing) (Marte 2019 October 10th). Approximately 70 billion $USD was applied to the overnight lending markets each night since September 17th 2019, and has continued in early November 2019.

This has been a remarkable deal for those favored institutions in the US (and Europe). Economic activity and industrial activity was indeed impacted with the discontinuation of QE3.

"It can be argued that we are living through the greatest financial experiment in history"

Chris Martenson – CEO and Co-founder of Peak Prosperity

The relationship between energy (oil in particular) and debt is illustrated in Figure 246. The spiral shown in Figure 246 was made possible due to all currencies being fiat, that Quantitative easing was allowed, and that all oil had to be priced in $USD (the global reserve currency). When it becomes apparent that the financial debt is far greater than the physical real assets, a systematic correction is probably unstoppable and possibly disruptive.

Oil consumption as an energy raw material supply input correlates with GDP (see Figure 16 and Figure 250, looking at the time period prior to 1971). Oil has been shown as a direct proxy to the functionality of the real economy. Economic activity while supported by energy inputs (oil) is also defined by economic affordability. How much money is available for consumers to engage in economic activity? Prior to 1971 (see Figure 250), the two above concepts were overlaid and correlated strongly. After 1971, currency supply decoupled from real economy.

Affordability for costlier oil was accommodated with growing credit/debt. This model is now subject to some strong headwinds. And the central banks have little room left on their balance sheets to address this situation but applying more quantitative easing. As the consequences from too much credit/debt starts to unwind (this may have already started), oil demand/consumption would have to drop accordingly (may have already happened) and the oil price to remain subdued (resulting in lower global economic activity in the real economy).

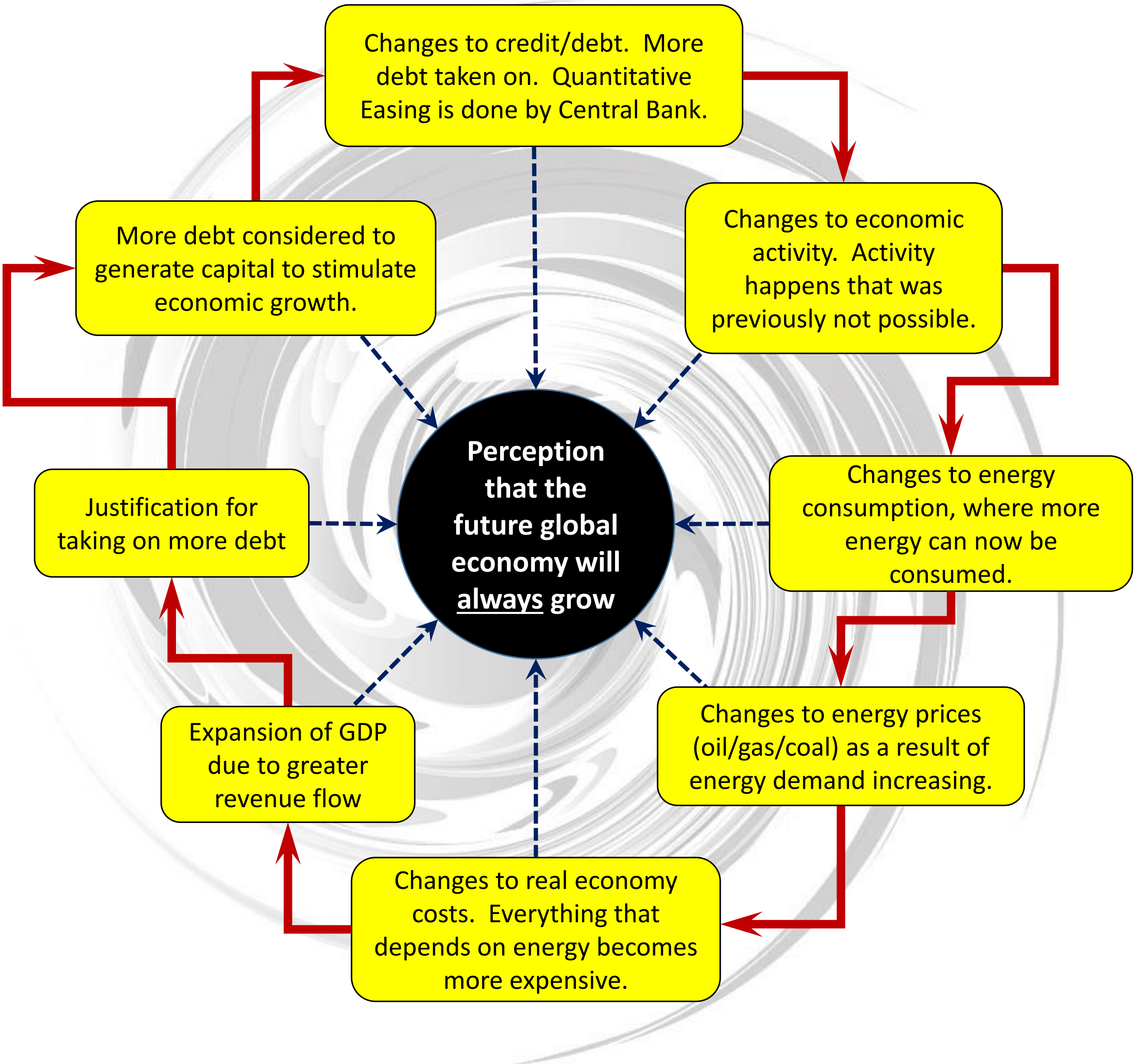


Figure 246. The debt to energy price to GDP to QE spiral (concept developed from Likvern 2019)

This will result in lower capital investment for new operations (expanding capacity as older operations are decommissioned after depletion). The reduction in consumer affordability of oil products will be due to economic recessionary drags. This means that investment in infrastructure and exploration will not happen, leading to reduced capacity in the future.

What the spiral shown in Figure 246 has achieved during the past 45 to 50 years has been to use growth in credit to pull demand forward in time. This has established a difficult paradox. The perceived value of the accrued debt far exceeds the physical assets it is based on. As oil will soon deplete in reserves and decline in production, the future of oil energy will be smaller than the past. This makes it very difficult to pay off a debt (plus interest) when the real economy would actually be contracting.

16.2 Connecting events

Between 2005 and 2008, global oil demand did outstrip global oil supply (Figure 247) (Saxena 2009). This supply gap happened when oil production plateaued in 2005, while demand continued to grow in line with GDP and human population (Figure 17 & 64). This was resolved with an increase in oil production, in particular the addition of the tight oil fields of the United States started producing, using fracking technology.

So an oil price rise between 2005 and 2008 was appropriate, but what was observed was over ridden by a speculative bubble. This left the industry set up for a major price bust, as the speculators dump oil shares the oil price crashes (Figure 242). This cripples investment for future development (which is increasingly expensive as has been shown in Section 9). Without that future investment, the current oil production value chain is set up for a reduction in production due to old fields depleting (this happens much more quickly for fracked tight oil plays, see Sections 6 and 7). A simplified sequence of events:

1. Global oil production plateaued in January 2005 (see Figure 230) for 58 months until October 2009. The market becomes inelastic in oil supply (Section 16.3). Global oil consumption continues to expand at the same rate.

2. The oil price rises 20% between January 2005 and January 2007 ($44.51 USD to $53.68 USD). It then spikes 147% in the time period January 2007 to July 2008 ($53.68USD to $132.72 USD). Speculation on oil price clearly had a role in pushing the price up to $147USD/barrel. There is also a supply gap between supply and demand.

3. In 2008, the largest economic correction since the 1929 Great Depression started (The Global Financial Crisis). The GFC began in 2007 with a crisis in the subprime mortgage market in the United States, and developed into a full-blown international banking crisis with the collapse of the investment bank Lehman Brothers on September 15, 2008.

4. The United States Federal Reserve Bank intervenes into the finance markets with the first program of Quantitative Easing (QE1) in November 2008. A historically unprecedented volume of debt is taken on. A new kind of economics now underpins the global economy.

5. A new technology in oil extraction (horizontal drilling of fracking wells) was developed in the United States, opening up the tight oil field plays (Rapier 2018). This allows global oil production to expand again at the same rate as consumption demand. The oil supply gap is resolved, but the underlying issues are merely postponed.

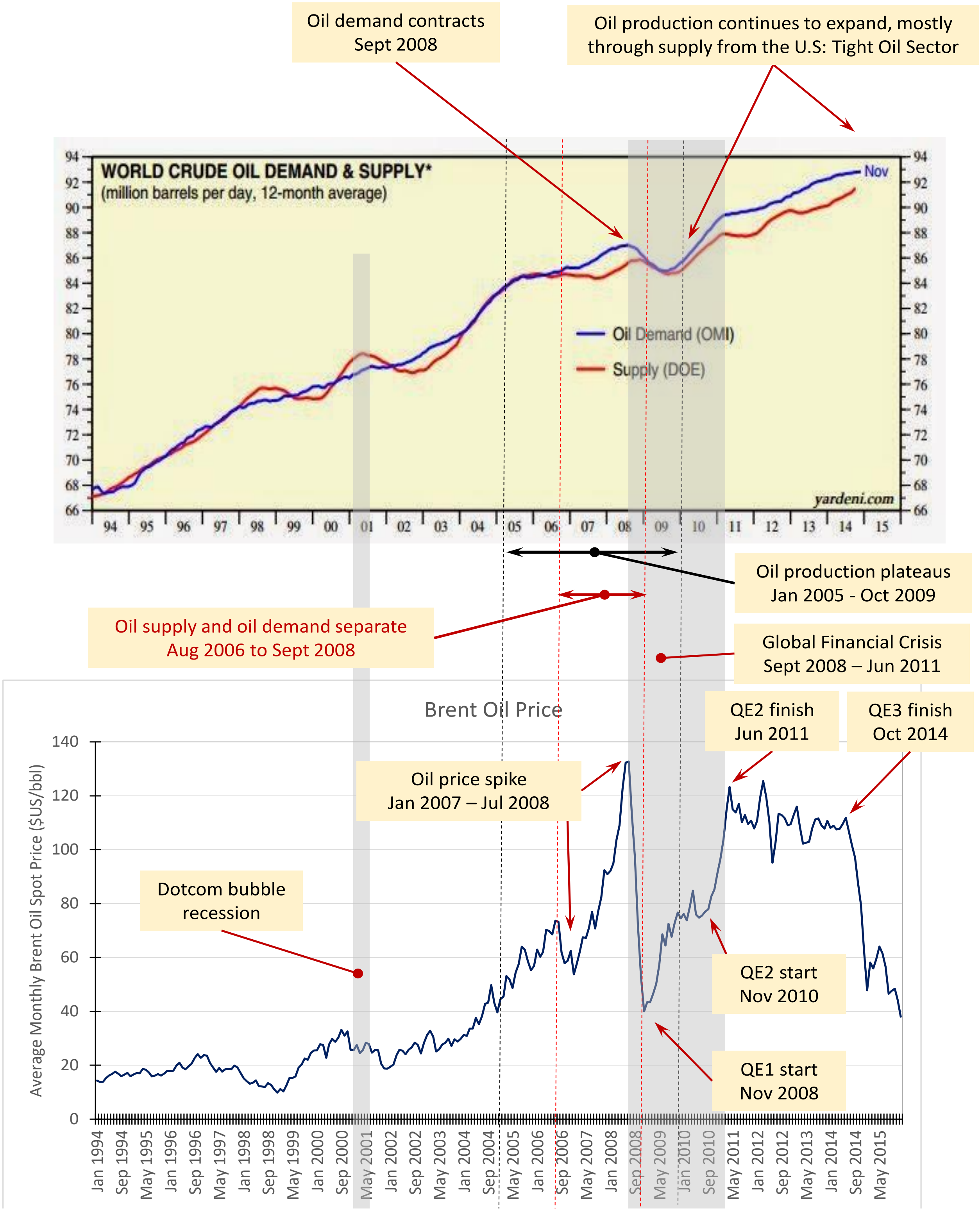


Figure 247. Oil consumption demand, oil production and Brent oil price sequence of events. Differences between these world consumption figures and world production statistics are accounted for by stock changes, consumption of non-petroleum additives and substitute fuels, and unavoidable disparities in the definition, measurement or conversion of oil supply and demand data.
(Source: Yardeni Research 2016, BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011, Europe Brent Spot Price FOB, EIA, https://www.eia.gov/dnav/pet/hist/RBRTED.htm)
(Copyright for top chart: Yardeni Research and Oil Market Intelligence granted)

The difference between oil production and oil consumption in the BP Statistical Review of World Energy 2019 is explained by a difference of what is included in each category. World oil consumption, as collected by BP, includes consumption of products not derived from crude oil like biogasoline (such as ethanol), biodiesel and derivatives of coal and natural gas. World oil production, as collected by BP, includes crude oil, shale oil, oil sands, condensates (both lease condensate and gas plant condensate) and NGLs (natural gas liquids – ethane, LPG and naphtha separated from the production of natural gas). Excludes liquid fuels from other sources such as biomass and derivatives of coal and natural gas. This consumption is shown as larger than production. For a short time, crude oil consumption did outpace crude oil production between 2006 and late 2008 (Saxena 2009, and Yardeni Research 2016). Since the year 2006 (to at least 2016), demand has outpaced supply (Yardeni Research 2016) as shown in Figure 247.

Figure 247 shows that modelling oil, energy, finance and actions of political administrations as a single system, is appropriate. It also shows that if political and financial decision makers underestimated the influence of oil price before the year 2008, they certainly do after 2008 (See Sections 14 and 15).

Comparing Figure 242 and Figure 244 shows the relationship between the price of oil and financial quantitative easing support. This suggests the whole global economy is propped up by Quantitative Easing.

In a macro scale steep financial correction (often referred to as a financial crunch), price speculation to the downside and a sharp fall in demand go hand in hand, as demand isn't what consumers want, but what they can pay for. This is especially so for a product that is critical for the functioning of society (less so for a product considered a luxury).

Prices can fall a very long way, but as it does, product affordability gets worse, since purchasing power of the consumer falls faster than product price, when the system is saturated with debt.

A price fall would be temporary, since an essential product (like petroleum) will receive relative price support in a deflationary spiral (i.e. a much larger percentage of a much smaller money supply would be attempting to demand the same volume of supply).

The result would be pricing most of the market (most of average everyday consumers) out of access to oil derived products almost entirely, because the lack of purchasing power would last much longer than the temporary fall in price. This is exactly what was seen in the post GFC United States.

Demand will increase again, but the real economy (the market exchange of real physical goods as opposed to the fiat economy, with financial products like derivatives) will have contracted and will take time to recover. In the GFC case study, most of the global markets at all scales (National governments, corporations and individual citizens) are now heavily loaded with debt of all kinds. This means that the real economy cannot really recover until that debt level is reduced. Economic growth is now very difficult, and in some cases not really possible.

All Critical Raw Materials (CRM) as defined by the European Union (European Commission 2017), could be modelled in this fashion as it goes through a scarcity vs. relevance cycle and be examined in this context.

16.3 Time periods operating to different influencing constraints

Figure 248 shows the world spot price of crude oil vs. crude oil production at the time of the spot price, for the data range 1990-2018. As can be seen there is four populations in the data. Prior to 2005, oil supply was elastic and could match demand, thus has a shallow gradient in the data cloud. Post to 2005, the oil supply was inelastic and could not match demand, leading to price swings.

This concept was first published in 2012 (Murray and King 2012) where two clear subpopulations where shown, before and after 2005.

Figure 249 shows the same data as Figure 248, but the data is split into several sub-populations. Figure 249 also compares the sub-populations against patterns seen in the Brent oil spot price (yearly average). As can be seen, there is several time periods that all seem to operate according to different influences.

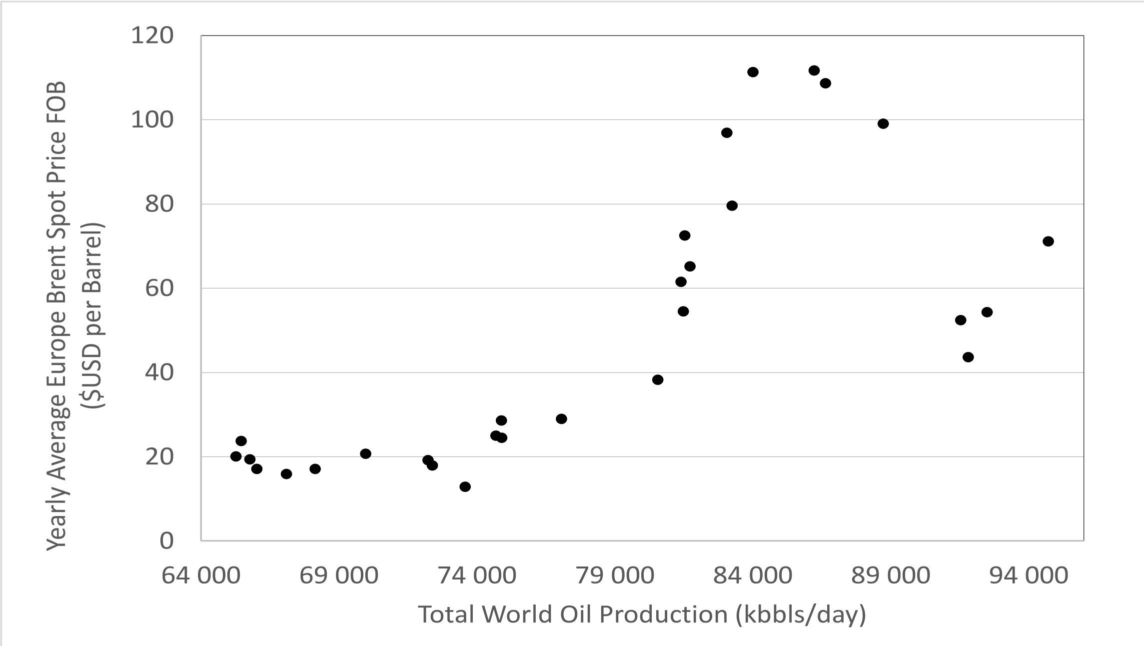


Figure 248 Total world production (yearly average) vs. Brent oil spot price (yearly average) (Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011, Europe Brent Spot Price FOB, EIA, https://www.eia.gov/dnav/pet/hist/RBRTED.htm)

A case can be made that shown in Figure 249 are four separate time periods, each operating to a different set of economic constraints. As it has been shown that oil price is correlated to many aspects of our industrial ecological system, it could be argued that in such a short time, the structural underpinning foundations changed three times from conditions seen prior to 2004.

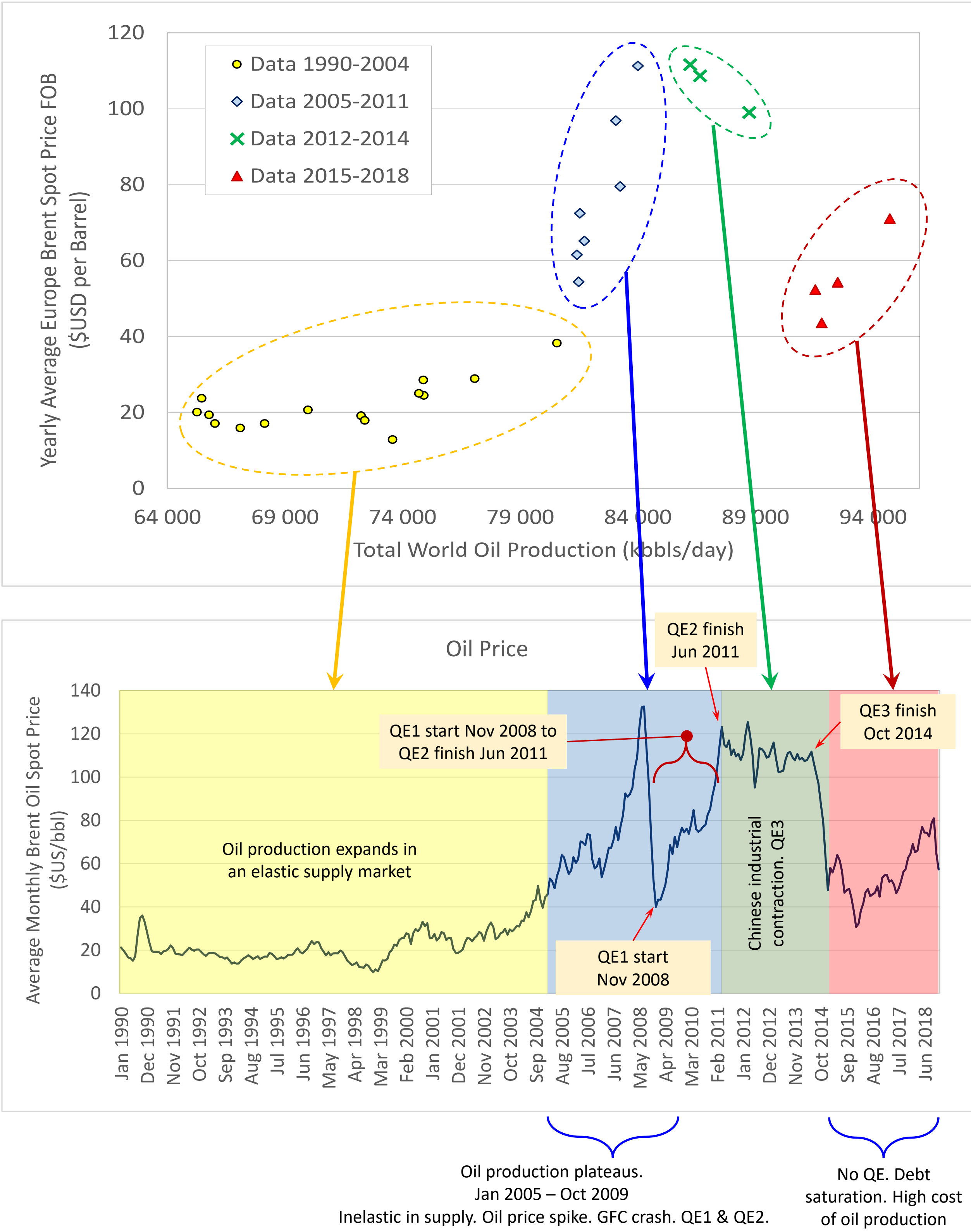


Figure 249. Patterns and sub-populations in oil production and oil spot price (Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011, Europe Brent Spot Price FOB, EIA, https://www.eia.gov/dnav/pet/hist/RBRTED.htm)

This concept can be extended to many other time periods, but they tend to be much longer in scope, lasting for decades. Figure 250 shows the annual global oil production, and annual global Gross Domestic Product (GDP), indexed to the value 100 in the year 1965. A very important data signature becomes apparent.

Prior to 1971, oil production and GDP overlaid each other and correlated very strongly. That is an increase in GDP had a very similar increase in the production of oil. Energy and economic activity directly correlated. This is still the case only now the relationship is quite different. After 1971, changes in GDP start to separate from oil production. An increasing gap progressed, and does so for as long as there is data available. There are two events of significance that could be relevant in explaining this:

- In August 15th 1971, the U.S. dollar (the global reserve currency) was decoupled from the international gold standard, and existing Bretton Woods currency agreement was suspended. The U.S. dollar became a fully-fledged *fiat* currency (Rickards 2014 and Patel 2009).
- In 1973, a deal was struck between Saudi Arabia and the United States in which every barrel of oil purchased from the Saudis would be denominated in U.S. dollars. Under this new arrangement, any country that sought to purchase oil from Saudi Arabia would be required to first exchange their own national currency for U.S. dollars. In exchange for Saudi Arabia's willingness to denominate their oil sales exclusively in U.S. dollars, the United States offered weapons and protection of their oil fields from neighboring nations (Emerson 1985 and Simmons 2005).

This allowed the U.S. government to balance the federal budget with the printing of money. Due to the authority projected by the U.S. dollar, the rest of the world was forced to engage in the dollar system by virtue of Saudi Arabia being the dominant world supplier of oil (once the U.S. oil production started to decline in 1970). Oil has been demonstrated as a critical master resource that underpins the global industrial system. So the global financial currency systems were not only tied directly to oil production, but were subject currency debasement through expansion of supply of U.S. dollars. GDP became inflated in comparison to the real economy of physical goods and services.

Also of note in Figure 250 is a change in gradient around the year 2001. From that point, GDP increased at a greater rate than ever before. A change in the United States law could explain this:

- The financial derivatives market was deregulated. The Commodity Futures Modernization Act, (CFMA) signed into law on December 21, 2000 updates commodity trading regulations. The most notable change was in addressing newer types of financial contracts such as over-the-counter derivatives. This was just after the Dotcom Bubble had burst (1994-2000).

When credit markets froze up in the latter half of 2008, many economists pronounced the crisis both inexplicable and unforeseeable. This could be because the roots of the catastrophe lay not in changes in the markets, but changes in the law (Stout 2009). The Commodity Futures Modernization Act was signed into law as a consequence of lobbying from the private finance sector, in response to the DotCom financial bubble busting. The logic being that the money that could be made by the financial industry could stabilize the rest of the economy by forming a buffer, where an economic crash would not happen again in our lifetimes (Schomberg & Jones 2017). Clearly, we are in the largest financial experiment in history, with a high risk of structural hyperinflation/hyperdeflation of hyperstagflation, in all economies around the world, all at the same time.

The printing of money (which was done consistently since 1971) became directly linked to the creation of financial derivatives and credit default swaps, creating the largest bubble ever observed.

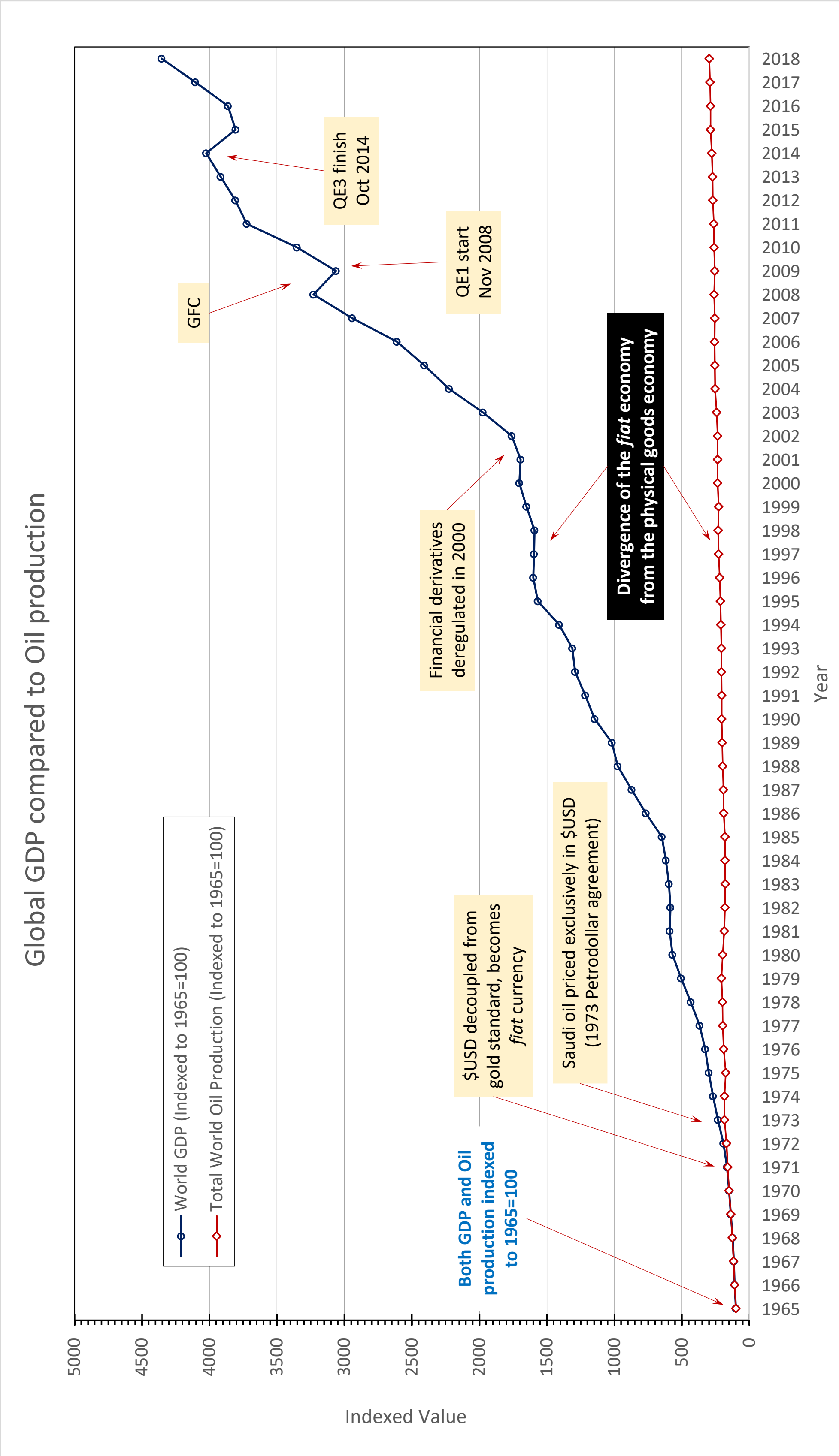


Figure 250. Global GDP and Crude Oil Production
(Source: BP Statistical Review of World Energy 2019, BP Statistical Review of World Energy 2011, World Bank Data)

As Figure 250 shows, the real economy has diverged from the fiat economy for some years. Between 1965 and 2018, oil production has increase 298%. Alternatively, GDP has been growing steadily (through quantitative easing) and has increased in the same time span, 4 355%.

For the last 40 years, US government debt creation has been approximately twice the rated economic growth (Rickards 2014). This spiraling volume of debt since the 1970's has been historically unprecedented. What has facilitated this to continue working is the Saudi Arabian commitment to price all of their oil contracts in $USD. For the last 46 years, the increase in debt can be related to the higher cost of energy (the 1973 Petrodollar agreement). As the cost of energy went up, there was a need to increase the volume of debt to the system to maintain growth. Most nation state economies (all fiat currency based) now have debt to GDP ratio that exceeds 90% (US Debt Clock 2019). This means that each of those economies that have such high debt/GDP ratios have to go further into debt to maintain their economies and maintain debt repayments (Rickards 2014).

Figure 250 in conjunction with Figure 244 shows that growth in GDP is a debt fueled mirage. If debt is a promised claim on the future, the total amount of goods and services has been growing, while debt levels and other kinds of promises have been growing more rapidly than their physical collateral. Figure 251 shows how this may have happened.

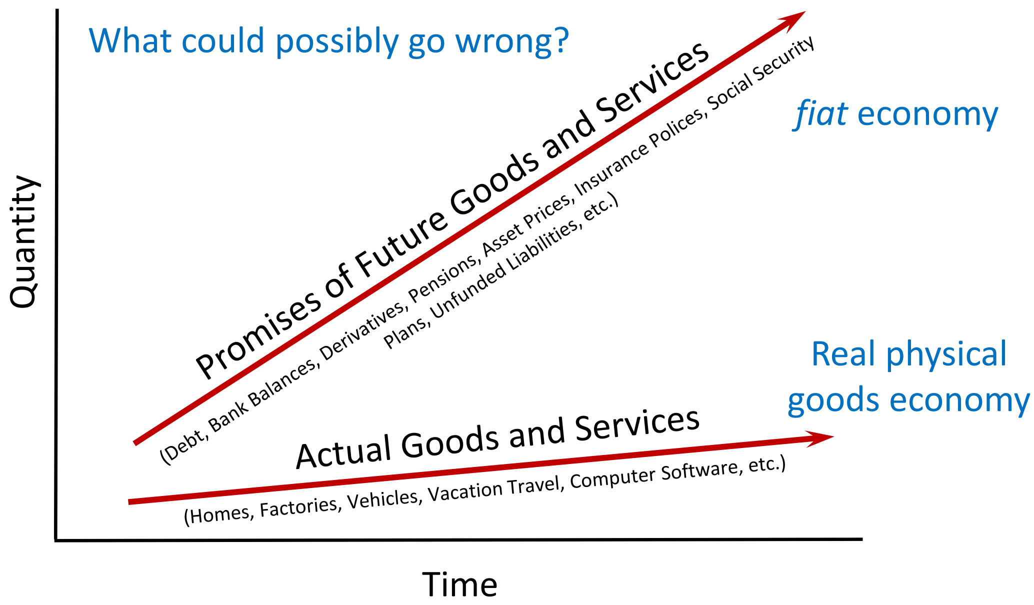


Figure 251. Promises of future goods and services tend to rise much more rapidly than actual goods and services. (Source: Figure recreated from Tverberg 2019).

> "Many things can go wrong with this system. If the growth in added debt slows too much, we can expect to start seeing financial problems similar to those we saw in 2008. Also, if the level of debt (such as student debt) gets too high, its payback interferes with the purchase of other needed goods, such as a home. If energy providers decide prices are too low and stop producing, then promised Future Goods and Services can't really appear. Huge defaults on promises of all kinds can be expected. This happens because the laws of physics require the dissipation of energy for physical processes underlying GDP growth."

Gail Tverberg – Retired Financial Actuary (Tverberg 2019)

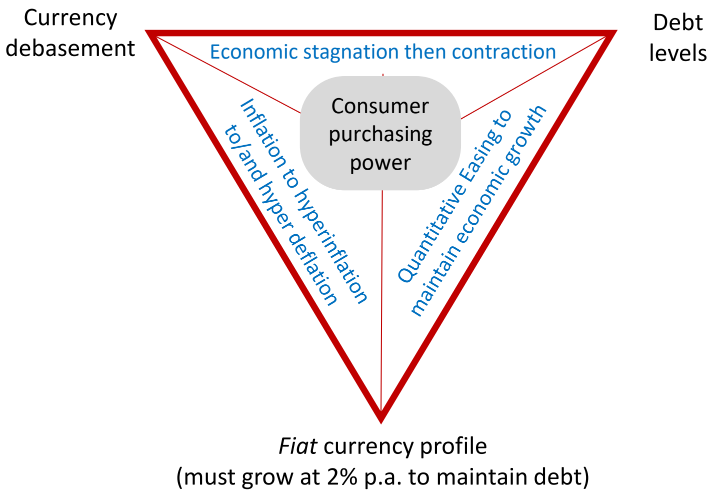


Figure 252. Forces and influences interacting around consumer purchasing power

Figure 252 shows the discussed concepts in context of influencing consumer purchasing power. This directly affects the ability for the consumer to purchase products like petroleum or food.

Compare Figure 250 to the price of oil (West Texas Intermediate WTI) shown in Figure 253. Note the sharp change in oil price just after 1971.

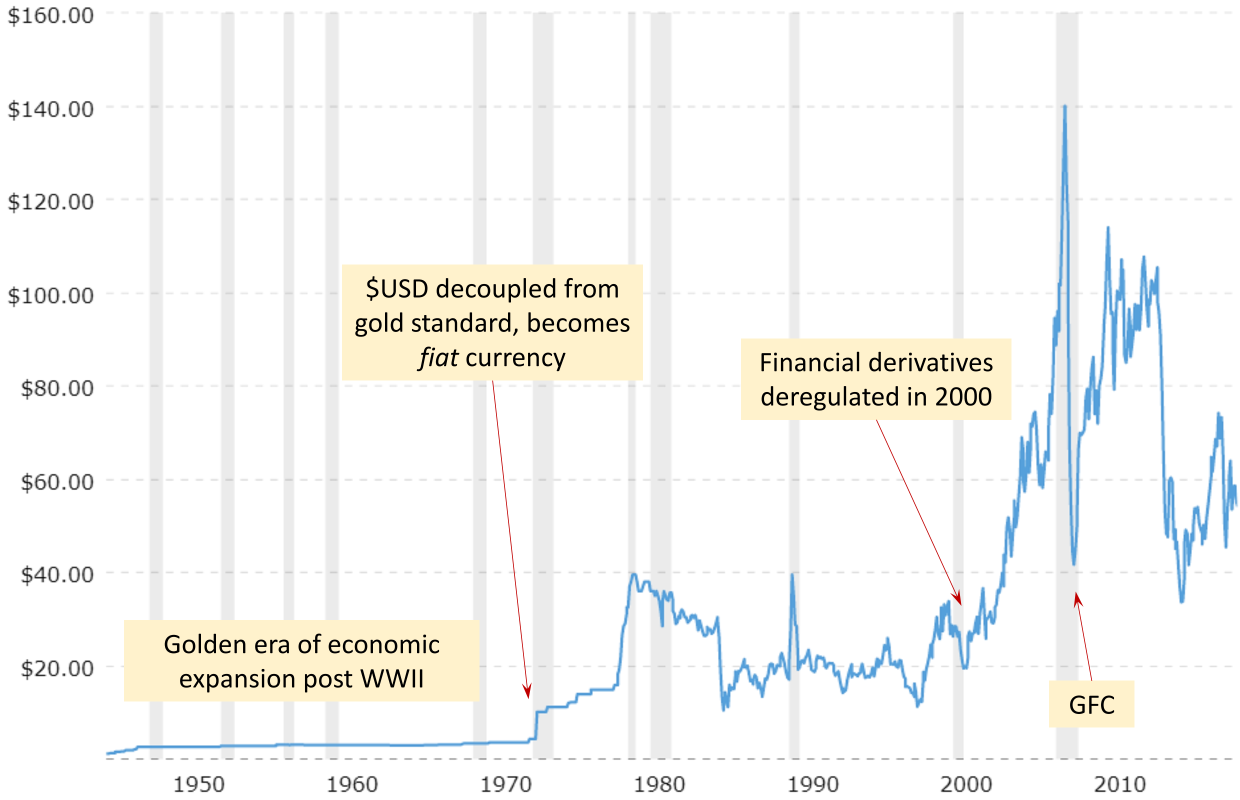


Figure 253. West Texas Intermediate (WTI or NYMEX) crude oil prices per barrel back to 1946. Not inflation adjusted. (Source: MacroTrends) (Copyright: https://www.macrotrends.net/terms)

The time period between the end of World War II and the 1973-75 global economic recession was signature with remarkable economic growth unprecedented industrial activity and comparatively very cheap energy prices.

The post–World War II economic expansion, also known as the golden age of capitalism (Marglin & Schor 1992) and the postwar economic boom or simply the long boom, was a broad period of worldwide economic expansion. The United States, Soviet Union, Western European and East Asian countries in particular experienced unusually high and sustained growth, together with full employment. Keynesian economic policies in countries of the capitalist West were successful in generating rapid growth with high employment.

Contrary to early predictions, this high growth also included many countries that had been devastated by the war, such as Japan (Japanese economic miracle), West Germany and Austria (Wirtschaftswunder), South Korea (Miracle on the Han River), France (Trente Glorieuses), Italy (Italian economic miracle) and Greece (Greek economic miracle).

This whole era was made possible while oil was abundantly available and very cheap in price. It all came to a halt in the early 1970’s when the U.S. dollar became a *fiat* currency and the petrodollar agreement was in force. It was at this point when the real economy decoupled from the fiat currency, where the printing of money was used by most nations around the world to achieve economic growth targets.

16.4 From the oil producer point of view

The oil industry in the early 1900’s was a way to get fabulously wealthy. Over time it became apparent that the oil industry went through cycles. An upcycle when cash flows were positive and fortunes were made. Then there was the occasional down cycle when the oil price exceeded what the market demand would support, and net profits declined. The long term viability of oil producing companies was exceedingly bright for many decades. Up until the last 10 years, the oil industry business cycle resembled Figure 254.

The production cost of bringing saleable oil products to the global market has risen several hundred percent in the last 40 years.

- Cost of oil exploration has risen. To find an oil deposit, an exploration well has to be drilled. These wells are often in deep water and also are very deep. The costs of doing this have been consistently rising, in the last 20 years in particular. Often, a large proportion of exploration wells come up dry and do not produce viable oil volumes to justify an extraction grid.

- Cost of extraction has risen. Often oil and gas wells are in very deep water and require very deep holes to reach the oil. A large off shore oil rig is often needed to be commissioned for each producing well. Alternatively oil could be produced with horizontal fracking in the tight oil plays. Often requiring ever increasing rates of new wells drilled just to maintain existing production.

- Cost of refining to produce a quality product has risen. Most of light sweet crude has been consumed. Most of what is left is high sulfur content heavy sour crude that requires more refining steps to produce saleable petroleum products. The CAPEX and OPEX of these oil refineries have increased over the last few decades.

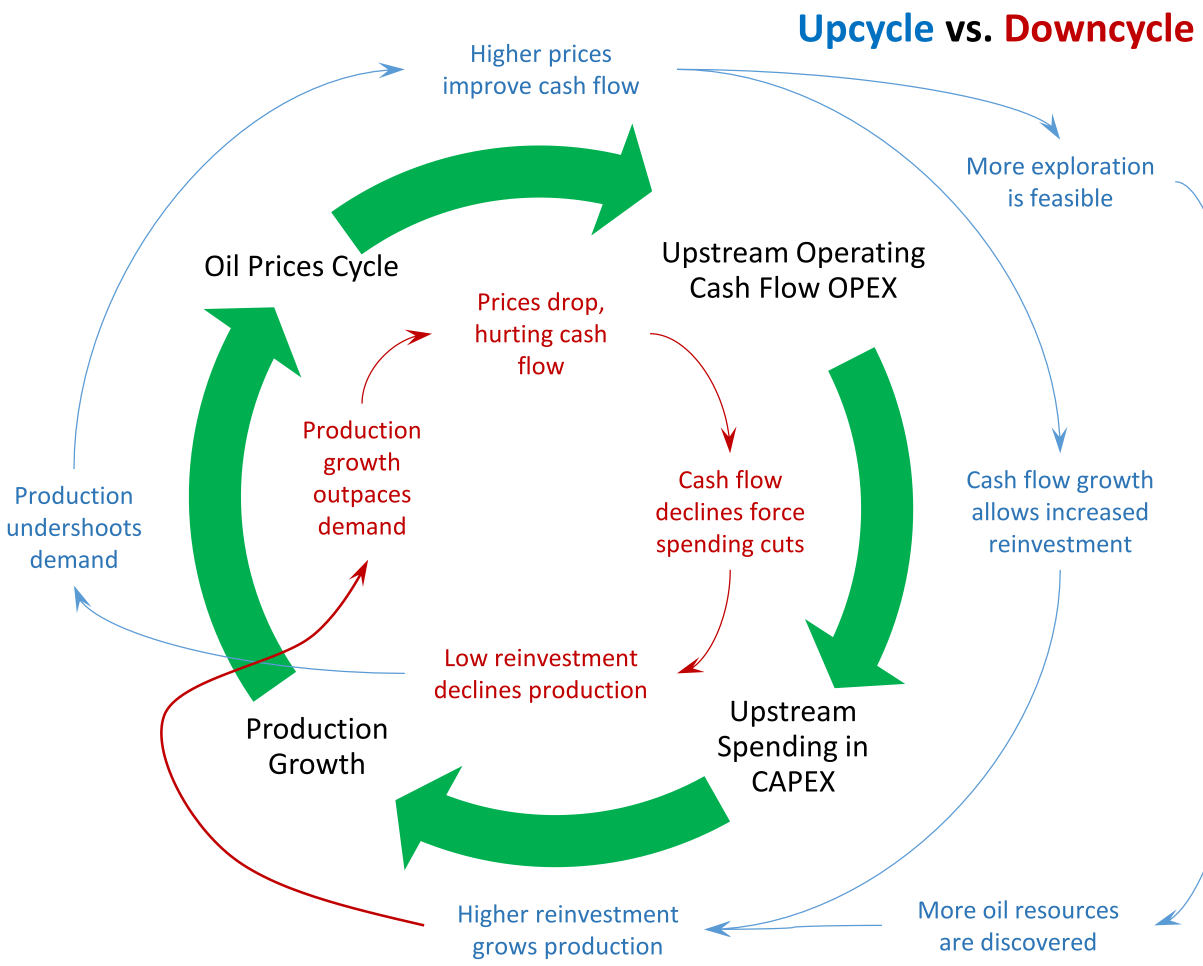


Figure 254. The conventional oil industry upcycle vs. downcycle

What is driving this rise in cost is simply that all the easy to find, extract and refine oil has already been consumed. The hard to work and hard to find oil that is really expensive to process is what is left. Oil discoveries of new oil deposits have been declining in quality and volume since the mid 1960's. Scarcity of viable oil deposits are driving this change, creating an inelastic supply market for oil. This combination is driving down the Energy Returned on Energy Invested ratio (ERoEI). There comes a point when the ERoEI ratio is so low that the energy resource is no longer viable for society to use.

Alternatively, oil is demanded at an increasing rate as vital and critical energy resource that supports the entire industrial ecosystem. All attempts to substitute oil with anther energy source have not been successful. The plan to phase out petroleum powered Internal Combustion Engines (ICE) technology with Electric Vehicle (EV technology) is under resourced, and is a much larger task than what is currently understood (Michaux 2020). The combination of these concepts produces an inelastic demand for oil and oil products. These concepts are shown in Figure 255.

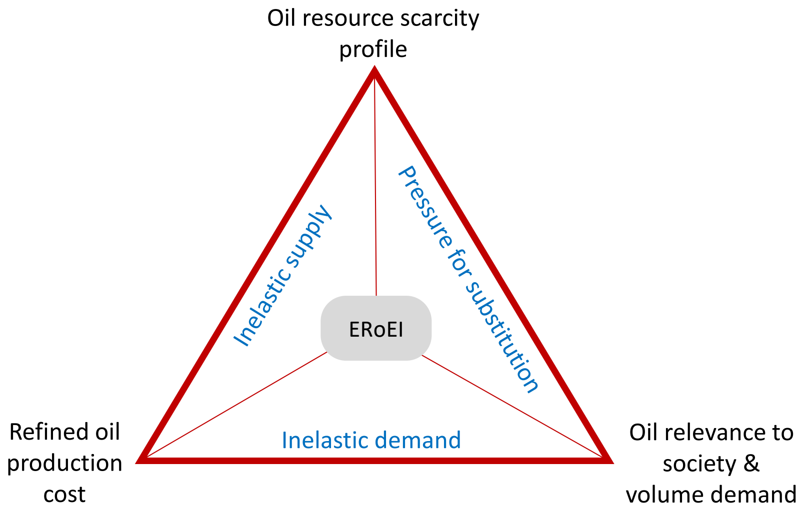


Figure 255. Influences on the production of oil

If the resource is relevant in that there is no real substitution and it is critical for the function of the industrial economy, then demand will increase. If the resource is scarce and accessibility and process ability is difficult, the cost of production will go up, which will affect demand. If the market cannot support a selling price, then demand will go down. If the sell price is too high then economic growth becomes difficult, and the market cannot support the price, resulting in the resource price reducing. If the sell price is not high enough to meet the cost of production, then it is not viable for producers to operate or develop new resources through exploration. The quality of the resource (ERoEI), its accessibility (scarcity) and its processability (relating to ERoEI) drive everything else.

The problem is not just that oil prices are too low (2014 to 2019, oil producers have warned that oil price is too low to justify future investment). Prices are too low for almost every type of energy producer, and in many parts of the global industrial ecosystem.

OPEC oil producers have cut back production because they view oil prices as too low. OPEC reports a cutback in production of 2.7 million barrels per day between November 2018 and July 2019 (from 32.3 million bpd to 29.6 million bpd) (Tverberg 2019 Sept 12th).

In the United States, there has been an increase in bankruptcies of oil producers during 2019, relative to 2018. There has also been a reduction in the number of oil drilling rigs of 17% since the week of November 16, 2018, according to reports by Baker Hughes. These are signs of producer distress (Tverberg 2019 Sept 12th).

16.5 From the consumer point of view

Market demand is not driven by what consumers desires, but what they can pay for. Especially when considering inelastic demand for a vitally critical product, commodity or service. When a resource commodity (in this case oil) exceeds what the consumer market can sustain, a price correction happens through demand destruction. Demand destruction comes to the people and from the people. All product and service industries, and even the bureaucracy and the military ultimately exist to fulfil some (often only perceived) consumer need. Only if price increases can no longer be passed on through the supply chain to the end user because a too large number of potential buyers can no longer afford the product, pressure to deal with a critical resource (oil) shortage is exercised.

Consumers will purchase products and services based on need and desire. For the last few years, economic conditions for the average consumer have become more difficult. This means that only what is needed is resourced. Figure 256 shows a thought experiment to illustrate this point.

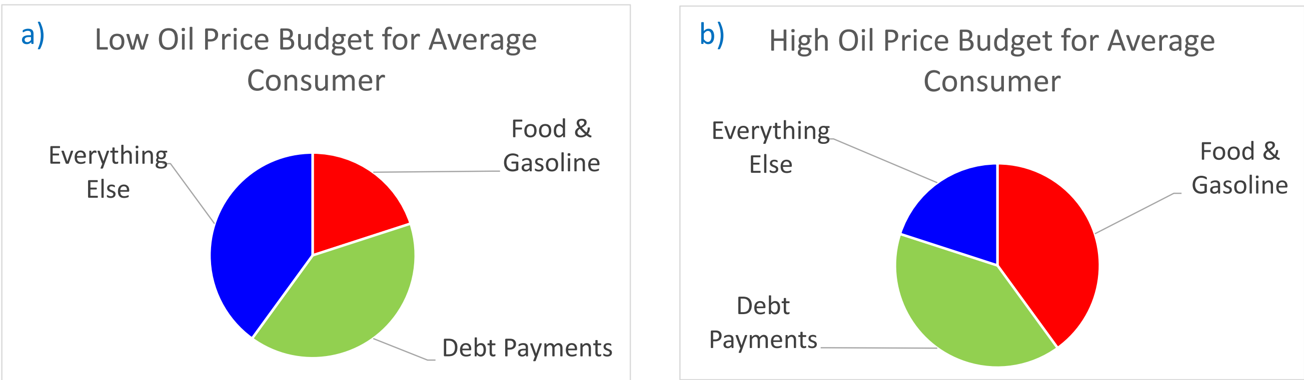


Figure 256. Oil price budget for the average consumer (concept developed in Tverberg 2019 Aug 22)

Figure 256 a) shows a thought experiment simulation of a consumer, where the debt load is 40% of monthly costs, critically vital inputs like food and gasoline are 20% and everything else is 40%. The Figure 256 b) shows the same consumer where the cost of food and fuel have doubled, and debt is maintained at the legally required rate. The only sector that can reduce is everything else.

If the critically vital costs of operation (for example food and gasoline for a family) was to increase, the only thing that can proportionally decrease is the ‘everything else’ category in Figure 256 b). This would mean the contraction of the real economy as consumers are not able to pay for goods and services, resulting in demand destruction in other sectors.

If the price of food and gasoline was to continue to increase, then there will come a point when the consumer cannot reduce operating costs of everything else any more. The only option then becomes to default on the debt and declare bankruptcy.

At the time of writing this report, debt saturation was a distinct possibility (when compared to consumers debt level in the 1950’s) for consumers of all scales. This was the case for individual people, corporations and nation states. Payment of that debt was possible while operating costs remained comparatively low. Not maintaining this debt meant declaring bankruptcy and the complete dismantling of operations. This was a thought experiment to illustrate the choices facing a consumer if the cost of gasoline (oil) and food (related to oil) was to significantly increase.

So, first, high oil prices destroy demand from people who physically just cannot pay the price, no matter how urgently they would need petroleum products or are dependent on oil based services. This will mainly apply to very poor people around the world (not necessarily only in developing countries) with a dependency on oil but without capacity to compensate for drastically rising prices. The inflation imported with the oil cannot easily be compensated by the local economy – the country's value creation just cannot keep pace with the rapid energy price increases.

This rising cost outcome cycle is already happening all over the world. Americans on average spent more on taxes in 2018 than they did on the basic necessities of food, clothing and health care combined, according to the Bureau of Labor Statistics Consumer Expenditure Survey (United States Department of Labor 2019). At the same time, bankruptcies and house defaults are also happening at significant rate. In the United States, retailers are filing for bankruptcy at record-high rates (Peterson 2018). This rate has exceeded what happened in the U.S. in the 2008 GFC (Peterson 2018).

There are three strategies that an end user can use to deal with rising energy prices:

1. Consumer spending is supported with credit and hope the crisis is going to go away soon. This means taking on more debt. In a global market context, Quantitative Easing was used in an unprecedented fashion.

2. Allow the real economy to contract and manage a fundamental market correction/reset. Substitute the commodity if possible. Reprioritize spending – stop or reduce spending in one area to be able to continue spending in another.

3. In some fashion use less of the commodity to achieve the same physical tasks. Increase efficiency and conserve – downsize, use things longer, eliminate frivolous waste, invest in more efficient technology, recycle.

16.6 The production price market viability contracting window

Figures 155 shows the dynamic where the price spikes to a maximum and then crashes, several times. As oil is a critical raw material for our industrial society, demand forces the price up. Oil producers struggle when the price is too low and often go out of business. Meanwhile, capital investment for future projects is harder to justify (and has been decreasing). This suggests an oil supply shortfall as a function of above ground issues. Before 1970, this was not an issue, the oil price was acceptably low and such price swings were not observed.

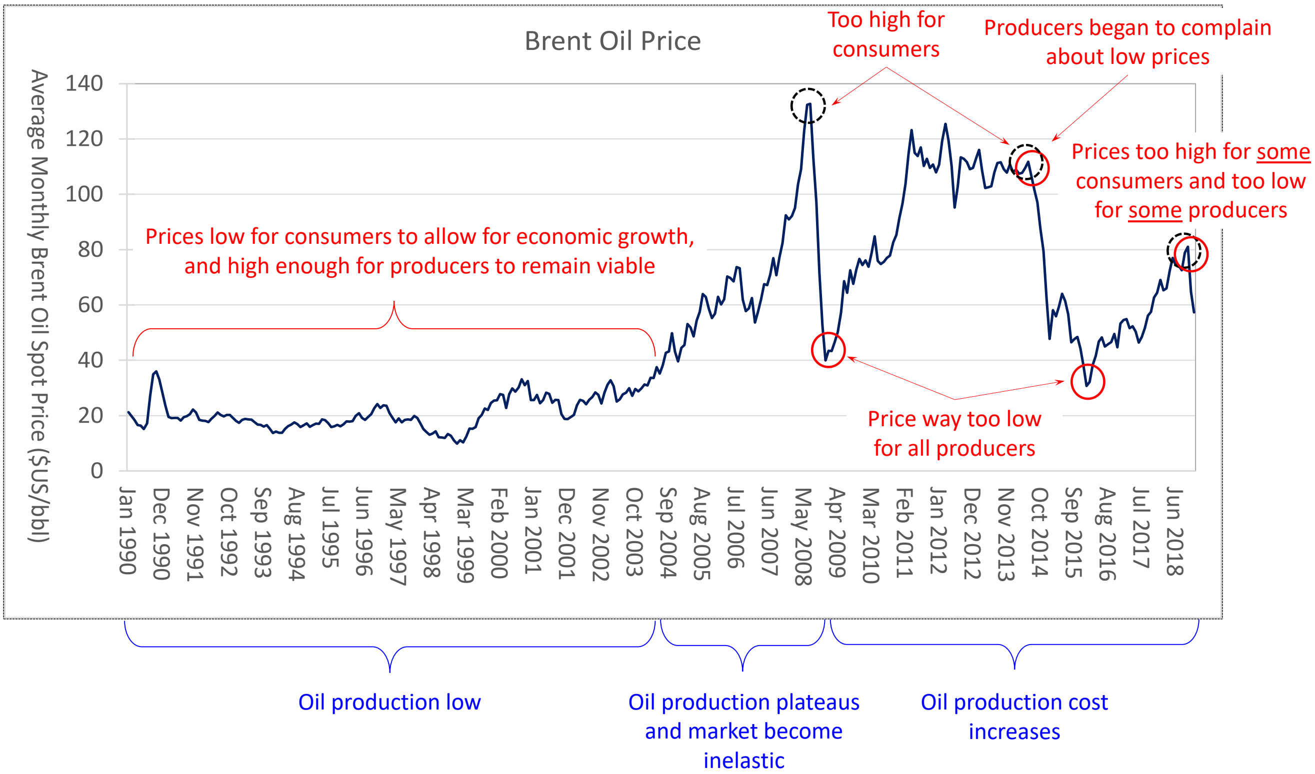


Figure 257. Brent oil price. Oil prices are Europe Brent Spot Price FOB ($USD Dollars per Barrel), without inflation adjustment
(Source: EIA, https://www.eia.gov/dnav/pet/hist/RBRTED.htm)

As shown in Figure 257 above, monthly average peaks started at $132.72 in July 2008. More recently, peaks have fallen as follows (Tverberg 2019):

- Peak of $125.25 for the month of March 2012
- Peak of $109.54 for May 2014.
- Low month average price of $30.70 in January 2016.
- Most recent average peak was $81.03, for the month of October 2018.

From this pattern of falling peaks, we can see that the stimulus being used recently (which includes Quantitative Easing in some parts of the world) has become less and less effective at stimulating demand for food and energy products.

Figure 258 shows the same concept as in Figure 257 but in West Texas Intermediate (WTI or NYMEX) crude oil prices that have been inflation adjusted (where Figure 257 shows the European Brent oil price that has not been inflation adjusted). From Figure 257:

- Oil price peaks and crashes July 11th 2008
- QE1 starts November 2008 (US Federal Reserve)
- Oil price bottoms out Dec 26th 2008, price too low for all producers (Knoema Statistics)
- Oil price crashes again on June 19th 2014, price too low for some producers (Knoema Statistics, Kleinberg 2018)
- Oil price in 2014 too high for some consumers and economic growth is stagnant (Word Bank)
- Oil price bottoms out January 20th 2016, price too low for some producers (Knoema Statistics, Kleinberg 2018)
- Oil price crashed on October 1st 2018, price too low for some producers (Knoema Statistics)

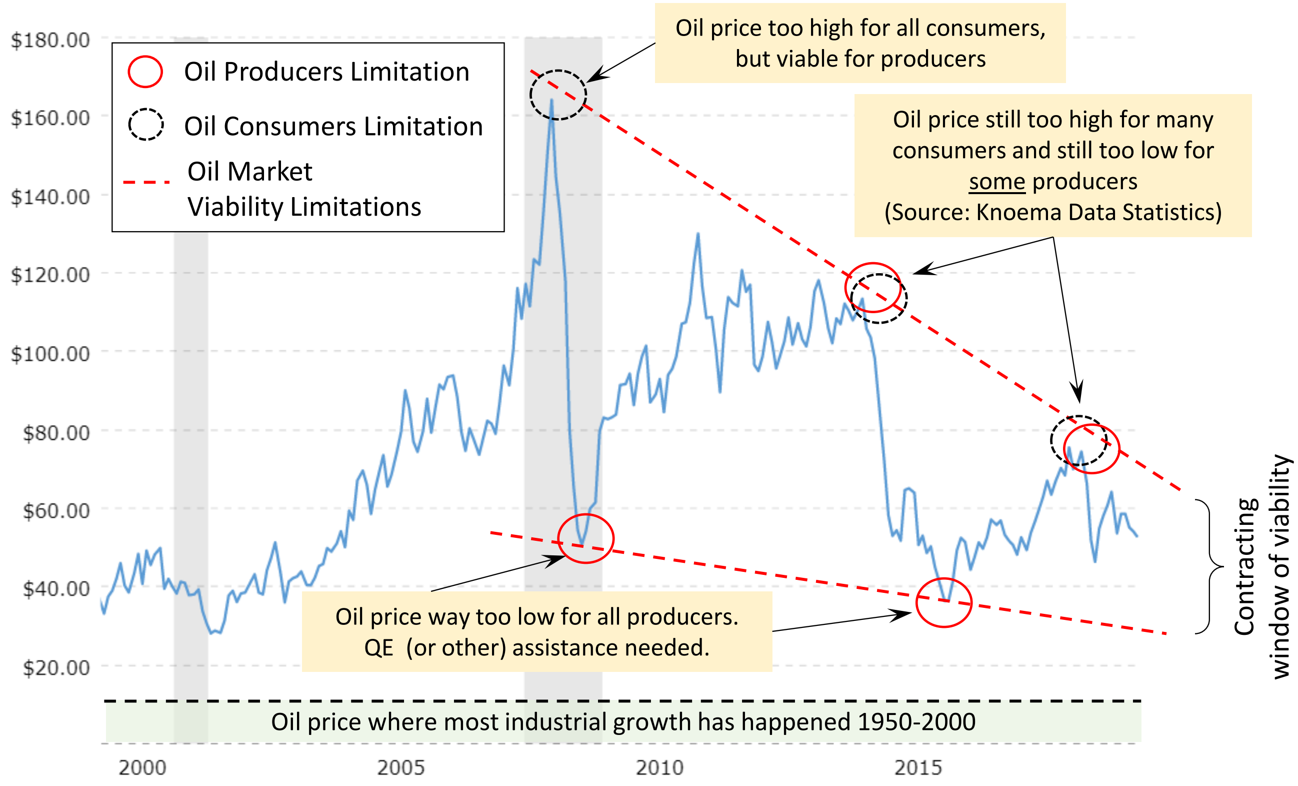


Figure 258. West Texas Intermediate (WTI or NYMEX) crude oil prices per barrel October 1999 to October 2019, Inflation adjusted (Source: MacroTrends) (Copyright: https://www.macrotrends.net/terms)

Figure 258 shows that the window of oil market viability is closing. Also, the lower limit (before change is required by the market) for the oil price is also declining, even though the production price is going up. Either a substitute for oil energy will be found or oil production will not be accessible for the average consumer. Predicting the time the window will completely close is not appropriate as this is a nonlinear system with unknown influences. It could be postulated though that the window of viable operation could close between 2020 and 2025.

To put this in perspective, most industrial growth in the last 100 years happened in the 'Golden Era' in the 1950's to the 1960's, where oil was approximately $2 to $3 USD ($25 USD inflation adjusted). In the U.S. golden era of prosperity (1950's and 1960's), for every dollar of debt created, a ratio of $1 to $2.41 was in effect (Rickards 2014). That is, for every $1 printed, $2.41 in economic growth was generated. In 1970, just before President Nixon decoupled the gold standard to the US dollar, the ratio was $1 to $0.41. For every dollar of debt created, $0.41 of economic growth was generated. In 2014, that ratio had fallen to $1 to $0.03. For every dollar of debt created, $0.03 or 3 cents of economic growth was generated. This is not sustainable or even useful in the short term. The current state of the US economy is that its currency is now so debased that its purchasing power has been reduced by 97% (Rickards 2014). As oil has been traditionally forced to be priced in $USD, this will also impact oil sale price. Currently, the oil market and the capability of the $USD as a world reserve currency are linked.

Figure 259 and Figure 246 in conjunction present two system maps that shows how the window is being forced closed for the viability of the oil market.

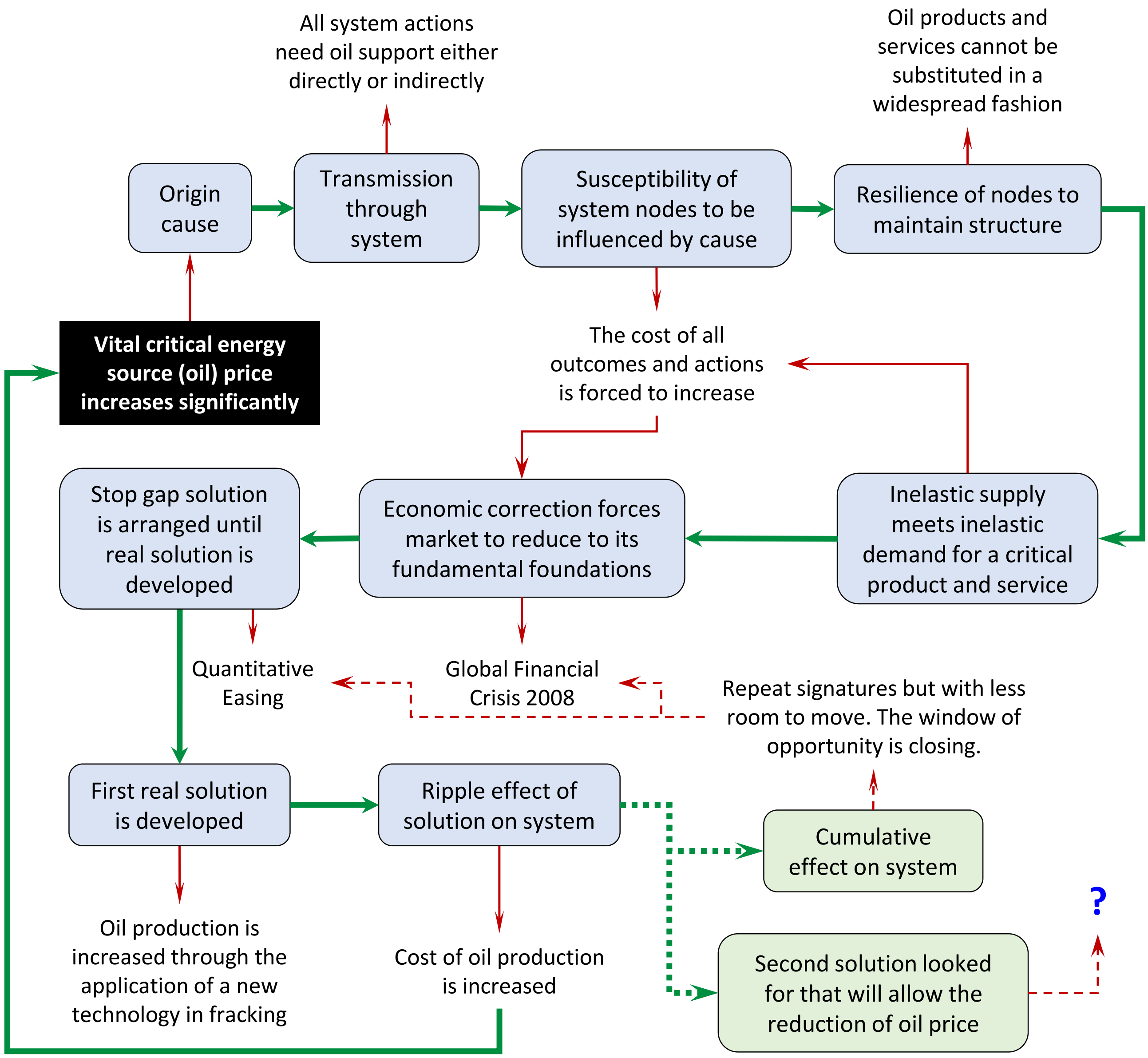


Figure 259. Systems map of the influences that is forcing close the window of viability for the oil market

Figure 260 shows how the concepts in Figure 259 and Figure 246 have changed the conventional oil industry cycle (Figure 254).

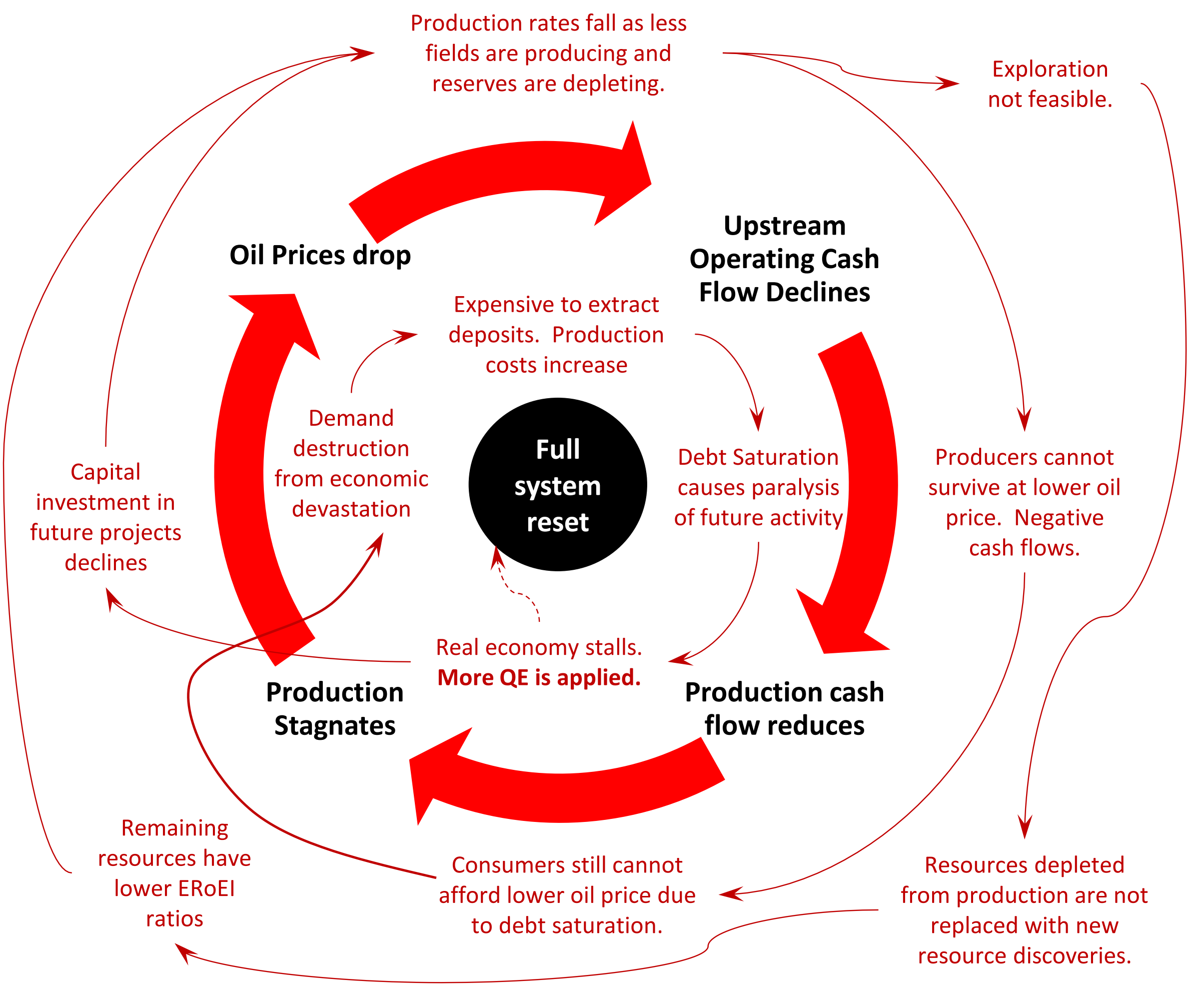


Figure 260. Oil industry production downward spiral

By the time the industrial ecosystem is forced into a full system reset, peak oil production would have happened years before hand.

16.7 Oil finance dynamic interaction with strategic policy decisions over a sequence of events

So oil production and finance structures are linked and dynamically interact. Events and strategic decisions made that have dynamically interacted to create the current circumstances include:

- The decoupling if the U.S. dollar from the international gold standard in 1971, allowing the printing of money to regulate the markets of physical goods and services.
- The Petrodollar agreement in 1973, requiring all Saudi Arabian oil contracts to be priced in $USD, forcing the global industrial economy to engage in this system.

- The changes in U.S. law, resulting in the deregulation of the financial derivatives market and credit default swaps. The Commodity Futures Modernization Act, (CFMA) signed into law on December 21, 2000 updates commodity trading regulations. The most notable change was in addressing newer types of financial contracts such as over-the-counter derivatives. This created an unprecedented bubble in the finance markets.

- The production of conventional crude oil plateaued in 2005 while demand continued to grow, creating a speculative bubble on top of a real supply and demand gap. Much of this speculative bubble was associated with the international financial derivatives market.

- The Global Finance Crisis of 2008, the largest economic correction since the 1929 Great Depression. The banking finance system came within a few hours of complete paralysis, which had the capacity to trigger a currency scale default on debt. As all currencies were fiat based, this would have triggered a global systemic meltdown of all systems associated with currency finance. Quantitative Easing prevented this from happening.

- The introduction of Quantitative Easing programs QE1, QE2 and QE3 by the U.S. Federal Reserve Bank between years 2008 to 2014. This resulted in a historically unprecedented volume of money printed, for which most nation state governments are now in debt.

- The development of a new oil extraction technology in 2008, horizontal drilling of fracking wells, opening up a new oil frontier in the United States. This allowed oil production to increase in line with demand once more. This resulting in an increase in the production of oil to an unprecedented level.

- All parts of the global economy at all scales of operation become loaded up with financial debt at an unprecedented volume. So much so that future economic activity has become very difficult in terms of flexibility and options for development. Money supply and debt have grown faster than the real economy. Debt saturation and paralysis is now a very real risk, requiring a global scale reset.

- The extraction of oil is getting more expensive as time goes on. The window of operation that allows price of oil production to be less than the oil price consumers can support is closing.

- The rate of oil resource discovery has been declining since the 1960's. The discovery of new reserves of high ERoEI oil and gas deposits the size of the Saudi Arabian oil field is increasingly unlikely. The era of cheap and abundant energy is long gone.

- Oil remains the master resource for the global industrial ecosystem. Complete substitutions for oil based technology may be beyond the logistical and practical capability of the global industrial ecosystem. Alternatives exist but it may not be economically viable to make them accessible to the entire global human population.

"The great unwinding of the financial sector showed that the smartest mathematical minds on the planet, backed by some of the deepest pockets, had not built a sleek engine of permanent prosperity but a clown car of trades, swaps and double dares that, inevitably fell to bits."

– Raj Patel 2009

17 PEAK OIL

Oil is a finite natural non-renewable resource. The planet Earth is a finite system. At some point, rates of resource discovery and oil extraction rates will peak and decline. Has all the oil deposits been discovered, or is there vast reserves yet to be tapped? A pertinent question is when this date might be. Another pertinent question would be how society might manage this supply gap in oil supply.

Data collected over the last several decades show that peak oil is now an observation in several oil producing regions (Norway, United Kingdom, etc.) and is not just a theory. In the past, as one region peaked and declined, a new region was developed to take over production growth, thus the global production could continue to grow. So what happens when all regions on the planet are in decline and there are no more new regions to exploit?

What is to be remembered is that not all oil deposits are equal and some will be much harder to exploit than others. It is appropriate to state that the easy to find, extract and refine oil deposits have all be exploited decades ago, and what is left is the less economic deposits. Technology has been the mechanism that has allowed the continued economic extraction and delivery to market.

17.1 Oil & Gas Industry and Peak Oil

In the review process for this report, it became clear that the current paradigm in the oil industry is that the concept of finite reserves or peak oil production is ridiculous and not considered a worthwhile topic of discussion. The following reasons are routinely encountered when interacting with the oil and gas industry when enquiring about how long oil supply can be sustained:

1. Oil based technology and products will be simply phased out when it becomes too difficult to supply, and replaced by more economic substitutes.
2. Electric vehicles (EV) and hydrogen fuel cell cars will replace internal combustion engine (ICE) technology vehicles are the technologies that will make oil (and all fossil fuels) irrelevant.
3. Economics and market forces will ensure this is done. When the substitute system is cheaper than petroleum based ICE systems, they will naturally become dominant and oil will be left behind.
4. More deposits will be discovered once the oil price goes up making lower quality resources viable.
5. Fracking technology can continue in the same rate and economic footprint as conventional oil production.

There are a number of difficulties with these paradigms. The assumption that EV technology will work the same way and be assemble to all parts of society like ICE technology does now is unlikely to work out as planned. A parallel report done (Michaux 2020) examines the logistical practicalities of transforming the existing ICE felt to EV, with the purpose of estimating the needed extra capacity required in the global (and EU, US and Chinese) electrical power grids to charge the necessary number of batteries. The report (Michaux 2020) shows that the task to transform the existing fleet of ICE vehicles into EV's and manage their operation is a far larger challenge than currently understood. Another study being planned is to examine the volume quantity of minerals needed to manufacture the required batteries, solar panels and wind turbines to support a fully renewable power system that supports a fully EV fleet of vehicles. Preliminary results at the time of writing this report suggest that global mineral reserves of cobalt, nickel, lithium, and neodymium are not large enough to supply raw materials for this task.

Then there is the question of time. It will take time to implement this kind of industrial reform. Once a substitute system has been diagnosed, it would take 10 to 20 years to phase out the ubiquitous application of ICE technology and its supporting infrastructure (Hirsch 2005). If the transition was started at a larger scale than what is being done now, will petroleum supply be stable for another 10 to 20 years? This is a question that is required to be addressed.

This suggests that the assumption that the EV revolution will overturn oil as the preferred and more economically viable system, is far from certain. Just so, assessing the long term stability of such an important resource is required to be examined in context of physical supply and demand of that resource, in conjunction with market economic forces. Assuming market forces on their own will address society's industrial needs in a timely fashion may not be appropriate.

Points 4 and 5 will be examined later in this report.

The implications of the statements in this section require that oil be examined in context of what it does for society now, and if no widespread economically viable and logistically practical solution was developed, how long will oil supply be stable. The perception that peak oil does not need to be discussed because electric vehicles and renewable energy will replace oil may not be appropriate. Oil is required to be studied as a system as it is now, not what it might be in a decade from now.

This difference in paradigm has resulted in some aspects of the oil industry not being studies at all (at least publically). That there was no publically available oil Critical Raw Material study published by the oil industry, was the motivation to write this report.

17.2 Definition of peak oil

The concept of Peak Oil is best described by the analysts from the blog websites

'The Oil Drum' (http://www.theoildrum.com/). The next few paragraphs have been paraphrased from this website.

Peak Oil is the moment in time when, on a global scale, the maximum rate of oil production is reached. The moment after which oil production, by nature, must decline forever. Since Earth is a closed system, next to this production (supply) event, there must be an equal demand event: Peak Oil Consumption. Since there are no substantial above ground deposits, Peak Oil Production and Peak Oil Consumption must coincide. The world consists of a lot of different countries, some of which are already far beyond peak oil production. That leads to the assumption the world as a whole reaches peak oil production. On the demand side, it is worth looking, because different countries have different economies, different degrees of development, and so on, if, while some countries still experience significant growth in oil consumption, some countries are already well beyond Peak Oil Consumption by now.

17.3 Production vs Consumption

The production history of crude oil is well documented. It is clear some countries have reached peak oil production long time ago. Still world oil production could still grow, because some countries make up for the countries that are losing production.

17.4 The Bell-Shaped Curve

Finite resources tend to be exploited as fast as possible, resulting in an ever increasing "production" ("mining" is the more correct term), until a limit is reached, after which production declines. This can be modelled as an example of the maximum power principle or Lotka's principle (Tilley 2004, Cai *et al* 2006, and Chen 2006). The maximum power principle or Lotka's principle has been proposed as the fourth principle of energetics in open system thermodynamics, where an example of an open system is a biological cell.

> "The maximum power principle can be stated: During self-organization, system designs develop and prevail that maximize power intake, energy transformation, and those uses that reinforce production and efficiency."
>
> Howard T. Odum – Industrial Ecologist

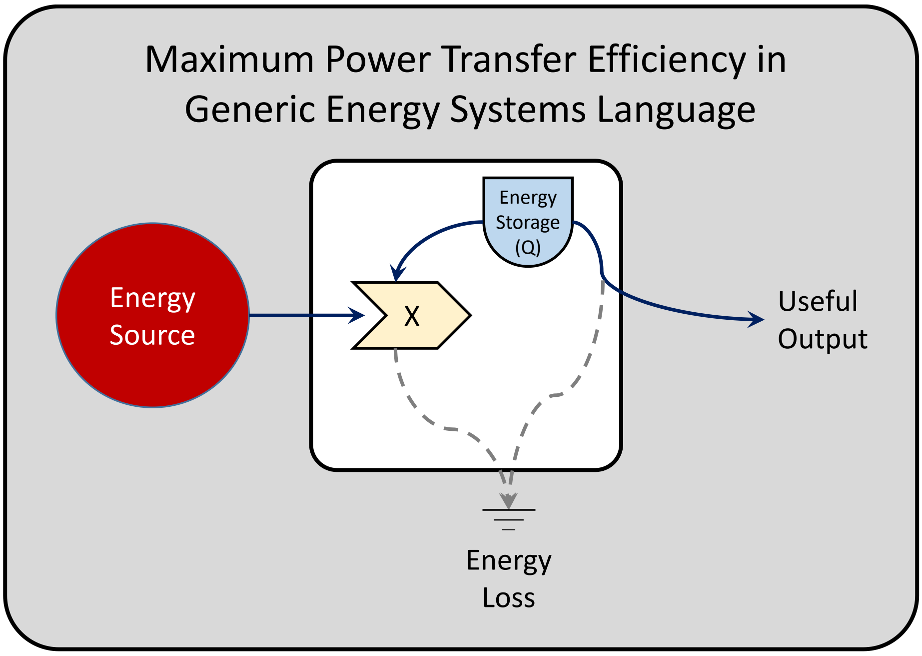


Figure 261. The maximum power principle or Lotka's principle

Figure 261 shows the systems flow model for the maximum power principle. This systems theory allows for all the easy to process resources to be consumed first, and the harder to process resources to be processed later. This produces an approximately bell shaped curve.

A milestone study done by geologist Marion King Hubbert (M. K. Hubbert 1956) made the observation that this is what production from an oil field looks like (Figure 262). A non-technical description of who Hubbert was and how he developed the peak oil theory can be found at link:

http://www.stuartmcmillen.com/comic/peak-oil/?fbclid=IwAR1Y6hfqxMbYN_wKD4RwVCOGSZPxOZWx3m4ZmmZ8WGW49p9kFx4kGKTt5Fs

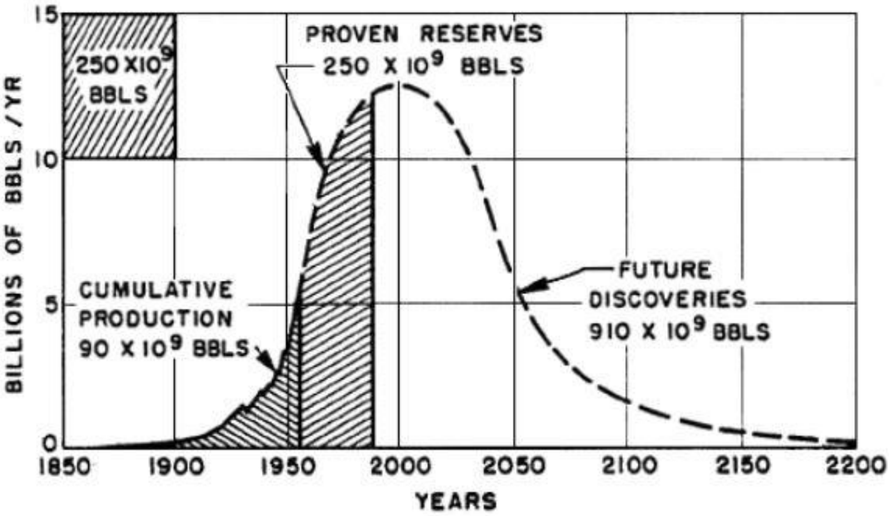


Figure 262. M. K. Hubbert's oil field bell shaped production curve.
(Hubbert 1956 & 1962)

Hubbert argued that production of oil from a single field would follow a bell shaped curve. He also argued that a region of oil producing fields would follow a similar pattern, combining into an aggregate bell curve.

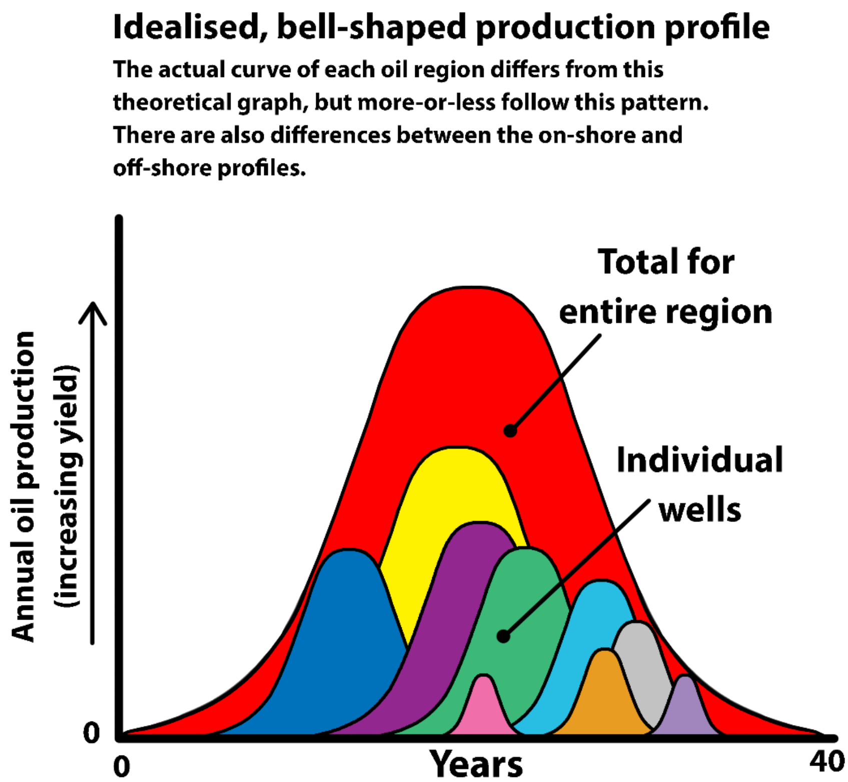


Figure 263. Idealized, bell shaped production profile for an entire region
(Source: Image by Tania Michaux, developed from Campbell and Laherrère 1998)

Hubbert also promoted the idea that there would be a peak in oil discovery and after a lag time of an estimated 40 years, a peak in oil production from extraction.

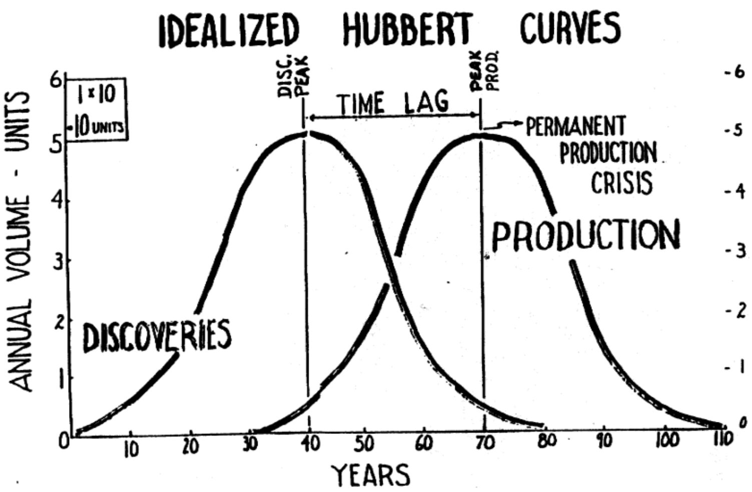


Figure 264. Idealized (original sketch) Hubbert curves for discovery and production (Hubbert 1956 & 1962)

Hubbert predicted in 1956 that:

- US oil extraction would peak production in 1970
- Global oil extraction would peak production in 2000, at 13 billion barrels per year

World production of oil is now of the order of 32 billion barrels of oil per year. Hubbert would have been unaware of the technology of deep water drilling as it had not been invented yet in 1956. The model that Hubbert developed has shown to be too simplistic, but it facilitated the development of more appropriate tools to examine this issue.

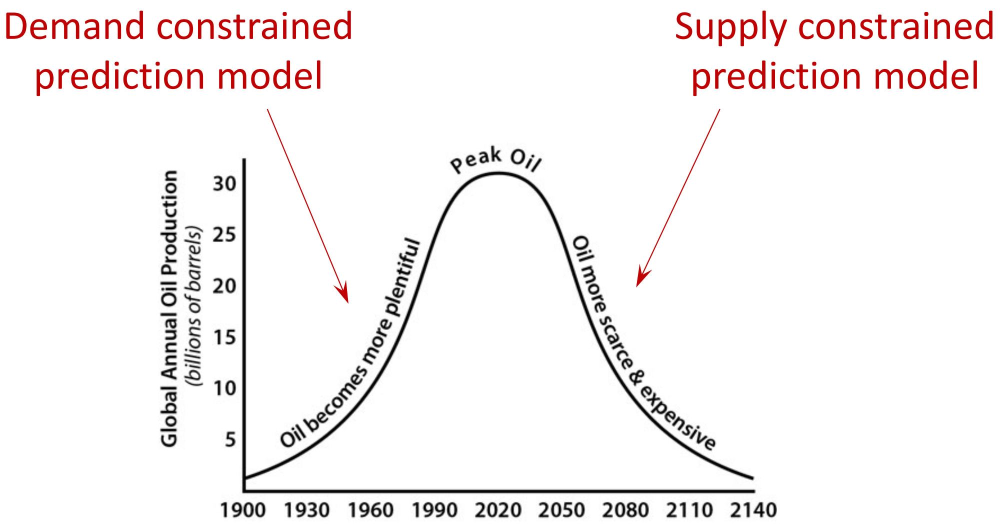


Figure 265. Demand constrained prediction vs. supply constrain prediction shown on an oil depletion bell curve

With the benefit of 20/20 hindsight, it is now known how these predictive theories have fared against history. It is now well understood how the rate of production an oil field now follows, as offshore production often looks more like Figure 266 while conventional on shore early oil fields look like Figure 263 with the conventional bell curve.

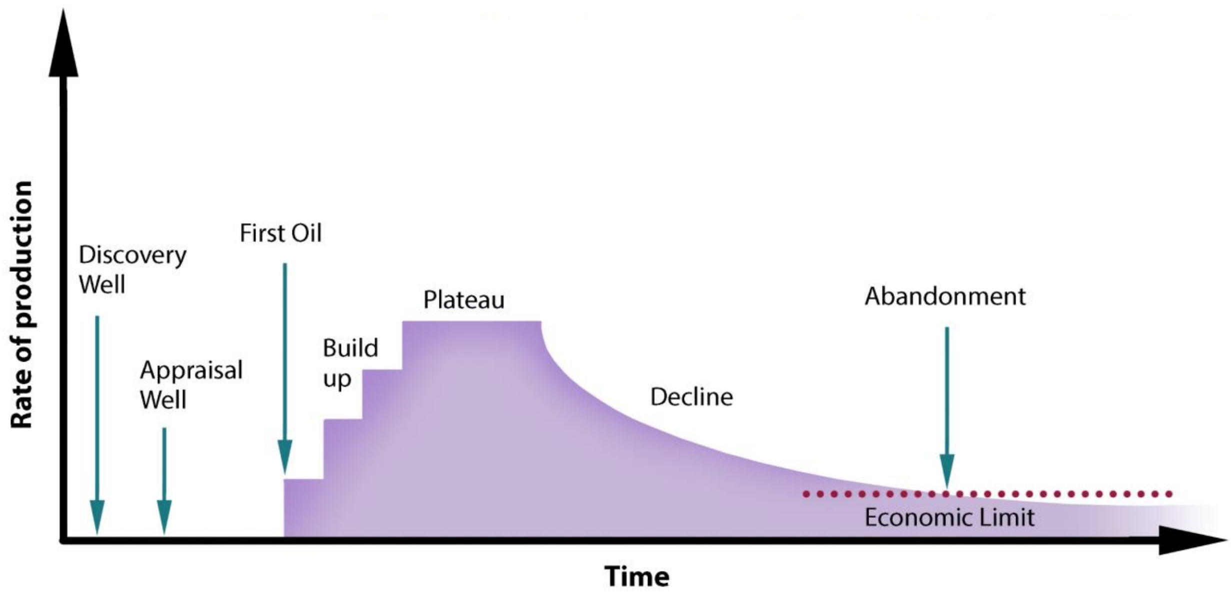


Figure 266. Stylized oil field production curve, describing the various stages of maturity (Redrawn from Davies 2001, Image: Tania Michaux)

17.5 The Net Hubbert Bell Curve

The Net Hubbert Curve is calculated by applying ERoEI concepts to the conventional Hubert curve. As the high quality light sweet crude has been extracted first and the heavy sour crude is what is left. This happens due to the lower density (light) oil tends to flow through porous rock more easily than the high density (heavier) oil.

The Net Hubbert Curve is calculated based on the concept that the best and easy to work resources will be consumed by society first, leaving the more difficult resources to be processed last. This has been shown to be appropriate empirically. Currently ¼ of oil being processed is light sweet crude (low sulfur content and higher ERoEI) and ¾ of oil processed is graded as heavy sour crude (high sulfur content and lower ERoEI).

> *"Humans like most other biological organisms use the highest quality, richest and easiest to obtain resources first."* - Chris Martenson 2008, (updated in Martenson 2014)

In context of all oil fields summed together, declining ERoEI implies that the amount of discretionary energy available to society is far less than that predicted by a Hubbert curve. The Hubbert curve represents the total gross quantity of energy available, and, as it is calculated, there are equal quantities of energy available on the left and right side of the peak. This, however, is only true in the context of energy content of oil as it resides in the ground. The net energy available (i.e. discretionary energy, or energy that is available to do useful work) is less. In terms of a practical outcome, declining ERoEI means that there will be much less net energy extracted post-peak than pre-peak on the Hubbert curve.

Unlike the original Hubbert curve that shows equal quantities of gross energy resources on the left and right side, the Net Hubbert Curve is skewed so that most resources are on the left. For example, according to the original Hubbert curve, 50% of the energy resource is remaining when production levels reach the peak, but this is quite different for the Net Hubbert curve. Due to declining ERoEI, by the time peak production is reached, 73% of the net energy available is already used.

While this concept is useful in abstract terms, it has since been shown that above ground limitations and actions need to be integrated into any depletion modelling of oil producing reagions.

17.6 Depletion of oil resource

Decline rates accelerate in the final stages of a field's lifecycle, as technology only delays the onset of decline. The IEA (2013 WEO) has argued that using a single decline rate is not a robust basis for long-term supply forecasts, as decline rates evolve through the different stages of a field's decline (Figure 267). In its analysis of decline rates, the agency divides post-peak decline into 3 phases:

- phase 1, when production remains consistently above 85% of peak level;
- phase 2, when production is between 50% and 85% of peak;
- phase 3, when production falls below 50% of peak.

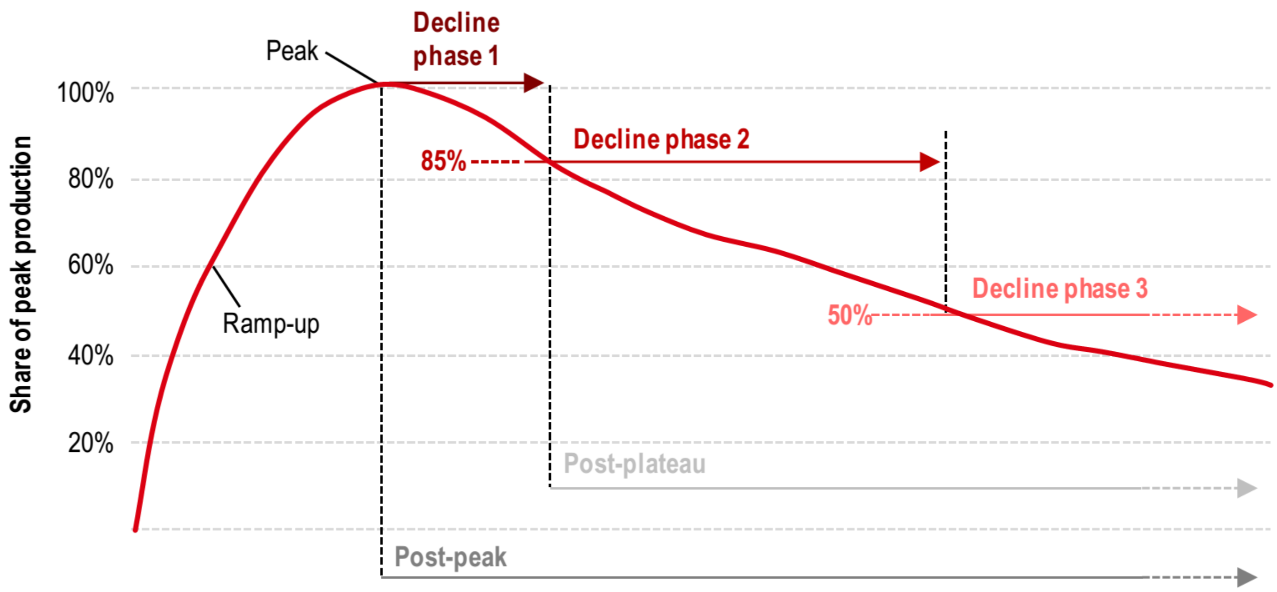


Figure 267. Indicative illustration of decline phases and concepts of peak oil
(Source: IEA World Energy Outlook 2013, Fustier et al 2016)

17.7 Attempting to predict the date of global peak oil production

Peak Oil is a date that has been predicted by many analysts. Most of these predictions have been unsuccessful due to the complex and dynamic interactions of a number of issues around the oil industry (most notably geopolitical actions and the effect on Quantitative Easing). The original theory of peak oil was too simplistic and did not account for above ground influences.

The actual date of peak oil is defined by the cost of production vs. the market ability to sustain a high price. There is plenty of oil left but it is increasingly expensive to access. The current economic system cannot sustain oil prices above $100 a barrel, and engage in genuine growth in the real economy for very long (Tverberg 2017). Alternatively, producers cannot sustain oil prices as low as $45 a barrel and still make a profit (without some support of some kind), for most of the new fields being brought online (Tverberg 2017). The ability to bring oil to the market becomes more difficult as peak production is found and then passed. The decade of the 2020's are projected to be somewhat chaotic in terms of oil production (Cunningham 2017).

The dependency of oil by the industrial grid has been demonstrated. The 2008 spike in oil price reaching $147 a barrel has been likened to a "massive stroke for industrial civilization" (Casey 2017). Once next turning point for oil supply vs. economic output happens, capability to operate in general will start deteriorating much more quickly. The second phase of the thermodynamic collapse starts when the growing ineffectiveness of these financial measures against stark net energy realities hits a brick wall (paraphrased from Casey 2017).

From a geological point of view peak oil is predicted in a range from to be around 2012- 2022 (Zittel 2013, Hughes 2011, Hughes 2018). The contribution of the U.S. Tight Oil sector is a hotly debated subject. On one hand tight oil peak production is predicted to be around 2030 (EIA 2013). On another hand those same oil fields are predicted to peak around 2020 (Hughes 2018 and Hughes 2019). Whatever the real date is, it is predicted to be seen in the next few years. Considering the scale of the problem, the precise date is not really that important. The true peak oil date cannot be correctly defined until it has been passed by 5-6 years of reliable data. The longer the peak production record holds for, the more difficult it becomes to beat (Simmons 2005).

It can also be demonstrated that oil production can be impacted by above ground influences (see Section 14). Figure 276 presents a more holistic model for peak oil. It suggests that there is a closing window for the viability of the oil market, with rising cost of oil production as one limitation and an upper limit for the price of oil consumers can tolerate in terms of market support.

17.8 Transitioning time required away from oil makes the date of peak oil less important

In 2005, a report was published that was commissioned by the United States DOE (Hirsch 2005) to examine the issue peak oil and make recommendations to mitigate risk. Figure 268 and 269 shows the basic mitigation model Hirsch proposed.

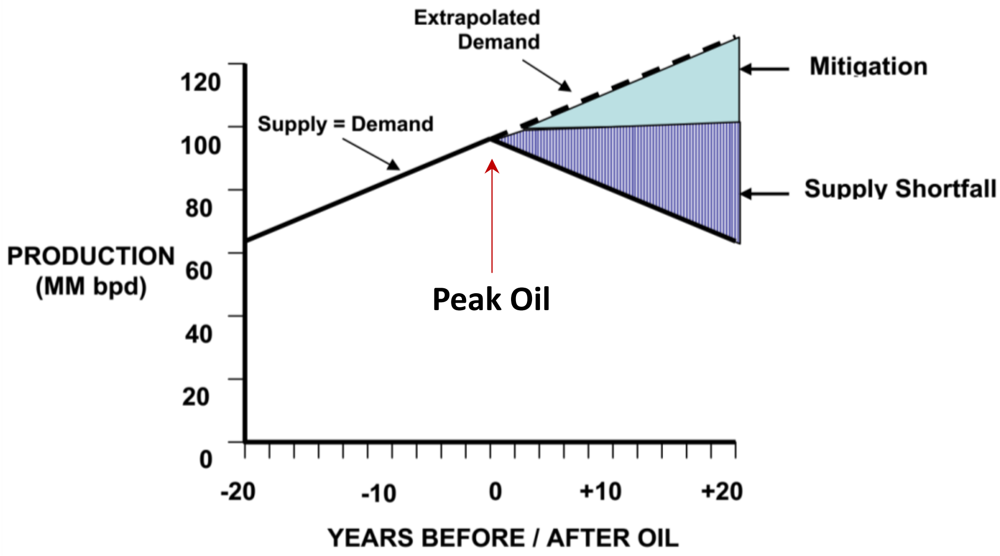


Figure 268. Mitigation crash programs started at the time of world oil peaking: A significant supply shortfall occurs over the forecast period. (Source: Hirsch et al. 2005 report commissioned by US DOE) (Copyright License: https://www.energy.gov/about-us/web-policies)

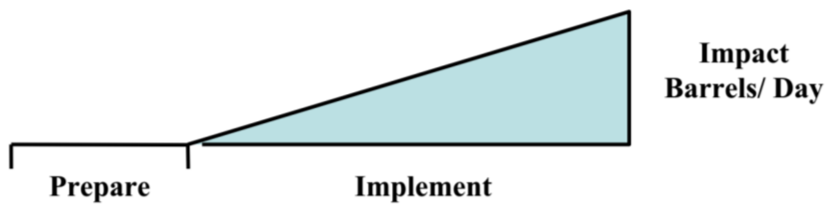


Figure 269. Delayed wedge approximation for various mitigation options
(Source: Hirsch et al. 2005 report commissioned by US Department of Energy)
(Copyright License: https://www.energy.gov/about-us/web-policies)

Once a credible set of solutions to replace fossil fuels (oil in particular) have been identified, Hirsch recommended that it would take time to prepare and implement those replacement solutions (Figure 268 and 269). For oil, this process would take society about 20-30 years at a comfortable but seriously invested rate. This process could be shortened to 10 years if society undertook the forced industrialization like what the United States did in preparation for World War II. If this forced industrialization adaptation were attempted at or post peak oil production, the additional energy required for adaptation would be at the expense of all society's other priorities, which would probably cause society to collapse before adaptation could be achieved.

As such, the precise date of peak oil is not that relevant. If peak oil is around now or possibly a few years in our past (masked by economic stagnation), and no credible solutions to oil replacement, let alone steps to retool the energy supply system have been undertaken, then the exact date no longer matters. This diagnoses an outcome. The following combination suggests it is already too late for an orderly planned transition, where the world will move away from the "agreement" based system.

- It would probably take 20-30 years to phase oil systems out and substitute a replacement system
- Oil production will probably peak sometime in the next few years
- Mitigation has not really started beyond mostly talking about it. EV's and associated infrastructure has practical and logistical limitations to completely replace ICE technology (Michaux 2020)

17.9 Case Study: Peak oil (conventional crude) observed in Norway

In Norway, giant fields of more than 1bnbbls have fallen to less than 35% of total production, down from nearly three-quarters 20 years ago. Conversely, the contribution of every other category of field (small, medium fields but also "elephants" of >500mb) has risen (Fustier *et al* 2016).

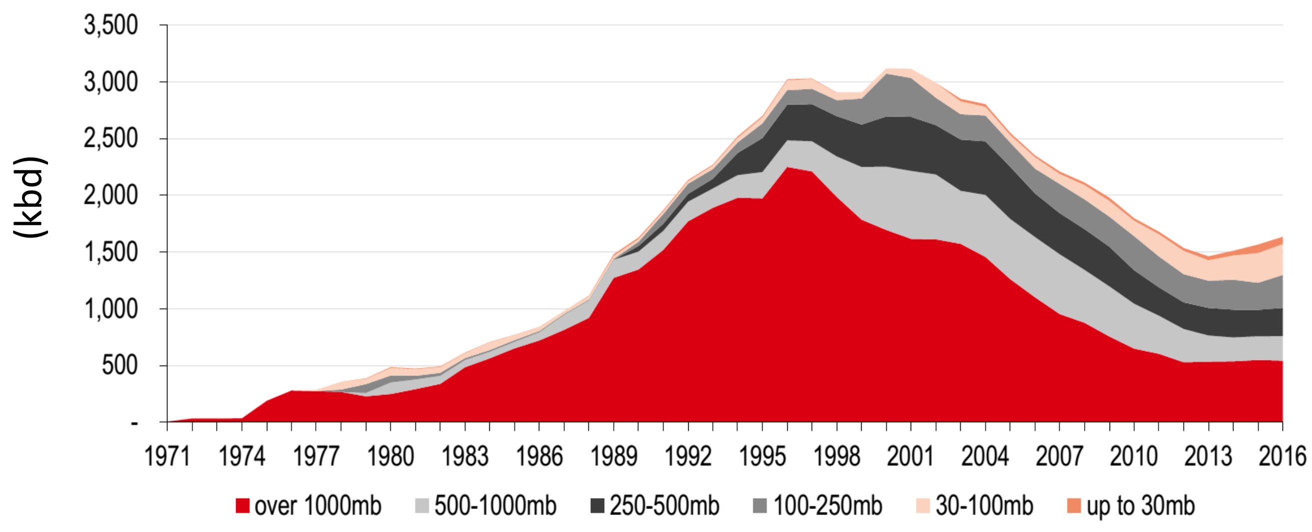


Figure 270. Norwegian Continental Shelf (NCS) crude production, ranked by field size, Ranked by estimated ultimate recoverable reserves URR. (Source: Fustier et al 2016, Norwegian Petroleum Directorate)

17.10 Case Study: Peak oil (conventional crude) observed in North Sea (UK)

The United Kingdom has equally been reliant on a few very large fields, but the latter tend to be "elephants" (500mb-1bnb) rather than true giants as in Norway. Following the Norwegian trend, the proportion of giants has collapsed from just under 20% to only 6% of production (Fustier *et al* 2016).

However, unlike its northern neighbor, in the UK even medium-sized fields have dropped from 45% to 1/3 of total production. This is seen as evidence of the UK's greater maturity. Meanwhile, the contribution from small fields of <100mb has grown from 13% to one-third.

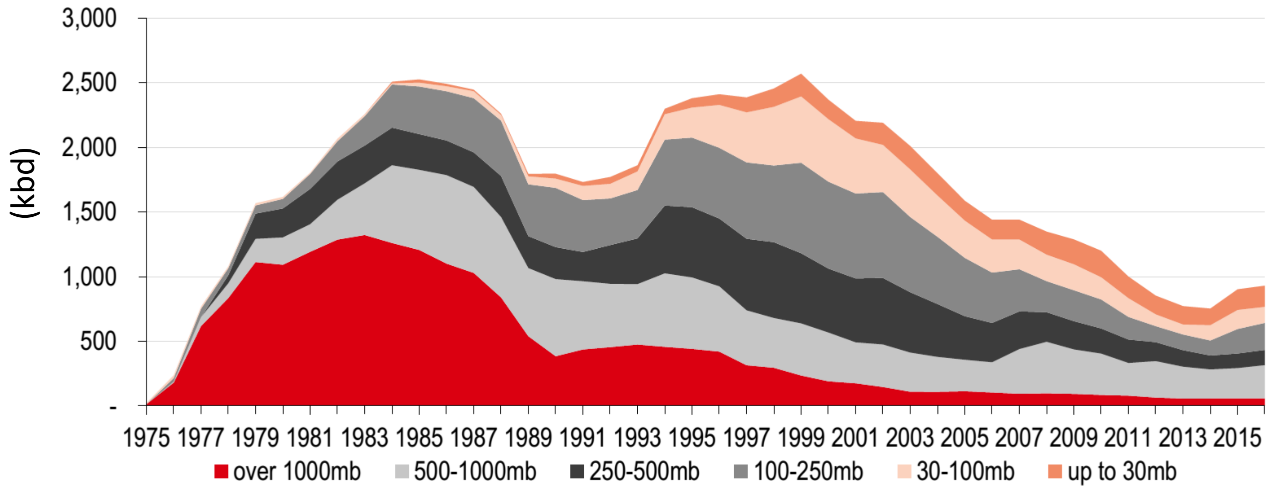


Figure 271. United Kingdom liquids production, ranked by field size, Ranked by estimated ultimate recoverable reserves URR. (Source: Fustier et al 2016, Norwegian Petroleum Directorate)

The North Sea oil fields had the highest production reserves ratio in the world. This energy bonanza was exploited very quickly and for short term financial gain, with little thought for long term sustainability. The United Kingdom also converted their power generation from coal to gas, based on take or pay contracts lasting only 15 years. Now the North Sea gas supply is depleting in double digit percentages per year. The United Kingdom is now dependent on Russian gas supply for energy, and is in a difficult net position due to its position in the energy supply value chain (this is relevant as oil and gas are usually produced together).

The potential to ensure the United Kingdom's long term energy security, was poorly developed into strategic dependence on a foreign power (who has been diplomatically difficult to trade with). This was a consequence of poor foresight and ill-informed insight into the true nature of the opportunity the North Sea oil and gas fields represented.

17.11 Case Study: Peak oil (conventional crude) predicted in the United States

As can be noted, U.S. peak production was in 1970 and the peak of oil resource discovery was 40 years earlier in 1930, as Hubbert predicted in 1956. After decades of aggressive exploitation, these American oil fields (lower 48 states) peaked production and declined (Figure 272 blue and red). This was one of the first and best documented observations of the concept of Peak Oil.

In approximately 2008, the tight oil production bonanza stated up in the United States, using the horizontal drilling technology applied to the hydraulic fracturing (fracking) industry. That stated, the peak oil production (of conventional crude) date for the lower United States was correctly predicted decades ahead of time (Hubbert 1956 and 1962).

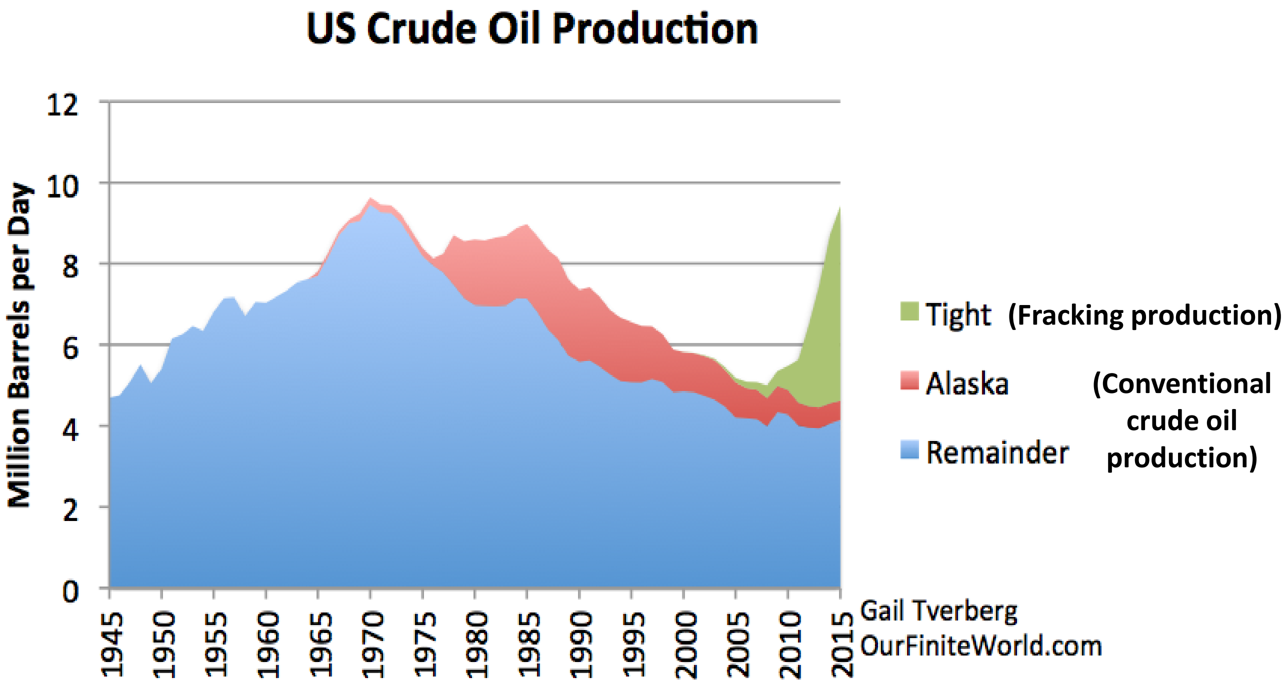


Figure 272. US Crude Oil Production
(Source: OurFiniteWorld.com)

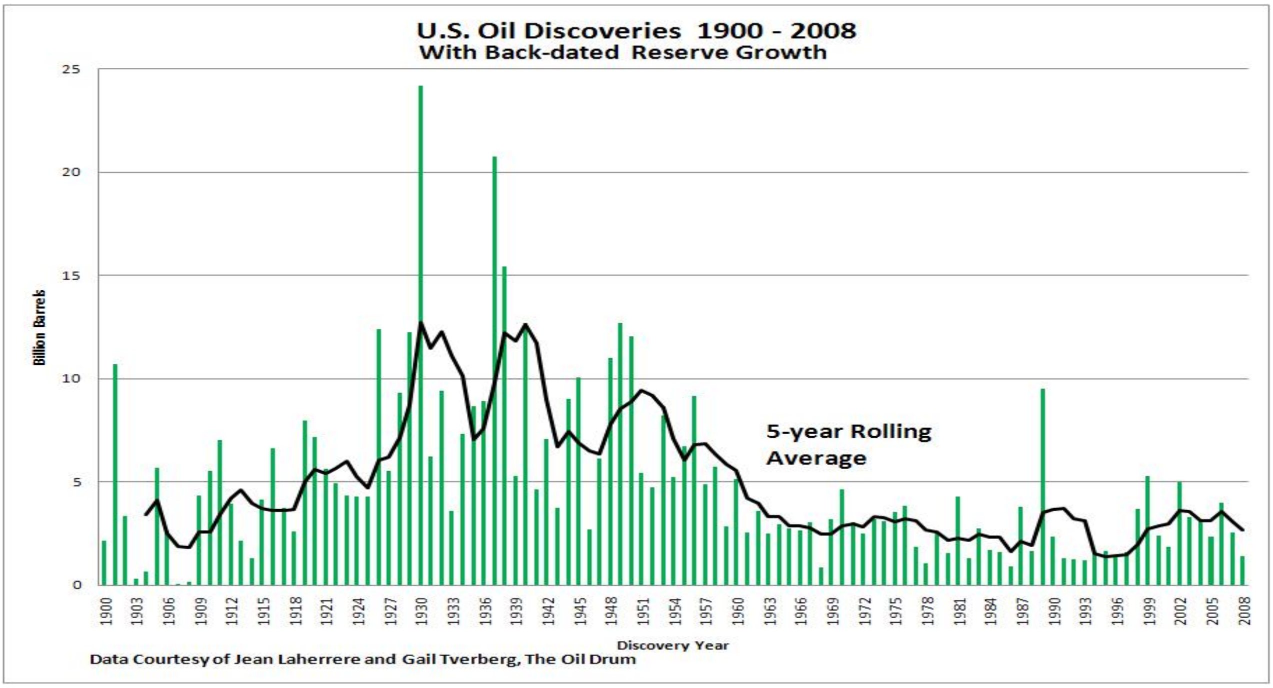


Figure 273. U.S. oil discoveries 1900-2008
(Source: Jean Laherrere, Gail Tverberg & The Oil Drum)

Figure 273 shows the discovery history of oil deposits in the United States, showing a peak discovery in 1930. What is curious is the 40 year gap between peak discovery and peak production in the United

States, which had peak production in 1970. A very similar gap was observed in the global conventional crude oil profile.

Since the peak and decline of U.S. oil fields, other international sources of oil production like the Middle East have dominated the market for the last five decades.

17.12 Prediction of global peak oil (conventional crude)

The prediction that global oil production would peak in the year 2000 was not been correct (Hubbert 1962). Figure 230 shows that conventional crude oil plateaued in 2005. For some time this was believed to be peak oil for conventional crude oil, to the point where the International Energy Agency (IEA) issued a statement admitting the this to be the case (Staniford 2010). Later, conventional oil production was increased in approximately 2013 (see Figure 113).

However, the 1973 First Oil Shock and the 1979 Second Oil Shock dramatically impacted oil price and then oil production, pushing peak oil back a few years. Also, the impact of deep water drill technology and unconventional oil extraction methods have pushed the peak back, but only by 20 years or so.

The situation for oil is particularly critical, especially given that it is by far the world's major source of liquid fuel, powering 95% of all transport. At this time, approximately 60–80% of conventional oil fields are in terminal decline (Fustier et al. 2016). It is estimated that to maintain current supply rates of oil by 2040 the world would need to find four Saudi Arabia Ghawar elephant fields (the largest to date single producing oil field) worth of additional oil just to maintain current rates of supply. If the projected demand in 2040 is to be met, eight Saudi Arabia Ghawar elephant fields would need to be found and operating by that date.

On September 14th 2019, the Aramco oil refining facility at Abqaiq in Saudi Arabian was subject to a precision attack (an estimated 17 points of impact at key infrastructure) (Rapier 2019 Sept 16th). The resulting destruction meant that Saudi Arabia (Armco) reduced crude oil production by 5.7 million barrels a day. The drone attacks on Saudi Arabia's oil infrastructure are unprecedented in the history of the global oil industry.

This was equivalent to about half the kingdom's output. This had the capacity to create an instant supply gap on the global oil market. The current supply demand gap is estimated to be about 1 million barrels a day (Fustier et al 2016). So this incident had the capacity to crash the oil market. The U.S. Tight Oil sector was able to ramp up refinery capacity to make up the supply gap. This shows how the U.S. Tight Oil sector is now the global swing producer.

At the time of writing this report (a few days after the attack), Aramco announced it was able to reroute refined oil through alternative facilities. The recovery is quicker than analysts had been anticipating, with state oil company Saudi Aramco acting to fire up spare capacity at offshore fields and bring production back online, while restoring processing capacity at one of the damaged facilities (Sheppard *et al* 2019 Sept 25th). Saudi Arabian oil production would still be 1.5 million barrels a day below what it was before the attacks.

While this incident had the capacity create havoc, the refined oil market supply fallout looks like it has been contained. That being stated, it really highlights how vulnerable the current supply of oil really is.

A recent public domain analysis of total energy consumption suggests a peak of total oil production very soon (a case can be made that peak production was 2018) (World Energy Outlook 2018), shown in Figure 274.

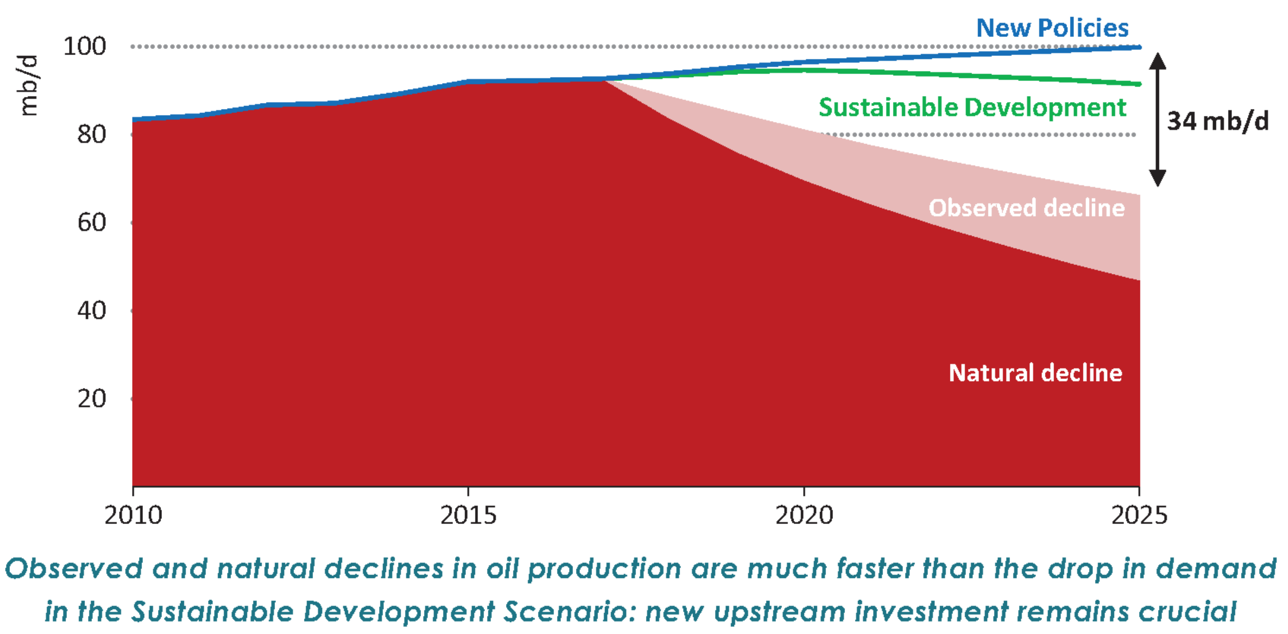


Figure 274.Declines in current oil production and demand in the New Policies and Sustainable Development scenarios. (Source: World Energy Outlook 2018) (Copyright License: https://www.iea.org/media/copyright/Termsandconditions_2019update_FINAL.docx.pdf)

Figure 275 (Li 2018) shows the historical and projected world primary energy consumption from 1980 to 2050. World oil production (including crude oil and natural gas liquids) was 4,387 million metric tons (92.6 million barrels per day) in 2017. Between 2007 and 2017, world oil production grew at an average annual rate of 1 percent.

Table 26 summarizes the projected peak production level and year for the world's ten largest oil producers, the rest of the world, and the world as a whole. World cumulative oil production up to 2017 was 192 billion metric tons. One study (Li 2018) predicts that world oil production will peak at 4,529 million metric tons in 2021. For Peak Production and Peak Year, regular characters indicate historical peak production and year and italicized blue characters indicate theoretical peak production and year projected by statistical models. So far most peak oil predictions have not been correct. It is postulated that not enough above ground influences are included in their modelling. So it remains to be seen if this study is indeed correct. That being stated, most indicators are suggesting that peak oil will happen in the next few years.

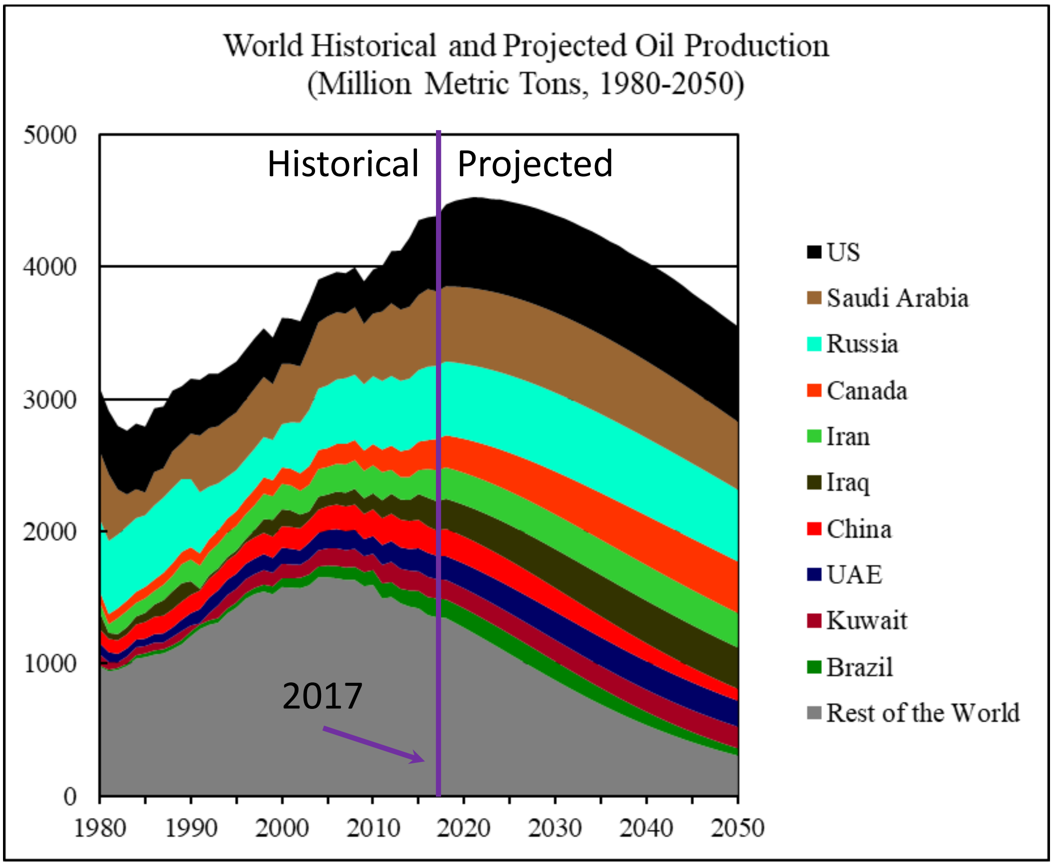


Figure 275. World Historical and Projected Oil Production, 1980-2050
(Sources: Li 2018, Historical oil production from 1980 to 2017 is from BP (2018))

Table 26. World Oil Production: Peak Production – 2018 estimates (Source: Li 2018, Cumulative production up to 2007 is from BGR (2009, Table A 3-2), extended to 2017 using annual production data from BP 2018)

Country or Region	2017 Production (mtoe)	Cumulative Production (billion metric tons)	Peak Production (mtoe)	Peak Year	Estimation Study
United States	571	33.5	751	2042	EIA
Saudi Arabia	562	21.5	606	2030	BP Reserves
Russia	554	24.5	598	2033	Hubbert
Canada	236	6.3	391	2049	BP Reserves
Iran	234	10.4	269	2039	BP Reserves
Iraq	221	5.8	324	2042	BP Reserves
China	192	6.9	215	2015	Hubbert
UAE	176	5.2	218	2037	BP Reserves
Kuwait	146	6.7	197	2040	BP Reserves
Brazil	143	2.6	151	2024	Hubbert
Rest of World	1351	68.9	1654	2004	Hubbert
World Total	4387	192.3	4529	2021	

17.13 Holistic model for peak oil

Figure 276 shows a combined force map for oil as a resource being used by society. This is for oil specifically. Each of the raw materials listed on the European CRM list (and gas, coal and uranium) can be examined in this context.

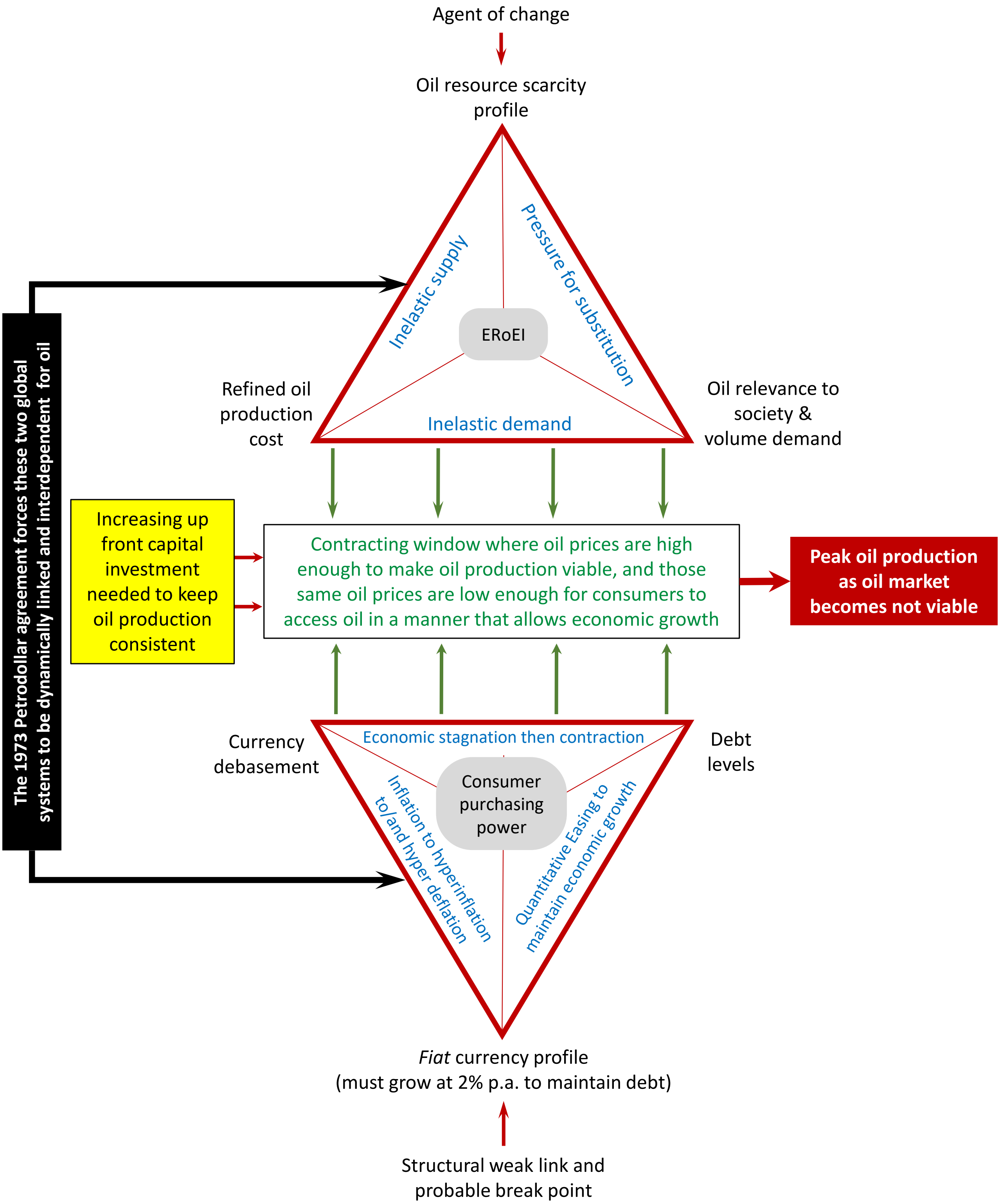


Figure 276. Oil in a Critical Resource Material profile and a holistic model for peak oil production

The conventional theory of peak oil is not able to model the oil market in context of predicting when oil supply will contract away from oil demand. It was not able to account for above ground influences like currency purchasing power or geopolitical events.

Oil production will eventually peak and decline. The fact that oil resource discovery peaked in 1966 and has declined ever since dictates this will be true eventually. The date of decline will not be dictated solely by oil reserves in the ground.

Not all oil reserves are equal. Most of the oil reserves left have a much lower ERoEI ratio compared to what was consumed in the early 1900's. The cost of exploration, extraction and refinement is now much more expensive and requires constant upstream capital investment. All of this is forcing the oil price to rise.

The consumer demand in the oil market also has an influence. There is a great deal of empirical evidence now to show that in spite of oil being such a vital and critical commodity that is the master resource in the global industrial ecosystem, there comes a point when consumers cannot support high oil prices. This can be linked to debt saturation and reduction in currency purchasing power as a consequence of structural changes over a period of several decades.

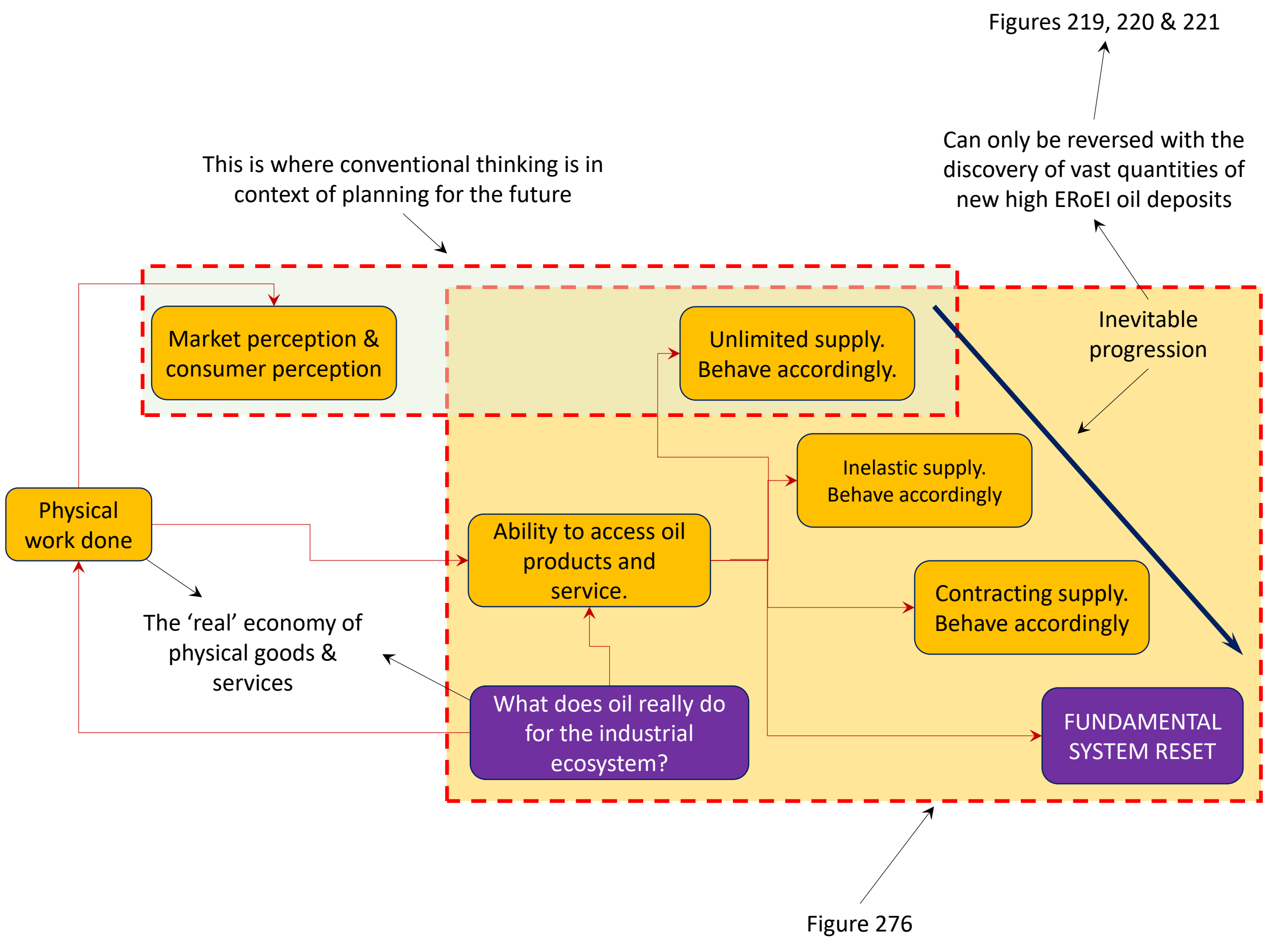


Figure 277. Transition from current market planning for the future to Figure 276

18 TEMPORAL DATA SIGNATURES THAT INDICATE HOW CLOSE PEAK OIL MAY BE

It has been shown how important oil is for the functioning of the industrial ecosystem. It also has been shown that discoveries are being outpaced by oil production (only 16% of oil production is being replaced with a resource discovery – Rystad 2018) and the cost of production is increasing. There have now been four so called oil shocks (see Figure 223) and several eras of economic industrial operation operating to different limitations (see Figure 249).

The concept of classic Hubbert peak oil may well be too simplistic to predict the actual date of oil production peak. That fact oil production will one day peak and decline is inevitable. So the question becomes how close in time is the pain threshold for the oil market where supply and demand separate resulting in an antagonistic fashion. The attempts to phase out fossil fuels are much more onerous than currently understood, and peak oil will come well before any practical solution to substitute oil is viable (Michaux 2020).

Figure 276 shows a more holistic model. In context of this holistic model, the whole industrial ecosystem should be studied to determine if any data structures are showing strain in the system that could be related to oil.

Figure 278 below shows an oil outlook analysis conducted by the International Energy Agency (IEA – World Energy Outlook 2018) that shows currently producing oil fields are declining in output, while demand is increasing (Figure 64). The green and orange wedges come from new projects, all of which require timely capital investment. If this does not happen, then supply will decline further and would not be able to meet demand. Also shown below is the international perception that the best source for new oil projects would come from the US shale fields (European Central Bank 2015).

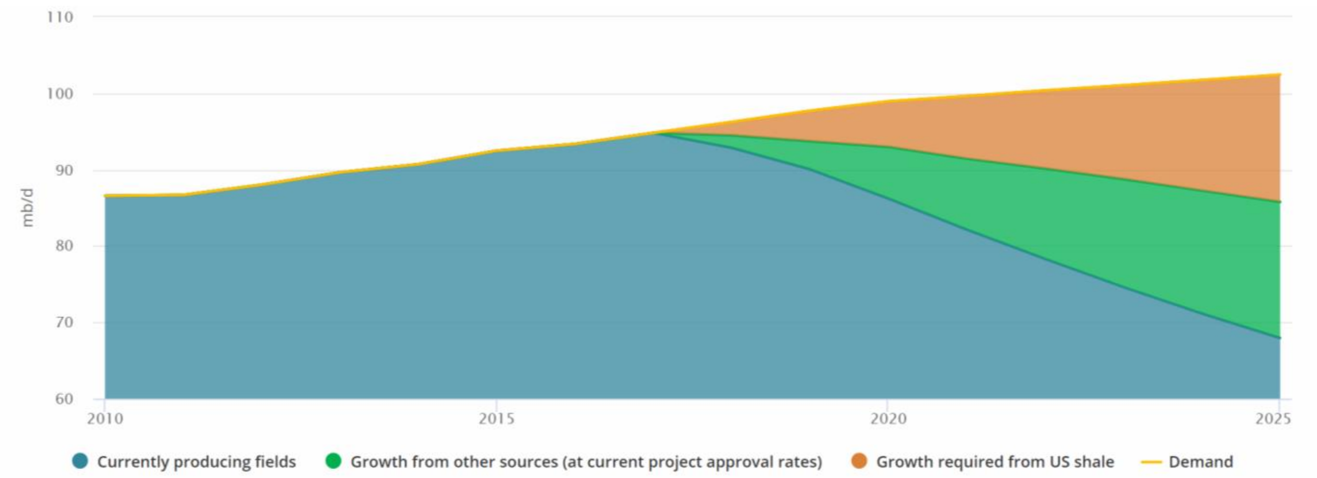


Figure 278. Oil outlook to 2025, without a pick-up in conventional oil investment
(Source: World Energy Outlook 2018) (Copyright License:
https://www.iea.org/media/copyright/Termsandconditions_2019update_FINAL.docx.pdf)

This suggests that oil may become unreliable as an energy source sometime in the next few years. It is possible that difficulties in the oil supply to the industrial market have already caused structural volatility.

18.1 Data signatures of temporal markers for industrial structural change

Figures 279 to 292 show a series of data signatures that could diagnose how close the ecosystem is to the fundamental turning point of contracting energy supply. Figure 279 shows the United States weekly import of crude oil and petroleum products. It is to be remembered that the U.S. imports crude oil to be refined and then sold internationally.

Note the clear peak in 2005 in Figure 279. It is to be remembered that the US is the largest consumer of oil in the world, and holds the current global reserve currency. This peak is 3 years before the rollout of the new horizontal well drilling used in fracking that allowed the opening up of the U.S. Tight Oil production bonanza. It also is 3 years before the Global Financial Crisis in 2008.

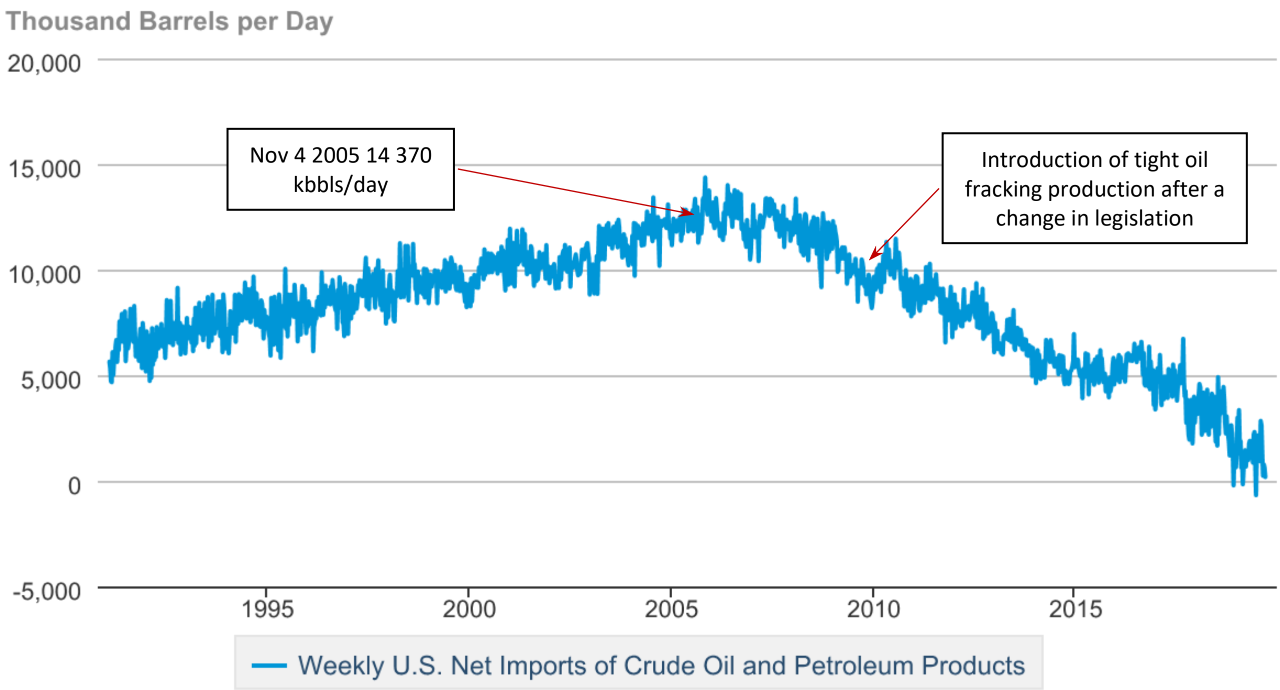


Figure 279. Weekly U.S. Net Imports of Crude Oil and Petroleum Products (Source: EIA statistics, petroleum and other liquids)

Figure 280 shows the The Baltic Dry Index from the time it was developed in 1985. The Baltic Dry Index (BDI) is an economic indicator issued daily by the London-based Baltic Exchange. Not restricted to Baltic Sea countries, the index provides "an assessment" of the price of moving the major raw materials by sea. This index is a good proxy for the health of the real economy as it measures the bulk transfer movement of real physical goods around the world (Rothfeder 2016). It is not subject to variability and volatility that other retail market measures are and tends to be more stable over time.

Figure 280 shows a breakout around the end of 2003 from the stable pattern from 1985 -2003 where the BDI was below 1800 most of the time. From 2003 till 2005 was an unprecedented volume movement of goods by shipping container. In November 2005, the BDI entered into a hyperinflationary bubble that peaked, in May, 2008, at 11,793. This peak in the BDI eclipses all other measurements before and since. The peak of 2008 was an extraordinary movement of real physical goods on a global scale (the real economy). Shortly after this peak, there was a proportional crash to a BDI of 633.

This suggests that the real economy was subject to a speculative bubbles between years 2003 to 2005, then another peak bubble from 2005 to 2008. This happened just before the largest economic correction seen since the 1929 Great Depression (the GFC or the Great Recession).

In February 12th 2016, the BDI crashed to 291, an all-time low, with no new signature to correlate with. As such the problematic issues of the previous decade in the real economy were never resolved.

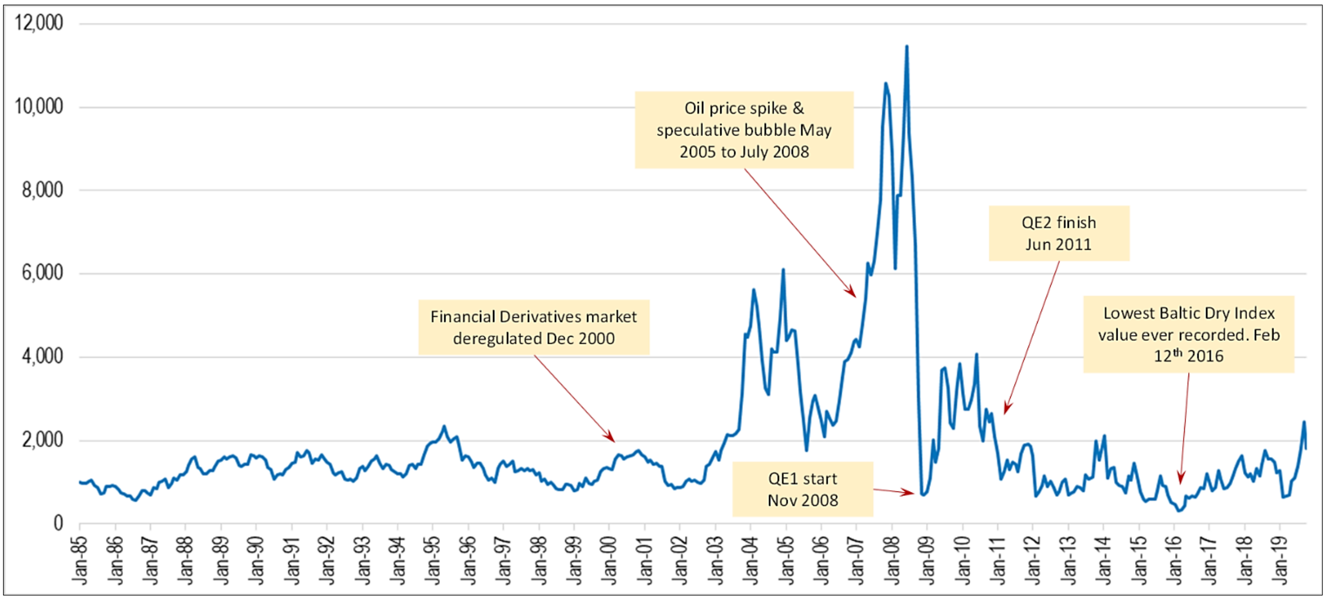


Figure 280. The Baltic Dry Index, 1985 to 2019
(Source: Data published by the Baltic Dry Exchange. Chart complied by Jean-Paul Rodrigue)

The Vehicle Miles Travelled (VMT) metric that is collected by the U.S Department of Transport is a good proxy in conjunction with BDI to map the structural signatures of the real economy (where physical goods and services are exchanged as opposed to fiat financial instruments). Figure 281 shows the average annual VMT as measured between years 1970 to 2018. The clearest structure that can be seen is the year 2007, where the first effects of the Global Financial Crisis were felt in the real economy (officially classified as a recession in June 2008). So the real economy started to stagnate and contract.

Most significantly, the end of the third quantitative easing program QE3 in 2014 show the VMT signature increasing. Thus the real economy really was assisted with QE financial stimulus. The consequences of taking on so much more debt have yet to be felt however.

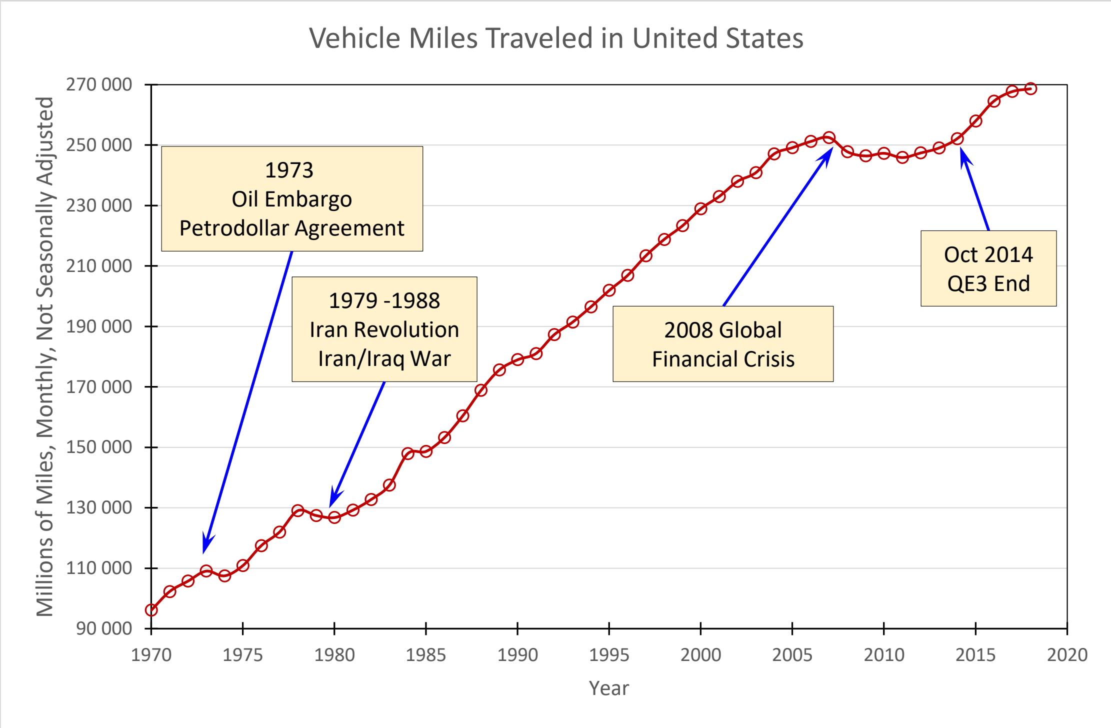


Figure 281. Vehicle Miles Travelled in United States 1970 to 2018
(Source: U.S. Federal Reserve Research and U.S. Department of Transport)

Table 27 shows how the monthly price for the 13 commodities (used by the World Bank to track volatility) are indexed to the number 100 to a reference date.

Table 27. Metals and energy resource prices Indexed to January 1970=100
(Source: World Bank Commodity Index data)

Commodity	Price in August 1971 ($USD)	Unit of Sale	Indexed to 100		Price in January 2010 ($USD)	Index reference against Aug 1971=100
Industrial Metals						
Aluminium	US$606,27	($/mt)	100		US$2 235,15	368,7
Iron ore, cfr spot	US$9,84	($/dmtu)	100		US$125,72	1277,6
Copper	US$1 626,30	($/mt)	100		US$7 386,25	454,2
Lead	US$324,70	($/mt)	100		US$2 368,38	729,4
Tin	US$3 842,70	($/mt)	100		US$17 714,75	461,0
Nickel	US$2 846,20	($/mt)	100		US$18 439,25	647,9
Zinc	US$302,40	($/mt)	100		US$2 434,45	805,0
Precious Metals						
Gold	US$34,94	($/troy oz)	100		US$1 117,96	3199,7
Platinum	US$132,50	($/troy oz)	100		US$1 557,90	1175,8
Silver	US$1,88	($/troy oz)	100		US$17,75	945,9
Energy Resources						
Crude oil, average	US$1,21	($/bbl)	100		US$77,12	6373,6
Coal, Australian	US$7,80	($/mt)	100		US$97,00	1243,6
Natural gas, US	US$0,17	($/mmbtu)	100		US$5,81	3415,8

The implications of this report can be shown to be effecting all parts of the industrial ecosystem. Mining of metal as shown by market price is another example. It is the transfer point between metal mining, heavy industry and manufacturing industry. Conventionally, the industrial society sources its raw materials from mining. How this happens is an underlying foundation of the industrial society. Figures 282 to 289 show the metal price for 13 commonly traded commodities that the World Bank uses to track the performance of the global economy and the global industrial ecosystem.

The data trend lines were overlaid by indexing the real price to the date January 1970 to the number 100 for Figures 282 to 289, and to the date of December 2001 to the number 100 for Figure 289. This is the price of metals market. These dates were picked based on patterns seen elsewhere in this report, where the reference point is about 20 months before the significant change date.

The purpose of indexing the price data is to overlay the price curves, which shows time periods of relative stability and time periods of volatility. The data selected is the following commodity groups used by the World Bank to map the performance of the global industrial economy:

Energy Resources

- Oil
- Gas
- Coal

Precious Metals

- Gold
- Silver
- Platinum

Industrial Metals

- Aluminum
- Copper
- Tin
- Zinc
- Iron ore
- Lead
- Nickel

By examining this combination of commodities in context of monthly sell price, a good summary of the global industrial ecosystem. The metal sell price is the transfer point between raw material extraction and the manufacturing sector to use the metals to make products.

Figures 282 to 289 show a series of interesting patterns. There are five clear time periods of significance shown in these Figures and seen elsewhere in this report. They are:

- 1960 to August 1971
- August 1971 to January 2005
- January 2005 to June 2008
- June 2008 to November 2011
- November 2011 to 2019

Figure 282 shows all patterns together and how they interrelate.

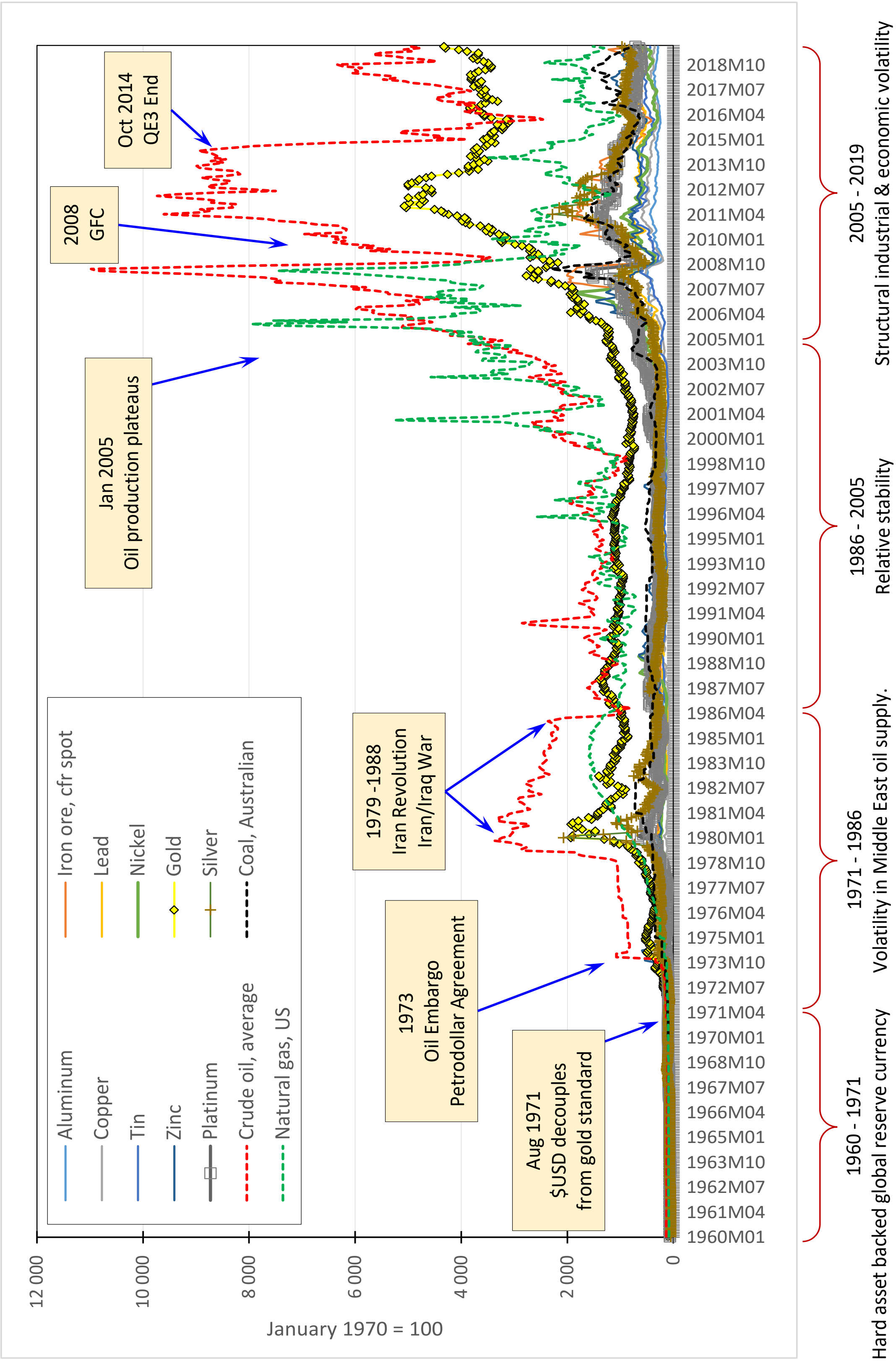


Figure 282. The price of industrial metals, precious metals and energy resources, January 1960 to September 2019, Indexed to the year January 1970 = number 100
(Source: World Bank Commodity Price Data used to calculate Indices, monthly data updated Oct 2019)

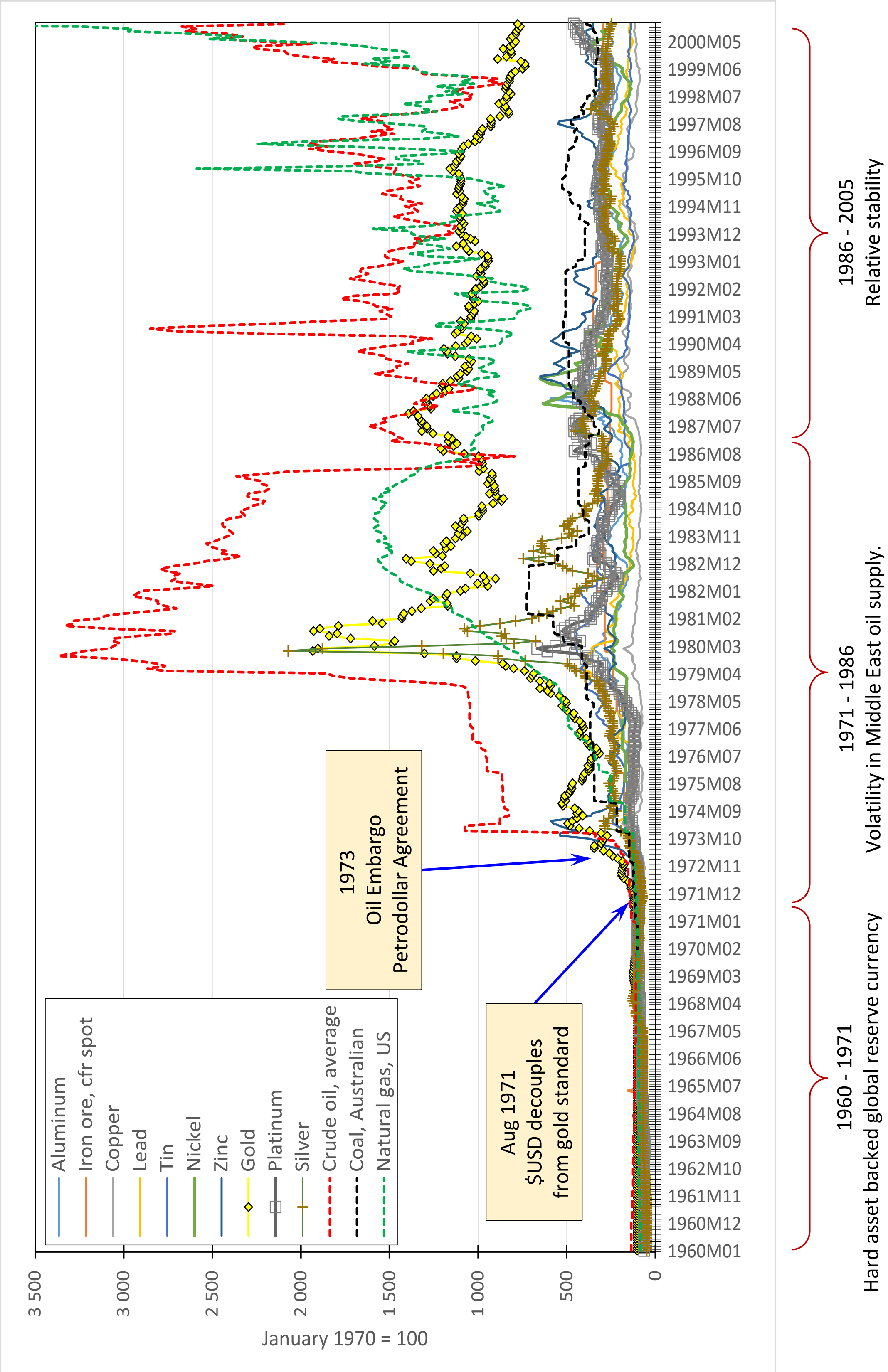


Figure 283. The price of industrial metals, precious metals and energy resources, January 1960 to December 2000, Indexed to the year January 1970 = number 100
(Source: World Bank Commodity Price Data used to calculate Indices, monthly data updated Oct 2019)

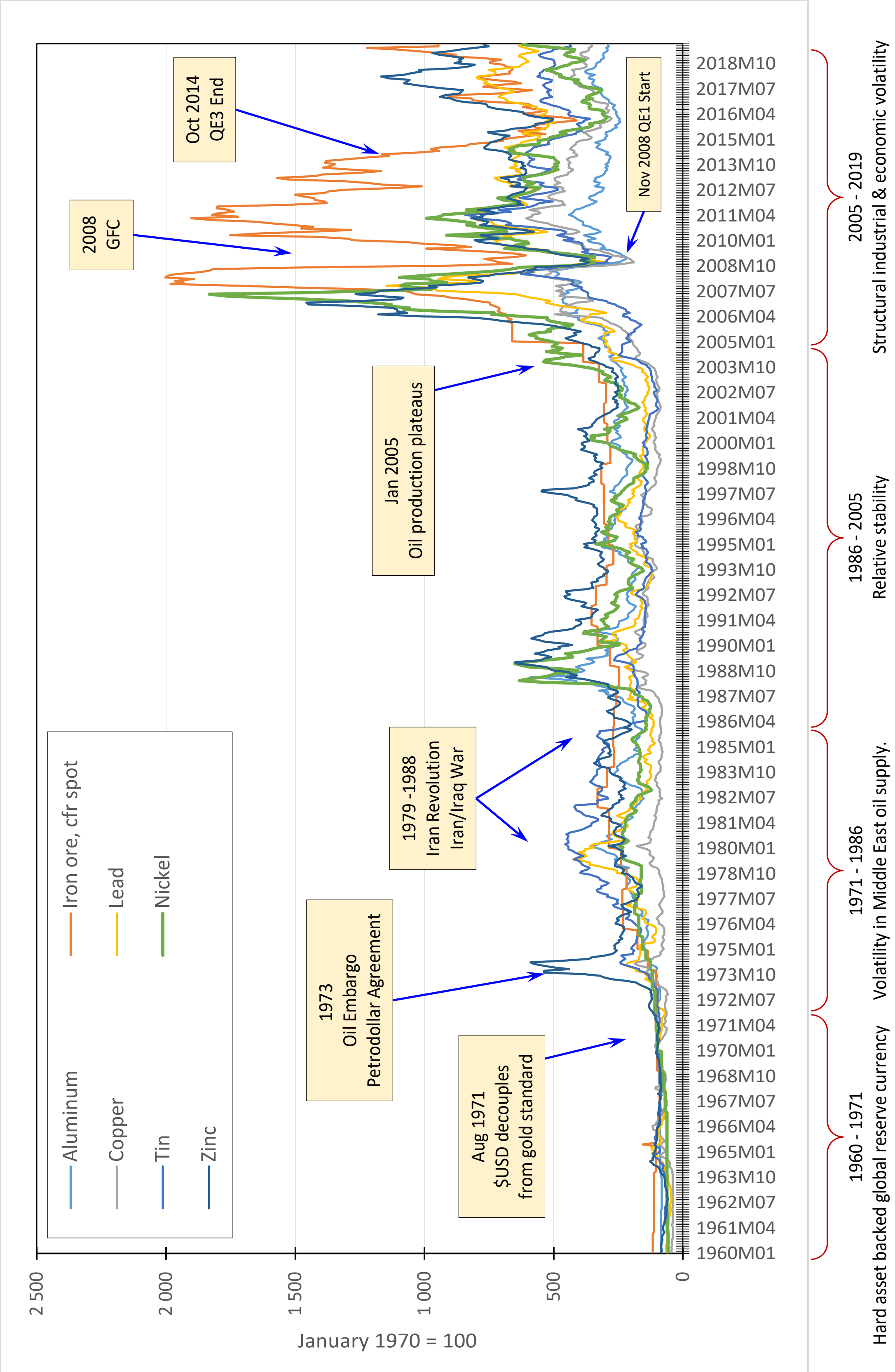


Figure 284. The price of industrial metals January 1960 to September 2019, Indexed to the year January 1970 = 100 (Source: World Bank Commodity Price Data used to calculate Indices, monthly data updated Oct 2019)

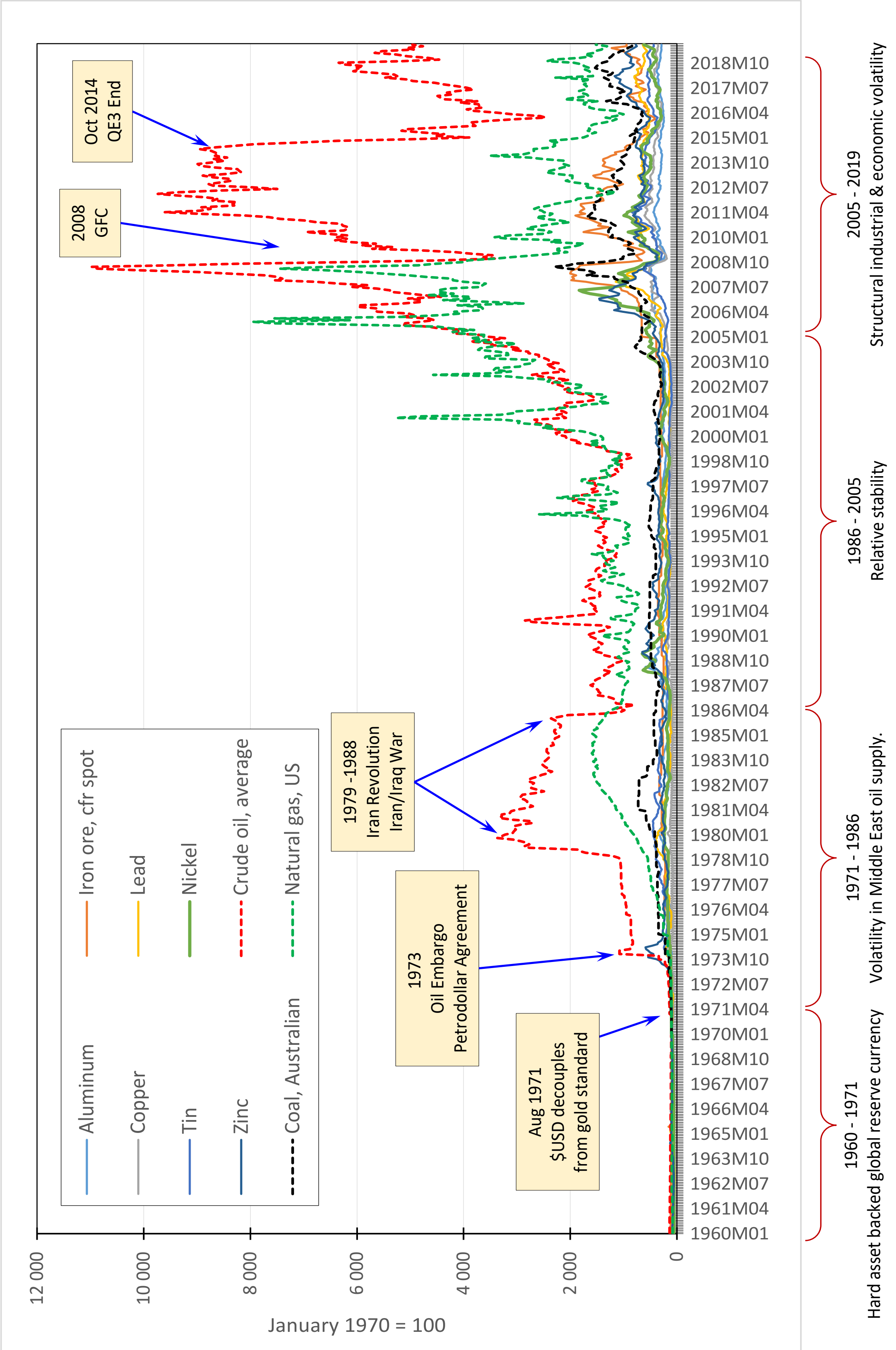


Figure 285. The price of industrial metals, and energy resources, January 1960 to September 2019, Indexed to the year January 1970 = number 100
(Source: World Bank Commodity Price Data used to calculate Indices, monthly data updated Oct 2019)

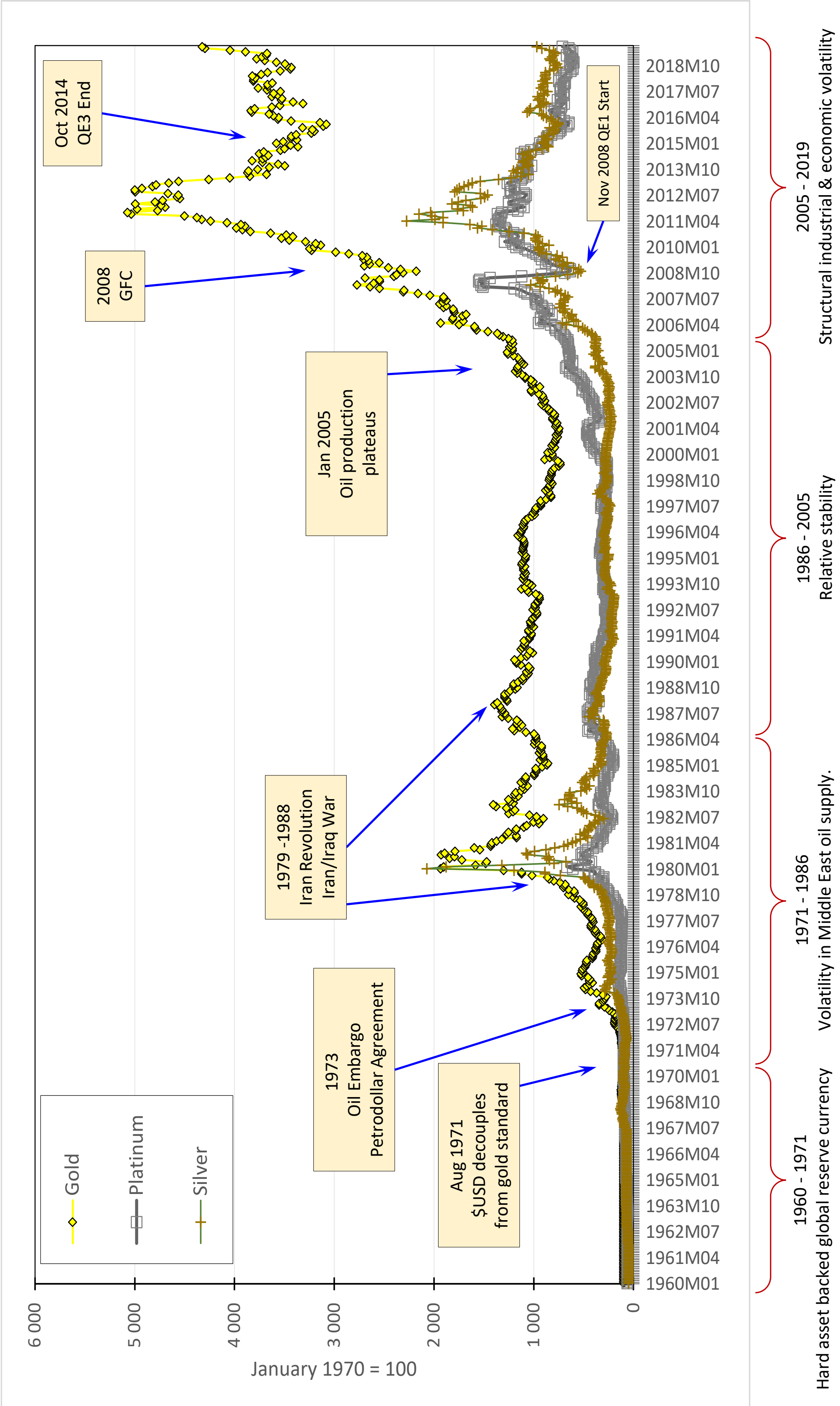


Figure 286. The price of precious metals, January 1960 to September 2019, Indexed to the year January 1970 = number 100
(Source: World Bank Commodity Price Data used to calculate Indices, monthly data updated Oct 2019)

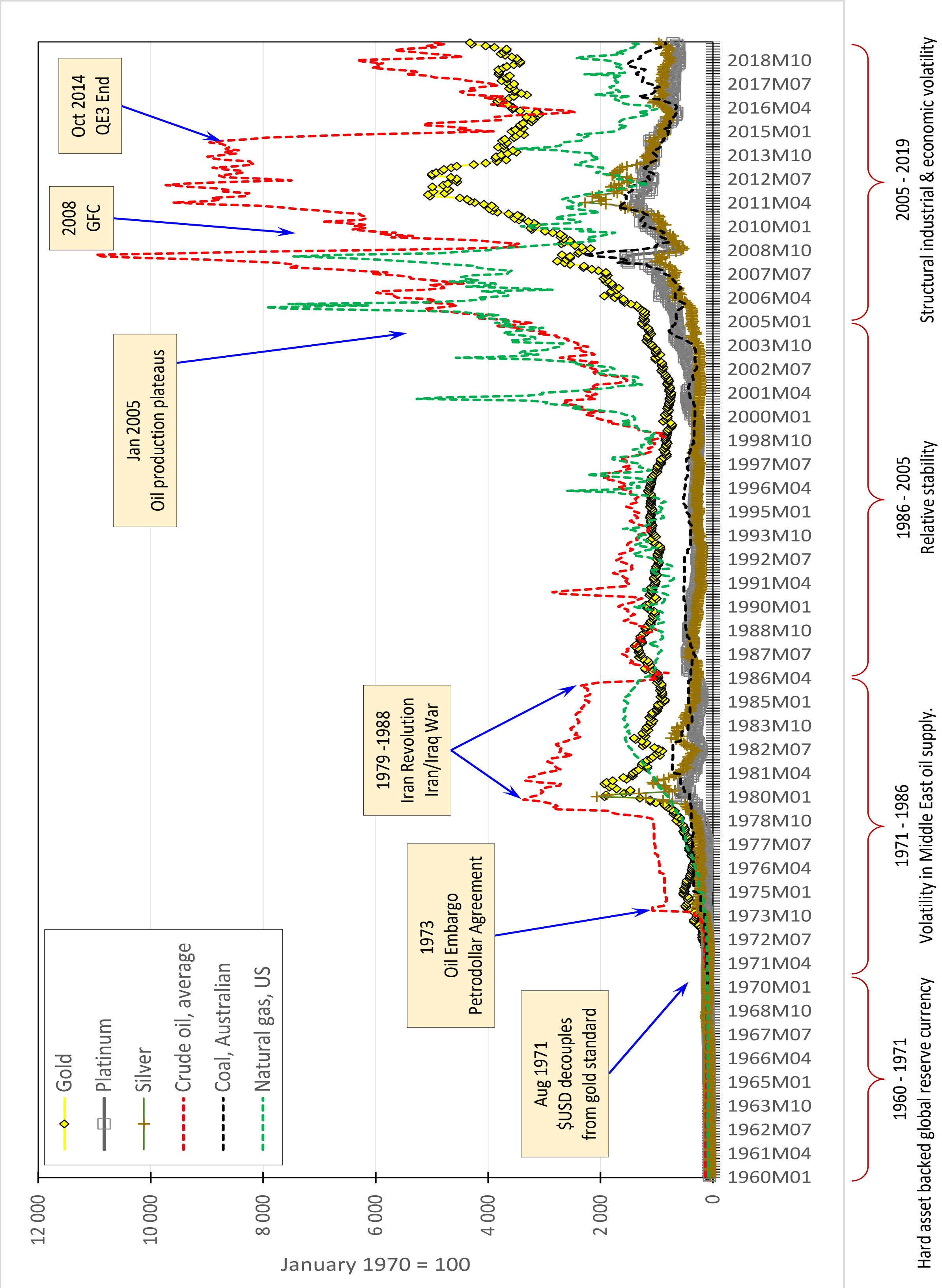


Figure 287. The price of precious metals and energy resources, January 1960 to September 2019, Indexed to the year January 1970 = number 100
(Source: World Bank Commodity Price Data used to calculate Indices, monthly data updated Oct 2019)

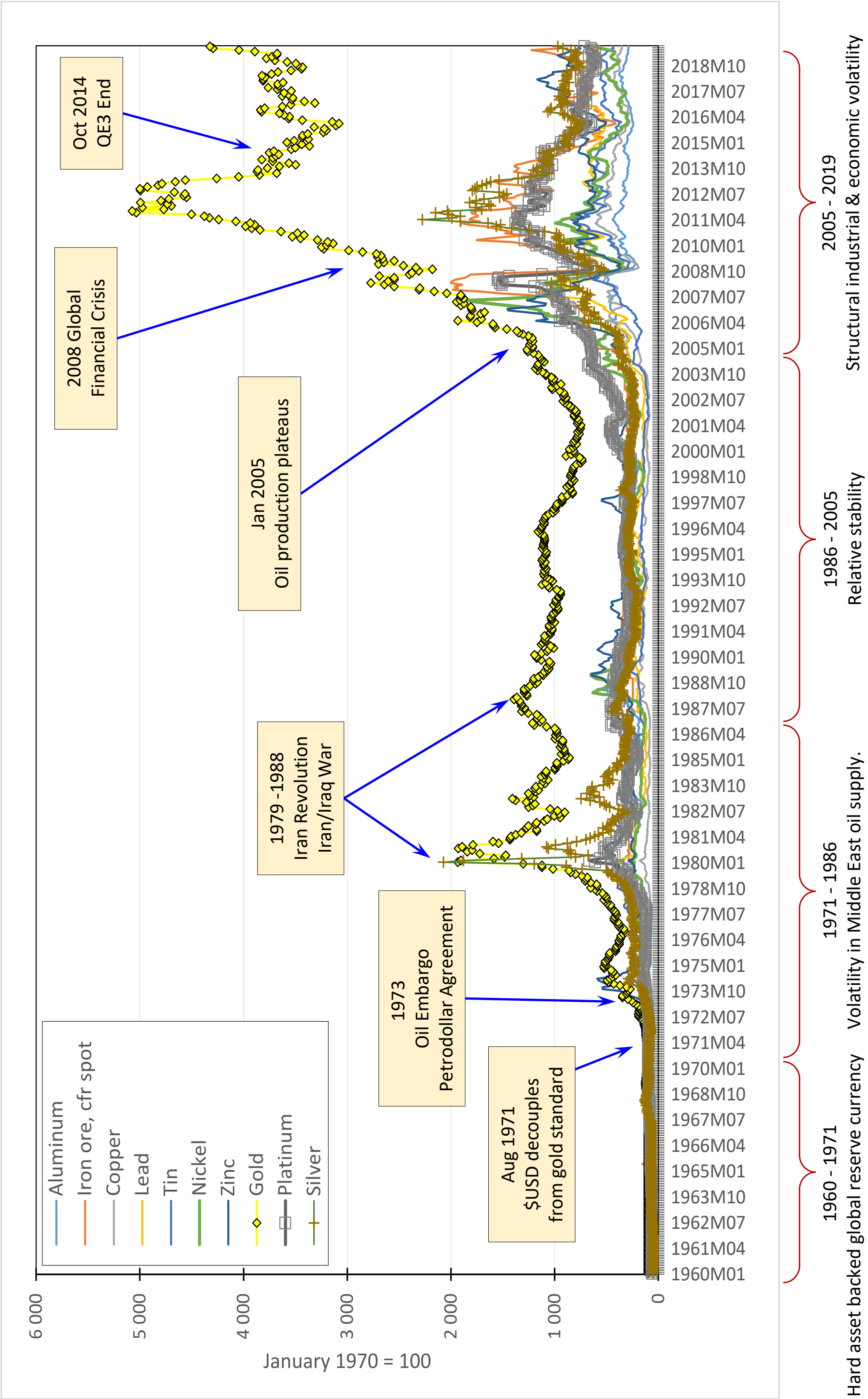


Figure 288. The price of precious metals and industrial metals, January 1960 to September 2019, Indexed to the year January 1970 = number 100
(Source: World Bank Commodity Price Data used to calculate Indices, monthly data updated Oct 2019)

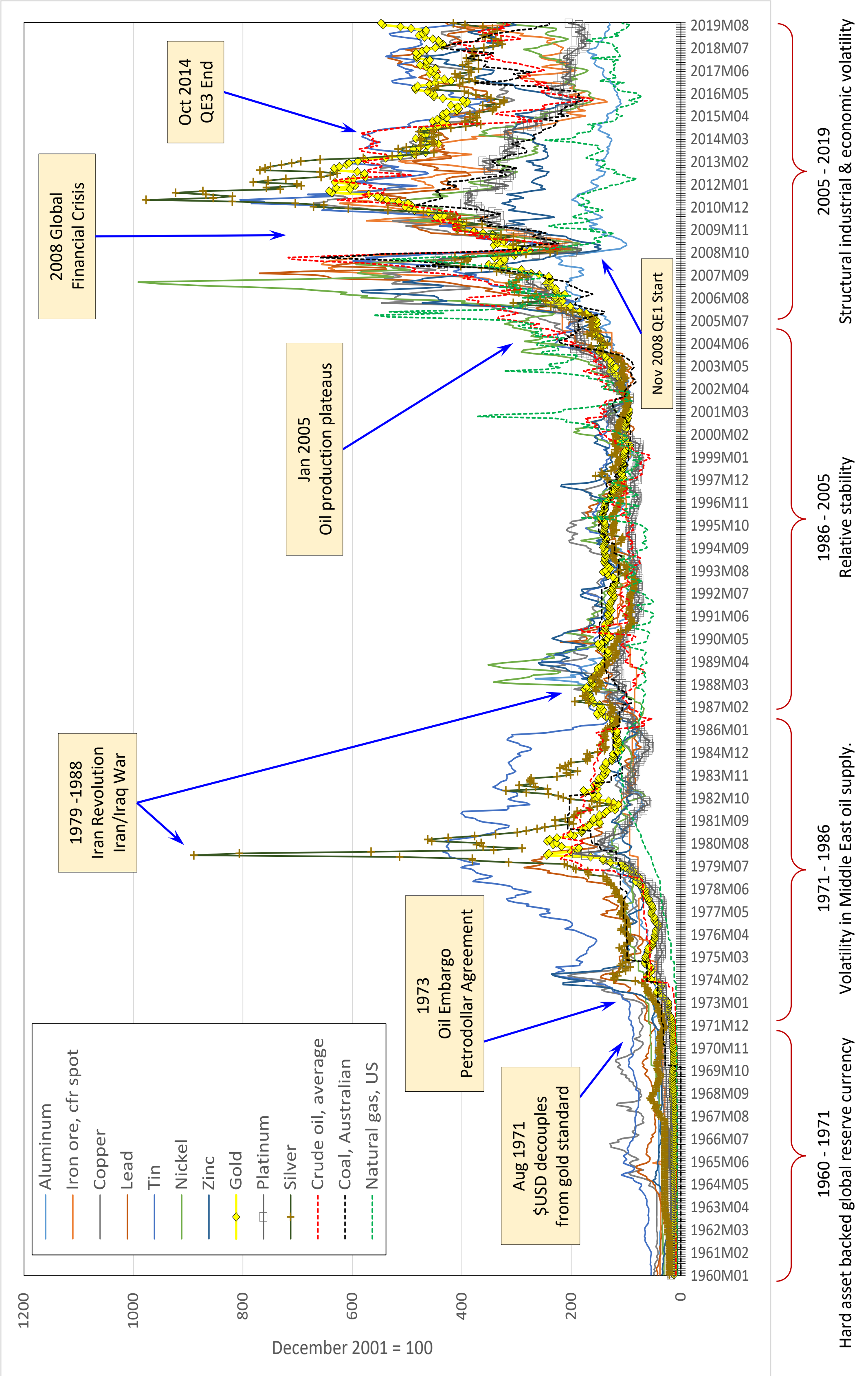


Figure 289. The price of industrial metals, precious metals and energy resources, January 1960 to September 2019, The price of metals Indexed to the year December 2001 = number 100
(Source: World Bank Commodity Price Data used to calculate Indices, monthly data updated Oct 2019)

18.2 1960 to August 1971

Prior to August 1971, the U.S. dollar was a hard asset backed currency. The 1944 Bretton Woods agreement established a new global monetary system. It replaced the gold standard with the U.S. dollar as the global currency. By so doing, it established America as the dominant power in the world economy. After the agreement was signed, America was the only country with the ability to print dollars. The agreement created the World Bank and the International Monetary Fund. These U.S.-backed organizations would monitor the new system.

Before Bretton Woods, most countries followed the gold standard. That meant each country guaranteed that it would redeem its currency for its value in gold. After Bretton Woods, each member agreed to redeem its currency for U.S. dollars, not gold. At the time, the United States held three-fourths of the world's supply of gold. No other currency had enough gold to back it as a replacement. The dollar's value was 1/35th of an ounce of gold. Bretton Woods allowed the world to slowly transition from a gold standard to a U.S. dollar standard. This meant that commodity prices (and everything else) were subject to classical economic theory that enforced economic corrections in a fashion that supported foundational market value.

In this era, the U.S. dollar had now become a substitute for gold as a hard asset currency. Historically, gold bullion was the currency of exchange. As a result, the value of the dollar began to increase relative to other currencies, in its capacity of the world reserve currency. There was more demand for it, even though its worth in gold remained the same.

18.3 August 1971 to January 2005

On the 15th of August 1971, the United States government decoupled the U.S. dollar from its gold standard. The U.S. dollar decoupling from the gold standard ended the Bretton Woods system agreement. Two years later, the 1973 Petrodollar agreement secured the U.S. as the world reserve currency with the use of $USD to purchase oil from Saudi Arabia. This meant that prior to 1971, the $USD was backed with gold and post 1973, the $USD was backed with oil, but was still a fiat currency, where extra money supply could be created any time by the U.S. Federal Reserve bank (Krause 1999, Rickards 2014).

The date of January 1970 was chosen to be one of the index points for Figures 281 to 288 due to the signatures seen in Figure 250, where relative GDP and oil production diverged 20 months later on the date August 1971. The decision to decouple the U.S. dollar from the gold hard asset standard would prove strategically significant. A case can be made where the implications of the 1971 decoupling could have laid part of the foundation of the ultimate trivialization of the U.S. dollar as a viable currency. The only other decision that has similar structural implications was the formation of the U.S. Federal Reserve Bank in 1913, and the implementation of fractional reserve banking practices (Krause 1999, Rickards 2014).

Figure 283 shows the same data as Figure 282 but across a shorter time frame. When the $USD became a fiat currency, its value became the collective perception of the world market and it trust in the United States. The relative relationship between all curves prior to August 1971 was quite stable and clustered in a small bandwidth. The relative relationship of the same curves post to August 1971 was comparatively blown out. Each metal price curve was 150-400% higher in direct comparison to prior to August 1971, moving in a bandwidth between 150 and 400 compared to the 100 reference point.

Figure 284 shows the period between August 1971 and January 2005, but with just the industrial base metal prices. This time range has the same consistent signature, different to time periods before 1971 and after 2005.

The implication of this time period is that anytime a geopolitical issue arose, that issue could be resolved taking on more debt (actually currency creation or the printing money). Prices did not blow out immediately. The first instance of this was shown in the 1973 Oil Embargo two years later.

In Figures 282 to 289, it can be seen that an era of volatility can be seen in years between 1973 to1986. This could be seen as geopolitical instability in the Middle East, affecting the oil production supply to the international markets. This ear is dominated by:

- Iranian Revolution 1979
- Iran/Iraq war 1980 to 1988
- The Saudi Arabian cut in production in response to the oil glut in the market at the time

18.4 January 2005 to June 2008

Figure 289 shows the same data as the previous figures, but this time, the commodity prices where indexed to December 2001 = 100. The purpose of this was to highlight the relative change that happened 36 months later in January 2005.

Compared to the January 2005 reference point (100), the time period after this point varies between 150 and 500, with two spikes up to 1000. Comparing this January 2005 reference point of 100 to the August 1971 reference point, commodities would range from 30 to 80.

This date is seen as a fundamental turning point in multiple figures in this report. Something fundamental changed on this date, something that had the rippled effect to be felt through the global system. It can be seen clearly in the industrial metal prices, energy resource prices and in the precious metal prices markets. It can be seen in real economy (see Figure 279, Figure 280 and 281).

This time period can be seen as one of the major turning points in the operation of the industrial economy (Figure 249 and Section 16.2), and can be referred to the Third Oil Shock (see Figure 231 shock and Section 14.3). This temporal signature significantly affected the industrial ecosystem.

The production of oil plateaued in January 2005 (Figure 290), and the supply market became inelastic. In the year 2006, global oil demand started to outpace supply (Saxena 2009, and Yardeni Research 2016). Demand and supply separated between the years 2006 to 2008, where the supply gap closed briefly (Saxena 2009, and Yardeni Research 2016). Unconventional oil production capacity would later make up extra global supply to meet demand, but not in meaningful quantities until 2009.

The data shown in Sections 14.3 and 16.2 suggest that the genesis cause of this major turning point is related to the oil market. The economic signatures are lagging indicators, not leading indicators. Figure 290 (Figure 230 reproduced) shows the answer. This plateau of production is postulated to be caused by the inability of Saudi Arabia to increase its production as shown in Figure 291 (Figure 232 reproduced). There was a second increase in Saudi Arabian oil rig count in 2014. This did not correlate with a market change as in 2014, the U.S. Tight Oil Sector had become the global oil swing producer.

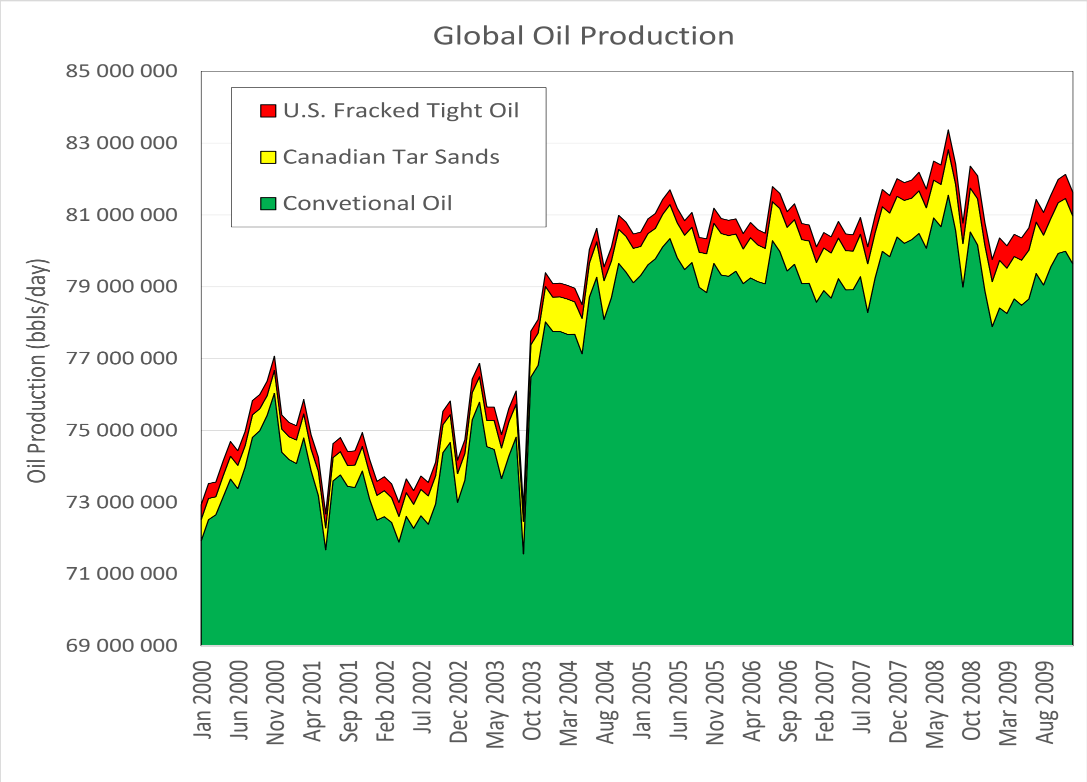


Figure 290. Global oil production 2000 to 2009
(Source: data from BP Statistical Review of World Energy 2019 and BP Statistical Review of World Energy 2011)

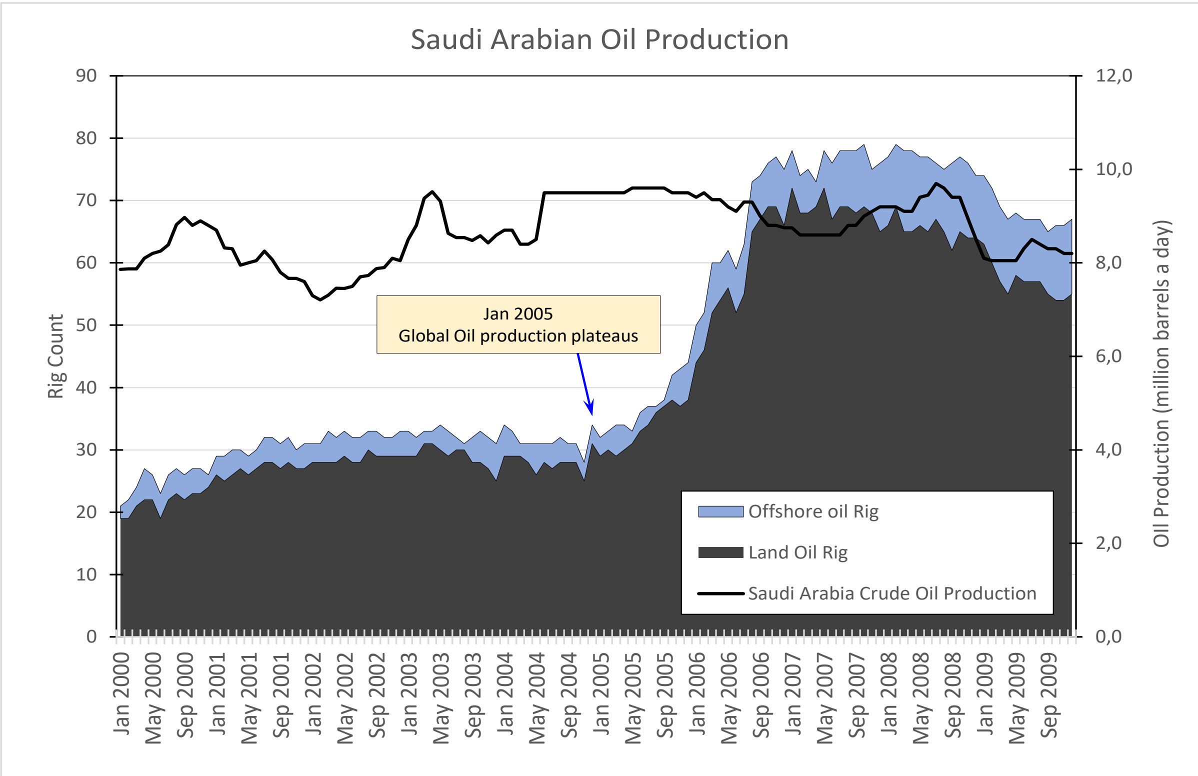


Figure 291. Saudi Arabian rig count and crude oil production, January 2000 to December 2009
(Source. Baker Hughes Rig Count data, EIA monthly production data)

18.5 June 2008 to November 2011

A major correction can be seen in all charts and all commodities in the years 2008 to 2011. This correlates with the Global Financial Crisis (GFC), or the Great Recession of 2008. The Great Recession is a period of general economic decline (recession) observed in world markets during 2008 to 2011. The International Monetary Fund (IMF) has concluded that it was the most severe economic and financial meltdown since the 1929 Great Depression and it is often regarded as the 2nd worst downturn of all time (IMF 2009).

This severe economic downturn that started in 2008 (the GFC), had the capacity to fundamentally destroy the entire monetary system and came within a few hours of permanently paralyzing the banking credit system (Mathiason 2008 and Kingsley 2012). Figure 26 (Chinese industrial output % YOY change in Section 1) shows this signature at exactly the same time, where the output of largest industrial producer in the world (China) mirrors the crash that was seen in the financial markets.

In this time period, oil demand exceeded oil supply (Yardeni Research 2016).

Figure 292 shows how the 2008 Global Financial Crisis affected the real economy (where the data is indexed to January 2015 = 100). As can be seen, the European Union (EU-28) industrial production crashed in 2008 and still has not recovered. Since 2008, China has underpinned global industrial output, but as shown in Figure 26, Chinese industrial production is now declining.

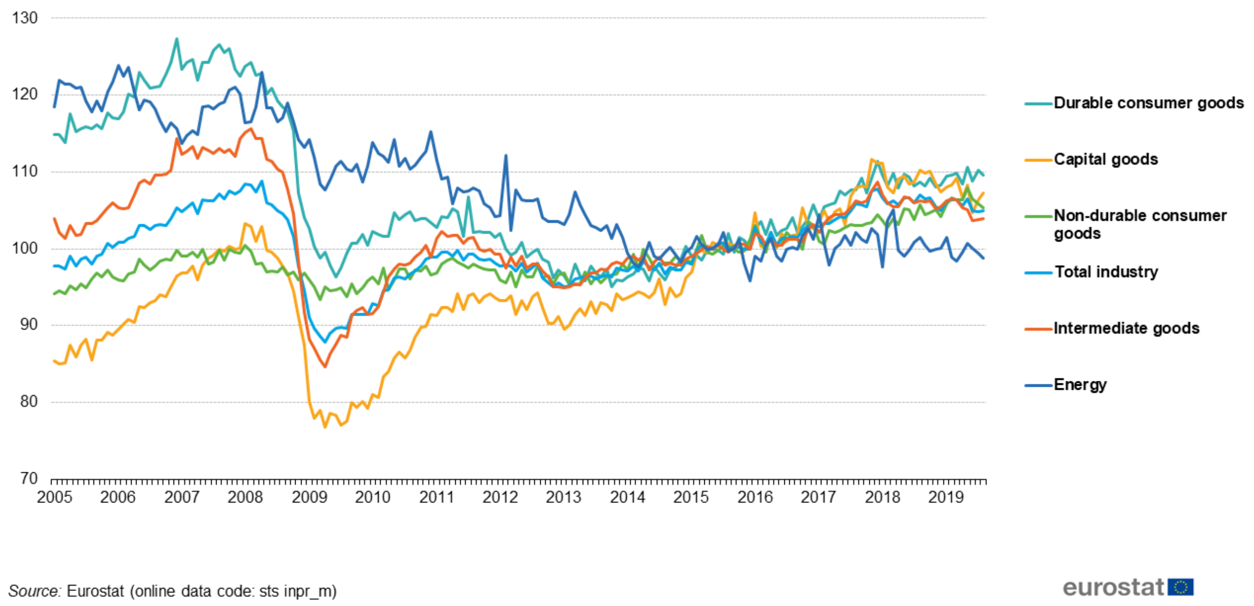


Figure 292. EU-28, Industrial production for total industry and main industrial groupings, 2005-2019, Jan 2015 = 100, (Data Source: Industrial production (volume) index overview. Updated 17th Oct 2019 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:EU-28,_Industrial_production_for_total_industry_and_main_industrial_groupings,_2005-2019.png) (Copyright License: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Copyright/licence_policy)

The global industrial ecosystem has been underpinned by inexpensive and abundantly available energy and abundantly available credit. As of January 2005, energy markets became inelastic (both oil and gas, but not coal) and the era of cheap energy was officially over. In the same time frame, the Credit

Default swaps (Credit Derivatives) markets were deregulated a few years before in 2001, allowing for the later unrestrained expansion of credit. The temporal signature of January 2005 significantly put the industrial ecosystem under unprecedented strain, where this combination of circumstances forced the weakest link to break. As the financial systems were now fiat (since August 1971) and literally virtual (where 97% of all $USD were not paper notes but digital numbers in a database – Rickards 2014), they were the first to crack under pressure and break. Within the financial markets, the U.S. sub-prime mortgage market was found to be the weakest link of all. A market correction (crash) started, which would correct all financial markets back to their intrinsic value. As those markets were over leveraged and were no longer backed by anything that was not negotiable, there was a very high risk for the systematic fragmentation of all fiat currency markets (which were heavily interlocked and interdependent).

As a direct consequence of the GFC, quantitative easing (QE1, QE2 and QE3 programs) were deployed by the U.S. Federal Reserve Bank (Yellen 2017), starting with the QE1 program in November 2008. Since then central banks around the world have been engaging in Quantitative Easing (colloquially referred to as the printing of money) at an unprecedented scale. This is dangerous as it deteriorates the integrity of the monetary system. The volumes of money being created through QE is historically unprecedented. This has been referred to as “The Road to Zimbabwe” in reference to the risk of hyperinflation on an unprecedented scale (Michaux 2017).

18.6 November 2011 to 2019

The time period between years November 2011 to 2019 can be clearly seen in Figure 289. Immediately after the GFC, the commodity prices spiked to a similar level to just before the GFC. After this spike, commodity prices settle into a bandwidth value between 150 to 500 (compared to the December 2001=100 reference point). This spike corresponds to the duration of quantitative easing programs QE1 and QE2 (November 2008 to June 2011). The QE1 program was a direct response to the crash in the financial markets. Examining Fourth Oil Shock Section 14.4 and Figure 234, it appears that QE1 did not go far enough, QE2 and later QE3 was needed finish the task of stabilizing the markets. Figure 281 shows that the QE1, QE2 and QE3 were successful in stimulating the real economy markets and arresting an economic correction.

Comparing the time period of November 2011 to 2019 to January 2005 to June 2008, the same volatility can be seen (even when the price spike before the GFC and the spike just after are removed). The largest quantitative easing money creation in history was not enough in resolving the fundamental problems that created the start of commodity price volatility that started in January 2005. As shown in Figure 26, the Year On Year % change in Chinese industrial activity is seen to consistently reduce <u>after</u> the GFC.

It was possible that if the QE program was to be stopped or even tapered, the stock markets in the US and around the world would be devastated. QE3 was stopped in October 2014. The years 2015 and 2016 were marked with economic and industrial volatility. At the time of the writing of this report, the U.S. Federal Reserve intervened in the banking sector in the Repo market (and taking great lengths to reassure the public that this is NOT quantitative Easing) (Marte 2019 October 10th). Approximately 70 billion $USD was applied to the overnight lending markets each night since September 17th 2019, and has continued in early November 2019.

Something fundamental was permanently changed in January 2005, and the second worst economic correction of all time (IMF 2009) did not resolve the underlying issues. This suggests that whatever is causing the volatility, it is not an overvalued market, nor was it the result of a speculative bubble bursting. **The underlying issues are still in play** and the current markets are held together with more money creation programs.

18.7 How Commodity Groups Interrelate

Figures 282 to 289 show an interesting pattern of significance. The purpose of indexing all the commodity price curves to a single point (August 1971=100) is to show relative patterns with each other. Previous parts of this chapter have shown that there are time periods of structural change, where the point January 2005 was very significant. Not all commodities blow out at the same time. There is a very interesting pattern that shows a sequence of commodities that blow out around 2005.

Figure 282 shows that the energy resources of gas and oil proportionally increase in price compared to all other commodities. Compared to the August 1971=100 reference point, oil and gas have the value of around 900 in the years 1985 to 2003, and spike up to the 4000 to 6000 after around 2003. In the same time frames, precious metals have the values around 300 to 500 from 1985 to 2003, and spike to 1000 to 2000 after 2003. Industrial metals (and coal) have in the same time frames, values of around 180 to 400 from 1985 to 2005, spike to 1500 in 2007, and settle into a bandwidth of 300 to 700 after 2010.

In summary:

- Gas and Oil (gas leads) blows out to a proportionally much larger value set than precious metals, starting around 2002
- Precious metals blows out to a proportionally much larger value set than industrial base metals. This precious metals blow out signature starts in approximately 2003, after oil and gas, before base metals.
- Base metals blows out in 2005. Coal (an industrial energy resource) behaves more like a industrial base metal, than like oil or gas.

These signatures are still visible when the reference point of December 2001=100 is used but they are not as clear (see Figure 289). This suggests that the structural problems facing the current industrial ecosystem started with a blowout in the real cost of energy, which had a ripple effect, which took time to be felt in the base industrial metal markets. As it requires energy to mine minerals and more energy to refine them into metals, it is appropriate that the price blowout of the metals market (which are the fundamental lifeblood of the industrial ecosystem) is triggered by a signature in the energy market (oil production plateaus in January 2005).

A systems analysis of the industrial ecosystem starts with energy inputs, and conclusions are generally based around what form the physical streams of goods being manufactured take. In macro terms, energy inputs and how energy is used to interact with material streams and flows define what outcomes are possible. Money is just the language of exchange in context of who does what and who administers the outcome.

The $USD, gold and oil

It is worth noting the change in the status of the United States dollar. The $USD has been the world reserve currency since the Bretton Woods agreement came into effect in 1944. At the time, and up until August 15th 1971, the $USD was pegged to the gold standard. The gold market and the supply of $USD was related. When the $USD decoupled from gold, so did the $USD monetary supply and the gold market price.

As of 1973, with the Petrodollar agreement, the $USD retained its status as the world's reserve currency, but now is backed with oil. Oil and the $USD became linked, only this time, the $USD was a fiat currency and could be created at will by the U.S. Federal Reserve.

It is for this reason that Figures 282 to 289 show oil proportionally blowing out, sooner and higher in perceived value than gold. Oil is priced in dollars, which have been steadily and disproportionally created since 1971.

18.8 Energy and the Mining of Metals

How this signature in metal price relates to energy is as follows. The mining of metal is dependent on energy to happen. It also is dependent on a variety of industrial services. Those industrial services are in turn dependent on a petroleum supported economy. Conventional oil plateaued in production in 2005 and the oil market became inelastic. This sent a disruptive ripple through the whole ecosystem.

More directly, mining of minerals is becoming increasingly dependent and sensitive to energy costs as ore grade is generally decreasing (Michaux 2017). In the year 2014, feasibility study copper mine cutoff grade for future projects is now 0.1%, with deposit size requiring an open pit 1km deep and 4km in lateral length, yet available ERoEI is now approximately 20:1. Energy resources are now comparatively quite small, very poor quality and expensive to extract. Copper resources alternatively are massive in size, very poor quality, requiring vast amounts of energy to process.

This can be described with the resource pyramid conundrum (Figure 292).

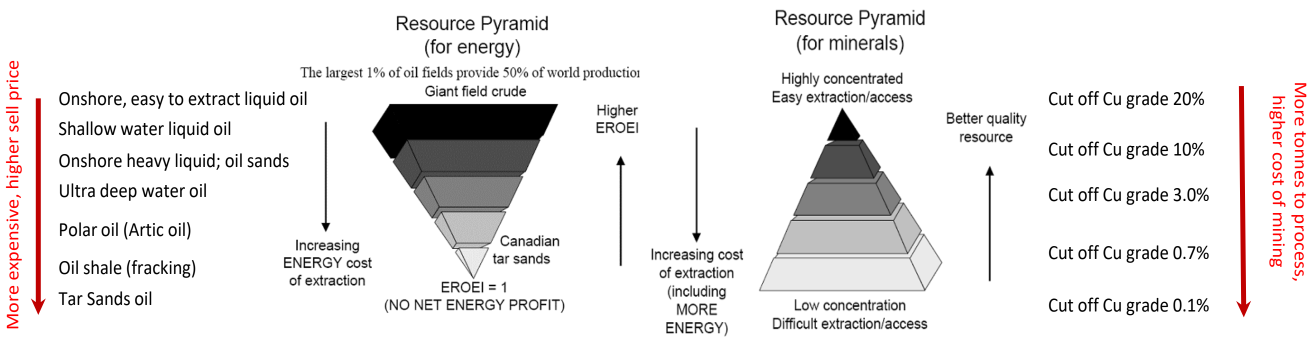


Figure 293. The resource pyramid conundrum

The deepest global recession in the entire post-war period can mask the signatures shown in this report while demand is contracting; peak oil isn't a problem if the economy it powers is shrinking. But recessions, even the deepest, only last so long. The first thing to be noticed about a recovering economy is that it starts burning more fuel. The second is that oil prices are rising once again.

Yet the current ‘Great Recession’ has been persistent, where the real economy contracted in 2008 and 13 years later in 2019, still has not recovered. This suggests something fundamental in the energy sector has changed.

18.9 Temporal Sequence

The following temporal events have shown to be significant in understanding the net position of the industrial ecosystem.

1. 15th of August 1971. The United States decouples it currency form the gold standard and becomes a fiat currency. This allows monetary creation at will to solve all geopolitical and domestic problems.

2. The Petrodollar agreement in 1973. The petrodollar is any oil purchase or trade by an oil-exporting country is to be done in $USD. Since the dollar is a global reserve currency, all international transactions are priced in dollars. All nation states were then forced to interact with the $USD fiat currency system, and any internal issues within the $USD were automatically transferred to all over the world.

3. Oil production plateaued in January 2005, while oil demand continued to grow, creating an inelastic supply market. Possible cause, Saudi Arabia unable to increase production.

4. The price of industrial metals blows out in 2005.

5. The real economy starts to contract in 2005. A persistent turning point.

6. The Global Financial Crisis starting in early 2008. The worst economic correction since the 1929 Great Depression.

7. The initiation of unprecedented quantitative easing monetary creation program QE1 by U.S. Federal Reserve Bank (November 2008 to June 2010).

8. Bank of China QE program from 2008 till present.

9. A new technology of horizontal precision drilling applied in oil fracking operations, triggering the oil shale revolution in the U.S. Tight Oil frontier. Oil supply stabilizes with global demand.

10. Bank of England QE program March 2009 to January 2010.

11. Chinese industrial activity starts to contract in 2009

12. U.S. Federal Reserve Bank QE2 program from November 2010 to June 2011.

13. U.S. Federal Reserve Bank QE3 program from September 2012 to October 2014.

14. Bank of Japan QE program April 2013 till present.

15. European Central Bank QE program March 2015 to December 2018

16. U.S. Federal Reserve Bank repo market bailout September 17th 2019 till (unknown?).

The prognosis of this sequence of events suggests that:

- Something fundamental changed in the industrial ecosystem in 2005
- In 2008 the financial markets were structurally damaged by the application of quantitative easing in response to the most serious economic crash seen in the previous 75 years, the GFC.
- The GFC was a market correction as a consequence of what happened in 2005.
- Whatever caused the volatility in the commodity markets in 2005, was not resolved by a major economic crash, and the fundamental issues are still in play.
- The current market systems are now dependent on more quantitative easing to maintain stability.
- There will come a point when QE is not possible anymore and the correction that was started in 2008 will resume.

Figure 294 (Figure 258 reproduced) shows that the window of oil market viability is closing, which suggests the resumption of the 2008 correction will be soon.

Predicting the time the window will completely close is not appropriate as this is a nonlinear system with unknown influences. It could be postulated though that the window of viable operation could close between now and 2025.

Figure 295 shows the global crude oil production, excluding the United States and Iraq. What can be seen here is that without the U.S. and Iraq, global oil production actually peaked in 2016 and is now declining. This really does highlight that any expansion in supply is dependent on the United States (the Tight Oil sector in particular). This also shows that the United States is now the supporting supplier (or swing producer) for the global oil market, in the same fashion that Saudi Arabia has been for the previous 50 years.

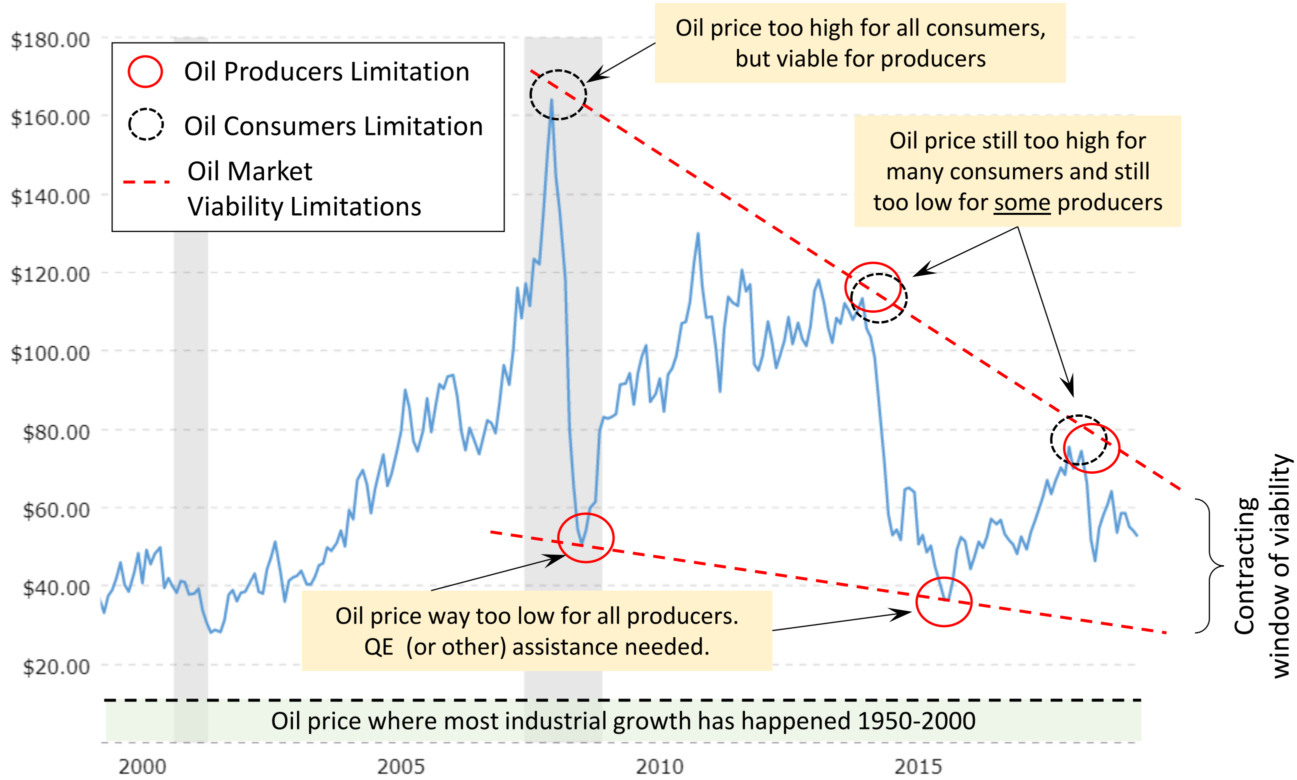


Figure 294. West Texas Intermediate (WTI or NYMEX) crude oil prices per barrel October 1999 to October 2019, Inflation adjusted (Source: MacroTrends) (Copyright: https://www.macrotrends.net/terms)

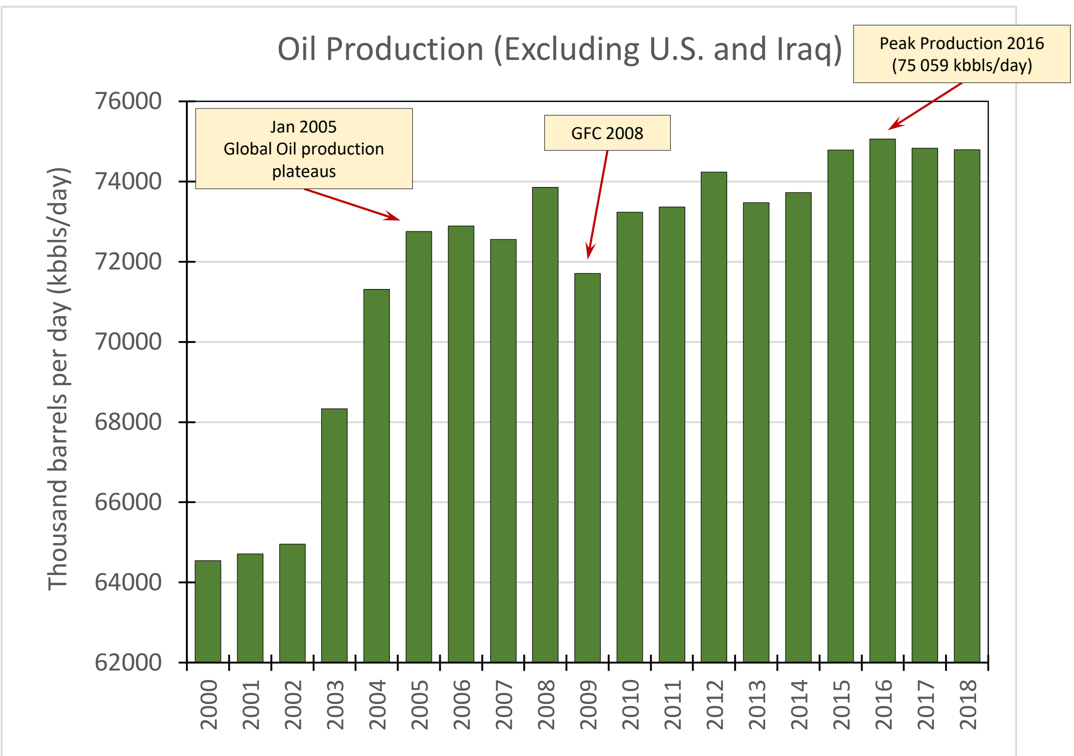


Figure 295. Global oil production, excluding the United States and Iraq (Source: BP Statistical Review of World Energy 2019 & 2011)

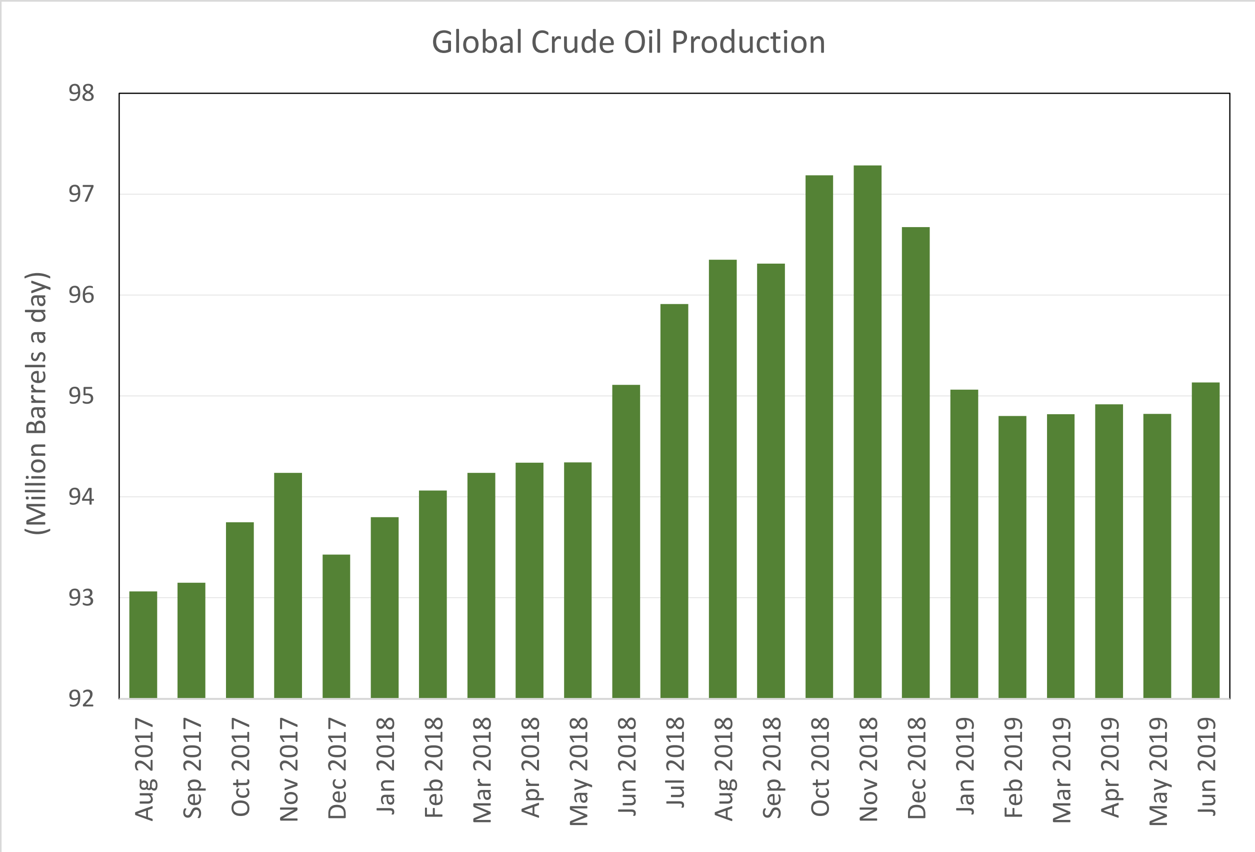


Figure 296. OPEC and world oil supply, in chart
(Source: OPEC Monthly Oil Market Report for February 2019, OPEC Secretariat)

Figure 296 shows oil production may have peaked in November 2018. For the validity of this data pattern to be accepted, the peak date of November 2018 would have to remain the record for at least a period of 5 years following recording. Due to depleting reserves, with each passing month, that peak record would be more difficult to surpass.

Oil will peak in production, not because there is not enough reserves in the ground to meet demand, but because consumers cannot support the oil price at a level that allows oil producers to remain economically viable. The implications of Figures 295 and 296 both suggest that global peak crude oil production is relatively soon. The EIA projections of peak oil around 2040, are highly unlikely.

Figure 276 shows how this interaction may happen. Figure 296 shows this may already have happened in November 2018. This may or may not be peak oil, depending on whether more investment is put into the oil industry. The longer the peak persists though, the harder it is to overcome with a new record due to the depletion of conventional oil reserves.

19 THE IMPLIED CHANGE IN THE INDUSTRIAL PARADIGM

The conclusions of this report suggest our industrial civilization is approaching a fundamental transformation. Currently, our society, technology, industry and economy are all supported by and dependent on oil in some form. This high quality energy source became so abundant and inexpensive, that it became the supporting energy source for all aspects of the industrial system in the 1900 to 1970 period of time. While it can be proposed that it is not so cheap and abundant anymore, the modern world certainly does require it to function.

Substitution of petroleum products (and oil derived products) with another energy source will require a high ERoEI, abundant in supply and an inexpensive cost of production. This substitution system needs to be in place and accessible by all parts of the industrial ecosystem in the next few years if it is to be useful in context of maintaining stability of the energy system in terms of what it does for us now. Any future economic growth is dependent on this, as is our capability to pay back the enormous financial debt the current economic ecosystem is now required to pay back.

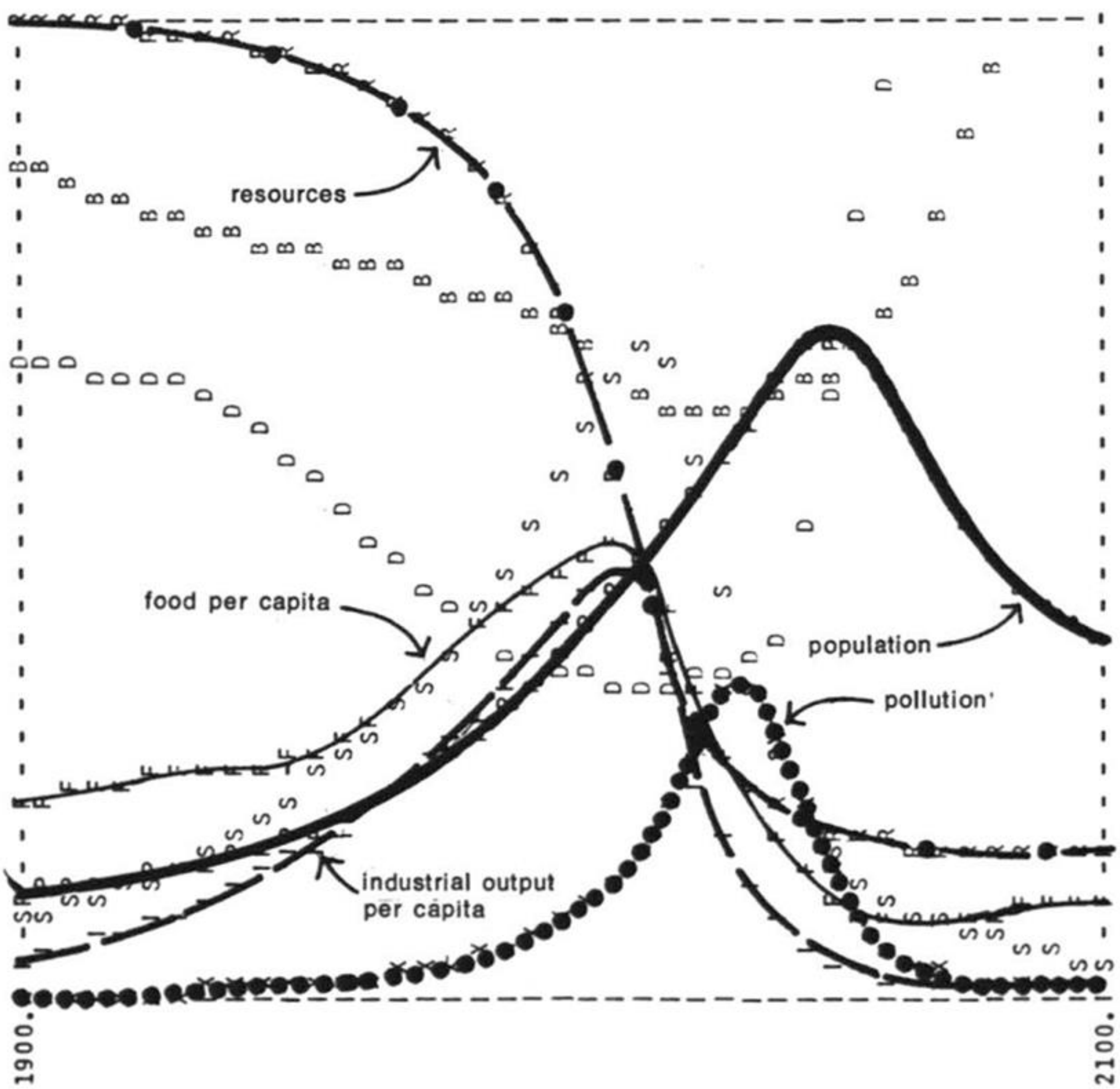
As a society, we have become defendant on the consumption of resources of all kinds, and have developed our industrial systems with the belief that these resources are infinitely abundant. Yet most of these resources are non-renewable finite natural resources, and the planet we live on is a closed finite system. We have not planned for the possible phasing out of the dependence on our primary master resource of fossil fuel energy.

A number of significant data based signatures have been observed in the industrial ecosystem between the years 2000 and 2017 (Michaux 2017). A case has been made in this report that the industrial ecosystem has been operating in several different sets of economic conditions in several time periods in the last few decades. This has been done in context of the oil market and associated markets. There are others. A relevant question is why this happening now, and why this combination of data signatures has not been seen before the last few decades? The fundamental origins of the answers to these questions will most certain be related to multiple parts of the industrial ecosystem in a global context. A useful explanation could be the conclusions of the Limits to Growth systems analysis (Meadows *et al.* 1972).

In 1968 the Club of Rome was formed to study the direction human society was developing. One of the technical outcomes was a sophisticated system dynamics based analysis of human society and its supporting resources, published as 'The Limits to Growth' (Meadows *et al.* 1972). During the course of this study, 13 scenarios were considered, where strategic changes in human society were made.

The objective was to stabilize all inputs and outputs to human society. The base case scenario where the existing direction of human society development in the early 1970's was maintained with no change, then projected forward in time to the year 2100 (shown in Figure 297).

This remarkable study was one of the first of its kind in that it was conducted on one of the first computers available to civilians. Using a well thought out network of systems in an elegant experimental simulation design, the rates of consumption, population growth and associated pollution were each predicted.



The "standard" world model run assumes no major change in the physical, economic, or social relationships that have historically governed the development of the world system. All variables plotted here follow historical values from 1900 to 1970. Food, industrial output, and population grow exponentially until the rapidly diminishing resource base forces a slowdown in industrial growth. Because of natural delays in the system, both population and pollution continue to increase for some time after the peak of industrialization. Population growth is finally halted by a rise in the death rate due to decreased food and medical services.

Figure 297. The base case projected outcome of 1972 systems analysis modelling of global industrial society (Source: Meadows *et al.* 1972)

While this study was done in the early 1970's, an update that compare historical data mapped against the model predictions, show that the base case scenario model was conceptually correct (Turner 2008). Figures 298 to 300 shows some actual historical data from 1970 to 2000 projected onto the original 1970 study.

The implications of Figures 298 to 300 are that the basic prediction of the original limits to Growth systems study was conceptually correct. Just so, it should be considered that the industrial ecosystem and the society it supports may soon contract in size.

The underpinning paradigm of this study was to look at the resource limitations in context of growing human population. Figure 298 shows the 1972 study human population growth scenarios (with a model future prediction between 1970 and the year 2000), overlaid with historical data from 1970 to the year 2000 as measured (Turner 2008). The historical data shows that human population is following the Standard Run model from the 1972 Limits to Growth study. This is most pertinent as human population is one of the fundamental underpinning parameters in mapping resource consumption.

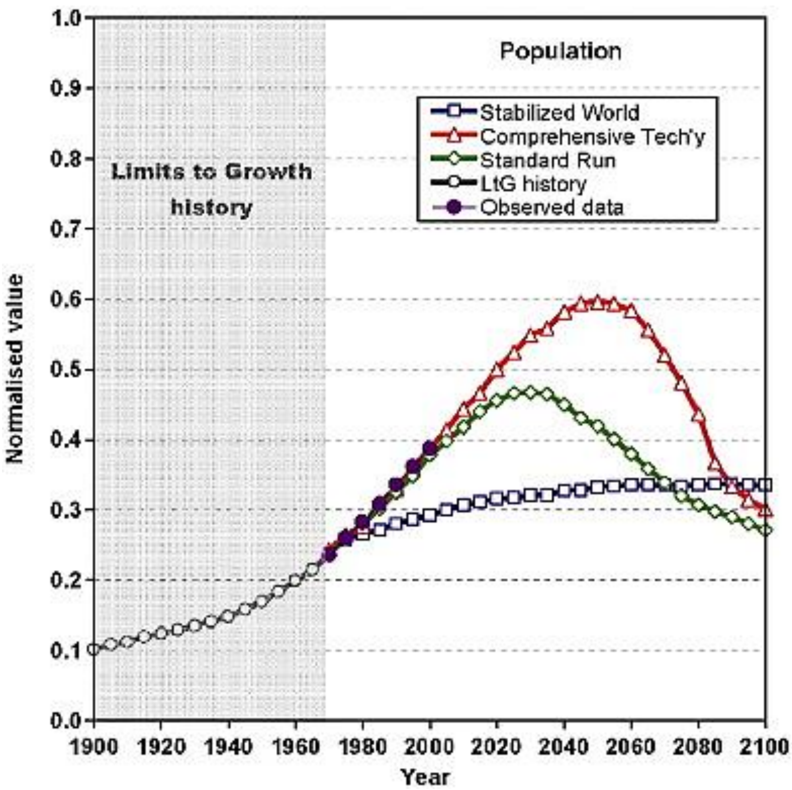


Figure 298. Comparing 'Limits to Growth' scenarios to observed global data – human population (Source: Turner 2008)

Figure 299 shows the 1972 study industrial output per capita scenarios (with a model future prediction between 1970 and the year 2000), overlaid with historical data from 1970 to the year 2000 as measured (Turner 2008). The historical data shows that industrial output per captia is following the Standard Run model from the 1972 Limits to Growth study.

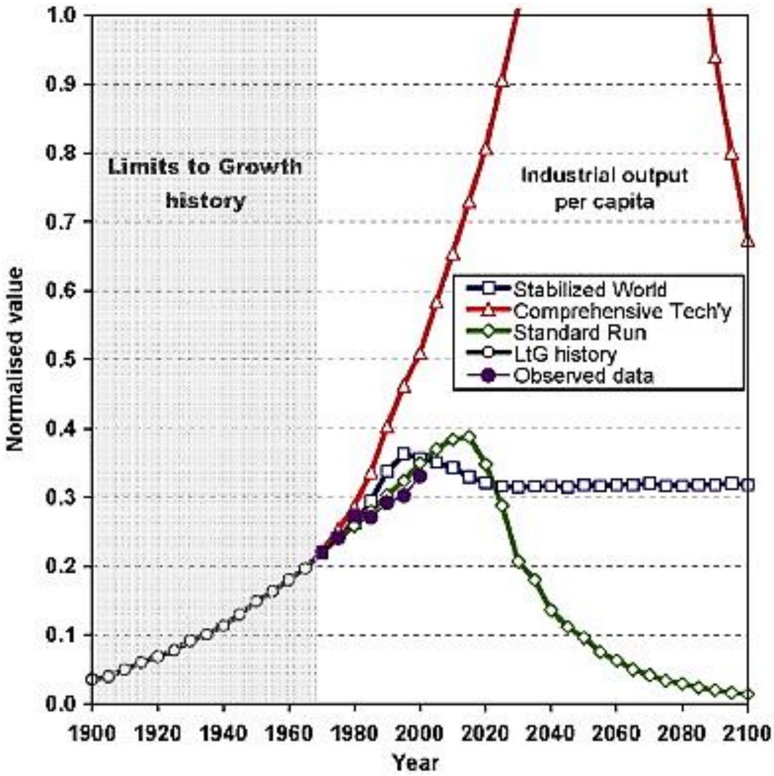


Figure 299. Comparing 'Limits to Growth' scenarios to observed global data – industrial output (Source: Turner 2008)

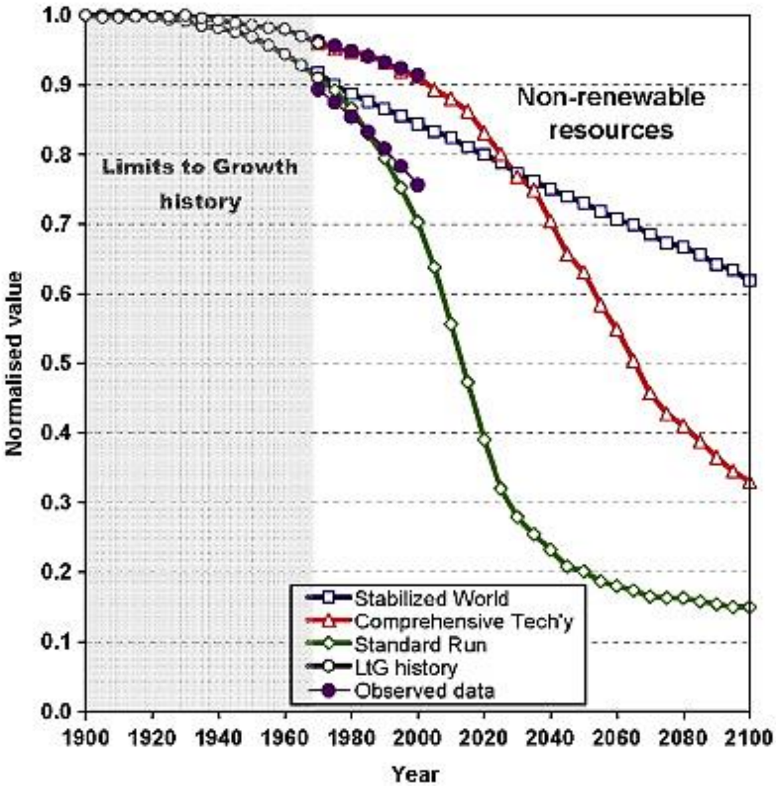


Figure 300. Comparing 'Limits to Growth' scenarios to observed global data – Non-renewable resources (Source: Turner 2008)

Figure 292 (peak in European industrial output in 2008), Figure 26 (Chinese industrial output YOY % change), in conjunction with the possibility that the energy systems (oil in particular) may soon contract, suggest the industrial ecosystem is approaching the peak of industrial output per captia sometime in the next few years. This is projected timing of the first peak predicted in the Standard Run model (Figure 297).

This implies that the global industrial ecosystem is going through the Limits to Growth standard run. This means that industrial production per capita is about to peak and decline, and non-renewable resources will continue to deplete. This has very serious implications to the global population. It also very clearly shows that the industrial ecosystem is about to transform into something else entirely.

19.1 Implications for future energy supply

This report has shown that oil will soon become unreliable as a consistent energy supply to support the global industrial ecosystem. The fossil fuels of gas and coal have a similar profile, but are not in such a difficult supply net position (Michaux 2017).

Figure 300 shows the 1972 study non-renewable resources scenarios (with a model future prediction between 1970 and the year 2000), overlaid with historical data from 1970 to the year 2000 as measured (Turner 2008). The historical data shows that non-renewable resources is following the Standard Run model from the 1972 Limits to Growth study. Energy resources like oil are part of this predictive model. This implies that as the global industrial ecosystem goes through a transformation and contraction (as per Figure 297), it will do so with a contracting energy (oil in particular) sector.

Existing alternatives like nuclear power, solar, wind, hydroelectric and geothermal all have their limitations. A case can be made that these alternative power sources are not strong enough in context their ability to deliver the same energy to the industrial ecosystem that oil and gas currently does (Michaux 2020).

The widespread manufacture and application of these alternative non fossil fuel energy systems *in their current form* has its practical limitations (Michaux 2020). What is required is a fundamental development of an entirely new energy system based around an entirely different paradigm. Conventional research and development has always been done but not looked at seriously due to the ubiquitous effectiveness of fossil fuels (oil in particular).

Historically, a change in paradigm is based on something discovered by accident, or developed in challenging circumstances where conventional methods no longer work, but the outcome is vital for the functioning of the industrial ecosystem. An example of this could be the invention of the steam engine to pump water out of coal mines. In the Great Britain in the early 1700's, coal was used as an energy source as most forests had been cut down for wood fuel. Most of the coal seams had been mined out above the water table, but were unable to proceed because the coal was underwater.

The solution was Thomas Newcomen's 1712 invention of a simple single-piston pump steam engine (Allen 2009). Newcomen engines were quickly put to use all over England to pump out the water that regularly flooded the coal mines. In allowing coal mines to delve deeper into the ground, the Newcomen caused an expansion in England's coal industry. A new technological paradigm allowed the development of industry in ways never considered before.

What is required, is to create a high technology society that uses an entirely new form of energy and operates to a different societal paradigm. If this is not achieved, the alternative is the degradation (and fragmentation) of the current industrial ecosystem. This stark choice of outcome is a consequence of not examining these fundamental issues decades ago it was first understood the nature of the challenge in front of us. For the last 20 years, our most competent technical professionals have not been working on this most serious challenge.

19.2 The Proposed Paradigm for the Next Generation of the Circular Economy

The conclusions of this report are that oil is not only a critical input into the current industrial ecosystem, but also has a potential unreliability which could become a demand/supply gap. It is recommended that energy in all its forms be included, as well as CRM's in the development of the next generation of the Circular Economy in Europe.

Figure 301 is a merging of Figure 27 and 28 with an addition of energy. The proportionate size of the energy blocks are based around what would be required in context of extra supply capacity from the global electricity generation grid, if fossil fuels were completely phased out (Michaux 2020). Note that oil is much larger than all the others combined. This suggests that the nature of the challenge to phase petroleum products out is much larger than currently believed.

The systems modelling approach has been successful in relating patterns and bottle necks of complex concepts in industrial ecosystems. It is recommended that this approach is continued.

As shown in this report, the oil CRM perspective is not only a global scale problem, by oil supply is limited to a small number of sources. This means that all major industrial clusters in a global context should work together in how to transition away from oil and fossil fuels in general. The alternative is conflict.

It could be considered to do a systems modelling study in context of Figure 306 on the following scales:

- Global
- Europe EU-28
    - Southern Europe
    - Northern Europe
    - Former Soviet Bloc Europe
- China
- United States
- Russian Federation
- Brazil
- India

19.3 Implications for corporate strategy

The implications of the conclusions of this report are troubling for the corporate basic business model and intrinsic strategy of endless growth. If a corporation cannot show a profit each year (growth), it will lose investment as capital would go to more profitable enterprises. But if the world was to peak and then contract in terms of physical work done, as production of natural resources becomes more difficult, then basic model of conventional corporate growth cannot function normally.

Almost all corporations and government entities have some kind of debt to serve. A common trend has been to go further into debt to maintain growth targets. In addition to this, the structure and foundation of monetary systems (*fiat*) are also highly vulnerable and are not in a fit state to engage in fundamental industrial reform on a global scale.

This means that a contracting energy sector may make corporate operation (in its current form) more challenging. The implication is that corporate operations may evolve into something else when the energy sector starts to contract (peak energy) into an entity not seen before.

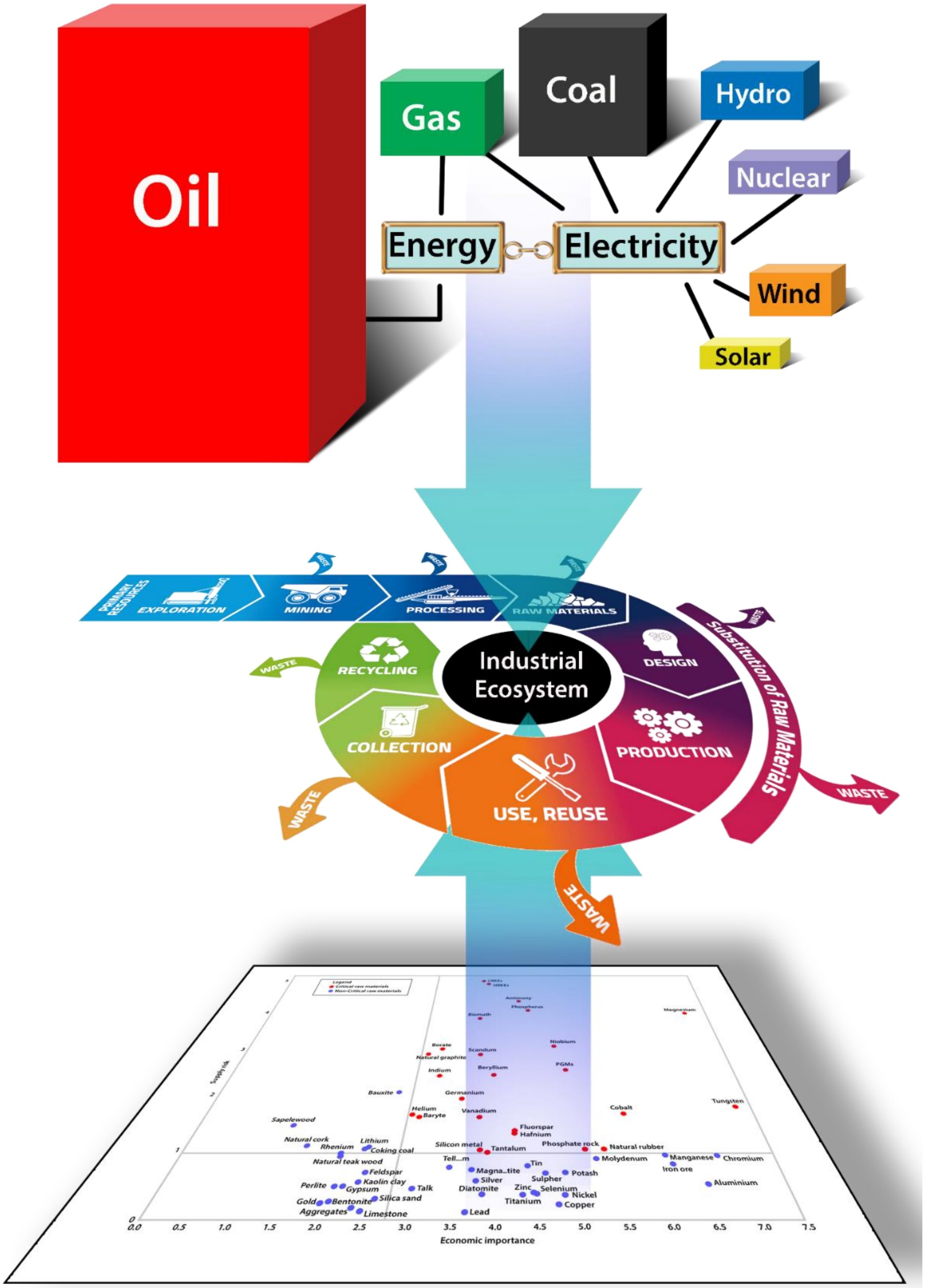


Figure 301. Proposed paradigm for the next generation of the Circular Economy
(Image: by Tania Michaux, EIT Raw Materials, and European Commission)

20 PROGNOSIS AND CONCLUSIONS

Conclusions of this report are as follows:

20.1 Relevance of oil

- Oil may be the most critical of the raw material resources the current industrial ecosystem consumes. It correlates strongly with industrial output (YOY% change in Chinese Industrial output and economic activity (% change in GDP) (Figure 26).
- Charts that relate oil to steel, coal, GDP all can map the major turning points in the global industrial ecosystem (Figures 22 to 24).
- Industrial agriculture is dependent on oil to function. The World Bank Food Index and the World Bank crude oil index correlate strongly (Figure 33). The production of food is dependent on oil, and petroleum products at several places along the value chain.
- There is a correlation between the price of food, the price of oil and civil unrest. When the price of food passes 205 on the World Bank Food Index, incidence of civil unrest increases (Figure 36).
- 14% of oil consumption in 2018 was used in the petrochemical industry (manufacture of plastics and fertilizers). There is no viable substitute for oil as a raw material input into the petrochemical industry.
- Oil price may be the most effective data signature to study to map the evolution of the current industrial ecosystem.
- Oil has facilitated that exponential growth of our society, industrial complexity and technological capability (Figure 17). For this reason, oil production correlates with human population.
- Oil is the most calorically dense energy resource. All other resources would have to be used in greater quantities or at much greater levels of efficiency to replace what oil contributes to our system.
- In 2018, fossil fuels accounted for 84.7% of primary energy consumption.
- Oil accounts for 33.62% of global primary energy consumption in 2018.
- Currently Europe is heavily dependent on fossil fuels (71% of energy consumed) and oil (86% of energy consumed).
- 47.5% of oil and petroleum products in Europe is consumed by transport.
- 70.56% of oil and petroleum products in the United States is consumed by transport
- Due to the critical contribution oil makes to our industrial society, a change in supply will have measureable consequences across the whole ecosystem.

20.2 Oil Reserves

- Total global proved reserves at the end of 2018 was 1729.7 thousand million barrels or 244.1 billion metric tons.

- Most oil and gas deposit discoveries happened decades ago, with most of it prior to 1970.

- In the year 2017, explorers replaced just 6% of resources consumed.

- The maximum of net addition to global oil reserve inventory was in 1981 (Figure 221).

20.3 New oil deposit discovery rate

- Peak oil discovery was in 1962, since then rates of resource discovery has been declining persistently (Figure 219 and 221).

- New discoveries are limited: the exploration success rate in 2017 was a record low of 5%, and the average discovery size was 24 million barrels. This is also called Reserves Replacement Ratio, where less oil quantity is discovered than is consumed in a given time period (annual).

- The quantities discovered in 2017, 2018 and 2019 were the lowest on record since the initial discovery of oil. This discovery rate is about 1/10th of the discovery rate in the 1960's.

20.4 Oil Production Supply

- Global conventional crude oil produced in 2018 was 94.718 million barrels per day (or 4474.3 million tonnes).

- The oil market may be oversupplied with an 'oil glut' at the time of writing this report.

- Approximately 70% of our daily oil supply comes from oil fields discovered prior to 1970.

- Most of global oil supply comes from 10 to 20 huge oil fields. In 2006, 10 oil fields accounted for 29.9% of the global proved reserves.

- Production of oil is sourced from different methods of extraction
  - Conventional on shore oil extraction 60.27%
  - Conventional offshore shallow water oil extraction 21.59%
  - Conventional offshore deep water oil extraction 8.10%
  - U.S. Tight Oil (Fracking) oil extraction 6.93%
  - Canadian Oil Sands oil extraction 3.10%

- Three nation states (United States 16.16%, Saudi Arabia 12.97% and Russian Federation 12.08%) dominate the global oil supply with 41.2% of the market between them.

- 74% of the current global oil reserves is geographically concentrated in what is termed the Strategic Ellipse, which is the Middle East and Central Asia.

- The quality of oil being extracted is degrading. The sulfur content is increasing. Most oil being extracted currently is increasingly heavy and sour.

- Conventional crude oil plateaued in January 2005. In late 2013, it broke the plateau and started to increase once more.

- In January 2005, Saudi Arabia increased its number of operating rig count by 144%, to increase oil production by only 6.5%. This suggests that the market swing producer (as Saudi Arabia was seen) was not able increase production enough to meet increasing demand.

- Since then, unconventional oil sources like tight oil (fracked Tight Oil, and oil sands) have made up the demand shortfall.

- The cost of oil exploration is rising.

- The required CAPEX for oil operations is rising.

- The cost of OPEX oil production is rising.

20.5 Oil Demand Consumption

- Global consumption for oil in 2018 was 99.843 million barrels per day.

- When the market returns to demand taking up all global supply, effective spare capacity could shrink to just 1% of global supply/demand of 99 million barrels per day, leaving the market far more susceptible to disruptions than has been the case in recent years.

- The three largest economies in the world (United States, Europe EU-28 and China), which represent 65% of global GDP and % of global oil demand are dependent on oil imports.
  - United States – 2018 deficit of 5 145 kbbls/day or 25.2% of domestic demand
  - EU-28 - 2018 deficit of 11 769 kbbls/day or 88.5% of domestic demand
  - China - 2018 deficit of 9 727 kbbls/day or 72% of domestic demand

- Oil demand is still growing by ~1mbd every year, and no central scenarios that recently was assessed predict oil demand peaking before 2040.

- Global demand for crude oil in 2040 is predicted to be approximately 120 million barrels per day (EIA International Energy Outlook 2019 with projections to 2050). In 2050, global demand is predicted to be approximately 127 million barrels per day.

- If the BRIC economies (Brazil, Russia, India and China) was to become as developed as the German economy in context of oil consumption, the BRIC economy 2018 oil consumption would have to expand by 254%.

- If the whole World was to become as developed as the 2018 German economy in context of oil consumption in 2018, the global oil consumption of 99.84 mbpd would have to expand by 117% and an extra 116.68 mbpd of oil would need to be brought to market.

20.6 US Tight Oil (Fracked Oil Shale)

- US tight oil produced in August 2019 was 7.73 million barrels per day, approximately 8.37% of global supply.

- The Oil Shale Revolution was facilitated by the application of precision horizontal drilling technology to the existing hydraulic fracking industry. This allowed a vast increase in production, very quickly.

- The U.S. tight oil sector accounted for 98% of global oil production growth in 2018.

- The U.S. tight oil sector accounted for 71.4% of new capacity of global oil between 2005 and 2019.

- The U.S. Tight Oil sector is dominated with just three of the basin plays. The Permian play, The Bakken Play (also known as Williston) and the Eagle Ford play account for 85% of the U.S. Tight Oil production. These three oil plays account for 60% of total U.S. oil production.

- Global demand growth is now dependent on the U.S. tight oil sector.

- Fracked well average production increased between 2010 and 2018 by 28%, but also water injection (and therefore chemical and proppant use) increased by 118%. This is an average across the whole U.S. Tight Oil Sector.

- Hydraulic fracked wells (used in Tight Oil) go through four basic stages in their life cycle. The three biggest tight oil producer basins of Permian, Eagle Ford and Bakken are all still growing but are in the mature stage of their life cycles. Mature is the third of four stages, where the fourth is decline.

- The productivity (per rig as measured by EIA) of the U.S. Tight Oil sector in 2018 is less effective than in 2016. This suggests that the U.S. Tight Oil sector is approaching its peak production reasonably soon.

- At the time of writing this report (Nov 2019), the United States had become self-sufficient in oil production. This is largely due to the production achievements in the U.S. Tight Oil sector.

- Tight Oil requires much greater meters of drilling per unit of oil produced compared to conventional oil production over their respective life cycles.

- Due to well depletion in fracking, 5 399 new wells are needed to be drilled to keep the U.S. tight oil production consistent in 2019. Each year a similar number of new wells are required.

- The environmental impacts of fracking tight oil is being largely ignored. Most of these are related to water way pollution and destruction of forestation habitat.

- Most tight oil operations are not economically viable without government subsidy in the current market. Currently, 9 out of 10 oil producers in the tight oil U.S. fracking sector have a negative cash flow.

- The U.S. Tight oil sector is heavily dependent on continued upfront capital investment in infrastructure and to maintain well drilling rates, to keep production consistent.

- The U.S. oil production peaked in 25th of January 2019, and dropped to 19th July 2019, with a decline of 1.1 million barrels a day.

20.7 Canadian Oil Sands

- The Canadian capacity to export oil is almost entirely dependent on the oil sands (also called tar sands) production, accounting for 64% of Canadian oil production, or 2.9 million barrels a day. Most of this is heavy quality crude.

- The environmental impacts of oil sands oil/bitumen extraction is being largely ignored. Most of these are related to water way pollution and destruction of forestation habitat.

20.8 Oil Refining

- The U.S. refined 20.45% of the global oil supply in 2018. The U.S. represents 18.75% of global refining capacity.

- China refined 15.0% of the global oil supply in 2018. China represents 15.65% of global refining capacity.

20.9 Depletion of existing oil reserves an decline of production

- 81% of existing world liquids production is already in decline (excluding future redevelopments).

- A projected range for average decline rate on post-peak production is 5-7%, equivalent to around 3-4.5mb/d of lost production every year.

- If 80% of the 2018 global supply of crude oil (94 718 thousand bbls/day – Appendix D) declined at a rate of 5% per year (Fustier et al 2016), by 2040, global crude oil supply would be 43 459 thousand barrels per day. To maintain 2018 global production rates of 94 718 kbbls/day, an extra 51 258 kbbs/day of production would have to be delivered to the market. This is 4.17 times the 2018 Saudi Arabian production rate (12 287 kbbls/day – Appendix D). Alternatively, if the Saudi Arabian elephant field Ghawar continues to produce 3.8 million barrels a day, then an extra 13.5 new oil fields the same size of Ghawar would need to be discovered, then developed to operate by 2040, just to maintain 2018 rates of global supply.

- If the projected global demand in 2040 is to be met (120 million barrels per day), an extra 25282 thousand barrels per day of consistent production capacity would have to be found in addition to the 2018 production capacity. To put this in perspective, this extra capacity would be a further 6.65 Ghawar fields.

- Small oilfields typically decline twice as fast as large fields, and the global supply mix relies increasingly on small fields: the typical new oilfield size has fallen from 500-1000mb 40 years ago to only 75mb this decade.

- A case can be made that the Saudi Arabia Ghawar field has passed its peak production. In any case, stated Ghawar production is substantially less at 3.8 mb/d, not the believed 5mb/d. (as per the Saudi Arabia Aramco IPO).

- Between January 2005 and September 2006, the Saudi Arabian oil rig count increased by 396%. Oil production in the same time period increased by 21%. The Saudi Arabian oil production productivity dropped in January 2005 and has consistently declined. This suggests that Saudi Arabia is approaching it peak production date.

- Energy Returned on Energy Invested (ERoEI) for oil has been declining for decades. Peak usefulness was approximately 1960.

- Step-change improvements in production and drilling efficiency in response to the downturn have masked underlying decline rates at many companies, but the degree to which they can continue to do so is becoming much more limited

20.10 Oil Investment

- The oil industry is now highly dependent on up front capital.

- 70% of investment in energy supply is government driven. The rest is market driven.

- The Compound Annual Growth Rate (CAGR) changed in 2000 from 0.9% to 10.9%.

- This suggests that the oil industry has shifted from a demand constrained system to a supply constrained system.

20.11 Different eras of economic and industrial activity seen in the oil market

- The year 2005 was highly significant to the industrial ecosystem (Figure 288). The oil market became inelastic in supply in this year. Supply and demand of oil separated. The metal price of many metals blew out. The Baltic Dry Index (BDI) started a hyperinflationary bubble. The US domestic oil consumption vs vehicle miles driven chart peaked and then declined. The years 2005 to 2011 were fundamentally different to prior to 2005 (Figure 249).

- The years 2008 to 2011 were distinguished by the Global Financial Crisis, the second worst economic correction in history (as defined by the IMF).

- The years 2012 to 2014 were distinctly different again. This era was defined by the effectiveness of quantitative easing (Figure 249).

- The years 2014 to 2019 were defined by a lack of quantitative easing. QE3 finished on October 2014 (Figure 249).

20.12 Oil Shocks

There have been four oil shocks (where the fourth is comparatively small).

- The 1st Oil Shock. The Oil Embargo 1973 (Section 14.1)
- The 2nd Oil Shock. The Iranian Revolution, Iran/Iraq War 1979 (Section 14.2)
- The 3rd Oil Shock. Oil production plateaus 2005 (Section 14.3)
- The 4th Oil Shock. The Arab Spring, Quantitative Easing 2010 (Section 14.4)

20.13 Peak Oil

- The conventional concept of peak oil on its own is too simplistic to be useful however. Energy supply is just one component, where oil is just one energy source (albeit the most influential one).

- A more holistic approach to model peak oil production is appropriate (Figure 276).

- Peak oil will be driven by a combination of a window of viability between an oil price low enough for consumers to support where economic growth is possible, and an oil price high enough for producers to be economically viable.

- It is not clear when peak oil production will happen, but it is clear that the viable window of oil market operation is closing (Figure 258).

- There was a global peak in oil production in November 2018. This peak is more related to the oil industry having a shortfall of upfront capital investment, than a geological limit of reserves in the ground. Whether this is a genuine peak will not be known for several years and is entirely dependent on investment in the oil and gas industry to support production from comparatively low ERoEI oil plays.

20.14 Environmental Pollution

- There is a series of environmental pollution problems with all of the unconventional oil sources.
- Most of these are related to water way pollution and destruction of forestation habitat.

20.15 Geopolitics of oil

- Governments and large corporations around the world are aware of peak oil. The banking sector and military as well as private corporations have all formed think tank groups and released reports. Most of these reports were made confidential and not for public consumption. The report commissioned by the German army has been leaked (BTC 2010).
- War has disrupted the oil markets more than anything else.
- The oil price fluctuations correlate with many geopolitical events.
- The 1973 oil embargo (the 1st Oil Shock) is an excellent case study in how an oil shortage could influence society in the short and medium terms.

20.16 Economic viability

- CAPEX, OPEX and CACR to explore for oil and start oil extraction operations has been increasing. Returns have been decreasing (per unit volume).
- Oil price could be the most relevant data signature to study in context of the evolution of the current industrial ecosystem.
- Oil price could be a good leading indicator for large finance market moves, with the understanding that it is heavily influenced by above ground factors.
- The price of oil has to be high enough for producers to stay in business and for exploration and production to be viable.
- The modern economy requires the price of oil to be low enough to facilitate economic growth.
- Oil is now in a very difficult business environment to stay economically viable.
- The year 2005 was highly significant to the industrial ecosystem. The oil market became inelastic in supply in this year. Supply and demand of oil separated. The metal price of many metals blew out. The Baltic Dry Index (BDI) started a hyperinflationary bubble. The US domestic oil consumption vs vehicle miles driven chart peaked and then declined.

20.17 The link between oil markets and finance

It can now be argued that there is a link between the finance markets and the oil markets. Relevant things to consider are:

- In 15th August 1971, the United States government decoupled the $USD from the gold standard asset backing to become a *fiat* currency, with the Bretton Woods agreement being discontinued. This date was shown to be highly significant for structural change in the markets (Figure 282 and 283). From this date onwards, any given large problem could be solved by spending money on it, then balance the national budget by creating money. All nations now have a fiat currency and problem solve in this manner.

- In 1973, an agreement between the United States and Saudi Arabia, where all oil market trades and transactions were to be conducted in $USD. This was called the Petrodollar agreement. It forced all other nation states in the global ecosystem to use $USD for transactions. This secured the $USD as a global reserve currency, after the decoupling of hard asset backing (gold). This forced all nation states to engage in and depend on a fiat currency, where money creation was a routine action.

- Quantitative easing (a formal name for the digital creation of money) was used to resolve structural problems, that it could be argued started in the oil markets (Section 14.3). The U.S. Federal Reserve started the QE1 program to arrest the GFC crash on November 2008. The amount of money created was done on an unprecedented scale. All major Central banks around the world (European Central Bank, Bank of China, Bank of Japan) have all engaged in quantitative easing on an unprecedented scale since 2008. In 2019, a form of quantitative easing is being engaged in to support the inter-bank lending repo markets.

20.18 The origins of the Global Financial Crisis

The Global Financial Crisis of 2008 was triggered by a fundamental change in the global industrial ecosystem a few years beforehand in early 2005. It is postulated that the sequence of events that led to the GFC was:

1. $USD decouples from gold standard in 1971. GDP and oil production diverge (Figure 250).
2. Oil production plateaued January 2005 for a short while, until Oct 2011 (Figure 230).
3. Saudi Arabia cannot raise production, in spite of a 144% increase in rig count, starting January 2005 (Figure 232).
4. Oil market becomes inelastic 2005 to 2008
5. Oil demand separates from oil supply in 2006 (Saxena 2009 and Yardeni Research 2016). This supply gap does not close until late 2008.
6. All metals and minerals tracked by the World Bank blow out in price, starting in January 2005 (Figure 289).
7. Conditions are created to start a speculative bubble in oil price, starting with an oil price rise in 2005 and a very steep oil price rise in 2006.
8. Oil price blows out and peaks on 11th of July 2008 at $143.68 USD (Brent spot price), and then crashes (Figure 242).

9. Declared an international banking crisis with the collapse of the investment bank Lehman Brothers on September 15th 2008.
10. Quantitative easing program QE1 starts on November 2008 (Figure 244).
11. Oil crashed to a low of $33.73 USD on 26th of December (Brent spot price) then starts to recover (Figure 242).
12. The era of instability reflected in the world oil production vs oil Brent spot price is 2005 to 2011. (Figure 249)
13. Continued quantitative easing has been necessary to maintain the stability of the global economy.

20.19 Implied Change in Industrial Paradigm

The industrial ecosystem changed in January 2005. This was marked by oil production became inelastic and the oil industry became dominated by much higher costs of production. Fossil fuels (oil in particular) have facilitated the development of the scope and complexity of the current industrial ecosystem. In addition to this dependency, the substitute plans to replace oil like Electric Vehicles and renewable energy systems is a much larger task than currently understood (Michaux 2020).

A fundamental problem that this report has shown for the example of oil, is consumption of all the finite nonrenewable natural resources follows an exponential curve. This is true for consumption of energy, metal and minerals (Bardi 2003, Frimmel & Muller 2011), food products (Muller et al. 2007) and textiles.

This highlights a wider and more fundamental problem in regard to what our industrial ecosystem does, why and for whom. For example, it is also true that the impact of our industrial civilization degrades the environment (biosphere, flora and fauna populations) (Ehrlich & Ehrlich 2013). The application of industrial agriculture has resulted in the exponential destruction of arable land (Pfeiffer 2006, Lagi et al. 2011 Martinez-Alier 2011) and depleting fisheries (FAO 2016).

The application of industrialization has resulting in the exponential pollution through dumping of waste of all kinds into the environment (UNEA 2017). The growth of human civilization has resulted in the widespread destruction of the global environment at large (MEA 2005, Ehrlich & Ehrlich 2013).

The implications of this report suggest that with the depletion and unreliability in supply of oil, our industrial ecosystem would be required to evolve into a lower energy consumption profile with less complexity. As there is no real replacement for oil in terms of what it contributes, this necessitates a complete restructure of the demand side of energy requirements. This has far reaching implications in the structure of the industrial ecosystem. Due to the widespread environmental impact of the current system, this would be required for long term stability of any modern industrial society (like Europe) in a sustainable fashion.

21 RECOMMENDATIONS

Some very challenging concepts have been put forward in this report. Recommendations in how GTK could respond are as follows.

21.1 Examine more closely the events between January 2005 to November 2010

Sections 18.4 and 18.5 of this report examine industrial, economic and financial events in the time periods between January 2005 and November 2010. On January 2005, the metal price of all metals tracked by the World Bank had a price spike. It is postulated this metal price spike set conditions that would later trigger the global financial crisis (GFC) of 2008.

The GFC was declared a banking crisis in September 2008. In November 2008, the U.S. Federal Reserve Bank intervened into the markets with an unprecedented volume application of quantitative easing program called QE1. This action was successful in arresting the market crash. QE1 was halted on June 2010. A short time later, the second program QE2 was started (Nov 2010 to June 2011). The third program QE3 was conducted Sept 2012 to Oct 2014.

It is also postulated that this metal price blow out was caused by the plateauing of the global crude oil production, also on January 2005 (Figure 230). When this happened, the global swing producer at the time (Saudi Arabia) was unable to raise oil production, creating an inelastic industrial market. This theory is supported by Saudi Arabia increasing their drill rig count by 144% starting in January 2005, yet for a short time production actually declined (Figure 232).

If this set of theories are valid, then the worst economic downturn since the 1929 Great Depression was caused by a chain reaction that had its genesis in the global oil supply becoming inelastic for a short time. If so, what is curious is that while global oil production has since continued to increase, largely due to the U.S. Tight Oil Sector (see Section 6), the metal price volatility continues for years after the GFC was declared over.

Are these theories correct?

It is recommended that these theories be tested and understood, where:

- A comprehensive systems analysis be conducted linking the industrial ecosystems of energy, metals, industrial manufacture and finance between the dates 1st January 2004 and July 2012. This time period will encompass the metal price blowout and oil industry production plateau in January 2005. It will also encompass the GFC, QE1 and QE2 (QE2 ended in June 2012).

- Use the outcomes of the above systems study to try and predict the data patterns observed in the systems networks examined:

    - Between dates August 2012 and October 2014. This time period can be used to try and model the effect of QE3.
    - Between dates August 2012 to present. This time period will encompass the Chinese Yuan revaluation in 2015, stagnate economic growth, and the lowest recorded value of the Baltic Dry Index on date February 12th 2016.

21.2 Conduct a new systems study of global industrial ecosystem

Repeat the 1972 Limits to Growth systems analysis with up to date information between years 1800 to 2019. Include in this study:

- Human population
- Food production
- Information systems
- Financial systems
  - Quantitative Easing
  - Debt levels
- Energy Resources
  - Oil
  - Gas
  - Coal
  - Uranium
- Renewable power systems
- Industrial metals
- Primary resource mining
- Secondary resource recycling
- Environment
  - Direct industrial pollution
  - Indirect systemic industrial pollution
  - Plastics
  - Bio-systems stress feedback loops
  - Species extinction
  - Species food chain instability

Capture the systems footprint in the time periods:

- 1900-1910 – Multiple financial panics
- 1912-1916 – Formation of the U.S. Federal Reserve Bank
- 1913-1918 – World War I
- 1928-1933 – Great Depression
- 1935-1945 – World War II
- 1950-1965 – Economic and industrial golden era
- 1971 – Decouple $USD from hard asset gold standard
- 2000 – Change in productivity of the mining industry
- 2005-2008 – Blowout of commodity price, plateau of oil production
- 2008-2010 – Global Financial Crisis
- 2014-2017 – Contraction of real physical goods economy
- 2018 – Possible peak in global oil production

21.3 Develop technical knowledge and capability in oil resources

Currently GTK does not study oil as a resource. At the time of writing this report, there are no known oil deposits in Finland. However, oil is still a highly relevant resource to study. The critical influence oil has as an energy source to the global industrial ecosystem is unparalleled by any other resource.

GTK should develop capability to understand oil, its refining issues, and its use applications in all forms. That is, to develop understand and knowledge of the true state of affairs in the oil sector in context of what deposits there are in a global context and what the true implications of their extraction will be (and by whom). As this will lead to an advisory role to the Finnish ministry (and perhaps the European Commission), this will require a willingness to look at geopolitical influences. It may not be necessary to engage in oil exploration directly to achieve this task. Other organizations do this quite well and it would be unnecessary for GTK to develop oil mapping expertise.

Develop understanding of peak oil and what it means to a level of technical sophistication where GTK can advise other European entities.

The implications of the current vulnerability of Europe to an oil supply shock is collectively unknown in the sphere of public debate amongst analysts and scientists doing work studying CRM minerals.

The assumption is that if there was a problem, then the relevant organizations (geological exploration groups that specialize in oil) would make a statement. The technical professionals tasked with tracking hydrocarbons have not published any publically available reports regarding this topic.

The net result, is that no technical group in Europe (or in a global scope) have published a publically available report. Such a task could be required of an internationally recognized government backed scientific group like GTK.

21.4 Conduct a precision audit on global crude oil production and demand

Figure 230 shows world crude oil production plateauing in January 2005. Figure 247 shows global crude oil supply and demand separating for a short time just prior to the GTC. When examined published data (BP Statistical Review of World Energy 2019) it soon becomes clear that demand and supply do not match up. This is because raw materials other than conventional crude oil is now included. For example, biofuel and refinery gains are now included, but were not always included. Determining exactly what was being extracted from the ground in terms of conventional oil, and what was biofuel has not been straight forward. This needs to be looked at in closer detail and quantified.

It is recommended that GTK (or another organization) conduct a country by country, producer by producer audit be done across the oil industry. This audit should include quantity and quality of oil extracted, how it is refined, where it is refined and what products come from that refinement. Then track and audit the trade movements of oil in the global system. Well hole depth and horizontal length would also be of use. If possible, also track and audit the corporate ownership, cash flows, CAPEX, OPEX and financial debt associated with each operation.

- Conventional crude oil – on land
- Conventional crude oil – off shore shallow water
- Conventional crude oil – off shore deep water
- Unconventional oil – hydraulic fracking (Tight Oil)
- Unconventional oil – oil sands
- Unconventional oil – biofuel

21.5 Consider adding oil, gas, coal and uranium to CRM list

Europe (and Finland) is currently heavily dependent on energy resources as they are extracted out of the ground. This state of affairs is likely to continue for decades, even with the penetration of the Electric Vehicle technology into the market place.

As such, the Critical Raw Material list should include energy raw materials. Just so, the following minerals should be added:

- Oil
- Gas
- Coal
- Uranium

This requires an evolution of the development of the Circular Economy (Figure 297). The current group think in Europe in context of not studying energy resources comes from two sources:

1. A policy decision made at the inception of the CRM map not to examine energy resources

2. As Europe imports most of its needed natural resources, the extraction of a resource like oil is to be examined by others and this is a market problem (the market firewall issue).

21.6 Understand that the industrial ecosystem currently is in a state of flux and inevitably about to change again at all scales of operation

Currently, our industrial ecosystem is highly dependent on finite non-renewable natural resources (oil, gas and coal). That reserves will eventually deplete and production peak and decline is accepted. The question is when. This report shows that that peak date is either imminent or in our recent past (possibly 2015). It is no longer a case of mitigation or avocation for a change in society practice.

It has been shown with updated data that the Limits to Growth model first proposed in 1972 was conceptually correct (Figure 296). In this model, the global economic and industrial ecosystem will undergo a series of structural changes in the next 5 to 10 years, where a number of fundamental metrics will peak and decline. The first of these metrics is industrial output per capitia. It can be argued that the global industrial ecosystem has already passed this point in 2008 (Figure 291).

Once the industrial ecosystem transitions into a contracting energy environment (possibly already has done so), a very different paradigm will be required for industrial operation. The current paradigm is one of expansion (desired rate approximately 2%) and increase in technological complexity. Currently, this is supported with the application of quantitative easing. In a contracting energy supply market, the reverse of this will happen as a matter of reality based practicality, where the system will contract in scope and complexity.

The system will evolve from "make it bigger, better and faster, and do it now" to "how do we make do with less CRM production with supply interruptions as long as 6 months" (Michaux 2017). One of the outcomes would be the difficulty of maintaining trade routes with long supply chains. The sourcing of useful goods and services will be forced to become localized, including the use of raw materials. <u>This means that mineral resources of all kinds will become much more valuable than they are now and would have to be managed much more carefully.</u>

As the industrial ecosystem will be forced to change, the Captains of industry will also be required to change in their administration. In doing so, advice would be required from relevant organizations that understand European natural resources. GTK would feature prominently on a very short list in this context.

Regardless of what GTK does in terms of strategic development in the next 5 - 50 years, it will be required to assist the Finnish ministry and the European Commission in terms of what to do with the available natural resources.

21.7 Lead a series of exploration campaigns to map Europe in terms of mining potential

All mineral resources are about to become more valuable. Battery minerals in particular will become very valuable and seen as strategic assets, thus become the focus of long term national security.

Europe is largely unexplored in context of modern exploration techniques. As local mineral resources will be required in context of unprecedented demand, each nation state could engage in a Europe wide mineral exploration campaign. The geological survey of each nation state would be required to take part.

As GTK is logistically more advanced than many of these groups, it could be possible to lead whole groups and projects in assistance to other exploration groups.

This will lead to the concept of mining in Europe which until now has been considered mostly undesirable. The issues of mining in such a developed area like Europe are not seen anywhere else in the world. <u>GTK could take the initiative and lead a European sustainable mining development capability.</u>

21.8 Understand that the current CRM list will evolve with an energy shortage

The current list of CRM's is based around the concept of long term security for European industrial businesses. Once the industrial ecosystem transitions into a contracting energy environment, a very different paradigm will be required for industrial operation.

Technological complexity will be steadily reduced. The supply of CRM's in general would be subject to supply disruptions ranging from temporary time periods of a few days (a problem in the current market) to medium time periods of a few months, to even permanent discontinuation of supply. In the early 1900's, the warehouse network based on a 6 month supply buffer. Society may return to this system.

A new list of CRM's would evolve in this working environment, not around market requirements based on economic whim ("buy the new iPhone"), but based around what is absolutely needed to keep the basic necessities of society to function.

Also, the current form of the CRM map can be regarded as too simplistic. Some CRM's have a greater influence than others. If for example barite became unavailable for a period of several months, how would this impact the operation of the new ecosystem? Alternatively, if natural gas was not available for the same time frame, how would this impact the system? Gas powers most industry applications. The ripple effect of a gas supply shortage would be much greater than a barite shortage.

The time frame in which shortage would become a crisis is different for each CRM.

<u>So a new CRM system would have to be developed that would capture how each CRM interacts with the system as a whole, as a function of time</u>.

22 GLOSSARY OF TERMS

Analytics - is the discovery, interpretation, and communication of meaningful patterns in data. Especially valuable in areas rich with recorded information, analytics relies on the simultaneous application of statistics, computer programming and operations research to quantify performance. Organizations may apply analytics to business data to describe, predict, and improve business performance. Specifically, areas within analytics include predictive analytics, prescriptive analytics, enterprise decision management, descriptive analytics, cognitive analytics, retail analytics, store assortment and stock-keeping unit optimization, marketing optimization and marketing mix modelling, web analytics, call analytics, speech analytics, sales force sizing and optimization, price and promotion modelling, predictive science, credit risk analysis, and fraud analytics. Since analytics can require extensive computation (see big data), the algorithms and software used for analytics harness the most current methods in computer science, statistics, and mathematics.

Arab Spring (The) - also referred to as Arab revolutions, was a revolutionary wave of both violent and non-violent demonstrations, protests, riots, coups and civil wars in North Africa and the Middle East that began on 17 December 2010 in Tunisia with the Tunisian Revolution. This was the evolution and rebranding of the Colour Revolutions.

Arctic drilling - or drilling in arctic environments are characterized by extreme cold winters where surface temperature can drop below −50 °C (−58 °F). The five Arctic regions of Russia, Alaska, Norway, Greenland, and Canada hold a tremendous potential for both discovered and undiscovered reserves of Oil and Gas. The north area of the Arctic Circle contains an estimated 90 billion barrels of undiscovered, technically recoverable oil, 1,670 trillion cubic feet of technically recoverable natural gas, and 44 billion barrels of technically recoverable natural gas liquids.

Asphalt - A dark brown-to-black cement-like material obtained by petroleum processing and containing bitumens as the predominant component; used primarily for road construction. It includes crude asphalt as well as the following finished products: cements, fluxes, the asphalt content of emulsions (exclusive of water), and petroleum distillates blended with asphalt to make cutback asphalts. Note: The conversion factor for asphalt is 5.5 barrels per short ton.

Aviation gasoline (finished) - A complex mixture of relatively volatile hydrocarbons with or without small quantities of additives, blended to form a fuel suitable for use in aviation reciprocating engines. Fuel specifications are provided in ASTM Specification D 910 and Military Specification MIL-G-5572. Note: Data on blending components are not counted in data on finished aviation gasoline.

Baltic Dry Index (The) – The Baltic Dry Index (BDI) is an economic indicator issued daily by the London-based Baltic Exchange. Not restricted to Baltic Sea countries, the index provides "an assessment" of the price of moving the major raw materials by sea. Taking in 23 shipping routes measured on a timecharter basis, the index covers Handysize, Supramax, Panamax, and Capesize dry bulk carriers carrying a range of commodities including coal, iron ore and grain.

Barrel - A unit of volume equal to 42 U.S. gallons. The unit of measure to describe volumes of oil.

bbl - The abbreviation for barrel(s).

bbl/d - The abbreviation for barrel(s) per day.

bbl/sd - The abbreviation for barrel(s) per stream day.

bcf - The abbreviation for billion cubic feet.

Base gas - The quantity of natural gas needed to maintain adequate reservoir pressures and deliverability rates throughout the withdrawal season. Base gas usually is not withdrawn and remains in the reservoir. All natural gas native to a depleted reservoir is included in the base gas volume.

Biodiesel - A fuel typically made from soybean, canola, or other vegetable oils; animal fats; and recycled grease. It can serve as a substitute for petroleum-derived diesel or distillate fuel. For EIA reporting, it is a fuel composed of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, designated B100, and meeting the requirements of ASTM (American Society for Testing materials) D 6751.

Biofuels - Liquid fuels and blending components produced from biomass feedstocks, used primarily for transportation. Essentially ethanol and biodiesel.

Biomass - Organic non-fossil material of biological origin constituting a renewable energy source.

Biomass-based liquid supplies - (BtL or BMtL) is a multi-step process of producing synthetic hydrocarbon fuels made from biomass via a thermochemical route. Such a fuel has been called grassoline.

Biomass gas (Biogas) - A medium Btu gas containing methane and carbon dioxide, resulting from the action of microorganisms on organic materials such as a landfill.

Biomass power generation (Bioenergy) - Bioenergy is renewable energy made available from materials derived from biological sources. Biomass is any organic material which has stored sunlight in the form of chemical energy. As a fuel it may include wood, wood waste, straw, manure, sugarcane, and many other by-products from a variety of agricultural processes. By 2010, there was 35 GW (47,000,000 hp) of globally installed bioenergy capacity for electricity generation, of which 7 GW (9,400,000 hp) was in the United States. In its most narrow sense it is a synonym to biofuel, which is fuel derived from biological sources. In its broader sense it includes biomass, the biological material used as a biofuel, as well as the social, economic, scientific and technical fields associated with using biological sources for energy. This is a common misconception, as bioenergy is the energy extracted from the biomass, as the biomass is the fuel and the bioenergy is the energy contained in the fuel. There is a slight tendency for the word bioenergy to be favoured in Europe compared with biofuel in America.

Bitumen - A naturally occurring viscous mixture, mainly of hydrocarbons heavier than pentane, that may contain sulphur compounds and that, in its natural occurring viscous state, is not recoverable at a commercial rate through a well.

Bituminous coal - A dense coal, usually black, sometimes dark brown, often with well-defined bands of bright and dull material, used primarily as fuel in steam-electric power generation, with substantial quantities also used for heat and power applications in manufacturing and to make coke. Bituminous coal is the most abundant coal in active U.S. mining regions. Its moisture content usually is less than 20 percent. The heat content of bituminous coal ranges from 21 to 30 million Btu per ton on a moist, mineral-matter-free basis. The heat content of bituminous coal consumed in the United States averages 24 million Btu per ton, on the as-received basis (i.e., containing both inherent moisture and mineral matter).

BOE - Barrels of Oil Equivalent (used internationally)

Boiler - A device for generating steam for power, processing, or heating purposes; or hot water for heating purposes or hot water supply. Heat from an external combustion source is transmitted to a fluid contained within the tubes found in the boiler shell. This fluid is delivered to an end-use at a desired pressure, temperature, and quality.

Boiler fuel - An energy source to produce heat that is transferred to the boiler vessel in order to generate steam or hot water. Fossil fuel is the primary energy source used to produce heat for boilers.

Blowout (Oil gusher) - A blowout is the uncontrolled release of crude oil and/or natural gas from an oil well or gas well after pressure control systems have failed. Modern wells have blowout preventers intended to prevent such an occurrence. Prior to the advent of pressure control equipment in the 1920s, the uncontrolled release of oil and gas from a well while drilling was common and was known as an oil gusher, gusher or wild well. An accidental spark during a blowout can lead to a catastrophic oil or gas fire.

Brent Crude - is a major trading classification of sweet light crude oil that serves as a major benchmark price for purchases of oil worldwide. This grade is described as light because of its relatively low density, and sweet because of its low sulphur content. Brent Crude is extracted from the North Sea and comprises Brent Blend, Forties Blend, Oseberg and Ekofisk crudes (also known as the BFOE Quotation).

Bretton Woods system - of monetary management established the rules for commercial and financial relations among the United States, Canada, Western Europe, Australia and Japan after the 1944 Bretton-Woods Agreement. The Bretton Woods system was the first example of a fully negotiated monetary order intended to govern monetary relations among independent states. The chief features of the Bretton Woods system were an obligation for each country to adopt a monetary policy that maintained the exchange rate (± 1 percent) by tying its currency to gold and the ability of the IMF to bridge temporary imbalances of payments. Also, there was a need to address the lack of cooperation among other countries and to prevent competitive devaluation of the currencies as well. Preparing to rebuild the international economic system while World War II was still raging, 730 delegates from all 44 Allied nations gathered at the Mount Washington Hotel in Bretton Woods, New Hampshire, United States, for the United Nations Monetary and Financial Conference, also known as the Bretton Woods Conference. Setting up a system of rules, institutions, and procedures to regulate the international monetary system, these accords established the International Monetary Fund (IMF) and the International Bank for Reconstruction and Development (IBRD), which today is part of the World Bank Group. The United States, which controlled two thirds of the world's gold, insisted that the Bretton Woods system rest on both gold and the US dollar. Soviet representatives attended the conference but later declined to ratify the final agreements, charging that the institutions they had created were "branches of Wall Street." These organizations became operational in 1945 after a sufficient number of countries had ratified the agreement.

British thermal unit (BTU) - The quantity of heat required to raise the temperature of 1 pound of liquid water by 1 degree Fahrenheit at the temperature at which water has its greatest density (approximately 39 degrees Fahrenheit).

Btu conversion factor - A factor for converting energy data between one unit of measurement and British thermal units (Btu). Btu conversion factors are generally used to convert energy data from physical units of measure (such as barrels, cubic feet, or short tons) into the energy-equivalent measure of Btu.

Btu per cubic foot - The total heating value, expressed in Btu, produced by the combustion, at constant pressure, of the amount of the gas that would occupy a volume of 1 cubic foot at a temperature of 60 degrees F if saturated with water vapor and under a pressure equivalent to that of 30 inches of mercury at 32 degrees F and under standard gravitational force (980.665 cm. per sec. squared) with air of the same temperature and pressure as the gas, when the products of combustion are cooled to the initial temperature of gas and air when the water formed by combustion is condensed to the liquid state.(Sometimes called gross heating value or total heating value.)

BTX - The acronym for the commercial petroleum aromatics-- benzene, toluene, and xylene.

Bubble (economic or asset) - An economic bubble or asset bubble (sometimes also referred to as a speculative bubble, a market bubble, a price bubble, a financial bubble, a speculative mania, or a balloon) is trade in an asset at a price or price range that strongly exceeds the asset's intrinsic value.

Byproduct - A secondary or additional product resulting from the feedstock use of energy or the processing of non-energy materials. For example, the more common byproducts of coke ovens are coal gas, tar, and a mixture of benzene, toluene, and xylenes (BTX).

Calorific value (or content) - The heating value (or energy value or calorific value) of a substance, usually a fuel or food (see food energy), is the amount of heat released during the combustion of a specified amount of it. ... It is measured in units of energy per unit of the substance, usually mass, such as: kJ/kg, kJ/mol, kcal/kg, Btu/lb.

Canadian syncrude - Syncrude Canada Ltd. is one of the world's largest producers of synthetic crude oil from oil sands and the largest single source producer in Canada.

Canadian tar sands – Often referred to as the massive deposits of oil sands or tar sands in Alberta Canada. See oil sands

Capital investment - The term Capital Investment has two usages in business. First, capital investment refers to money used by a business to purchase fixed assets, such as land, machinery, or buildings. Secondly, capital investment refers to money invested in a business with the understanding that the money will be used to purchase fixed assets, rather than used to cover the business's day-to-day operating expenses.

Capital expenditure or capital expense (CAPEX) - is the money a company spends to buy, maintain, or improve its fixed assets, such as buildings, vehicles, equipment, or land.[1][2] It is considered a capital expenditure when the asset is newly purchased or when money is used towards extending the useful life of an existing asset, such as repairs to a building’s roof.

Carbon black - An amorphous form of carbon, produced commercially by thermal or oxidative decomposition of hydrocarbons and used principally in rubber goods, pigments, and printer's ink.

Carbon dioxide emissions - There are both natural and human sources of carbon dioxide emissions. Natural sources include decomposition, ocean release and respiration. Human sources come from activities like cement production, deforestation as well as the burning of fossil fuels like coal, oil and natural gas.

Catalytic cracking - The refining process of breaking down the larger, heavier, and more complex hydrocarbon molecules into simpler and lighter molecules. Catalytic cracking is accomplished by the use of a catalytic agent and is an effective process for increasing the yield of gasoline from crude oil. Catalytic cracking processes fresh feeds and recycled feeds.

Club of Rome (The) - is a global think tank that deals with a variety of international issues, including the world economic system, climate change, and environmental degradation. Founded in 1968 at Accademia dei Lincei in Rome, Italy, the Club of Rome describes itself as "a group of world citizens, sharing a common concern for the future of humanity." It consists of current and former heads of state, UN bureaucrats, high-level politicians and government officials, diplomats, scientists, economists and business leaders from around the globe.

Coal - A readily combustible black or brownish-black rock whose composition, including inherent moisture, consists of more than 50 percent by weight and more than 70 percent by volume of carbonaceous material. It is formed from plant remains that have been compacted, hardened, chemically altered, and metamorphosed by heat and pressure over geologic time.

Coalbed methane - Coalbed methane (CBM or coal-bed methane), coalbed gas, **coal seam gas (CSG)**, or coal-mine methane (CMM) is a form of natural gas extracted from coal beds. In recent decades it has become an important source of energy in United States, Canada, Australia, and other countries. The term refers to methane adsorbed into the solid matrix of the coal. It is called 'sweet gas' because of its lack of hydrogen sulfide. The presence of this gas is well known from its occurrence in underground coal mining, where it presents a serious safety risk. Coalbed methane is distinct from a typical sandstone or other conventional gas reservoir, as the methane is stored within the coal by a process called adsorption. The methane is in a near-liquid state, lining the inside of pores within the coal (called the matrix). The open fractures in the coal (called the cleats) can also contain free gas or can be saturated with water.

Coal chemicals - Coal chemicals are obtained from the gases and vapor recovered from the manufacturing of coke. Generally, crude tar, ammonia, crude light oil, and gas are the basic products recovered. They are refined or processed to yield a variety of chemical materials.

Coal consumption - The quantity of coal burned for the generation of electric power (in short tons), including fuel used for maintenance of standby service.

Coal conversion – see coal liquefaction.

Coal fired power plants - are a type of power plant that make use of the combustion of coal in order to generate electricity. Their use provides around 40% of the world's electricity and they are primarily used in developing countries.

Coal gas - Substitute natural gas produced synthetically by the chemical reduction of coal at a coal gasification facility.

Coal gasification - The process of converting coal into gas. The basic process involves crushing coal to a powder, which is then heated in the presence of steam and oxygen to produce a gas. The gas is then refined to reduce sulfur and other impurities. The gas can be used as a fuel or processed further and concentrated into chemical or liquid fuel.

Coal grade - This classification refers to coal quality and application use.

Coal (lignite) - Lignite, often referred to as brown coal, is a soft brown combustible sedimentary rock formed from naturally compressed peat. It is considered the lowest rank of coal due to its relatively low heat content. It has a carbon content around 60–70 percent. It is mined all around the world and is used almost exclusively as a fuel for steam-electric power generation

Coal liquefaction - is a process of converting coal into liquid hydrocarbons: liquid fuels and petrochemicals. The conversion industry is commonly referred to as "coal conversion" or "Coal To X". "Coal to Liquid Fuels" is commonly called "CTL" or "coal liquefaction", although "liquefaction" is generally used for a non-chemical process of becoming liquid.

Coal rank - The classification of coals according to their degree of progressive alteration from lignite to anthracite. In the United States, the standard ranks of coal include lignite, sub-bituminous coal, bituminous coal, and anthracite and are based on fixed carbon, volatile matter, heating value, and agglomerating (or caking) properties.

Coal Seam Gas (CSG) – see Coalbed methane (CBM), and Hydraulic fracturing or fracking

Coke (coal) - A solid carbonaceous residue derived from low-ash, low-sulfur bituminous coal from which the volatile constituents are driven off by baking in an oven at temperatures as high as 2,000 degrees Fahrenheit so that the fixed carbon and residual ash are fused together. Coke is used as a fuel and as a reducing agent in smelting iron ore in a blast furnace. Coke from coal is grey, hard, and porous and has a heating value of 24.8 million Btu per ton.

Coke (petroleum) - A residue high in carbon content and low in hydrogen that is the final product of thermal decomposition in the condensation process in cracking. This product is reported as marketable coke or catalyst coke. The conversion is 5 barrels (of 42 U.S. gallons each) per short ton.

Coking - Thermal refining processes used to produce fuel gas, gasoline blendstocks, distillates, and petroleum coke from the heavier products of atmospheric and vacuum distillation.

Combustion - Chemical oxidation accompanied by the generation of light and heat.

Commodity price index - A commodity price index is a fixed-weight index or (weighted) average of selected commodity prices, which may be based on spot or futures prices. It is designed to be representative of the broad commodity asset class or a specific subset of commodities, such as energy or metals. It is an index that tracks a basket of commodities to measure their performance. These indexes are often traded on exchanges, allowing investors to gain easier access to commodities without having to enter the futures market. The value of these indexes fluctuates based on their underlying commodities, and this value can be traded on an exchange in much the same way as stock index futures.

Compound annual growth rate (CAGR) - is a business and investing specific term for the geometric progression ratio that provides a constant rate of return over the time period. CAGR is not an accounting term, but it is often used to describe some element of the business, for example revenue, units delivered, registered users, etc. CAGR dampens the effect of volatility of periodic returns that can render arithmetic means irrelevant. It is particularly useful to compare growth rates from various data sets of common domain such as revenue growth of companies in the same industry. CAGR is equivalent to the more generic exponential growth rate when the exponential growth interval is one year.

Condensate - See Lease Condensate

Conventional oil – is a term used to describe oil that can be produced (extracted from the ground) using traditional drilling methods. It is liquid at atmospheric temperature and pressure conditions, and therefore flows without additional stimulation.

Conventional gas – refers to natural gas that can be produced from reservoirs using traditional drilling, pumping and compression techniques.

Consumer Price Index (CPI) -The CPI is a statistical estimate constructed using the prices of a sample of representative items whose prices are collected periodically. Sub-indices and sub-sub-indices are computed for different categories and sub-categories of goods and services, being combined to produce the overall index with weights reflecting their shares in the total of the consumer expenditures covered by the index. It is one of several price indices calculated by most national statistical agencies. The annual percentage change in a CPI is used as a measure of inflation.

Cost neutral – Where the price–performance ratio (cost–performance or cost–benefit) is at unity. That is, the costs invested equal the costs returned.

Cost of capital - The rate of return a utility must offer to obtain additional funds. The cost of capital varies with the leverage ratio, the effective income tax rate, conditions in the bond and stock markets, growth rate of the utility, its dividend strategy, stability of net income, the amount of new capital required, and other factors dealing with business and financial risks. It is a composite of the cost for debt interest, preferred stock dividends, and common stockholders' earnings that provide the facilities used in supplying utility service.

Cost of debt - The interest rate paid on new increments of debt capital multiplied by 1 minus the tax rate.

CPI - Consumer Price Index

Credit default swap (CDS) - is a financial swap agreement that the seller of the CDS will compensate the buyer (usually the creditor of the reference loan) in the event of a loan default (by the debtor) or other credit event. That is, the seller of the CDS insures the buyer against some reference loan defaulting. The buyer of the CDS makes a series of payments (the CDS "fee" or "spread") to the seller and, in exchange, receives a payoff if the loan defaults. It was invented by Blythe Masters from JP Morgan in 1994.

In the event of default the buyer of the CDS receives compensation (usually the face value of the loan), and the seller of the CDS takes possession of the defaulted loan. However, anyone can purchase a CDS, even buyers who do not hold the loan instrument and who have no direct insurable interest in the loan (these are called "naked" CDS’s”). If there are more CDS contracts outstanding than bonds in existence, a protocol exists to hold a credit event auction; the payment received is usually substantially less than the face value of the loan.

Crude oil - A mixture of hydrocarbons that exists in liquid phase in natural underground reservoirs and remains liquid at atmospheric pressure after passing through surface separating facilities. Depending upon the characteristics of the crude stream, it may also include 1. Small amounts of hydrocarbons that exist in gaseous phase in natural underground reservoirs but are liquid at atmospheric pressure after being recovered from oil well (casing head) gas in lease separators and are subsequently comingled with the crude stream without being separately measured. Lease condensate recovered as a liquid from natural gas wells in lease or field separation facilities and later mixed into the crude stream is also included; 2. Small amounts of nonhydrocarbons produced with the oil, such as sulfur and various metals; 3. Drip gases, and liquid hydrocarbons produced from tar sands, oil sands, gilsonite, and oil shale. Liquids produced at natural gas processing plants are excluded. Crude oil is refined to produce a wide array of petroleum products, including heating oils; gasoline, diesel and jet fuels; lubricants; asphalt; ethane, propane, and butane; and many other products used for their energy or chemical content.

Debt (financial) - Debt is an amount of money borrowed by one party from another. In this context, debt is the amount of money owed by a nation state or a corporation to a bank (being itself usually a private corporation).

Debt Default - In finance, default is failure to meet the legal obligations (or conditions) of a loan, for example when a home buyer fails to make a mortgage payment, or when a corporation or government fails to pay a bond which has reached maturity. A national or sovereign default is the failure or refusal of a government to repay its national debt. The biggest private default in history is Lehman Brothers with over $600,000,000,000 when it filed for bankruptcy in 2008 and the biggest sovereign default is Greece with $138,000,000,000 in March 2012.

Decommissioning - is a general term for a formal process to remove something from an active status. Shut down and asset stripping is part of decommissioning.

Deep offshore drilling - is typically defined as drilling in a water depth that is greater than 500 feet (150 meters). In general, rigs drilling in this environment are drillships and semisubmersibles. Wells being drilled in deep offshore environments are typically extended reach and use cutting edge industry technology.

Deepwater Horizon oil spill - (also referred to as the BP oil spill, the BP oil disaster, the **Gulf of Mexico oil spill**, and the Macondo blowout) began on April 20, 2010, in the Gulf of Mexico on the BP-operated Macondo Prospect. Killing eleven people, it is considered the largest marine oil spill in the history of the petroleum industry and estimated to be 8% to 31% larger in volume than the previous largest, the Ixtoc I oil spill. The US Government estimated the total discharge at 4.9 million barrels (210 million US gal; 780,000 m^3). After several failed efforts to contain the flow, the well was declared sealed on September 19, 2010. Reports in early 2012 indicated the well site was still leaking.

Deflation - In economics, deflation is a decrease in the general price level of goods and services. Deflation occurs when the inflation rate falls below 0% (a negative inflation rate). Inflation reduces the real value of money over time; conversely, deflation increases the real value of money – the currency of a national or regional economy. This allows one to buy more goods and services than before with the same amount of money. Economists generally believe that deflation is a problem in a modern economy because it may increase the real value of debt, especially if the deflation was unexpected. Deflation may also aggravate recessions and lead to a deflationary spiral. Deflation is distinct from disinflation, a slow-down in the inflation rate, i.e. when inflation declines to a lower rate but is still positive.

Demand destruction (Economic destruction) – Demand destruction is a permanent downward shift on the demand curve in the direction of lower demand of a commodity, such as energy products, induced by a prolonged period of high prices or constrained supply.

Derivatives - In finance, a derivative is a contract that derives its value from the performance of an underlying entity. This underlying entity can be an asset, index, or interest rate, and is often simply called the "underlying".[1][2] Derivatives can be used for a number of purposes, including insuring against price movements (hedging), increasing exposure to price movements for speculation or getting access to otherwise hard-to-trade assets or markets.[3] Some of the more common derivatives include forwards, futures, options, swaps, and variations of these such as synthetic collateralized debt obligations and credit default swaps. Most derivatives are traded over-the-counter (off-exchange) or on an exchange such as the Bombay Stock Exchange, while most insurance contracts have developed into a separate industry. Derivatives are one of the three main categories of financial instruments, the other two being stocks (i.e., equities or shares) and debt (i.e., bonds and mortgages).

Disinflation - is a decrease in the rate of inflation – a slowdown in the rate of increase of the general price level of goods and services in a nation's gross domestic product over time. It is the opposite of reflation. Disinflation occurs when the increase in the "consumer price level" slows down from the previous period when the prices were rising.

Dotcom Bubble - The dot-com bubble (also known as the dot-com boom, the tech bubble, the Internet bubble, the dot-com collapse, and the information technology bubble) was a historic economic bubble and period of excessive speculation that occurred roughly from 1997 to 2001, a period of extreme growth in the usage and adaptation of the Internet by businesses and consumers. During this period, many Internet-based companies, commonly referred to as dot-coms, were founded, many of which failed. During 2000–2002, the bubble collapsed.

Dry natural gas - Natural gas which remains after: 1) the liquefiable hydrocarbon portion has been removed from the gas stream (i.e., gas after lease, field, and/or plant separation); and 2) any volumes of nonhydrocarbon gases have been removed where they occur in sufficient quantity to render the gas unmarketable. Note: Dry natural gas is also known as consumer-grade natural gas. The parameters for measurement are cubic feet at 60 degrees Fahrenheit and 14.73 pounds per square inch absolute. Also see Natural gas.

Dry natural gas production - The process of producing consumer-grade natural gas. Natural gas withdrawn from reservoirs is reduced by volumes used at the production (lease) site and by processing losses. Volumes used at the production site include (1) the volume returned to reservoirs in cycling, repressuring of oil reservoirs, and conservation operations; and (2) gas vented and flared. Processing losses include (1) nonhydrocarbon gases (e.g., water vapor, carbon dioxide, helium, hydrogen sulfide, and nitrogen) removed from the gas stream; and (2) gas converted to liquid form, such as lease condensate and plant liquids. Volumes of dry gas withdrawn from gas storage reservoirs are not considered part of production. Dry natural gas production equals marketed production less extraction loss.

Economic bubble (or Asset bubble) - Sometimes also referred to as a speculative bubble, a market bubble, a price bubble, a financial bubble, a speculative mania, or a balloon. This is a trade in an asset at a price or price range that strongly exceeds the asset's intrinsic value. It could also be described as a situation in which asset prices appear to be based on implausible or inconsistent views about the future. Asset bubbles date back as far as the 1600s and are now widely regarded as a recurrent feature of modern economic history. Historically, the Dutch Golden Age's Tulipmania (in the mid-1630s) is often considered the first recorded economic bubble. Because it is often difficult to observe intrinsic values in real-life markets, bubbles are often conclusively identified only in retrospect, once a sudden drop in prices has occurred. Such a drop is known as a crash or a bubble burst. Both the boom and the burst phases of the bubble are examples of a positive feedback mechanism, in contrast to the negative feedback mechanism that determines the equilibrium price under normal market circumstances. Prices in an economic bubble can fluctuate erratically, and become impossible to predict from supply and demand alone.

Economic stagnation - is a prolonged period of slow economic growth (traditionally measured in terms of the GDP growth), usually accompanied by high unemployment.

EIA - The U.S. Energy Information Administration (EIA) is a principal agency of the U.S. Federal Statistical System responsible for collecting, analyzing, and disseminating energy information to promote sound policymaking, efficient markets, and public understanding of energy and its interaction with the economy and the environment. EIA programs cover data on coal, petroleum, natural gas, electric, renewable and nuclear energy. EIA is part of the U.S. Department of Energy.

Endosomatic energy - Ecological economists distinguish between 'endosomatic' and 'exosomatic' use of energy by humans. Energy from inside the body is considered 'endosomatic'. Inside the body, as food energy, adult humans spend per day between 1,500 and 2,500 kcal on average. A convenient number easy to remember is 2,400 kcal, equivalent to 10 MJ (megajoules).

Energy - In physics, energy is the property that must be transferred to an object in order to perform work on – or to heat – the object, and can be converted in form, but not created or destroyed. The standard SI unit of energy is the joule, which is the energy transferred to an object by the mechanical work of moving it a distance of 1 metre against a force of 1 newton. Common energy forms include the kinetic energy of a moving object, the potential energy stored by an object's position in a force field (gravitational, electric or magnetic), the elastic energy stored by stretching solid objects, the chemical energy released when a fuel burns, the radiant energy carried by light, and the thermal energy due to an object's temperature. Mass and energy are closely related. Due to mass–energy equivalence, any object that has mass when stationary in a frame of reference (called rest mass) also has an equivalent amount of energy whose form is called rest energy in that frame, and any additional energy acquired by the object above that rest energy will increase an object's mass. For example, with a sensitive enough scale, one could measure an increase in mass after heating an object. Living organisms require available energy to stay alive, such as the energy humans get from food. Civilisation gets the energy it needs from energy resources such as fossil fuels, nuclear fuel, or renewable energy. The processes of Earth's climate and ecosystem are driven by the radiant energy Earth receives from the sun and the geothermal energy contained within the Earth.

Energy consumed per capita - all energy needed as input to produce fuel and electricity for end-users, per person for a nation state or region. It is known as Total Primary Energy Supply (TPES), a term used to indicate the sum of production and imports subtracting exports and storage changes.

Energy density - is the amount of energy stored in a given system or region of space per unit volume. Colloquially it may also be used for energy per unit mass, though the accurate term for this is specific energy. Often only the useful or extractable energy is measured, which is to say that inaccessible energy (such as rest mass energy) is ignored. Energy per unit volume has the same physical units as pressure, and in many circumstances is a synonym: for example, the energy density of a magnetic field may be expressed as (and behaves as) a physical pressure, and the energy required to compress a compressed gas a little more may be determined by multiplying the difference between the gas pressure and the external pressure by the change in volume. In short, pressure is a measure of the enthalpy per unit volume of a system. A pressure gradient has the potential to perform work on the surroundings by converting enthalpy to work until equilibrium is reached.

Energy returned on energy invested (ERoEI) - is the ratio of the amount of usable energy (the exergy) delivered from a particular energy resource to the amount of exergy used to obtain that energy resource.

Environmental rehabilitation – see Land rehabilitation

EU-28 - The European Union (EU) is a political and economic union of 28 member states that are located primarily in Europe. It has an area of 4,475,757 km^2, and an estimated population of over 510 million. The European Union (EU) was established on 1 November 1993 with 12 Member States. Their number has grown to the present 28 through a series of enlargements.

European Central Bank (ECB) - The European Central Bank (ECB; German: Europäische Zentralbank (EZB), French: Banque centrale européenne (BCE)) is the central bank for the euro and administers monetary policy of the eurozone, which consists of 19 EU member states and is one of the largest currency areas in the world. It is one of the world's most important central banks and is one of the seven institutions of the European Union (EU) listed in the Treaty on European Union (TEU). The capital stock of the bank is owned by the central banks of all 28 EU member states. The primary objective of the ECB, mandated in Article 2 of the Statute of the ECB, is to maintain price stability within the Eurozone. Its basic tasks, set out in Article 3 of the Statute, are to set and implement the monetary policy for the Eurozone, to conduct foreign exchange operations, to take care of the foreign reserves of the European System of Central Banks and operation of the financial market infrastructure under the TARGET2 payments system. The ECB has, under Article 16 of its Statute, the exclusive right to authorise the issuance of euro banknotes. The ECB is governed by European law directly, but its set-up resembles that of a corporation in the sense that the ECB has shareholders and stock capital.

Euro (€) - The euro (sign: €; code: EUR) is the official currency of the eurozone, which consists of 19 of the 28 member states of the European Union: Austria, Belgium, Cyprus, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Portugal, Slovakia, Slovenia, and Spain. The currency is also officially used by the institutions of the European Union and four other European countries, as well as unilaterally by two others, and is consequently used daily by some 337 million Europeans as of 2015.

Excess reserves - In banking, excess reserves are bank reserves in excess of a reserve requirement set by a central bank. In the United States, bank reserves for a commercial bank are held in part as a credit balance in an account for the commercial bank at the applicable Federal Reserve Bank (FRB). This credit balance is not separated into separate "minimum reserves" and "excess reserves" accounts. The total amount of FRB credits held in all FRB accounts for all commercial banks, together with all currency and vault cash, form the M0 monetary base. Holding excess reserves has an opportunity cost if higher risk-adjusted interest can be earned by putting the funds elsewhere. For banks in the U.S. Federal Reserve System, this earning process is accomplished by a given bank by making short-term (usually overnight) loans on the federal funds market to another bank that may be short of its reserve requirements. Other banks may instead choose, however, to hold their excess reserves to facilitate upcoming transactions or to meet contractual clearing balance requirements.

Exergy - In thermodynamics, the exergy (in older usage, available work and/or availability) of a system is the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir. ... After the system and surroundings reach equilibrium, the exergy is zero.

Exosomatic energy - Ecological economists distinguish between 'endosomatic' and 'exosomatic' use of energy by humans. Energy from outside of the body is ‘exosomatic’.

FAO Food Price Index (The) - is a measure of the monthly change in international prices of a basket of food commodities. It consists of the average of five commodity group price indices, weighted with the average export shares of each of the groups for 2002-2004.

Federal Reserve Bank (The) - A Federal Reserve Bank is a regional bank of the Federal Reserve System, the central banking system of the United States. There are twelve in total, one for each of the twelve Federal Reserve Districts that were created by the Federal Reserve Act of 1913. The banks are jointly responsible for implementing the monetary policy set forth by the Federal Open Market Committee, and are divided as follows:

- Federal Reserve Bank of Boston
- Federal Reserve Bank of New York
- Federal Reserve Bank of Philadelphia
- Federal Reserve Bank of Cleveland
- Federal Reserve Bank of Richmond
- Federal Reserve Bank of Atlanta
- Federal Reserve Bank of Chicago
- Federal Reserve Bank of St. Louis
- Federal Reserve Bank of Minneapolis
- Federal Reserve Bank of Kansas City
- Federal Reserve Bank of Dallas
- Federal Reserve Bank of San Francisco

Some banks also possess branches, with the whole system being headquartered at the Eccles Building in Washington, D.C.

***Fiat* Currency** - Fiat money is currency that a government has declared to be legal tender, but it is not backed by a physical commodity. The value of fiat money is derived from the relationship between supply and demand rather than the value of the material that the money is made of.

***Fiat* Economy (The)** - The part of the economy that is concerned with buying and selling on the financial markets. This includes trading of fiat currencies, derivate and trading of paper asset certificates as opposed to physical assets (for example, physical gold bullion vs. a paper certificate of ownership of gold stored in a bank vault).

Financial or fiscal year - a year as reckoned for taxing or accounting purposes, for example the British tax year, reckoned from 6 April.

Financial contagion - refers to "the spread of market disturbances – mostly on the downside – from one country to the other, a process observed through co-movements in exchange rates, stock prices, sovereign spreads, and capital flows". Financial contagion can be a potential risk for countries who are trying to integrate their financial system with international financial markets and institutions. It helps explain an economic crisis extending across neighbouring countries, or even regions. Financial contagion happens at both the international level and the domestic level. At the domestic level, usually the failure of a domestic bank or financial intermediary triggers transmission when it defaults on interbank liabilities and sells assets in a fire sale, thereby undermining confidence in similar banks. An example of this phenomenon is the subsequent turmoil in the United States financial markets. International financial contagion, which happens in both advanced economies and developing economies, is the transmission of financial crisis across financial markets for direct or indirect economies. However, under today's financial system, with the large volume of cash flow, such as hedge fund and cross-regional operation of large banks, financial contagion usually happens simultaneously both among domestic institutions and across countries.

Fossil fuel power station - is a power station which burns fossil fuel such as coal, natural gas, or petroleum to produce electricity. Central station fossil fuel power plants are designed on a large scale for continuous operation. In many countries, such plants provide most of the electrical energy used. Fossil fuel power stations have machinery to convert the heat energy of combustion into mechanical energy, which then operates an electrical generator. The prime mover may be a steam turbine, a gas turbine or, in small plants, a reciprocating internal combustion engine. All plants use the energy extracted from expanding gas, either steam or combustion gases.

Fossil water - or paleowater is an ancient body of water that has been contained in some undisturbed space, typically groundwater in an aquifer, for millennia. Other types of fossil water can include subglacial lakes, such as Antarctica's Lake Vostok, and even ancient water on other planets. UNESCO defines fossil groundwater as water that infiltrated usually millennia ago and often under climatic conditions different from the present, and that has been stored underground since that time. Many communities across the planet depend on fossilized water reserves for their livelihood.

Fracking – See Hydraulic fracturing

Fuel oil - A liquid petroleum product less volatile than gasoline, used as an energy source. Fuel oil includes distillate fuel oil, and residual fuel oil.

Gas - A non-solid, non-liquid combustible energy source that includes natural gas, coke-oven gas, blast-furnace gas, and refinery gas.

Gas Condensate Well Gas - Natural gas remaining after the removal of the lease condensate.

Gas processing unit - A facility designed to recover natural gas liquids from a stream of natural gas that may or may not have passed through lease separators and/or field separation facilities. Another function of natural gas processing plants is to control the quality of the processed natural gas stream. Cycling plants are considered natural gas processing plants.

Gas flare - A gas flare, alternatively known as a flare stack, is a gas combustion device used in industrial plants such as petroleum refineries, chemical plants, and natural gas processing plants as well as at oil or gas production sites having oil wells, gas wells, offshore oil and gas rigs and landfills. In industrial plants, flare stacks are primarily used for burning off flammable gas released by pressure relief valves during unplanned over-pressuring of plant equipment. During plant or partial plant startups and shutdowns, flare stacks are also often used for the planned combustion of gases over relatively short periods. Gas flaring at many oil and gas production sites protects against the dangers of over-pressuring industrial plant equipment. When petroleum crude oil is extracted and produced from onshore or offshore oil wells, raw natural gas associated with the oil is brought to the surface as well. Especially in areas of the world lacking pipelines and other gas transportation infrastructure, vast amounts of such associated gas are commonly flared as waste or unusable gas.

Gas to liquids (GTL) - is a refinery process to convert natural gas or other gaseous hydrocarbons into longer-chain hydrocarbons, such as gasoline or diesel fuel. Methane-rich gases are converted into liquid synthetic fuels either via direct conversion—using non-catalytic processes that convert methane to methanol in one step—or via syngas as an intermediate, such as in the Fischer Tropsch, Mobil and syngas to gasoline plus processes.

Gas turbine plant - A plant in which the prime mover is a gas turbine. A gas turbine consists typically of an axial-flow air compressor and one or more combustion chambers where liquid or gaseous fuel is burned and the hot gases are passed to the turbine and where the hot gases expand drive the generator and are then used to run the compressor.

Gas well - A well completed for production of natural gas from one or more gas zones or reservoirs. Such wells contain no completions for the production of crude oil.

Gas well productivity - Derived annually by dividing gross natural gas withdrawals from gas wells by the number of producing gas wells on December 31 and then dividing the quotient by the number of days in the year.

Gasification - A method for converting coal, petroleum, biomass, wastes, or other carbon-containing materials into a gas that can be burned to generate power or processed into chemicals and fuels.

Gasohol - A blend of finished motor gasoline containing alcohol (generally ethanol but sometimes methanol) at a concentration between 5.7 percent and 10 percent by volume. Also see Oxygenates.

Gasoil - European and Asian designation for No. 2 heating oil and No. 2 diesel fuel.

Gasoline blending components - Naphthas which will be used for blending or compounding into finished aviation or motor gasoline (e.g., straight-run gasoline, alkylate, reformate, benzene, toluene, andxylene). Excludes oxygenates (alcohols, ethers), butane, and pentanes plus.

Gasoline grades - The classification of gasoline by octane ratings. Each type of gasoline (conventional, oxygenated, and reformulated) is classified by three grades - Regular, Midgrade, and Premium. Note: gasoline sales are reported by grade in accordance with their classification at the time of sale.

- **Regular gasoline** - Gasoline having an antiknock index, i.e., octane rating, greater than or equal to 85 and less than 88. Note Octane requirements may vary by altitude.
- **Midgrade gasoline** - Gasoline having an antiknock index, i.e., octane rating, greater than or equal to 88 and less than or equal to 90. Note: Octane requirements may vary by altitude.
- **Premium gasoline** - Gasoline having an antiknock index, i.e., octane rating, greater than 90. Note: Octane requirements may vary by altitude.

Gasoline motor, (leaded) - Contains more than 0.05 grams of lead per gallon or more than 0.005 grams of phosphorus per gallon. The actual lead content of any given gallon may vary. Premium and regular grades are included, depending on the octane rating. Includes leaded gasohol. Blendstock is excluded until blending has been completed. Alcohol that is to be used in the blending of gasohol is also excluded.

Gasoline treated as blendstock (GTAB) - Non-certified Foreign Refinery gasoline classified by an importer as blendstock to be either blended or reclassified with respect to reformulated or conventional gasoline. GTAB is classified as either reformulated or conventional quality based on emissions performance, formulation, and intended end use.

Geographical marker - A geographical marker is any statement that helps answer the question, "Where did this happen?" Often used as an analytical tool to correlate causality or help define the existence of a relationship between events associated with a geographic location.

Geothermal power generation - is power generated by geothermal energy. Technologies in use include dry steam power stations, flash steam power stations and binary cycle power stations. Geothermal electricity generation is currently used in 24 countries, while geothermal heating is in use in 70 countries. As of 2015, worldwide geothermal power capacity amounts to 12.8 gigawatts (GW), of which 28 percent or 3,548 megawatts are installed in the United States. International markets grew at an average annual rate of 5 percent over the last three years and global geothermal power capacity is expected to reach 14.5–17.6 GW by 2020. Based on current geologic knowledge and technology, the Geothermal Energy Association (GEA) estimates that only 6.5 percent of total global potential has been tapped so far, while the IPCC reported geothermal power potential to be in the range of 35 GW to 2 TW. Countries generating more than 15 percent of their electricity from geothermal sources include El Salvador, Kenya, the Philippines, Iceland and Costa Rica. Geothermal power is considered to be a sustainable, renewable source of energy because the heat extraction is small compared with the Earth's heat content.

GFC of 2008 - The 2008 Global Financial Crisis was the worst economic disaster since the Great Depression of 1929. The root cause has been traced to no one single event or reason. Financial turbulence started in the United States but quickly became global in scope. Rather, it was the result of a sequence of events, each with its own triggering mechanism that led to near collapse of the banking system. Often referred to as “The Great Recession”.

Global Financial Crisis (GFC) – A worldwide period of economic difficulty experienced by markets and consumers. A global financial crisis is a difficult business environment to succeed in since potential consumers tend to reduce their purchases of goods and services until the economic situation improves.

Global Reserve Currency - In the foreign exchange market and international finance, a world currency, supranational currency, or global currency refers to a currency that is transacted internationally, with no set borders. In the period following the Bretton Woods Conference of 1944, exchange rates around the world were pegged to the United States dollar, which could be exchanged for a fixed amount of gold. This reinforced the dominance of the US dollar as a global currency. Since the collapse of the fixed exchange rate regime and the gold standard and the institution of floating exchange rates following the Smithsonian Agreement in 1971, most currencies around the world have no longer been pegged to the United States dollar. However, as the United States has the world’s largest economy, most international transactions continue to be conducted with the United States dollar, and it has remained the *de facto* world currency. This state of affairs has been facilitated by Saudi Arabia pricing all its oil contracts in $USD, forming the petrodollar.

Gold standard (The) - is a monetary system in which the standard economic unit of account is based on a fixed quantity of gold. Three types can be distinguished: specie, bullion, and exchange.

- In the gold specie standard the monetary unit is associated with the value of circulating gold coins, or the monetary unit has the value of a certain circulating gold coin, but other coins may be made of less valuable metal.
- The gold bullion standard is a system in which gold coins do not circulate, but the authorities agree to sell gold bullion on demand at a fixed price in exchange for the circulating currency.
- The gold exchange standard usually does not involve the circulation of gold coins. The main feature of the gold exchange standard is that the government guarantees a fixed exchange rate to the currency of another country that uses a gold standard (specie or bullion), regardless of what type of notes or coins are used as a means of exchange. This creates a de facto gold standard, where the value of the means of exchange has a fixed external value in terms of gold that is independent of the inherent value of the means of exchange itself.

Most nations abandoned the gold standard as the basis of their monetary systems at some point in the 20th century, although many hold substantial gold reserves.

Great Depression (The) - The Great Depression was a severe worldwide economic depression that took place during the 1930s. The timing of the Great Depression varied across nations; in most countries it started in 1929 and lasted until 1941. It was the longest, deepest, and most widespread depression of the 20th century. In the 21st century, the Great Depression is commonly used as an example of how far the world's economy can decline. The depression originated in the United States, after a major fall in stock prices that began around September 4, 1929, and became worldwide news with the stock market crash of October 29, 1929 (known as Black Tuesday). Between 1929 and 1932, worldwide gross domestic product (GDP) fell by an estimated 15%. By comparison, worldwide GDP fell by less than 1% from 2008 to 2009 during the Great Recession (GFC).

Gross Domestic Product (GDP) - GDP is the total value of everything produced by all the people and companies in the nation state.

Heating value (natural gas) - The average number of British thermal units per cubic foot of natural gas as determined from tests of fuel samples.

Heavy gas oil - Petroleum distillates with an approximate boiling range from 651 degrees Fahrenheit to 1000 degrees Fahrenheit.

Heavy crude oil (or extra heavy crude oil) - is highly-viscous oil that cannot easily flow to production wells under normal reservoir conditions. It is referred to as "heavy" because its density or specific gravity is higher than that of light crude oil. Heavy crude oil has been defined as any liquid petroleum with an API gravity less than 20°. Physical properties that differ between heavy crude oils and lighter grades include higher viscosity and specific gravity, as well as heavier molecular composition. In 2010, the World Energy Council defined extra heavy oil as crude oil having a gravity of less than 10° and a reservoir viscosity of no more than 10,000 centipoises. When reservoir viscosity measurements are not available, extra-heavy oil is considered by the WEC to have a lower limit of 4° °API. In other words, oil with a density greater than 1000 kg/m^3 or, equivalently, and a specific gravity greater than 1 and a reservoir viscosity of no more than 10,000 centipoises. Heavy oils and asphalt are dense nonaqueous phase liquids (DNAPLs). They have a "low solubility and are with viscosity lower and density higher than water." "Large spills of DNAPL will quickly penetrate the full depth of the aquifer and accumulate on its bottom."

Heavy industry - is industry that involves one or more characteristics such as large and heavy products; large and heavy equipment and facilities (such as heavy equipment, large machine tools, and huge buildings); or complex or numerous processes.

House of Saud - The House of Saud (Arabic: آل سعود Āl Saʻūd IPA: [ʔæːl saʕuːd]) is the ruling royal family of Saudi Arabia. The family has thousands of members. It is composed of the descendants of Muhammad bin Saud, founder of the Emirate of Diriyah, known as the First Saudi state (1744 - 1818), and his brothers, though the ruling faction of the family is primarily led by the descendants of Ibn Saud, the modern founder of Saudi Arabia. The family is estimated to comprise 15,000 members, but the majority of the power and wealth is possessed by a group of only about 2,000 people.

Hubbert peak (The) - theory says that for any given geographical area, from an individual oil-producing region to the planet as a whole, the rate of petroleum production tends to follow a bell-shaped curve. It is one of the primary theories on peak oil. Choosing a particular curve determines a point of maximum production based on discovery rates, production rates and cumulative production. Early in the curve (pre-peak), the production rate increases due to the discovery rate and the addition of infrastructure. Late in the curve (post-peak), production declines because of resource depletion.

Hubbert curve - In 1956, Hubbert proposed that fossil fuel production in a given region over time would follow a roughly bell-shaped curve without giving a precise formula; he later used the Hubbert curve, the derivative of the logistic curve, for estimating future production using past observed discoveries. Hubbert assumed that after fossil fuel reserves (oil reserves, coal reserves, and natural gas reserves) are discovered, production at first increases approximately exponentially, as more extraction commences and more efficient facilities are installed. At some point, a peak output is reached, and production begins declining until it approximates an exponential decline. The Hubbert curve satisfies these constraints. Furthermore, it is roughly symmetrical, with the peak of production reached when about half of the fossil fuel that will ultimately be produced has been produced. It also has a single peak.

Hydrocarbon Gas Liquids - Natural gas and crude oil are mixtures of different hydrocarbons. Hydrocarbons are molecules of carbon and hydrogen in various combinations. Hydrocarbon gas liquids (HGL) are hydrocarbons that occur as gases at atmospheric pressure and as liquids under higher pressures. HGL can also be liquefied by cooling. The specific pressures and temperatures at which the gases liquefy vary by the type of HGL. HGL may be described as being light or heavy according to the number of carbon atoms and hydrogen atoms in an HGL molecule.

Hydraulic fracturing (also fracking, fraccing, frac'ing, hydrofracturing or hydrofracking) - is a well stimulation technique in which rock is fractured by a pressurized liquid. The process involves the high-pressure injection of 'fracking fluid' (primarily water, containing sand or other proppants suspended with the aid of thickening agents) into a wellbore to create cracks in the deep-rock formations through which natural gas, petroleum, and brine will flow more freely. When the hydraulic pressure is removed from the well, small grains of hydraulic fracturing proppants (either sand or aluminium oxide) hold the fractures open. Used in tight oil formations.

International Energy Agency (IEA) - (French: Agence internationale de l'énergie) is a Paris-based autonomous intergovernmental organization established in the framework of the Organisation for Economic Co-operation and Development (OECD) in 1974 in the wake of the 1973 oil crisis. The IEA was initially dedicated to responding to physical disruptions in the supply of oil, as well as serving as an information source on statistics about the international oil market and other energy sectors. The IEA acts as a policy adviser to its member states, but also works with non-member countries, especially China, India, and Russia. The Agency's mandate has broadened to focus on the "3Es" of effectual energy policy: energy security, economic development, and environmental protection.

Industrial grid (The) – an informal term that describes the interconnecting and interdependent network of industrial facilities. Ranging from power generation to manufacture to raw material processing, all connected by networks like the electrical power grid, 'Just in Time Supply' of goods, potable water and waste removal.

Industrial Production Index (IPI) – The industrial production index (abbreviated IPI and sometimes also called industrial output index or industrial volume index) is a business cycle indicator which measures monthly changes in the price-adjusted output of industry. This report uses the industrial production index as it is calculated in the European Union (EU-28). The Industrial Production Index (IPI) is also an economic indicator published by the Federal Reserve Board of the United States that measures the real production output of manufacturing, mining, and utilities. It is not clear if both the EU and the US use exactly the same method of calculation.

Industrial Revolution (The) - was the transition to new manufacturing processes in the period from about 1760 to sometime between 1820 and 1840. This transition included going from hand production methods to machines, new chemical manufacturing and iron production processes, improved efficiency of water power, the increasing use of steam power, the development of machine tools and the rise of the factory system. Textiles were the dominant industry of the Industrial Revolution in terms of employment, value of output and capital invested; the textile industry was also the first to use modern production methods.

Inflation - In economics, inflation is a sustained increase in the general price level of goods and services in an economy over a period of time. When the price level rises, each unit of currency buys fewer goods and services; consequently, inflation reflects a reduction in the purchasing power per unit of money – a loss of real value in the medium of exchange and unit of account within the economy. A chief measure of price inflation is the inflation rate, the annualized percentage change in a general price index, usually the consumer price index, over time. The opposite of inflation is deflation.

Insolvency - is the state of being unable to pay the money owed, by a person or company, on time; those in a state of insolvency are said to be insolvent. There are two forms: cash-flow insolvency and balance-sheet insolvency.

- Cash-flow insolvency is when a person or company has enough assets to pay what is owed, but does not have the appropriate form of payment. For example, a person may own a large house and a valuable car, but not have enough liquid assets to pay a debt when it falls due. Cash-flow insolvency can usually be resolved by negotiation. For example, the bill collector may wait until the car is sold and the debtor agrees to pay a penalty.
- Balance-sheet insolvency is when a person or company does not have enough assets to pay all of their debts. The person or company might enter bankruptcy, but not necessarily. Once a loss is accepted by all parties, negotiation is often able to resolve the situation without bankruptcy.

A company that is balance-sheet insolvent may still have enough cash to pay its next bill on time. However, most laws will not let the company pay that bill unless it will directly help all their creditors. For example, an insolvent farmer may be allowed to hire people to help harvest the crop, because not harvesting and selling the crop would be worse for his creditors.

Installed power – See Name plate capacity.

Internal combustion engine (ICE) - is a heat engine where the combustion of a fuel occurs with an oxidizer (usually air) in a combustion chamber that is an integral part of the working fluid flow circuit. In an internal combustion engine the expansion of the high-temperature and high-pressure gases produced by combustion applies direct force to some component of the engine. The force is applied typically to pistons, turbine blades, rotor or a nozzle. This force moves the component over a distance, transforming chemical energy into useful mechanical energy. Automobiles and trucks use internal combustion engines powered by mostly petroleum products or sometimes gas.

International Monetary Fund (IMF) - is an international organization headquartered in Washington, D.C., of "189 countries working to foster global monetary cooperation, secure financial stability, facilitate international trade, promote high employment and sustainable economic growth, and reduce poverty around the world." Formed in 1944 at the Bretton Woods Conference primarily by the ideas of Harry Dexter White and John Maynard Keynes, it came into formal existence in 1945 with 29 member countries and the goal of reconstructing the international payment system. It now plays a central role in the management of balance of payments difficulties and international financial crises. Countries contribute funds to a pool through a quota system from which countries experiencing balance of payments problems can borrow money. As of 2016, the fund had SDR477 billion (about $668 billion).

IOC – International oil companies. The 20 largest oil & gas companies ranked in order of size: Saudi Aramco, Sinopec, China National Petroleum Corporation, PetroChina, Exxon Mobil, Royal Dutch Shell, Kuwait Petroleum Corporation, BP, Total SA, Lukoil, Eni, Valero Energy, Petrobras, Chevron Corporation, PDVSA, Pemex, National Iranian Oil, Gazprom, Petronas, China National Offshore Oil.

Just-in-time supply – The supply chain and supply networks of retail demand is delivered with as little lag time as possible. Thus orders for goods can be submitted just as those goods arrive to the point of sale from the supply network. This makes for an efficient business practice when the supply network is operating without bottlenecks and quoted delivery times match reality. This system has poor resilience when something unforeseen happens like a natural disaster or the market experiences a Black Swan event.

Just-in-time (JIT) manufacturing - also known as just-in-time production or the Toyota Production System (TPS), is a methodology aimed primarily at reducing flow times within production system as well as response times from suppliers and to customers.

Kerogen (oil) - is a mixture of organic chemical compounds that make up a portion of the organic matter in sedimentary rocks. It is insoluble in normal organic solvents because of the high molecular weight (upwards of 1,000 daltons or 1000 Da; 1Da= 1 atomic mass unit) of its component compounds. The soluble portion is known as bitumen. When heated to the right temperatures in the Earth's crust, (oil window c. 50–150 °C, gas window c. 150–200 °C, both depending on how quickly the source rock is heated) some types of kerogen release crude oil or natural gas, collectively known as hydrocarbons (fossil fuels). When such kerogens are present in high concentration in rocks such as shale, they form possible source rocks. Shales rich in kerogens that have not been heated to a warmer temperature to release their hydrocarbons may form oil shale deposits.

Land rehabilitation (or Environmental rehabilitation) - is the process of returning the land in a given area to some degree of its former state, after some process (industry, natural disasters, etc.) has resulted in its damage. Many projects and developments will result in the land becoming degraded, for example mining, farming and forestry.

Landfill gas - Gas that is generated by decomposition of organic material at landfill disposal sites. The average composition of landfill gas is approximately 50 percent methane and 50 percent carbon dioxide and water vapor by volume. The methane percentage, however, can vary from 40 to 60 percent, depending on several factors including waste composition (e.g. carbohydrate and cellulose content). The methane in landfill gas may be vented, flared, combusted to generate electricity or useful thermal energy on-site, or injected into a pipeline for combustion off-site.

Lb - Unit of mass the Pound

Lease Condensate - Light liquid hydrocarbons recovered from lease separators or field facilities at associated and non-associated natural gas wells. Mostly pentanes and heavier hydrocarbons. Normally enters the crude oil stream after production.

Liquid fuels - All petroleum including crude oil and products of petroleum refining, natural gas liquids, biofuels, and liquids derived from other hydrocarbon sources (including coal to liquids and gas to liquids). Not included are liquefied natural gas (LNG) and liquid hydrogen.

Liquefied natural gas (LNG) - Natural gas (primarily methane) that has been liquefied by reducing its temperature to -260 degrees Fahrenheit at atmospheric pressure.

Liquefied petroleum gases (LPG) - A group of hydrocarbon gases, primarily propane, normal butane, and isobutane, derived from crude oil refining or natural gas processing. These gases may be marketed individually or mixed. They can be liquefied through pressurization (without requiring cryogenic refrigeration) for convenience of transportation or storage. Excludes ethane and olefins. Note: In some EIA publications, LPG includes ethane and marketed refinery olefin streams, in accordance with definitions used prior to January 2014.

Low Btu gas - A fuel gas with a heating value between 90 and 200 Btu per cubic foot.

LTO - light tight oil, abbreviated LTO, known also as tight oil or shale oil.

Manufactured gas - A gas obtained by destructive distillation of coal or by the thermal decomposition of oil, or by the reaction of steam passing through a bed of heated coal or coke. Examples are coal gases, coke oven gases, producer gas, blast furnace gas, blue (water) gas, carburetted water gas. Btu content varies widely.

Mine rehabilitation - Modern mine rehabilitation aims to minimize and mitigate the environmental effects of modern mining, which may in the case of open pit mining involve movement of significant volumes of rock. Rehabilitation management is an ongoing process, often resulting in open pit mines being backfilled. After mining finishes, the mine area must undergo rehabilitation. Most natural energy resources can be examined in this fashion at the end of their extraction life.

Monterey shale oil reserves - The Monterey Formation is an extensive Miocene oil-rich geological sedimentary formation in California, with outcrops of the formation in parts of the California Coast Ranges, Peninsular Ranges, and on some of California's off-shore islands. The formation is the major source-rock for 37 to 38 billion barrels of oil in conventional traps such as sandstones. This is most of California's known oil resources. The Monterey has been extensively investigated and mapped for petroleum potential, and is of major importance for understanding the complex geological history of California. Its rocks are mostly highly siliceous strata that vary greatly in composition, stratigraphy, and tectono-stratigraphic history. The US Energy Information Administration (EIA) estimated in 2014 that the 1,750 square mile Monterey Formation could yield about 600 million barrels of oil, from tight oil contained in the formation, down sharply from their 2011 estimate of a potential 15.4 billion barrels. An independent review by the California Council on Science and Technology found both of these estimates to be "highly uncertain." Despite intense industry efforts, there has been little success to date (2013) in producing Monterey-hosted tight oil/shale oil, except in places where it is already naturally fractured, and it may be many years, if ever, before the Monterey becomes a significant producer of shale oil.

Motor gasoline (finished) - A complex mixture of relatively volatile hydrocarbons with or without small quantities of additives, blended to form a fuel suitable for use in spark-ignition engines. Motor gasoline, as defined in ASTM Specification D 4814 or Federal Specification VV-G-1690C, is characterized as having a boiling range of 122 to 158 degrees Fahrenheit at the 10 percent recovery point to 365 to 374 degrees Fahrenheit at the 90 percent recovery point. Motor gasoline includes conventional gasoline; all types of oxygenated gasoline, including gasohol; and reformulated gasoline, but excludes aviation gasoline. Note: Volumetric data on blending components, such as oxygenates, are not counted in data on finished motor gasoline until the blending components are blended into the gasoline.

Mtoe - The tonne of oil equivalent (toe) is a unit of energy defined as the amount of energy released by burning one tonne of crude oil. It is approximately 42 gigajoules or 11,630 kilowatt hours, although as different crude oils have different calorific values, the exact value is defined by convention; several slightly different definitions exist. The toe is sometimes used for large amounts of energy. Multiples of the toe are used, in particular the megatoe (Mtoe, one million toe) and the gigatoe (Gtoe, one billion toe). A smaller unit of kilogram of oil equivalent (kgoe) is also sometimes used denoting 1/1000 toe.

Multifactor Productivity Index (MFP) - Reflects the overall efficiency with which labour and capital inputs are used together in the production process. Changes in MFP reflect the effects of changes in management practices, brand names, organizational change, general knowledge, network effects, spillovers from production factors, adjustment costs, economies of scale, the effects of imperfect competition and measurement errors. Growth in MFP is measured as a residual, i.e. that part of GDP growth that cannot be explained by changes in labour and capital inputs. In simple terms therefore, if labour and capital inputs remained unchanged between two periods, any changes in output would reflect changes in MFP. This indicator is measured as an index and in annual growth rates.

Nameplate capacity - also known as the rated capacity, nominal capacity, installed capacity, or maximum effect, is the intended full-load sustained output of a facility such as a power plant, a chemical plant, fuel plant, metal refinery, mine, and many others. Nameplate capacity is the number registered with authorities for classifying the power output of a power station usually expressed in megawatts (MW). Power plants with an output consistently near their nameplate capacity have a high capacity factor.

Native gas - Gas in place at the time that a reservoir was converted to use as an underground storage reservoir in contrast to injected gas volumes.

Natural gas - A gaseous mixture of hydrocarbon compounds, the primary one being methane.

Natural gas field facility - A field facility designed to process natural gas produced from more than one lease for the purpose of recovering condensate from a stream of natural gas; however, some field facilities are designed to recover propane, normal butane, pentanes plus, etc., and to control the quality of natural gas to be marketed.

Natural gas gross withdrawals - Full well-stream volume of produced natural gas, excluding condensate separated at the lease.

Natural gas hydrates - Solid, crystalline, wax-like substances composed of water, methane, methane clathrate, and usually a small amount of other gases, with the gases being trapped in the interstices of a water-ice lattice. They form beneath permafrost and on the ocean floor under conditions of moderately high pressure and at temperatures near the freezing point of water.

Natural gas lease production - Gross withdrawals of natural gas minus gas production injected on the lease into producing reservoirs, vented, flared, used as fuel on the lease, and nonhydrocarbon gases removed in treating or processing operations on the lease.

Natural Gas Liquids (NGL) - A group of hydrocarbons including ethane, propane, normal butane, isobutane, and natural gasoline. Generally include natural gas plant liquids and all liquefied refinery gases except olefins.

Natural gas liquids production - The volume of natural gas liquids removed from natural gas in lease separators, field facilities, gas processing plants, or cycling plants during the report year.

Natural gas plant liquids (NGPL) - Butane, ethane, pentanes, propane and other non-methane components of raw natural gas. Those hydrocarbons in natural gas that are separated as liquids at natural gas processing, fractionating, and cycling plants. Products obtained include ethane, liquefied petroleum gases (propane, normal butane, and isobutane), and natural gasoline. Component products may be fractionated or mixed. Lease condensate and plant condensate are excluded. Note: Some EIA publications categorize NGPL production as field production, in accordance with definitions used prior to January 2014.

Natural resources - are resources that exist without actions of humankind. They are part of and are found in the natural environment. For example a coal or copper deposit found in the earth's crust.

Net Energy Cliff (The) – On a chart plot of "Energy available for consumption" (y axis) vs "ERoEI" (x axis). The net available energy to society follows a negative exponential curve. As society approaches the bend in the curve, available energy gradient becomes quite steep very quickly. Much like falling off a cliff.

Net energy yield - The net energy yield of the resource, which is the difference between the energy inputs required to produce the resource and the energy contained in the final product. The net energy, or “energy returned on energy invested” (ERoEI), of unconventional resources is generally much lower than for conventional resources. Lower EROEI translates to higher production costs, lower production rates, and usually more collateral environmental damage in extraction.

Net Hubbert Curve (The) – The traditional Hubbert curve is corrected for ERoEI of each of the oil resources, where the easy to extract and process resources are used first. The outcome is a skewed distribution for net available energy to do useful physical work. Calculated with the formula: Net Energy = Gross Energy * ((ERoEI – 1)/ ERoEI)

Non-renewable resource (also called a finite resource) - is a resource that does not renew itself at a sufficient rate for sustainable economic extraction in meaningful human time-frames. An example is carbon-based, organically-derived fuel. The original organic material, with the aid of heat and pressure, becomes a fuel such as oil or gas. Earth minerals and metal ores, fossil fuels (coal, petroleum, natural gas) and groundwater in certain aquifers are all considered non-renewable resources, though individual elements are almost always conserved.

Oil refinery (or petroleum refinery) - is an industrial process plant where crude oil is processed and refined into more useful products such as petroleum naphtha, gasoline, diesel fuel, asphalt base, heating oil, kerosene, and liquefied petroleum gas.

Oil reservoir - An underground pool of liquid consisting of hydrocarbons, sulfur, oxygen, and nitrogen trapped within a geological formation and protected from evaporation by the overlying mineral strata.

Oil sands - based synthetic crudes and derivative products, also known as tar sands, or more technically bituminous sands, are a type of unconventional petroleum deposit. Oil sands are either loose sands or partially consolidated sandstone containing a naturally occurring mixture of sand, clay, and water, saturated with a dense and extremely viscous form of petroleum technically referred to as bitumen (or colloquially as tar due to its superficially similar appearance).

Oil stocks - oil stocks include crude oil (including strategic reserves), unfinished oils, natural gas plant liquids, and refined petroleum products.

Oil bearing shale - is an organic-rich fine-grained sedimentary rock containing kerogen (a solid mixture of organic chemical compounds) from which liquid hydrocarbons called shale oil (not to be confused with tight oil—crude oil occurring naturally in shales) can be produced. Shale oil is a substitute for conventional crude oil; however, extracting shale oil from oil shale is more costly than the production of conventional crude oil both financially and in terms of its environmental impact.

Oil well - A well completed for the production of crude oil from at least one oil zone or reservoir.

Onshore or land base drilling - is defined as drilling with rigs that are moved in by ground transportation and the drilling site is not over water. Many of these wells are now being drilled using a technique called pad drilling where multiple wells are drilled from the same site in very close proximity of each other by shifting the rig slightly. Typically, these are mature fields, pushing the drilling envelope farther to more challenging well formations like new shale fields or very deep wells.

OPEC - Organization of the Petroleum Exporting Countries is an intergovernmental organization of 14 nations as of May 2017, founded in 1960 in Baghdad by the first five members (Iran, Iraq, Kuwait, Saudi

Arabia, Venezuela), and headquartered since 1965 in Vienna. As of 2016, the 14 countries accounted for an estimated 44 percent of global oil production and 73 percent of the world's "proven" oil reserves, giving OPEC a major influence on global oil prices that were previously determined by American-dominated multinational oil companies. OPEC's stated mission is "to coordinate and unify the petroleum policies of its member countries and ensure the stabilization of oil markets, in order to secure an efficient, economic and regular supply of petroleum to consumers, a steady income to producers, and a fair return on capital for those investing in the petroleum industry."

OPEX - An operating expense, operating expenditure, operational expense, operational expenditure or OPEX is an ongoing cost for running a product, business, or system.

Peak Gas - According to M. King Hubbert's Hubbert peak theory, Peak gas is the point in time at which the maximum global natural gas (fossil gas) production rate will be reached, after which the rate of production will enter its terminal decline. Natural gas is a fossil fuel formed from plant matter over the course of millions of years. It is a finite resource and thus considered to be a non-renewable energy source.

Peak Oil - an event based on M. King Hubbert's theory, is the point in time when the maximum rate of extraction of petroleum is reached, after which it is expected to enter terminal decline. Peak oil theory is based on the observed rise, peak, fall, and depletion of aggregate production rate in oil fields over time. It is often confused with oil depletion; however, peak oil is the point of maximum production, while depletion refers to a period of falling reserves and supply.

Peak Coal – The term Peak coal is used to refer to the point in time at which coal production and consumption reaches its maximum, after which, it is assumed, production and consumption will decline steadily. The term was originally used in connection with M. King Hubbert's Hubbert peak theory, in which the finite nature of the resource determines a constraint on production.

Peak Uranium - is the point in time that the maximum global uranium production rate is reached. After that peak, according to Hubbert peak theory, the rate of production enters a terminal decline. While uranium is used in nuclear weapons, its primary use is for energy generation via nuclear fission of the uranium-235 isotope in a nuclear power reactor. Each kilogram of uranium-235 fissioned releases the energy equivalent of millions of times its mass in chemical reactants, as much energy as 2700 tons of coal, but uranium-235 is only 0.7% of the mass of natural uranium. Uranium-235 is a finite non-renewable resource.

Per capita - The phrase in Latin means "by heads" or "for each head", i.e., per individual/person. The term is used in a wide variety of social sciences and statistical research contexts, including government statistics, economic indicators, and built environment studies. It is commonly and usually used in the field of statistics in place of saying "per person"

Pennsylvania oil rush (The) - was a boom in petroleum production which occurred in north western Pennsylvania from 1859 to the early 1870s. It was the first oil boom in the United States. The oil rush began in Titusville, Pennsylvania, in the Oil Creek Valley when Colonel Edwin L. Drake struck "rock oil" there. Titusville and other towns on the shores of Oil Creek expanded rapidly as oil wells and refineries shot up across the region. Oil quickly became one of the most valuable commodities in the United States and railroads expanded into Western Pennsylvania to ship petroleum to the rest of the country. By the mid-1870s, the oil industry was well established, and the "rush" to drill wells and control production was over. Pennsylvania oil production peaked in 1891, and was later surpassed by western states such as Texas and California, but some oil industry remains in Pennsylvania.

Petrodollar (The) – Petrodollar recycling is the international spending or investment of a country's revenues from petroleum exports ("petrodollars"). It generally refers to the phenomenon of major petroleum-exporting nations, mainly the OPEC members plus Russia and Norway, earning more money from the export of crude oil than they could efficiently invest in their own economies. The resulting global interdependencies and financial flows, from oil producers back to oil consumers, can reach a scale of hundreds of billions of US dollars per year – including a wide range of transactions in a variety of currencies, some pegged to the US dollar and some not. These flows are heavily influenced by government-level decisions regarding international investment and aid, with important consequences for both global finance and petroleum politics. The phenomenon is most pronounced during periods when the price of oil is historically high. The first major petrodollar surge (1974–1981) resulted in more financial complications than the second (2005–2014). These OPEC countries were advised on how to invest their surpluses by Western investment bankers and subsequently signed contracts with the U.S. on military bases, large arms deals, military training and cooperation on governmental and economic levels. Their governments' dependency on U.S. specialists remains unchanged to the present day. An agreement was made between the House of Saud in Saudi Arabia to price all oil they control in $US dollars, making the $USD the petrodollar and over time, the world reserve currency. In exchange for this, the United States government agreed to protect the House of Saud with its military against all aggressors domestic and foreign.

Petroleum and other liquids - All petroleum including crude oil and products of petroleum refining, natural gas liquids, biofuels, and liquids derived from other hydrocarbon sources (including coal to liquids and gas to liquids). Not included are liquefied natural gas (LNG) and liquid hydrogen.

Petroleum products - Petroleum products are obtained from the processing of crude oil (including lease condensate), natural gas, and other hydrocarbon compounds. Petroleum products include unfinished oils, liquefied petroleum gases, pentanes plus, aviation gasoline, motor gasoline, naphtha-type jet fuel, kerosene-type jet fuel, kerosene, distillate fuel oil, residual fuel oil, petrochemical feedstocks, special naphtha's, lubricants, waxes, petroleum coke, asphalt, road oil, still gas, and miscellaneous products.

Population growth - In biology or human geography, population growth is the increase in the number of individuals in a population. Global human population growth amounts to around 75 million annually, or 1.1% per year. The global population has grown from 1 billion in 1800 to 7 billion in 2012. It is expected to keep growing, and estimates have put the total population at 8.4 billion by mid-2030, and 9.6 billion by mid-2050. Many nations with rapid population growth have low standards of living, whereas many nations with low rates of population growth have high standards of living. Current World Population is 7,519,873,847 people. On 1 January 2017, the population of the European Union (EU-28) was estimated at 511.8 million.

Power - In physics, power is the rate of doing work. It is the amount of energy consumed per unit time. Having no direction, it is a scalar quantity. In the SI system, the unit of power is the joule per second (J/s), known as the watt in honour of James Watt, the eighteenth-century developer of the steam engine. Another common and traditional measure is horsepower (comparing to the power of a horse). The rate of producing, transferring, or using energy, most commonly associated with electricity. Power is measured in watts and often expressed in kilowatts (kW) or megawatts (MW).

Power Station - A power station, also referred to as a power plant or powerhouse and sometimes generating station or generating plant, is an industrial facility for the generation of electric power. Most power stations contain one or more generators, a rotating machine that converts mechanical power into electrical power. The relative motion between a magnetic field and a conductor creates an electrical current. The energy source harnessed to turn the generator varies widely. Most power stations in the world burn fossil fuels such as coal, oil, and natural gas to generate electricity. Others use nuclear power, but there is an increasing use of cleaner renewable sources such as solar, wind, wave and hydroelectric.

Power station output – Power delivered to the electrical power grid by that power station.

Power (electrical) - An electric measurement unit of power called a voltampere is equal to the product of 1 volt and 1 ampere. This is equivalent to 1 watt for a direct current system, and a unit of apparent power is separated into real and reactive power. Real power is the work-producing part of apparent power that measures the rate of supply of energy and is denoted as kilowatts (kW). Reactive power is the portion of apparent power that does no work and is referred to as kilovars; this type of power must be supplied to most types of magnetic equipment, such as motors, and is supplied by generator or by electrostatic equipment. Voltamperes are usually divided by 1,000 and called kilovoltamperes (kVA). Energy is denoted by the product of real power and the length of time utilized; this product is expressed as kilowatthours.

Price-performance - In economics and engineering, the price–performance ratio refers to a product's ability to deliver performance, of any sort, for its price. Generally speaking, products with a lower price/performance ratio are more desirable, excluding other factors. Price–performance is often written as cost–performance or cost–benefit. Even though this term would seem to be a straightforward ratio, when price performance is improved, better, or increased, it actually refers to the performance divided by the price, in other words exactly the opposite ratio to rank a product as having an increased price/performance.

Primary energy consumption - Consumption of primary energy. (Energy sources that are produced from other energy sources, e.g., coal coke from coal, are included in primary energy consumption only if their energy content has not already been included as part of the original energy source. This includes the following in energy consumption: coal consumption; coal coke net imports; petroleum consumption (petroleum products supplied, including natural gas plant liquids and crude oil burned as fuel); dry natural gas excluding supplemental gaseous fuels consumption; nuclear electricity net generation (converted to Btu using the nuclear plants heat rates); conventional hydroelectricity net generation (converted to Btu using the fossil-fuels plant heat rates); geothermal electricity net generation (converted to Btu using the fossil-fuels plant heat rates), and geothermal heat pump energy and geothermal direct use energy; solar thermal and photovoltaic electricity net generation (converted to Btu using the fossil-fuels plant heat rates), and solar thermal direct use energy; wind electricity net generation (converted to Btu using the fossil-fuels plant heat rates); wood and wood-derived fuels consumption; biomass waste consumption; fuel ethanol and biodiesel consumption; losses and co-products from the production of fuel ethanol and biodiesel; and electricity net imports (converted to Btu using the electricity heat content of 3,412 Btu per kilowatthour).

Primary energy consumption expenditures - Expenditures for energy consumed in each of the four major end-use sectors, excluding energy in the form of electricity, plus expenditures by the electric utilities sector for energy used to generate electricity. There are no fuel-associated expenditures for associated expenditures for hydroelectric power, geothermal energy, photovoltaic and solar energy, or wind energy. Also excluded are the quantifiable consumption expenditures that are an integral part of process fuel consumption.

Primary energy production - Production of primary energy. This includes the following in energy production: coal production, waste coal supplied, and coal refuse recovery; crude oil and lease condensate production; natural gas plant liquids production; dry natural gas excluding supplemental gaseous fuels production; nuclear electricity net generation (converted to Btu using the nuclear plant heat rates); conventional hydroelectricity net generation (converted to Btu using the fossil-fuels plant heat rates); geothermal electricity net generation (converted to Btu using the fossil-fuels plant heat rates), and geothermal heat pump energy and geothermal direct use energy; solar thermal and photovoltaic electricity net generation (converted to Btu using the fossil-fuels plant heat rates), and solar thermal direct use energy; wind electricity net generation (converted to Btu using the fossil-fuels plant heat rates); wood and wood-derived fuels consumption; biomass waste consumption; and biofuels feedstock.

Primary fuels - Fuels that can be used continuously. They can sustain the boiler sufficiently for the production of electricity.

Primary raw materials - Are the product of the primary production sectors, which encompass the extraction of natural resources from the environment and their transformation through processing or refining. The obtained raw materials are primary commodities, the base materials for further manufacturing and consumption processes.

Printing of Money or Money Creation - Money creation (also known as credit creation) is the process by which the money supply of a country or a monetary region (such as the Eurozone) is increased. A central bank may introduce new money into the economy (termed "expansionary monetary policy", or by detractors "printing money") by purchasing financial assets or lending money to financial institutions. However, in most countries today, most of the money supply is in the form of bank deposits, which is created by private banks in a fractional reserve banking system. Bank lending increases the amount of broad money beyond the amount of base money originally created by the central bank. Reserve requirements, capital adequacy ratios, and other policies of the central bank influence this process.

Probable (indicated) reserves, coal - Reserves or resources for which tonnage and grade are computed partly from specific measurements, samples, or production data and partly from projection for a reasonable distance on the basis of geological evidence. The sites available are too widely or otherwise in appropriately spaced to permit the mineral bodies to be outlined completely or the grade established throughout.

Probable energy reserves - Estimated quantities of energy sources that, on the basis of geologic evidence that supports projections from proved reserves, can reasonably be expected to exist and be recoverable under existing economic and operating conditions. Site information is insufficient to establish with confidence the location, quality, and grades of the energy source. Note: This term is equivalent to "Indicated Reserves" as defined in the resource/reserve classification contained in the U.S. Geological Survey Circular 831, 1980. Measured and indicated reserves, when combined, constitute demonstrated reserves.

Process fuel - All energy consumed in the acquisition, processing, and transportation of energy. Quantifiable process fuel includes three categories natural gas lease and plant operations, natural gas pipeline operations, and oil refinery operations.

Processed gas - Natural gas that has gone through a processing plant.

Project commissioning - is the process of assuring that all systems and components of a building or industrial plant are designed, installed, tested, operated, and maintained according to the operational requirements of the owner or final client. A commissioning process may be applied not only to new projects but also to existing units and systems subject to expansion, renovation or revamping. In practice, the commissioning process comprises the integrated application of a set of engineering techniques and procedures to check, inspect and test every operational component of the project, from individual functions, such as instruments and equipment, up to complex amalgamations such as modules, subsystems and systems.

Production, oil and gas - The lifting of oil and gas to the surface and gathering, treating, field processing (as in the case of processing gas to extract liquid hydrocarbons), and field storage. The production function shall normally be regarded as terminating at the outlet valve on the lease or field production storage tank. If unusual physical or operational circumstances exist, it may be more appropriate to regard the production function as terminating at the first point at which oil, gas, or gas liquids are delivered to a main pipeline, a common carrier, a refinery, or a marine terminal.

Proved (measured) reserves, coal - Reserves or resources for which tonnage is computed from dimensions revealed in outcrops, trenches, workings, and drill holes and for which the grade is computed from the results of detailed sampling. The sites for inspection, sampling, and measurement are spaced so closely and the geologic character is so well defined that size, shape, and mineral content are well established. The computed tonnage and grade are judged to be accurate within limits that are stated, and no such limit is judged to be different from the computed tonnage or grade by more than 20 percent.

Proved energy reserves - Estimated quantities of energy sources that analysis of geologic and engineering data demonstrates with reasonable certainty are recoverable under existing economic and operating conditions. The location, quantity, and grade of the energy source are usually considered to be well established in such reserves. Note: This term is equivalent to "Measured Reserves" as defined in the resource/reserve classification contained in the U.S. Geological Survey Circular 831, 1980. Measured and indicated reserves, when combined, constitute demonstrated reserves.

Proxy (technical) - A figure that can be used to represent the value of something in a calculation.

Purchasing power - (sometimes retroactively called adjusted for inflation) is the number and quality or value of goods and services that can be purchased with a unit of currency. For example, if one had taken one unit of currency to a store in the 1950s, it is probable that it would have been possible to buy a greater number of items than would today, indicating that one would have had a greater purchasing power in the 1950s. Currency can be either a commodity money, like gold or silver, or fiat money emitted by government sanctioned agencies.

PV - Photovoltaic

PVCs that convert sunlight directly into energy - A method for producing energy by converting sunlight using photovoltaic cells (PVCs) that are solid-state single converter devices. Although currently not in wide usage, commercial customers have a growing interest in usage and, therefore, DOE has a growing interest in the impact of PVCs on energy consumption. Economically, PVCs are competitive with other sources of electricity.

Pyrolysis - The thermal decomposition of biomass at high temperatures (greater than 400° F, or 200° C) in the absence of air. The end product of pyrolysis is a mixture of solids (char), liquids (oxygenated oils), and gases (methane, carbon monoxide, and carbon dioxide) with proportions determined by operating temperature, pressure, oxygen content, and other conditions.

Quantitative easing (QE) - is a monetary policy in which a central bank creates new electronic money in order to buy government bonds or other financial assets to stimulate the economy (i.e., to increase private-sector spending and return inflation to its target). An unconventional form of monetary policy, it is usually used when standard monetary policy has become ineffective at combating a falling money supply. A central bank implements quantitative easing by buying specified amounts of financial assets from commercial banks and other financial institutions, thus raising the prices of those financial assets and lowering their yield, while simultaneously increasing the money supply. This differs from the more usual policy of buying or selling short-term government bonds to keep interbank interest rates at a specified target value. Also called printing of money. QE1-3 added $4.5 Trillion to US Federal Reserve balance Sheet.

QE1 – Round 1 of quantitative easing by the United States Federal Reserve. December 2008 to March 2010.

QE2 – Round 2 of quantitative easing by the United States Federal Reserve. November 2010 to June 2011.

QE3 – Round 3 of quantitative easing by the United States Federal Reserve. September 2012 to December 2013.

Rate of energy supply (The) - that is, the rate at which the resource can be produced. A large insitu resource does society little good if it cannot be produced consistently and in large enough quantities—characteristics that are constrained by geological, geochemical, and geographical factors (and subsequently manifested in economic costs). For example, although resources such as oil shale, gas hydrates, and in situ coal gasification have a very large in situ potential, they have been produced at only miniscule rates, if at all, despite major expenditures over many years on pilot projects. Tar sands similarly have immense in situ resources, but more than four decades of very large capital inputs and collateral environmental impacts have yielded production of less than two percent of world oil requirements.

Raw material - Crude or processed material that can be converted by manufacture, processing, or combination into a new and useful product. The basic substances or mixtures of substances in an untreated state except for extraction and primary processing. They can be subdivided into primary and secondary raw materials.

Real economy (The) - The part of the economy that is concerned with actually producing goods and services, as opposed to the part of the economy that is concerned with buying and selling on the financial markets.

Refinery Processing Gain - The volumetric amount by which total output is greater than input. This difference is due to the processing of crude oil into products that, in total, have lower specific gravity than the crude oil processed. Therefore, in terms of volume, the total output of products is greater than input.

Renewable energy electricity generation - Renewable energy is energy that is collected from renewable resources, which are naturally replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat. Renewable energy often provides energy in four important areas: electricity generation, air and water heating/cooling, transportation, and rural (off-grid) energy services.

Saudi Arabia - officially the Kingdom of Saudi Arabia (KSA), is an Arab sovereign state in Western Asia constituting the bulk of the Arabian Peninsula. With a land area of approximately 2,150,000 km^2, Saudi Arabia is geographically the fifth-largest state in Asia and second-largest state in the Arab world after Algeria. Saudi Arabia is bordered by Jordan and Iraq to the north, Kuwait to the northeast, Qatar, Bahrain and the United Arab Emirates to the east, Oman to the southeast and Yemen to the south. It is separated from Israel and Egypt by the Gulf of Aqaba. It is the only nation with both a Red Sea coast and a Persian Gulf coast and most of its terrain consists of arid desert and mountains. Saudi Arabia has dominated the oil producing market for decades and maintains the Petrodollar.

Secondary raw materials – Primary raw materials are used and then will finally end up as waste, from which secondary raw materials can be derived through recycling. These recycled materials can be used as feed stock into manufacturing in place of primary raw materials.

Seigniorage - (from Old French seigneuriage "right of the lord (seigneur) to mint money"), is the difference between the value of money and the cost to produce and distribute it. The term can be applied in the following ways:

- Seigniorage derived from specie—metal coins—is a tax, added to the total price of a coin (metal content and production costs), that a customer of the mint had to pay to the mint, and that was sent to the sovereign of the political area.
- Seigniorage derived from notes is more indirect, being the difference between interest earned on securities acquired in exchange for bank notes and the costs of producing and distributing those notes.

The term also applies to monetary seignorage, where sovereign-issued securities are exchanged for newly minted bank notes by a central bank, thus allowing the sovereign to 'borrow' without needing to repay. However, monetary seignorage refers to the sovereign revenue obtained through routine debt monetization, including expanding the money supply during GDP growth and meeting yearly inflation targets. Seigniorage is a convenient source of revenue for some governments. By providing the government with increased purchasing power at the expense of the public's purchasing power, it imposes what is metaphorically known as an inflation tax on the public.

Shale gas - Natural gas produced from wells that are open to shale formations. Shale is a fine-grained, sedimentary rock composed of mud from flakes of clay minerals and tiny fragments (silt-sized particles) of other materials. The shale acts as both the source and the reservoir for the natural gas.

Shale oil - is an unconventional oil produced from oil shale rock fragments by pyrolysis, hydrogenation, or thermal dissolution. These processes convert the organic matter within the rock (kerogen) into synthetic oil and gas. The resulting oil can be used immediately as a fuel or upgraded to meet refinery feedstock specifications by adding hydrogen and removing impurities such as sulfur and nitrogen. The refined products can be used for the same purposes as those derived from crude oil. The term "shale oil" is also used for crude oil produced from shales of other very low permeability formations. However, to reduce the risk of confusion of shale oil produced from oil shale with crude oil in oil-bearing shales, the term "tight oil" is preferred for the latter. The International Energy Agency recommends to use the term "light tight oil" and World Energy Resources 2013 report by the World Energy Council uses the term "tight oil" for crude oil in oil-bearing shales.

Shallow offshore drilling - is typically defined as drilling in a water depth that is less than 500 feet (150 meters). In general, rigs drilling in this environment are drilling platforms, otherwise known as jackups, which are able to reach the sea bottom. Wells being drilled in shallow offshore environments are typically located in mature fields. A mature field is one where production has reached its peak and has started to decline.

Solar power generation - is the conversion of energy from sunlight into electricity, either directly using photovoltaics (PV), indirectly using concentrated solar power, or a combination. Concentrated solar power systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. Photovoltaic cells convert light into an electric current using the photovoltaic effect. Photovoltaics were initially solely used as a source of electricity for small and medium-sized applications, from the calculator powered by a single solar cell to remote homes powered by an off-grid rooftop PV system. Commercial concentrated solar power plants were first developed in the 1980s. The 392 MW Ivanpah installation is the largest concentrating solar power plant in the world, located in the Mojave Desert of California. As the cost of solar electricity has fallen, the number of grid-connected solar PV systems has grown into the millions and utility-scale solar power stations with hundreds of megawatts are being built. Solar PV is rapidly becoming an inexpensive, low-carbon technology to harness renewable energy from the Sun. The current largest photovoltaic power station in the world is the 850 MW Longyangxia Dam Solar Park, in Qinghai, China.

Sovereign debt default - is the failure or refusal of the government of a sovereign state to pay back its debt in full. Cessation of due payments (or receivables) may either be accompanied by formal declaration (repudiation) of a government not to pay (or only partially pay) its debts, or it may be unannounced. A credit rating agency will take into account in its grading's capital, interest, extraneous and procedural defaults, and failures to abide by the terms of bonds or other debt instruments. Countries have at times escaped the real burden of some of their debt through inflation. This is not "default" in the usual sense because the debt is honoured, albeit with currency of lesser real value. Sometimes governments devalue their currency. This can be done by printing more money to apply toward their own debts, or by ending or altering the convertibility of their currencies into precious metals or foreign currency at fixed rates. Harder to quantify than an interest or capital default, this often is defined as an extraneous or procedural default (breach) of terms of the contracts or other instruments.

Soviet Union - officially the Union of Soviet Socialist Republics (USSR; Russian: Сою́з Сове́тских Социалисти́ческих Респу́блик (СССР)), also known unofficially as Russia, was a socialist state in Eurasia that existed from 1922 to 1991. Nominally a union of multiple equal national Soviet republics, its government and economy were highly centralized. The country was a one-party federation, governed by the Communist Party with Moscow as its capital.

Sour crude oil - is crude oil containing a high amount of the impurity sulfur. It is common to find crude oil containing some impurities. When the total sulfur level in the oil is more than 0.5% the oil is called "sour". The impurities need to be removed before this lower-quality crude can be refined into petrol, thereby increasing the cost of processing. This results in a higher-priced gasoline than that made from sweet crude oil. Current environmental regulations in the United States strictly limit the sulfur content in refined fuels such as diesel and gasoline.   The majority of the sulfur in crude oil occurs bonded to carbon atoms, with a small amount occurring as elemental sulfur in solution and as hydrogen sulfide gas. Sour oil can be toxic and corrosive, especially when the oil contains higher levels of hydrogen sulfide, which is a breathing hazard. At low concentrations the gas gives the oil the smell of rotting eggs.

Spot price - is the current market price at which an asset is bought or sold for immediate payment and delivery. It is differentiated from the forward price or the futures price, which are prices at which an asset can be bought or sold for delivery in the future.

Stagflation - In economics, stagflation, a portmanteau of stagnation and inflation, is a situation in which the inflation rate is high, the economic growth rate slows, and unemployment remains steadily high. It raises a dilemma for economic policy, since actions designed to lower inflation may exacerbate unemployment, and vice versa. The term is generally attributed to a British Conservative Party politician who became Chancellor of the Exchequer in 1970, Iain Macleod, who coined the phrase in his speech to Parliament in 1965. Keynes did not use the term, but some of his work refers to the conditions that most would recognise as stagflation. In the version of Keynesian macroeconomic theory that was dominant between the end of World War II and the late 1970s, inflation and recession were regarded as mutually exclusive, the relationship between the two being described by the Phillips curve. Stagflation is very costly and difficult to eradicate once it starts, both in social terms and in budget deficits.

Standard & Poor's 500 Index (S&P 500) - or just "the S&P", is an American stock market index based on the market capitalizations of 500 large companies having common stock listed on the NYSE or NASDAQ. The S&P 500 index components and their weightings are determined by S&P Dow Jones Indices. It differs from other U.S. stock market indices, such as the Dow Jones Industrial Average or the Nasdaq Composite index, because of its diverse constituency and weighting methodology. It is one of the most commonly followed equity indices, and many consider it one of the best representations of the U.S. stock market, and a bellwether for the U.S. economy. The National Bureau of Economic Research has classified common stocks as a leading indicator of business cycles.

Steam engine - A steam engine is a heat engine that performs mechanical work using steam as its working fluid. Steam engines are external combustion engines, where the working fluid is separated from the combustion products.

Sub-bituminous coal - is a type of coal whose properties range from those of lignite to those of bituminous coal and are used primarily as fuel for steam-electric power generation.

Substitute (synthetic) natural gas - Substitute natural gas (SNG), or synthetic natural gas, is a fuel gas that can be produced from fossil fuels such as lignite coal, oil shale, or from biofuels (when it is named bio-SNG) or from renewable electrical energy.

Supply network - is a pattern of temporal and spatial processes carried out at facility nodes and over distribution links, which adds value for customers through the manufacturing and delivery of products. It comprises the general state of business affairs in which all kinds of material (work-in-process material as well as finished products) are transformed and moved between various value-added points to maximize the value added for customers.

Supply chain - is a special instance of a supply network in which raw materials, intermediate materials and finished goods are procured exclusively as products through a chain of processes that supply one another.

Sweet crude oil - is a type of petroleum. The New York Mercantile Exchange designates petroleum with less than 0.42% sulfur as sweet. Petroleum containing higher levels of sulfur is called sour crude oil.

Sweet crude oil contains small amounts of hydrogen sulfide and carbon dioxide. High-quality, low-sulfur crude oil is commonly used for processing into gasoline and is in high demand, particularly in the industrialized nations. Light sweet crude oil is the most sought-after version of crude oil as it contains a disproportionately large fraction that is directly processed (fractionation) into gasoline (naphtha), kerosene, and high-quality diesel (gas oil). The term sweet originates from the fact that a low level of sulfur provides the oil with a mildly sweet taste and pleasant smell. Nineteenth-century prospectors would taste and smell small quantities of oil to determine its quality.

Systemic banking crisis - is one where all or almost all of the banking capital in a country is wiped out. The resulting chain of bankruptcies can cause a long economic recession as domestic businesses and consumers are starved of capital as the domestic banking system shuts down.

Tar sands – see Oil sands

Temporal marker - A temporal marker is any statement that helps answer the question “When did this happen?” Often used as an analytical tool to correlate causality or help define the existence of a relationship between events over time.

Tidal power generation - Tidal power or tidal energy is a form of hydropower that converts the energy obtained from tides into useful forms of power, mainly electricity. Although not yet widely used, tidal energy has potential for future electricity generation. Tides are more predictable than the wind and the sun. Among sources of renewable energy, tidal energy has traditionally suffered from relatively high cost and limited availability of sites with sufficiently high tidal ranges or flow velocities, thus constricting its total availability. However, many recent[when? clarification needed] technological developments and improvements, both in design (e.g. dynamic tidal power, tidal lagoons) and turbine technology (e.g. new axial turbines, cross flow turbines), indicate that the total availability of tidal power may be much higher than previously assumed, and that economic and environmental costs may be brought down to competitive levels.

Tight gas - is natural gas produced from reservoir rocks with such low permeability that massive hydraulic fracturing is necessary to produce the well at economic rates. Tight gas reservoirs are generally defined as having less than 0.1 millidarcy (mD) matrix permeability and less than ten percent matrix porosity.[1][2] Although shales have low permeability and low effective porosity, shale gas is usually considered separate from tight gas, which is contained most commonly in sandstone, but sometimes in limestone. Tight gas is considered an unconventional source of natural gas. Rock with permeabilities as little as one nanodarcy, reservoir stimulation may be economically productive with optimized spacing and completion of staged fractures to maximize yield with respect to cost.

Tight oil - Tight oil (also known as shale oil, shale-hosted oil or light tight oil, abbreviated LTO) is light crude oil contained in petroleum-bearing formations of low permeability, often shale or tight sandstone. Economic production from tight oil formations requires the same hydraulic fracturing and often uses the same horizontal well technology used in the production of shale gas. While sometimes called "shale oil", tight oil should not be confused with oil shale, which is shale rich in kerogen, or shale oil, which is oil produced from oil shales.

Unconventional oil production - An umbrella term for oil and natural gas that is produced by means that do not meet the criteria for conventional production. This is oil which requires advanced production methods due to its geologic formations and/or is heavy and does not flow on its own. Note: What has qualified as "unconventional" at any particular time is a complex interactive function of resource characteristics, the available exploration and production technologies, the current economic environment, and the scale, frequency, and duration of production from the resource. Perceptions of these factors inevitably change over time and they often differ among users of the term. Unconventional oil included:

- oil shales
- oil sands-based synthetic crudes and derivative products
- tight oil
- heavy oil and extra-heavy oil (Orimulsion)
- coal-based liquid supplies
- biomass-based liquid supplies
- gas to liquid (GTL) - liquids arising from chemical processing of gas
- natural bitumen (oil sands)
- kerogen oil
- liquids and gases arising from chemical processing of natural gas (GTL)
- coal-to-liquids (CTL) and additives.

Unconventional natural gas production - An Unconventional gas is natural gas obtained from sources of production that are, in a given era and location, considered to be new and different. Sources at times considered to be unconventional include:

- Coalbed methane
- Methane clathrate (gas hydrate)
- Shale gas
- Synthetic natural gas, such as oil shale gas
- Tight gas

United States Department of the Treasury - is an executive department and the treasury of the United States federal government. It was established by an Act of Congress in 1789 to manage government revenue. The Department is administered by the Secretary of the Treasury, who is a member of the Cabinet.

United States treasury bonds – see United States Treasury Securities

United States Treasury Securities - are government debt instruments issued by the United States Department of the Treasury to finance the national debt of the United States. Treasury securities are often referred to simply as Treasuries. Since 2012 the management of government debt has been arranged by the Bureau of the Fiscal Service, succeeding the Bureau of the Public Debt. There are four types of marketable treasury securities: Treasury bills, Treasury notes, Treasury bonds, and Treasury Inflation Protected Securities (TIPS).

$USD – The United States dollar (sign: $; code: USD; also abbreviated US$ and referred to as the dollar, U.S. dollar, or American dollar) is the official currency of the United States and its insular territories per the United States Constitution. Unofficially seen as the global reserve currency.

US Federal Reserve – See Federal Reserve Bank

Water table - The water table is the upper surface of the zone of saturation. The zone of saturation is where the pores and fractures of the ground are saturated with water. The water table is the surface where the water pressure head is equal to the atmospheric pressure (where gauge pressure = 0). It may be visualized as the "surface" of the subsurface materials that are saturated with groundwater in a given vicinity. The groundwater may be from precipitation or from groundwater flowing into the aquifer. In areas with sufficient precipitation, water infiltrates through pore spaces in the soil, passing through the unsaturated zone. At increasing depths water fills in more of the pore spaces in the soils, until a zone of saturation is reached.

Wave power generation - is the transport of energy by wind waves, and the capture of that energy to do useful work – for example, electricity generation, water desalination, or the pumping of water (into reservoirs). A machine able to exploit wave power is generally known as a wave energy converter (WEC). Wave power is distinct from the diurnal flux of tidal power and the steady gyre of ocean currents. Wave-power generation is not currently a widely employed commercial technology, although there have been attempts to use it since at least 1890. In 2008, the first experimental wave farm was opened in Portugal, at the Aguçadoura Wave Park.

Wet natural gas - A mixture of hydrocarbon compounds and small quantities of various non hydrocarbons existing in the gaseous phase or in solution with crude oil in porous rock formations at reservoir conditions. The principal hydrocarbons normally contained in the mixture are methane, ethane, propane, butane, and pentane. Typical nonhydrocarbon gases that may be present in reservoir natural gas are water vapor, carbon dioxide, hydrogen sulfide, nitrogen and trace amounts of helium. Under reservoir conditions, natural gas and its associated liquefiable portions occur either in a single gaseous phase in the reservoir or in solution with crude oil and are not distinguishable at the time as separate substances. Note: The Securities and Exchange Commission and the Financial Accounting Standards Board refer to this product as natural gas.

Wind power generation - Wind power is the use of air flow through wind turbines to mechanically power generators for electric power. Wind power, as an alternative to burning fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation, consumes no water, and uses little land. The net effects on the environment are far less problematic than those of nonrenewable power sources. Wind farms consist of many individual wind turbines which are connected to the electric power transmission network. Onshore wind is an inexpensive source of electric power, competitive with or in many places cheaper than coal or gas plants. Offshore wind is steadier and stronger than on land, and offshore farms have less visual impact, but construction and maintenance costs are considerably higher. Small onshore wind farms can feed some energy into the grid or provide electric power to isolated off-grid locations. Wind power gives variable power which is very consistent from year to year but which has significant variation over shorter time scales. It is therefore used in conjunction with other electric power sources to give a reliable supply.

World Bank - The World Bank is an international financial institution that provides loans to countries of the world for capital programs. It comprises two institutions: the International Bank for Reconstruction and Development (IBRD), and the International Development Association (IDA). The World Bank is a component of the World Bank Group. The World Bank's stated official goal is the reduction of poverty. However, according to its Articles of Agreement, all its decisions must be guided by a commitment to the promotion of foreign investment and international trade and to the facilitation of capital investment.

World Energy Council (WEC) - is a global and inclusive forum for thought-leadership and tangible engagement with headquarters in London. Its mission is 'To promote the sustainable supply and use of energy for the greatest benefit of all people'. The World Energy Council is the principal impartial network of leaders and practitioners promoting an affordable, stable and environmentally sensitive energy system for the greatest benefit of all. Formed in 1923, the Council is the UN-accredited global energy body, representing the entire energy spectrum, with more than 3000 member organisations located in over 90 countries and drawn from governments, private and state corporations, academia, NGOs and energy-related stakeholders. The World Energy Council informs global, regional and national energy strategies by hosting high-level events, publishing authoritative studies, and working through its extensive member network to facilitate the world's energy policy dialogue.

World Energy Outlook (WEO) - The annual World Energy Outlook is the International Energy Agency's flagship publication, widely recognised as the most authoritative source for global energy projections and analysis. It represents the leading source for medium to long-term energy market projections, extensive statistics, analysis and advice for both governments and the energy business. It is produced by the Office of the Chief Economist, presently under the direction of Dr. Fatih Birol.

Year-over-year (YOY) - Is a comparison of a statistic for one period to the same period the previous year. The period is usually a month or quarter. The year-over-year growth rate calculates the percent change during the past twelve months.

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24 APPENDIX A - ENERGY FLOWS THROUGH INDUSTRIAL ECONOMIES

Figures A2 to A24 are Sankey diagrams developed mostly by the Lawrence Livermore National Laboratory, and examine Europe and the United States in context of Figure A1 below. The energy flow diagram shows, on the left side, the fuels (primary energy) as sources. Streams lead to energy generation (power plants) or directly to the consuming sectors on the right (industry, commercial, residential, transportation). 'Rejected energy' (losses) are shown in grey color and contrasted with 'Energy services' (useful energy).

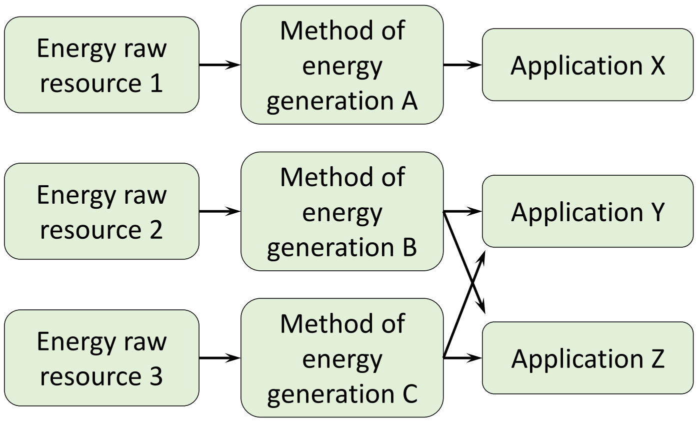

Figure A1. Relationship between energy resources and their application

What is clear in examining these diagrams is that energy is a support function for all activities, and that fossil fuels accounts for most of that energy supply in one form or another.

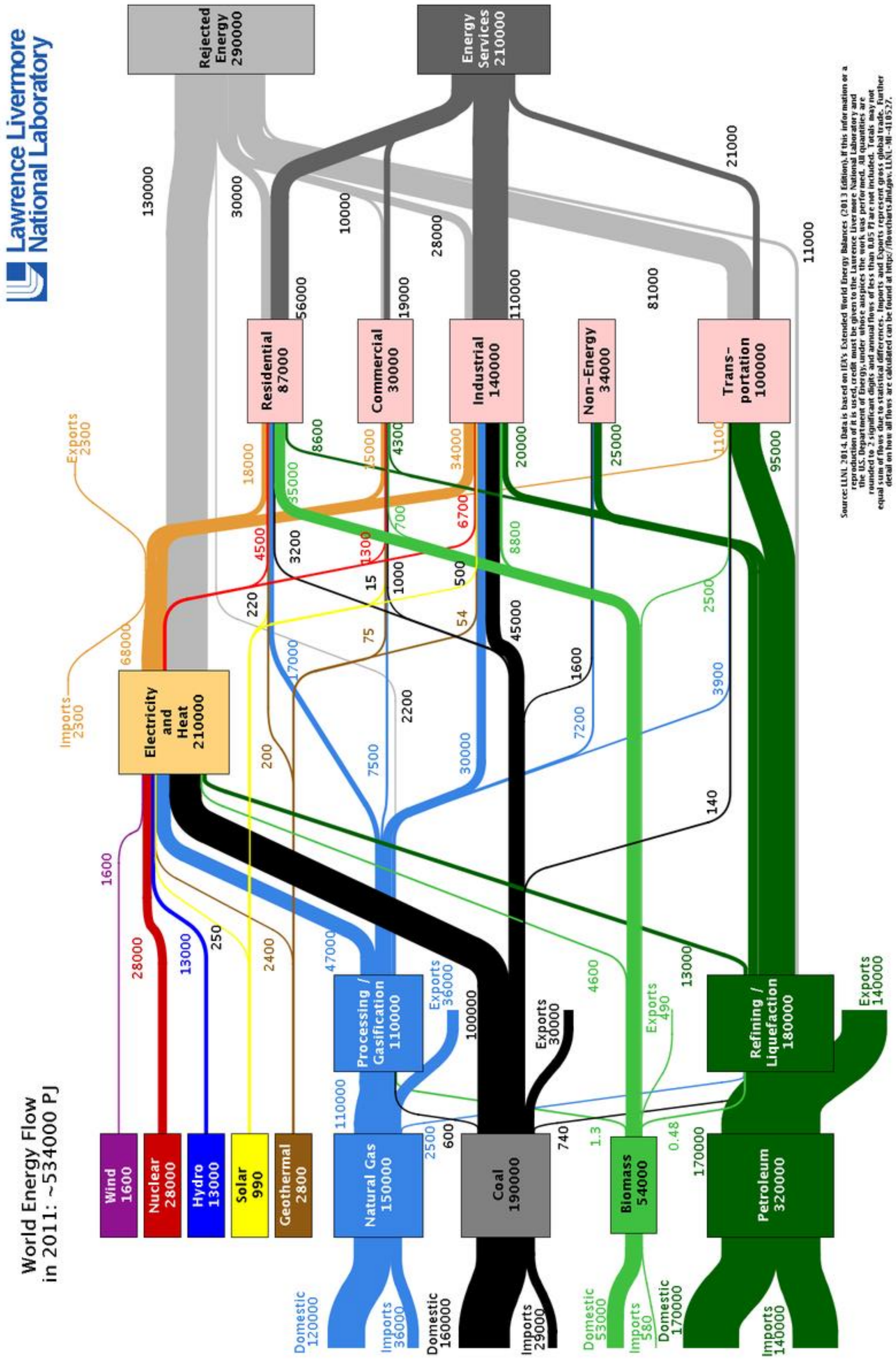

Figure A2. Global energy flow between energy source and application
(Source: Lawrence Livermore National Laboratory Energy Flow Charts)
(Copyright License: https://creativecommons.org/licenses/by-nc-sa/4.0/)

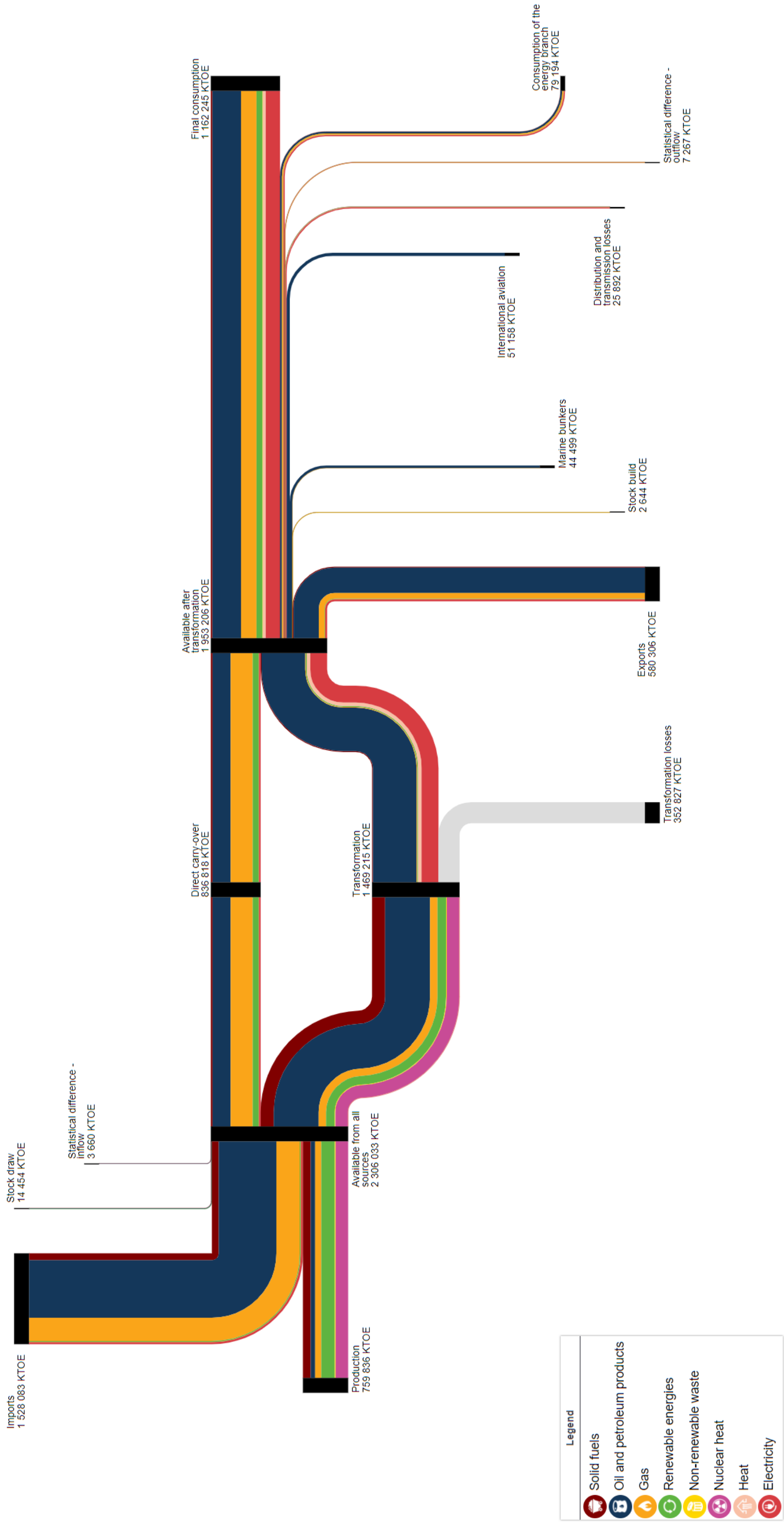

Figure A3. Energy balance flow for European Union EU-28 in 2017
(Source: European Commission Eurostat)
(https://ec.europa.eu/eurostat/web/products-eurostat-news/-/WDN-20190329-1)

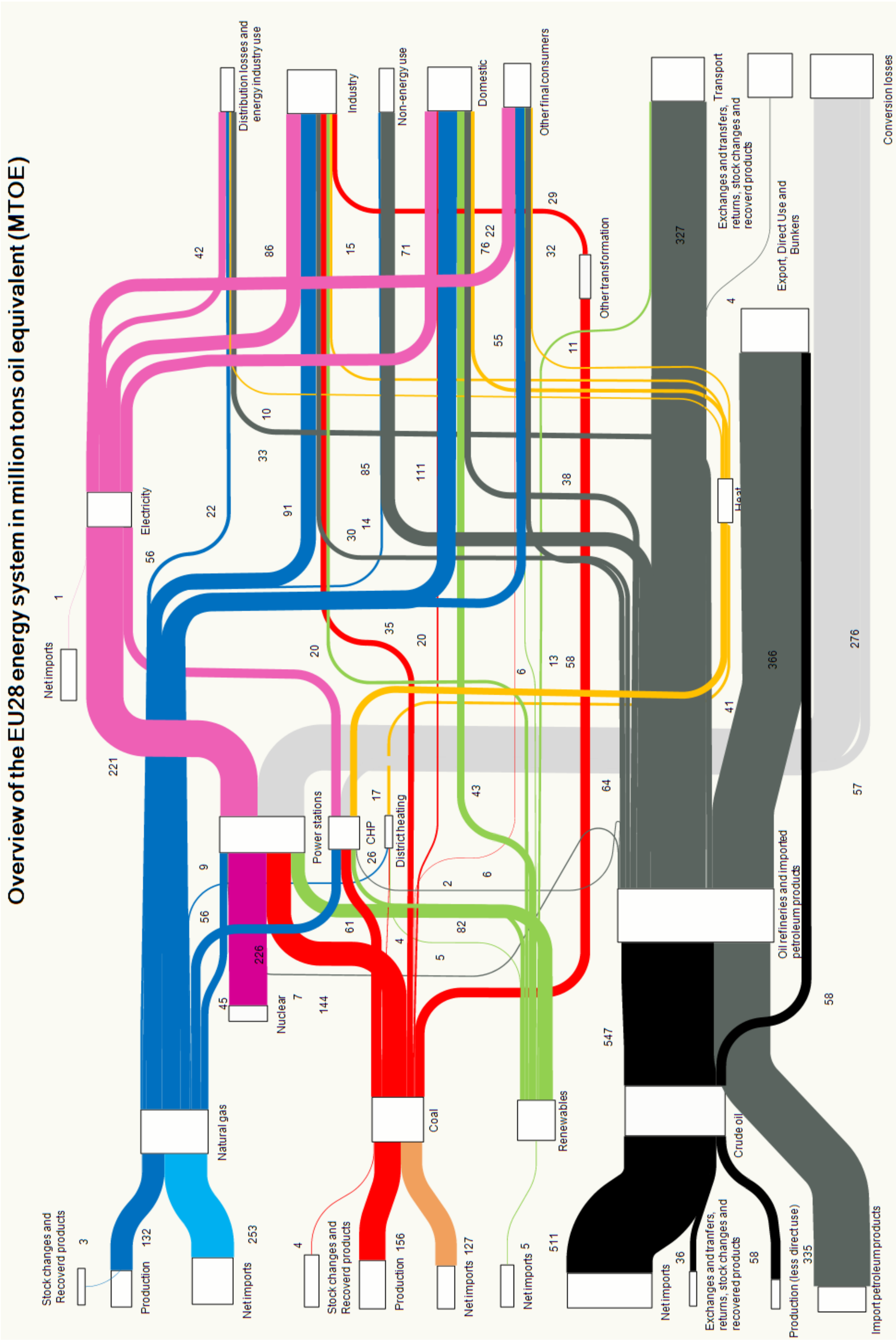

Figure A4. Composition of the primary energy entering the energy system of the EU-28 in 2013
(Source: European Environmental Agency, https://www.eea.europa.eu/)
(Copyright License: https://creativecommons.org/licenses/by-nc-sa/4.0/)

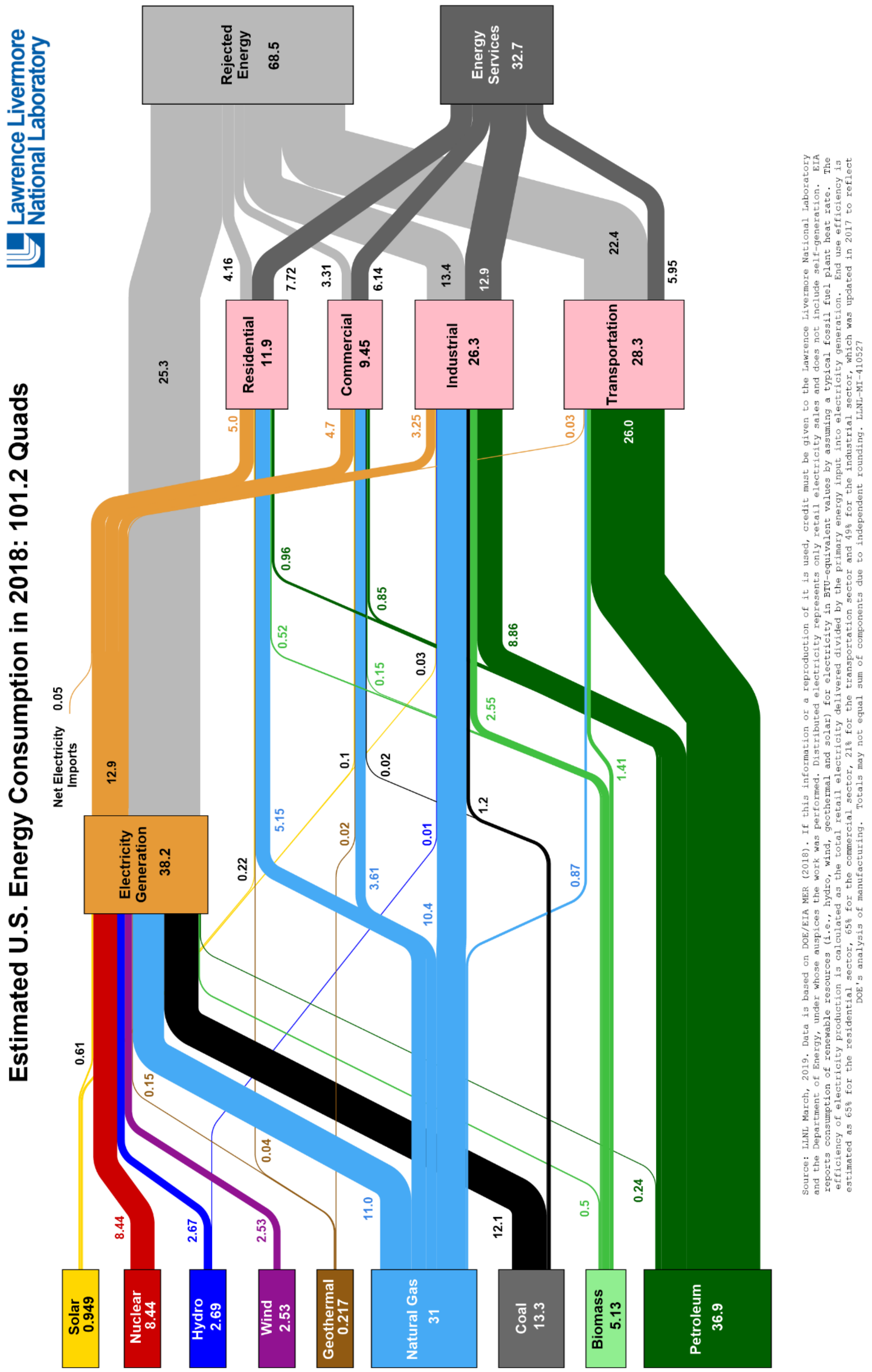

Figure A5. United States energy flow between energy source and application (Source: Lawrence Livermore National Laboratory 2019, EIA 2019) (Copyright License: https://creativecommons.org/licenses/by-nc-sa/4.0/)

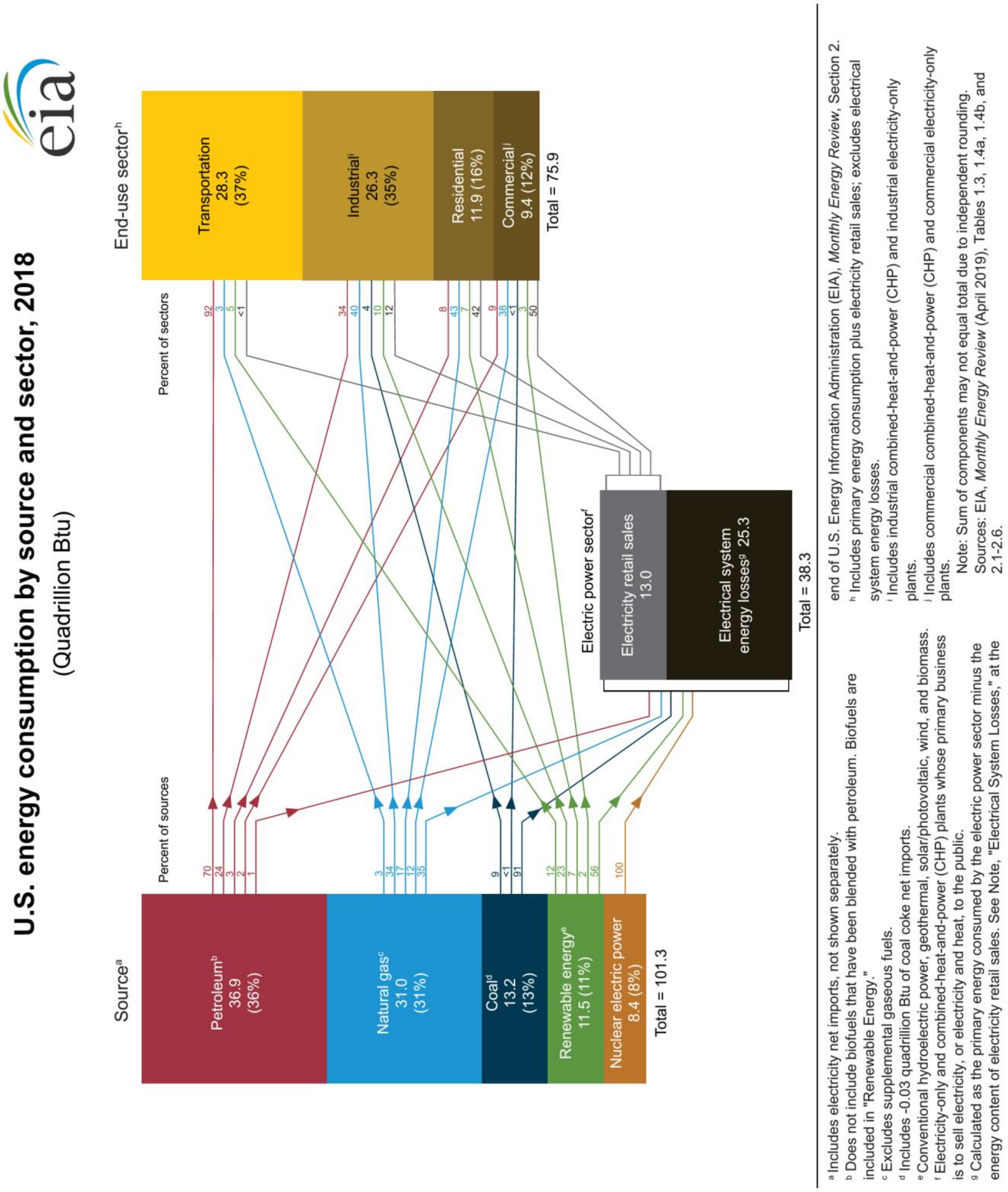

Figure A6. United States energy consumption
(Source: EIA 2019)

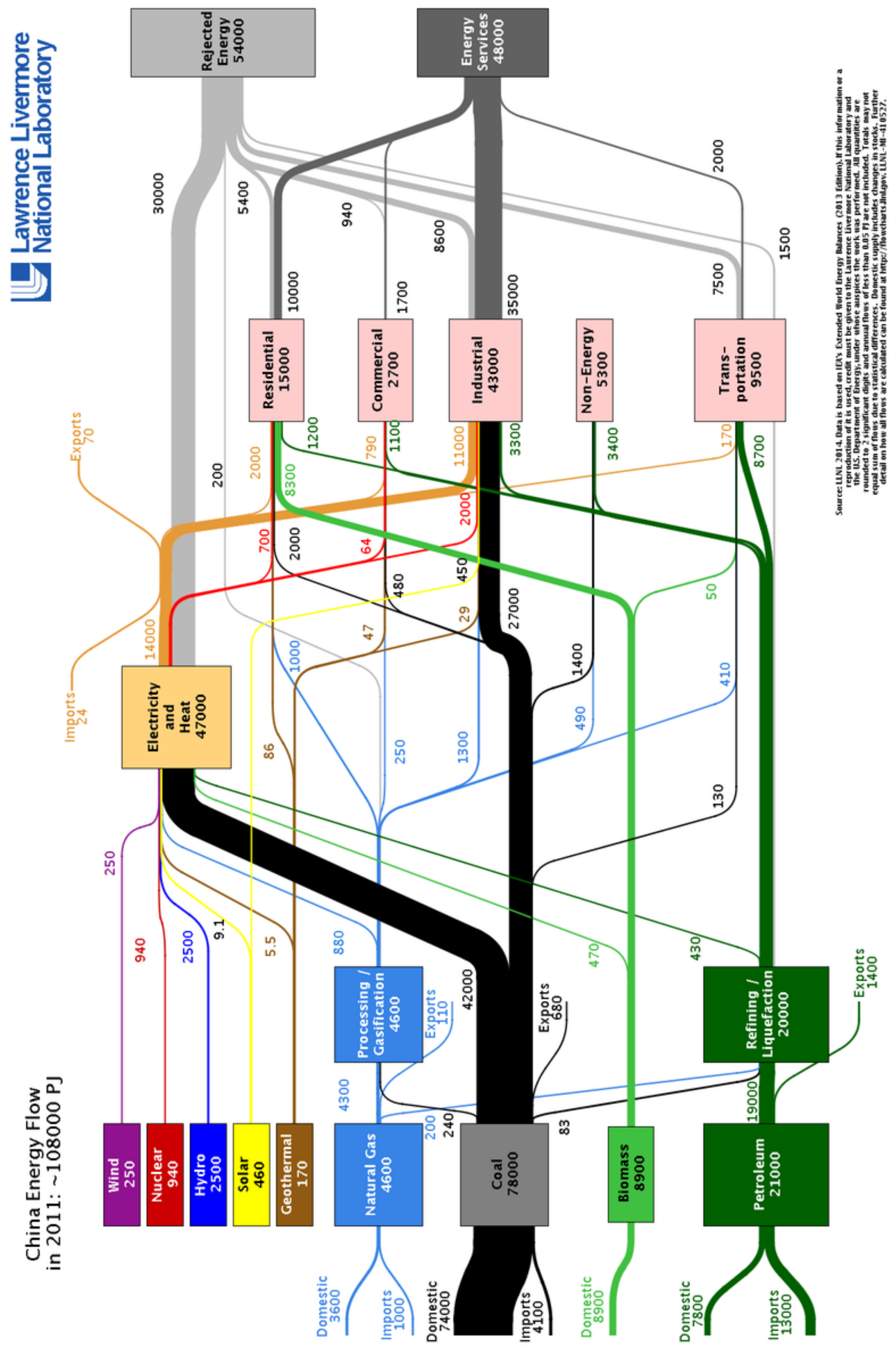

Figure A7. China energy flow between energy source and application
(Source: Lawrence Livermore National Laboratory Energy Flow Charts)

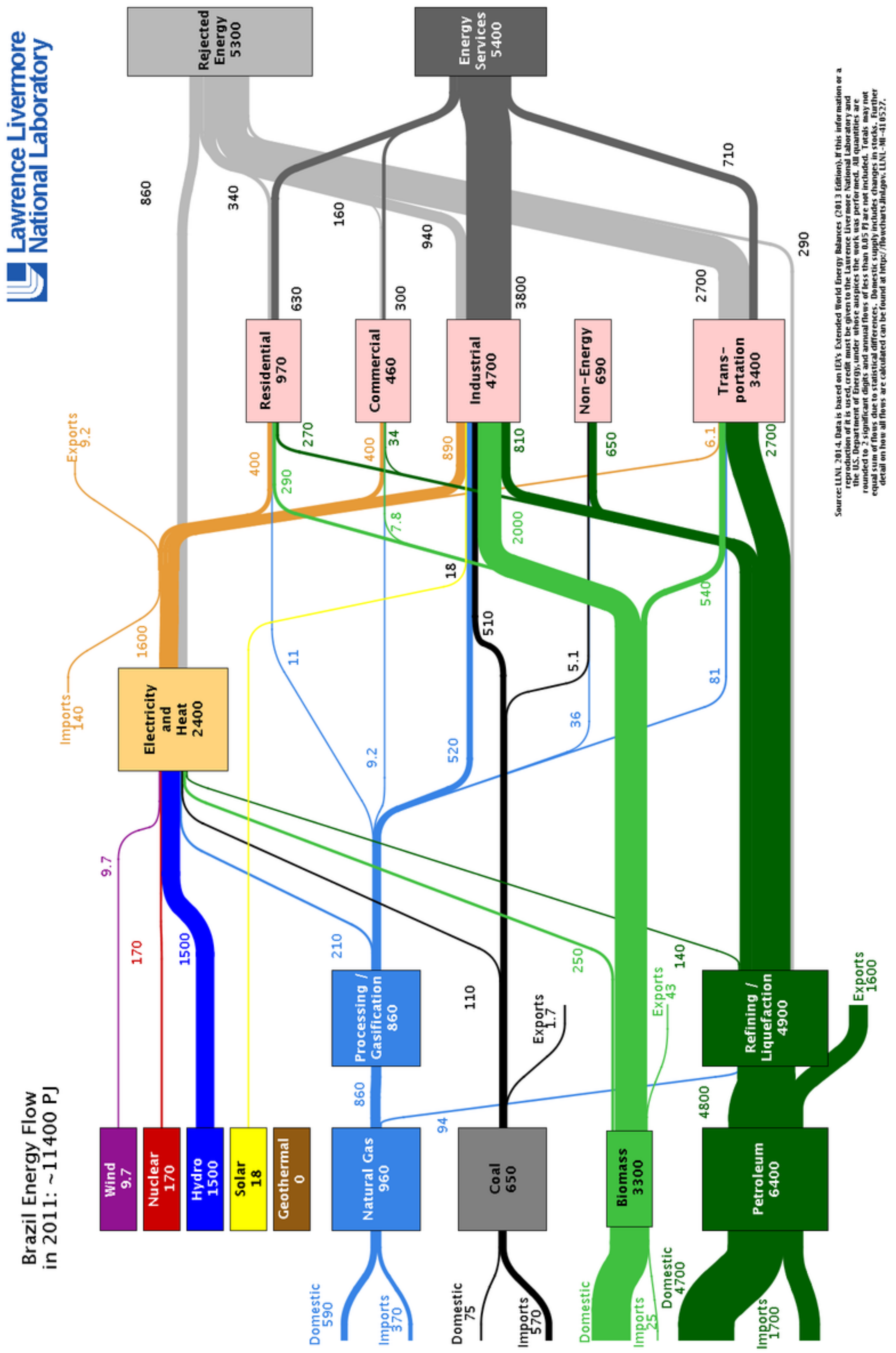

Figure A8. Brazil energy flow between energy source and application
(Source: Lawrence Livermore National Laboratory Energy Flow Charts)

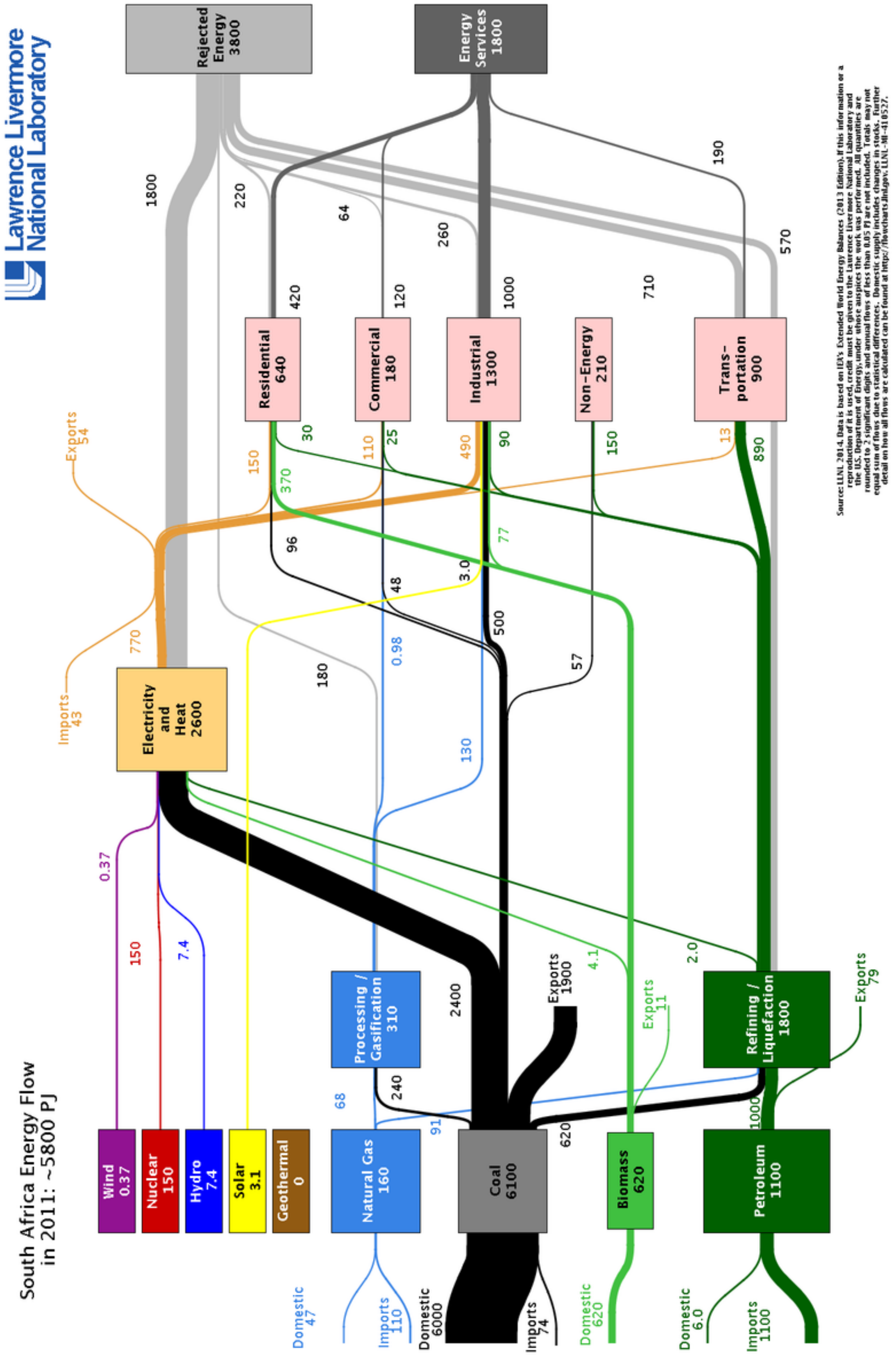

Figure A9. South Africa energy flow between energy source and application
(Source: Lawrence Livermore National Laboratory Energy Flow Charts)

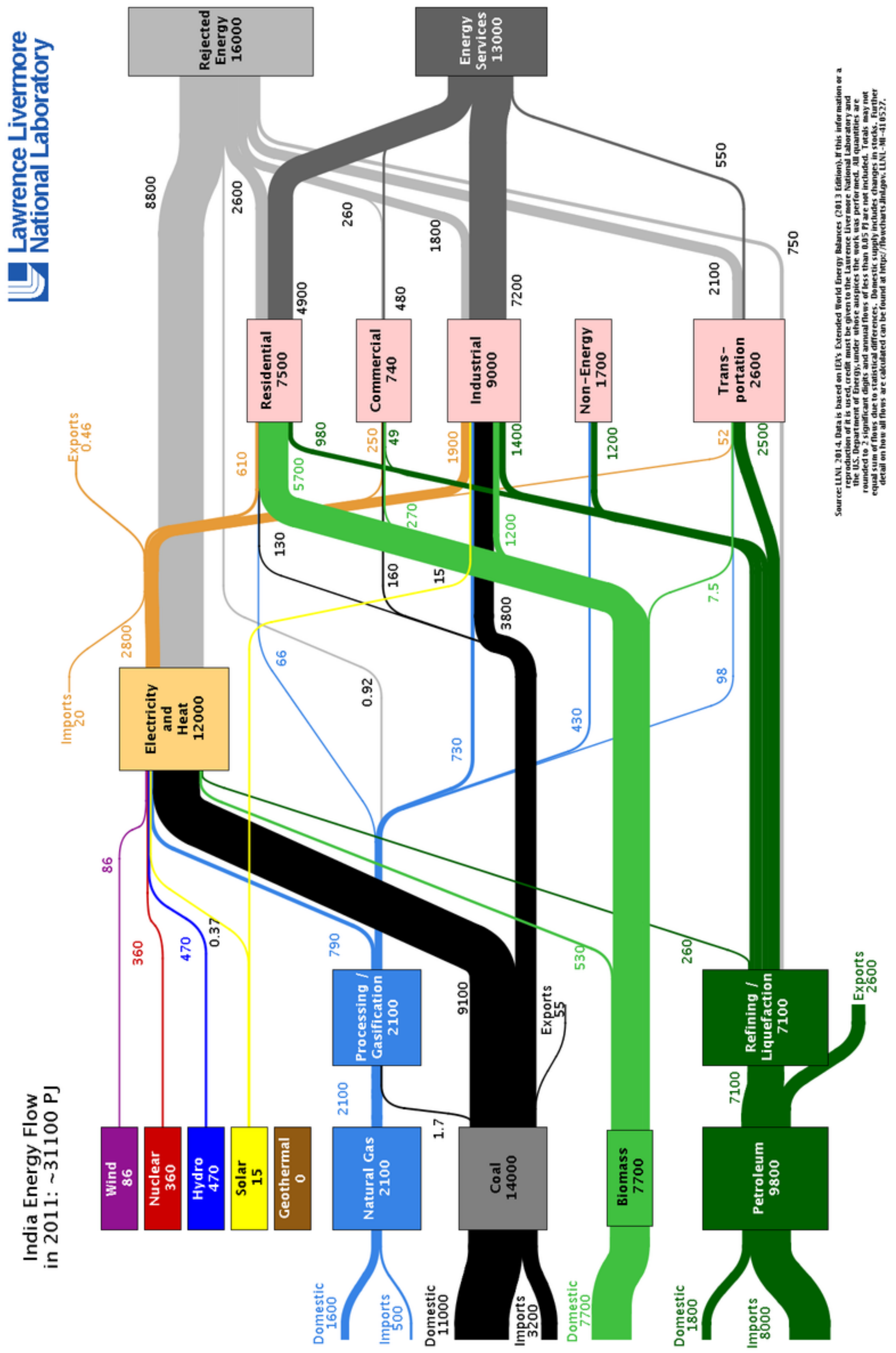

Figure A10. India energy flow between energy source and application
(Source: Lawrence Livermore National Laboratory Energy Flow Charts)

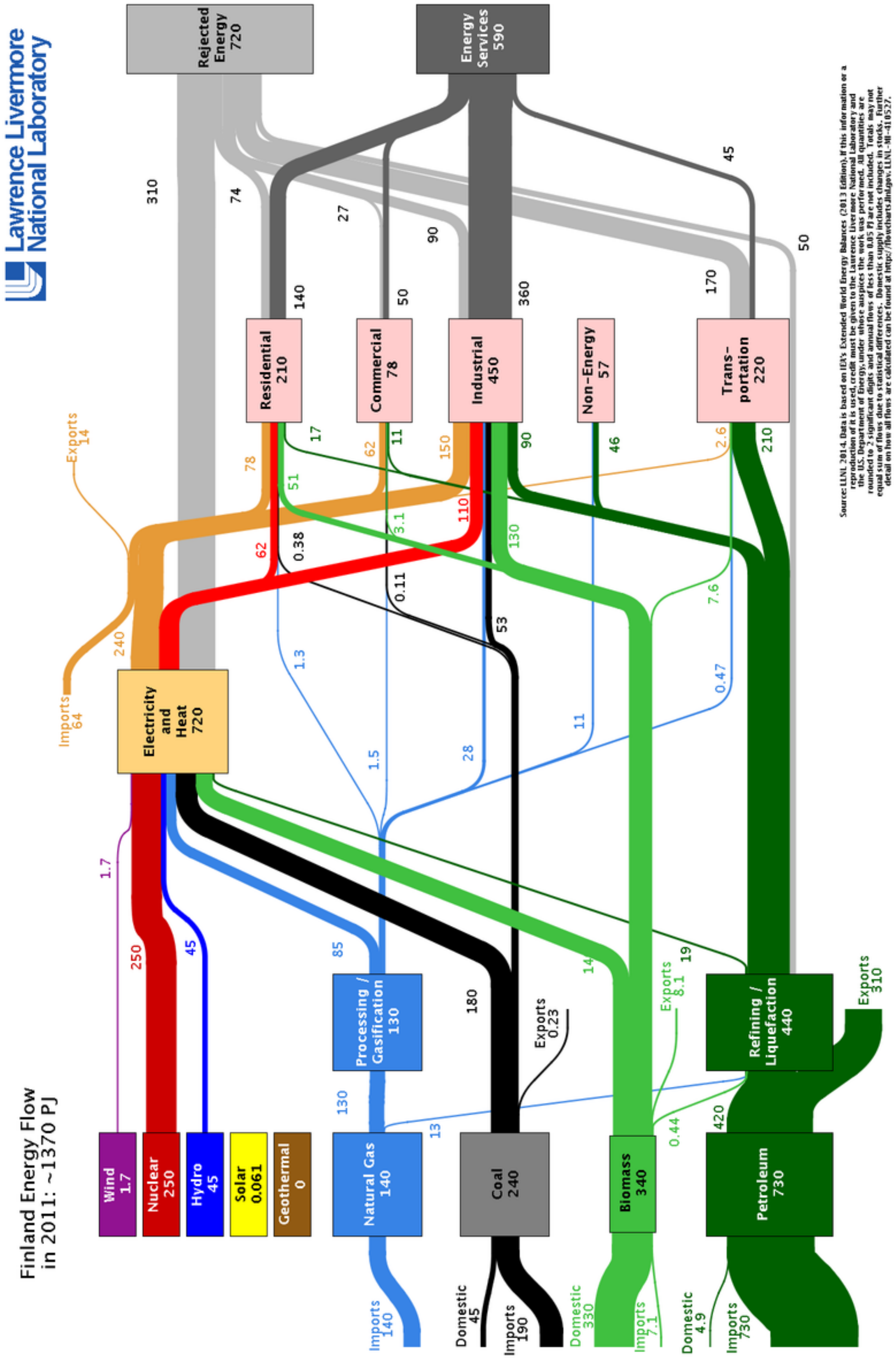

Figure A11. Finland energy flow between energy source and application
(Source: Lawrence Livermore National Laboratory Energy Flow Charts)

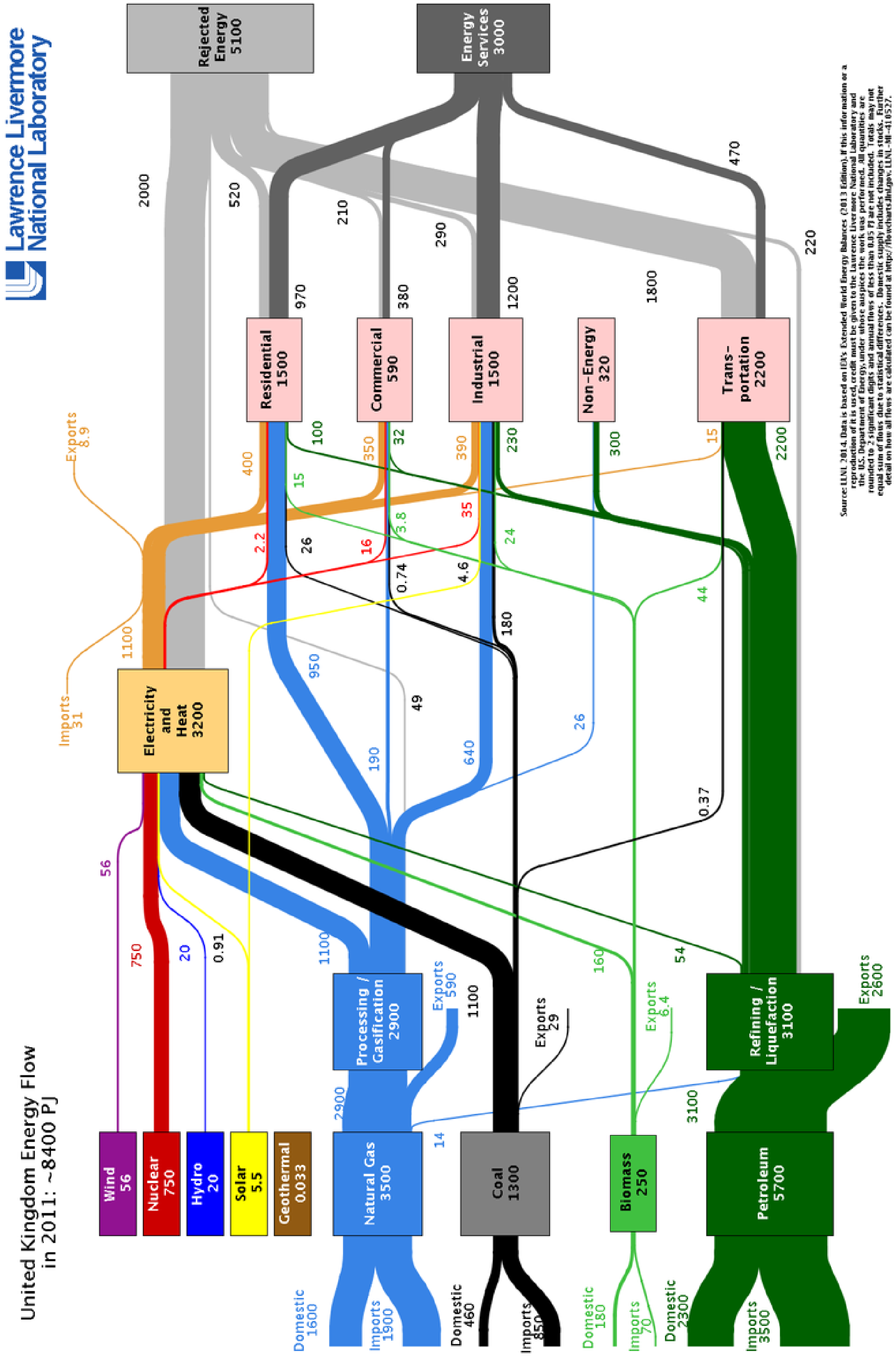

Figure A12. United Kingdom energy flow between energy source and application
(Source: Lawrence Livermore National Laboratory Energy Flow Charts)

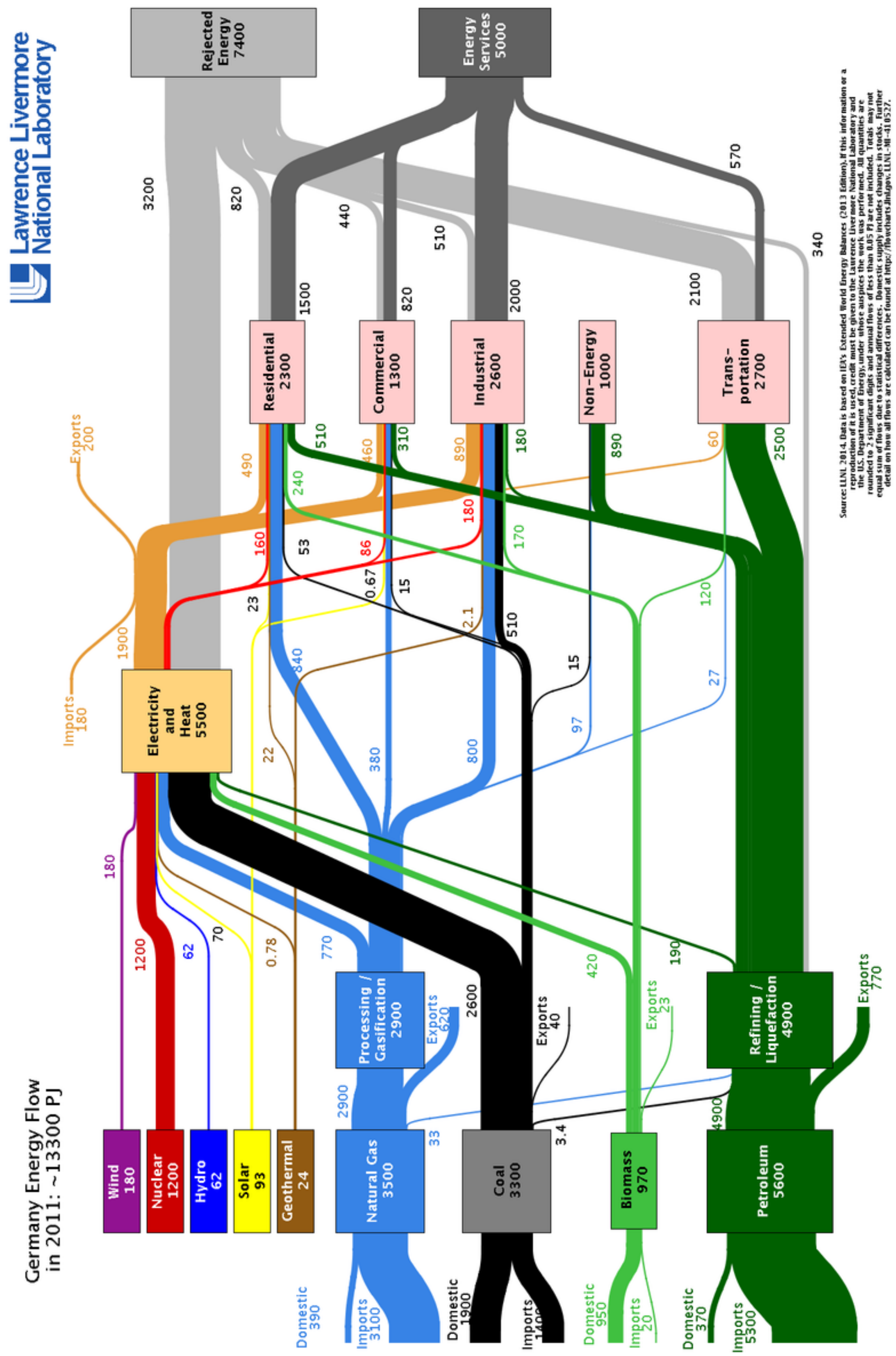

Figure A13. Germany energy flow between energy source and application
(Source: Lawrence Livermore National Laboratory Energy Flow Charts)

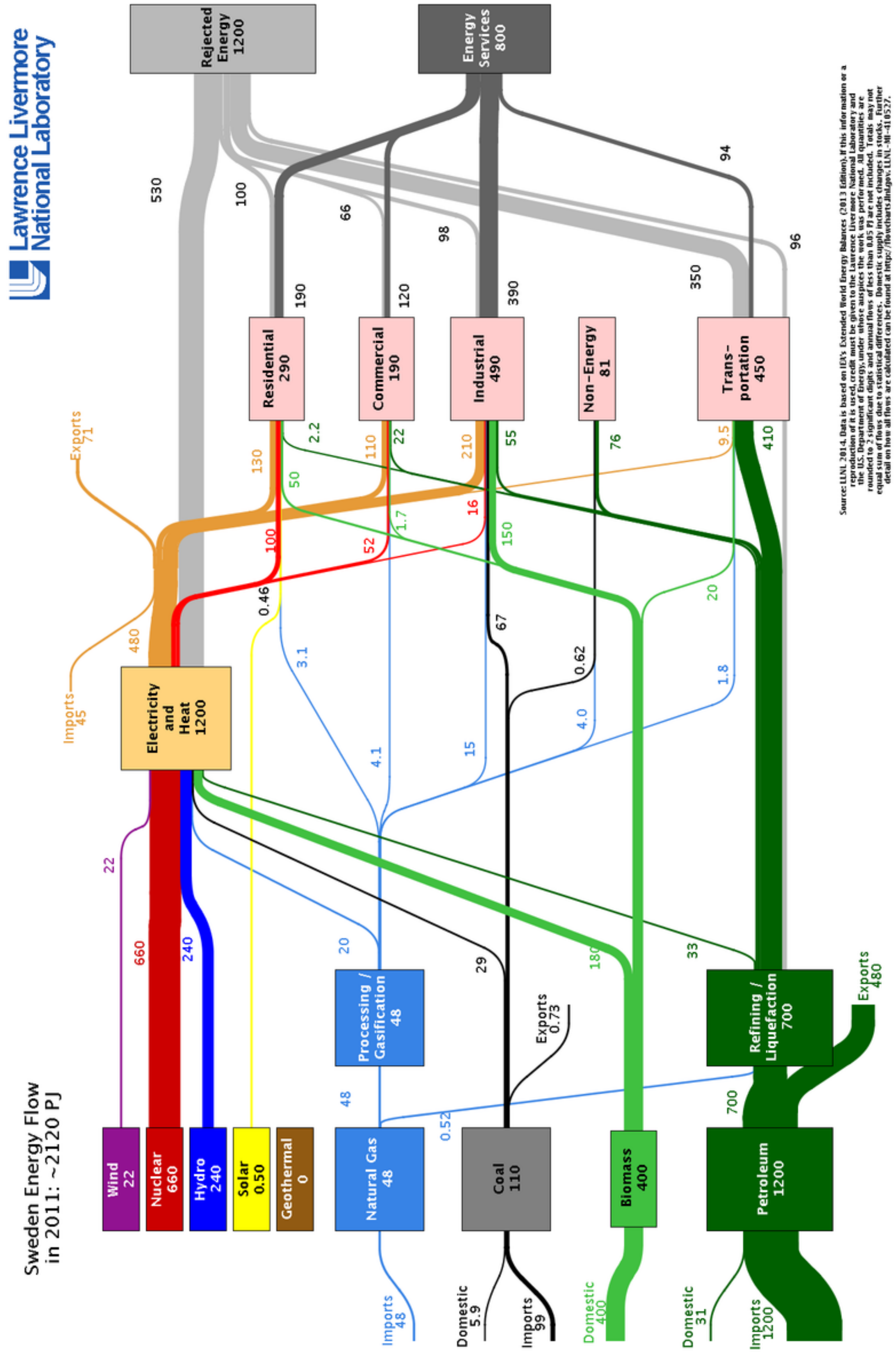

Figure A14. Sweden energy flow between energy source and application
(Source: Lawrence Livermore National Laboratory Energy Flow Charts)

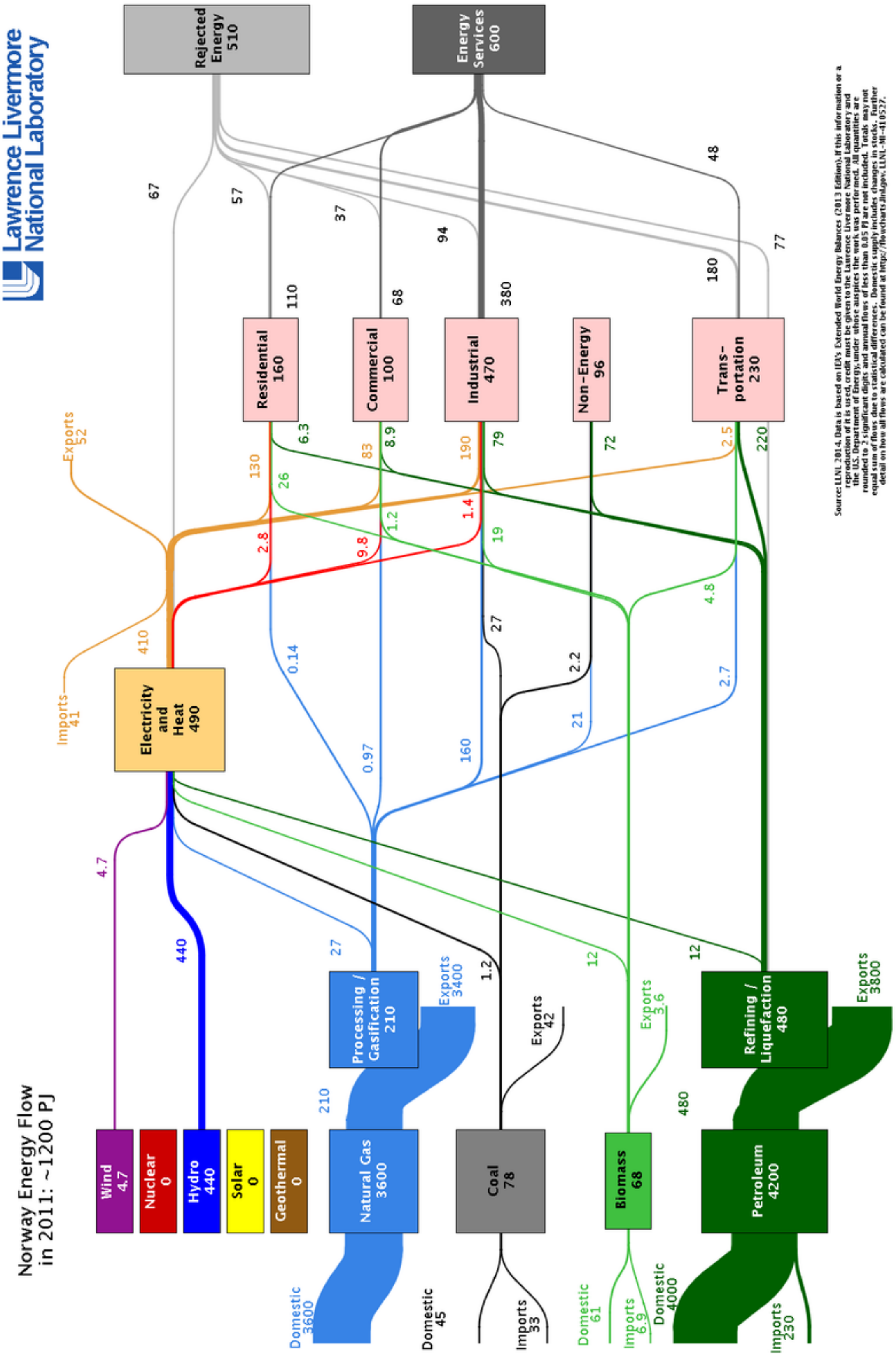

Figure A15. Norway energy flow between energy source and application
(Source: Lawrence Livermore National Laboratory Energy Flow Charts)

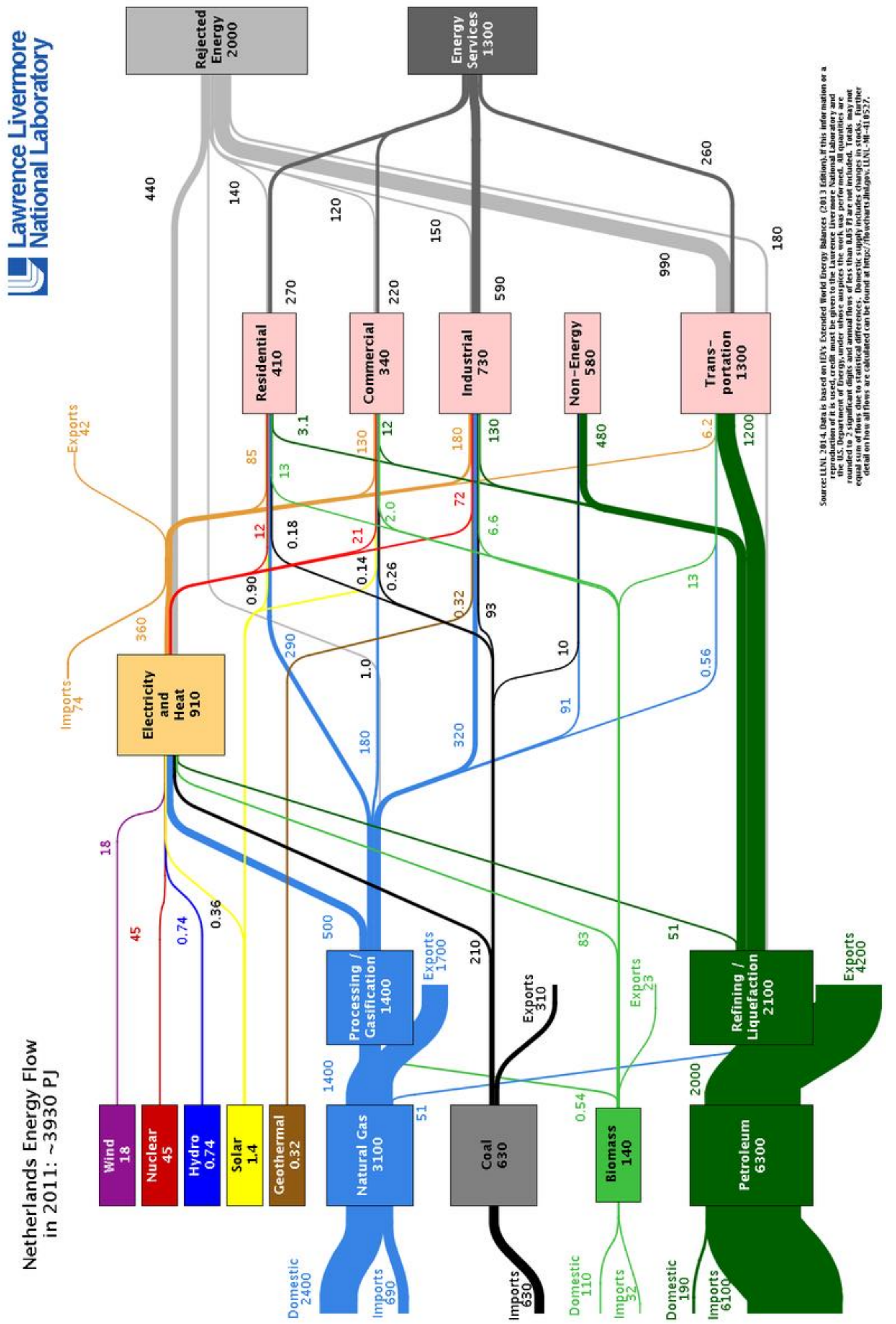

Figure A16. Netherlands energy flow between energy source and application
(Source: Lawrence Livermore National Laboratory Energy Flow Charts)

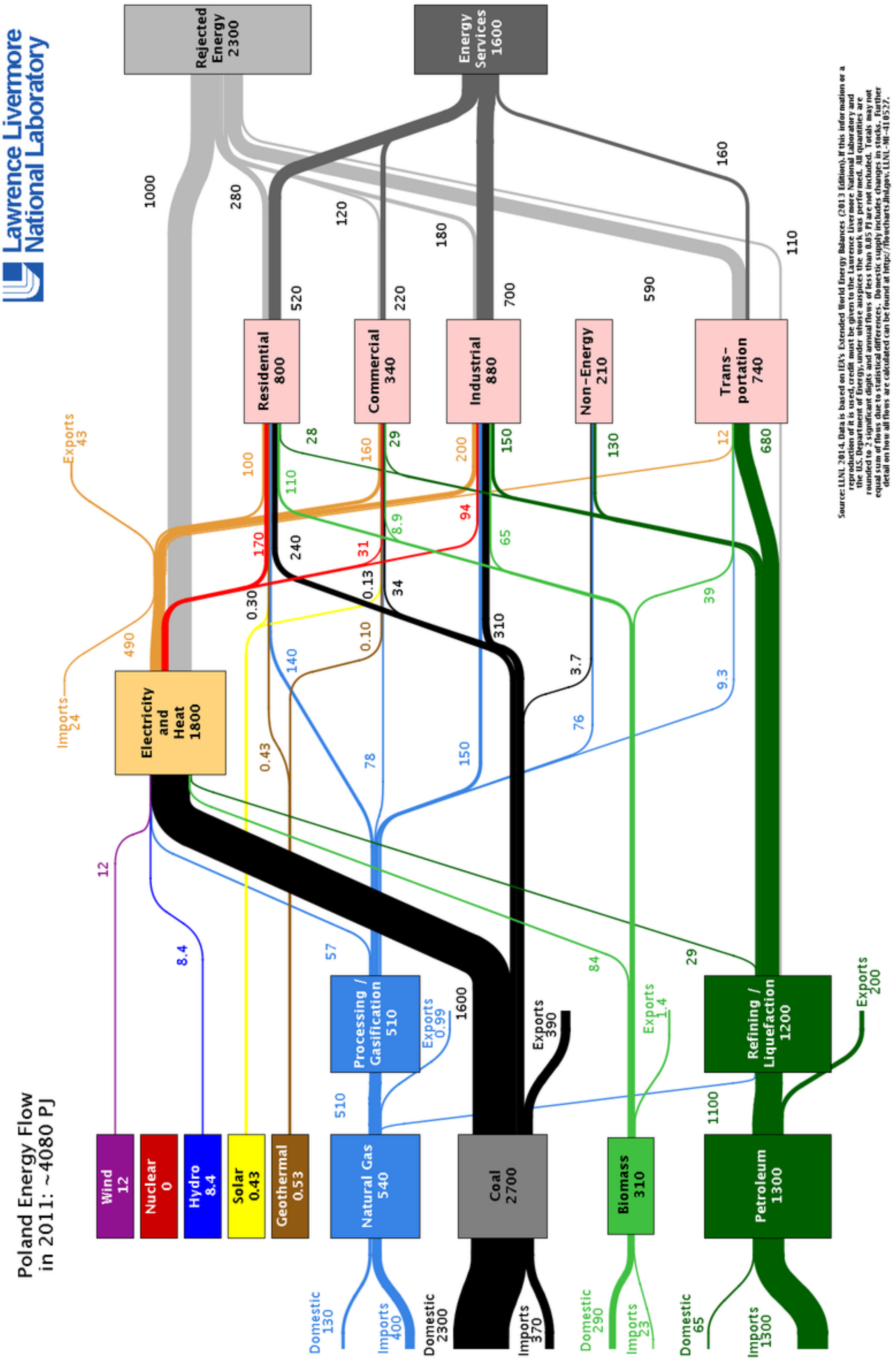

Figure A17. Poland energy flow between energy source and application
(Source: Lawrence Livermore National Laboratory Energy Flow Charts)

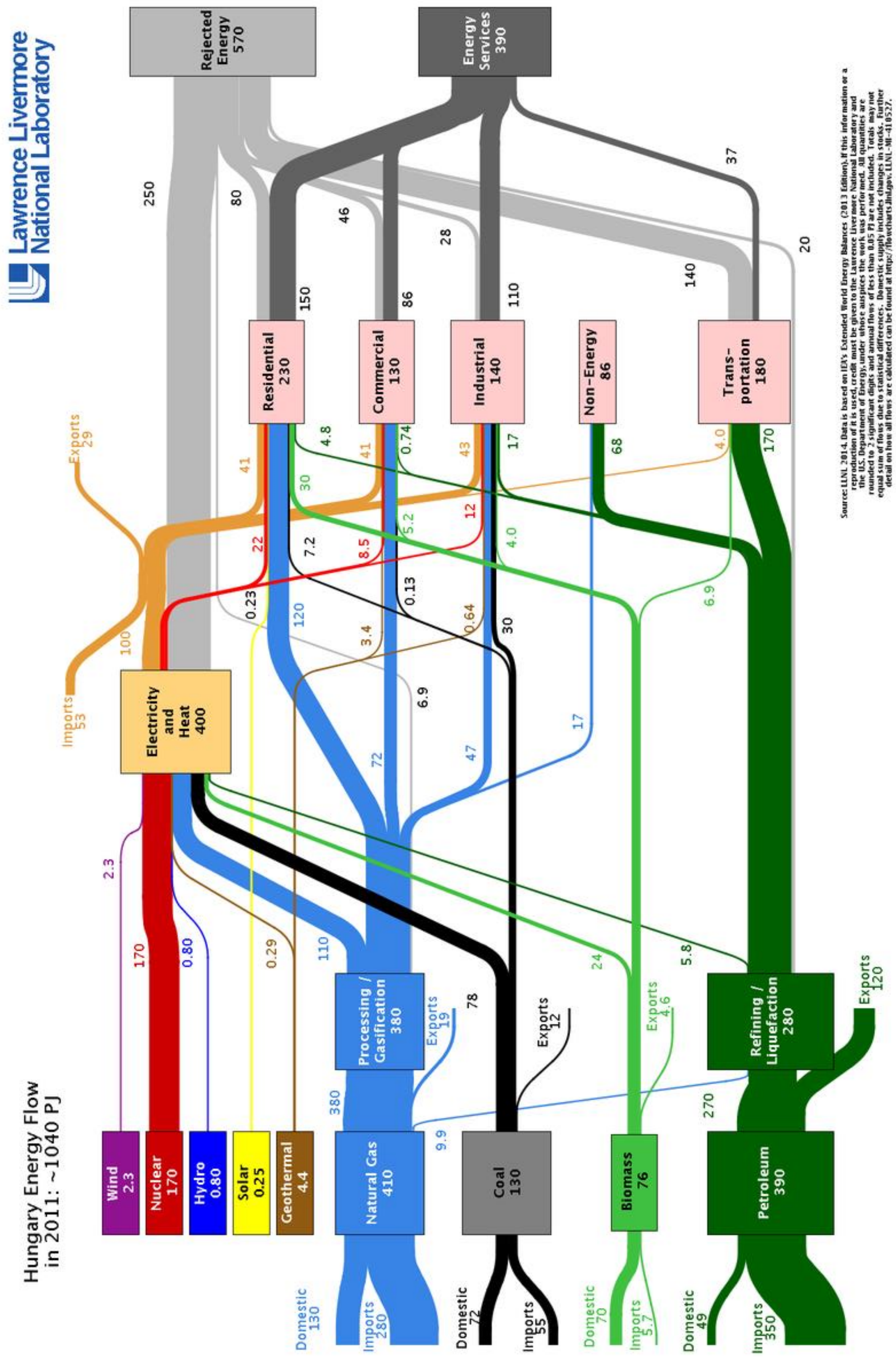

Figure A18. Hungary energy flow between energy source and application (Source: Lawrence Livermore National Laboratory Energy Flow Charts) (Copyright License: https://creativecommons.org/licenses/by-nc-sa/4.0/)

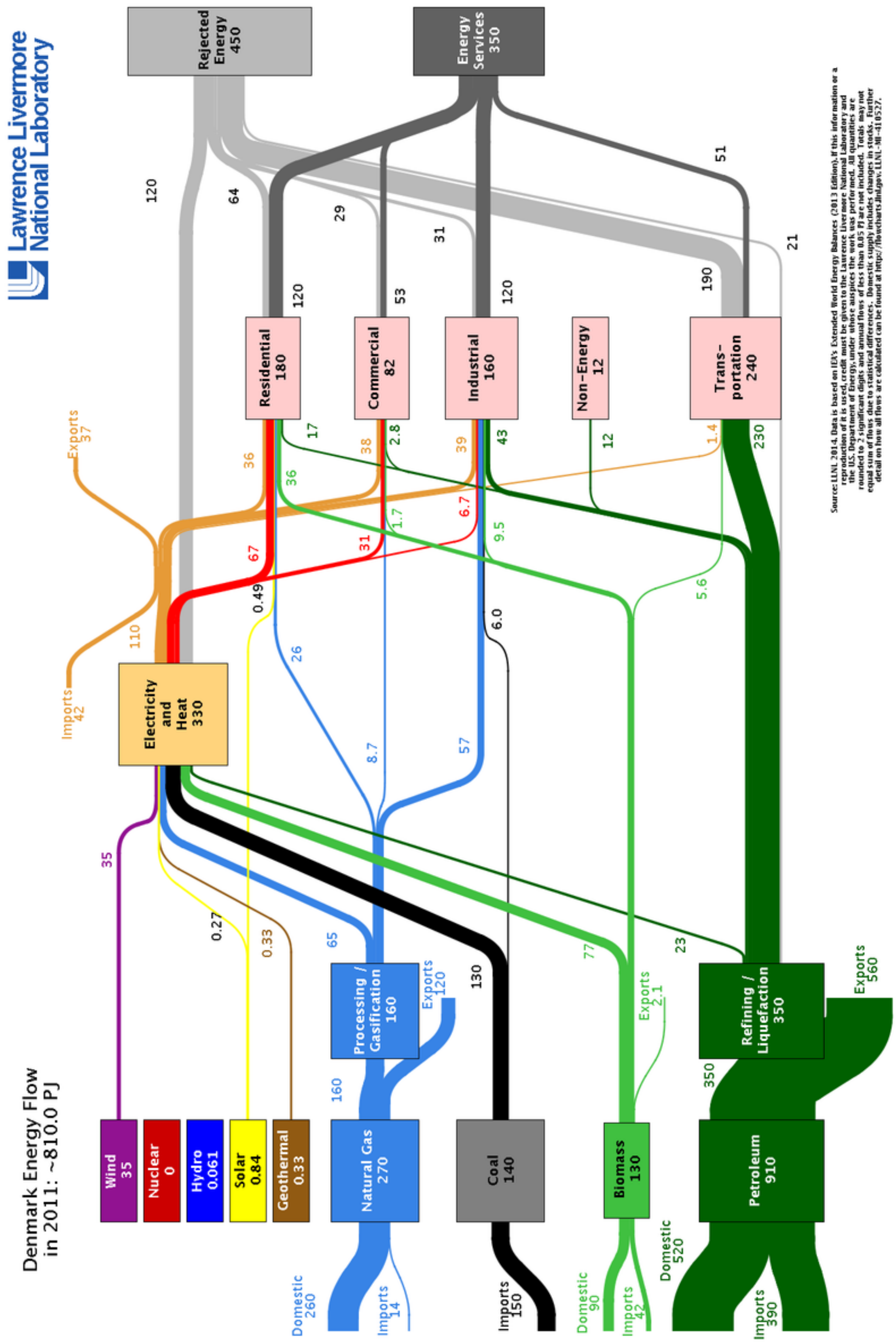

Figure A19. Denmark energy flow between energy source and application (Source: Lawrence Livermore National Laboratory Energy Flow Charts) (Copyright License: https://creativecommons.org/licenses/by-nc-sa/4.0/)

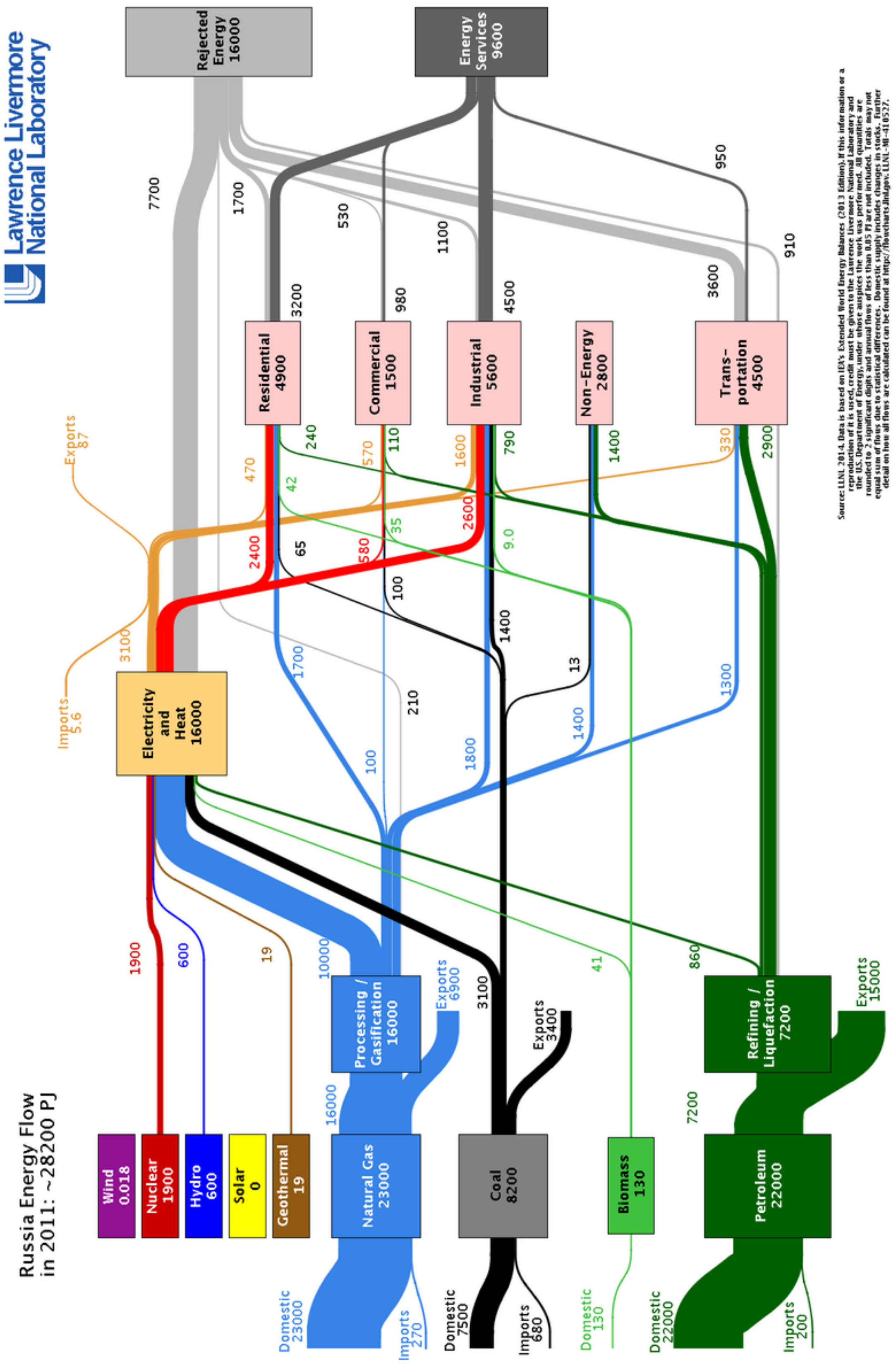

Figure A20. Russia energy flow between energy source and application (Source: Lawrence Livermore National Laboratory Energy Flow Charts) (Copyright License: https://creativecommons.org/licenses/by-nc-sa/4.0/)

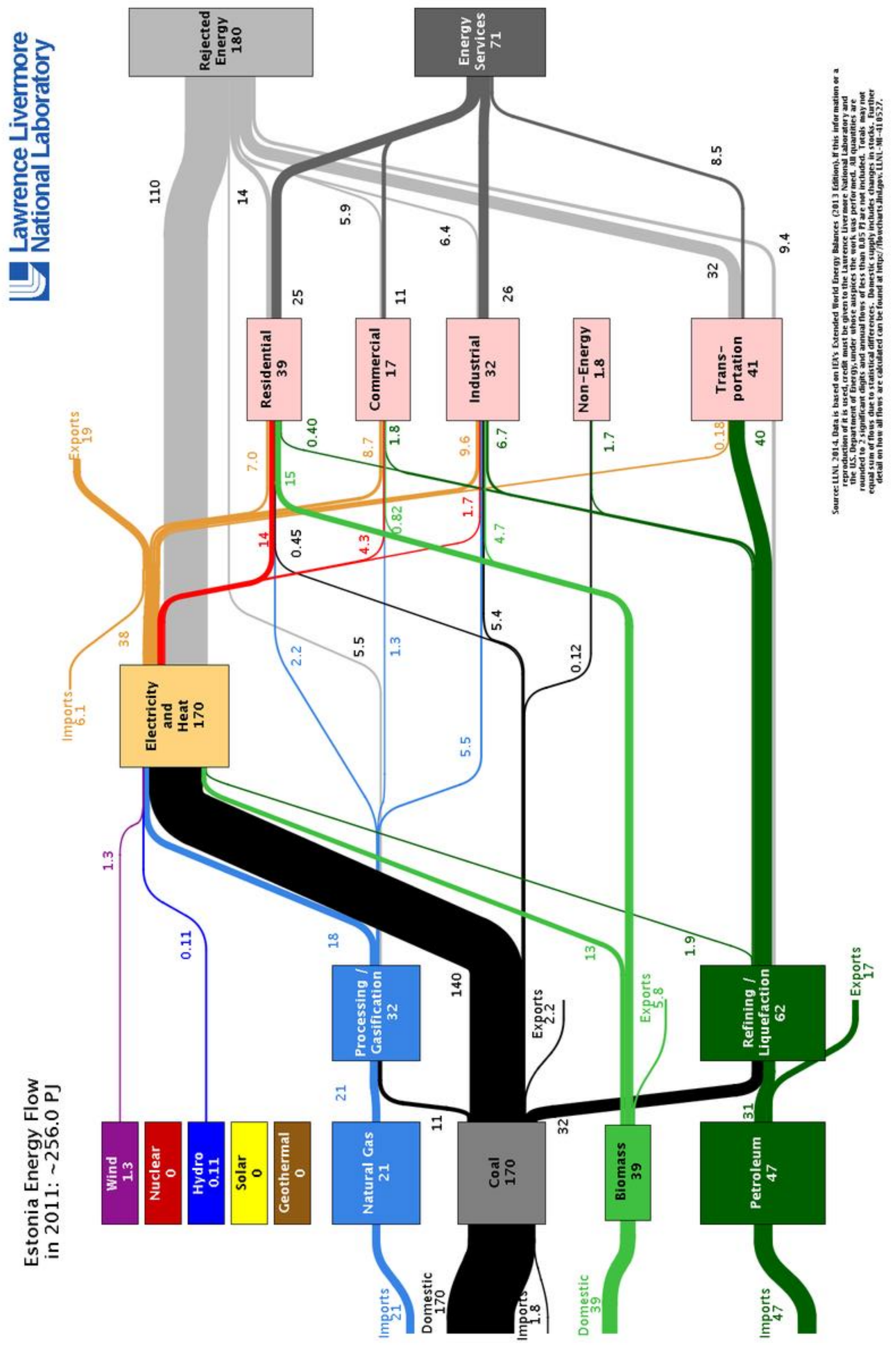

Figure A21. Estonia energy flow between energy source and application (Source: Lawrence Livermore National Laboratory Energy Flow Charts) (Copyright License: https://creativecommons.org/licenses/by-nc-sa/4.0/)

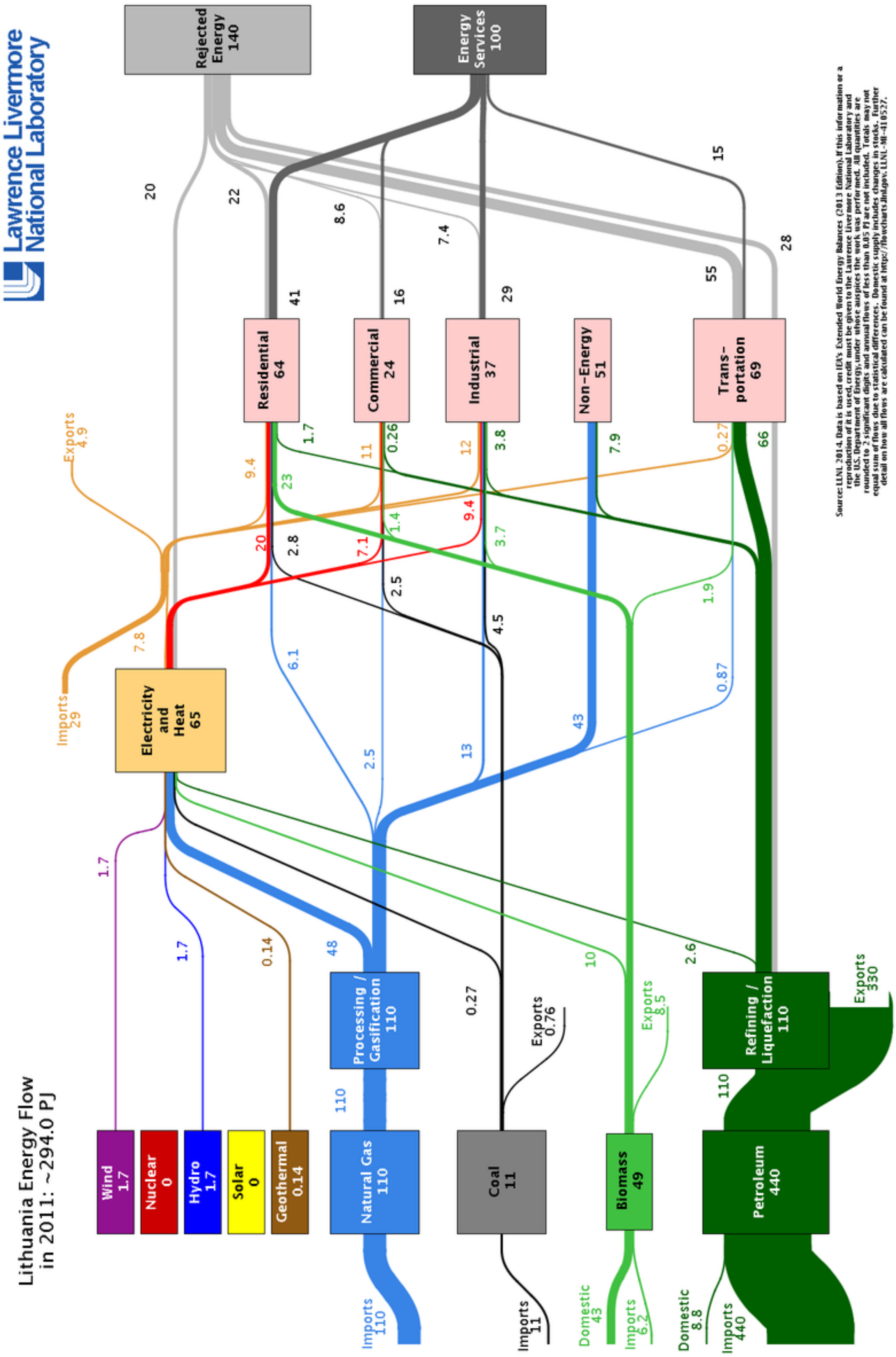

Figure A22. Lithuania energy flow between energy source and application
(Source: Lawrence Livermore National Laboratory Energy Flow Charts)

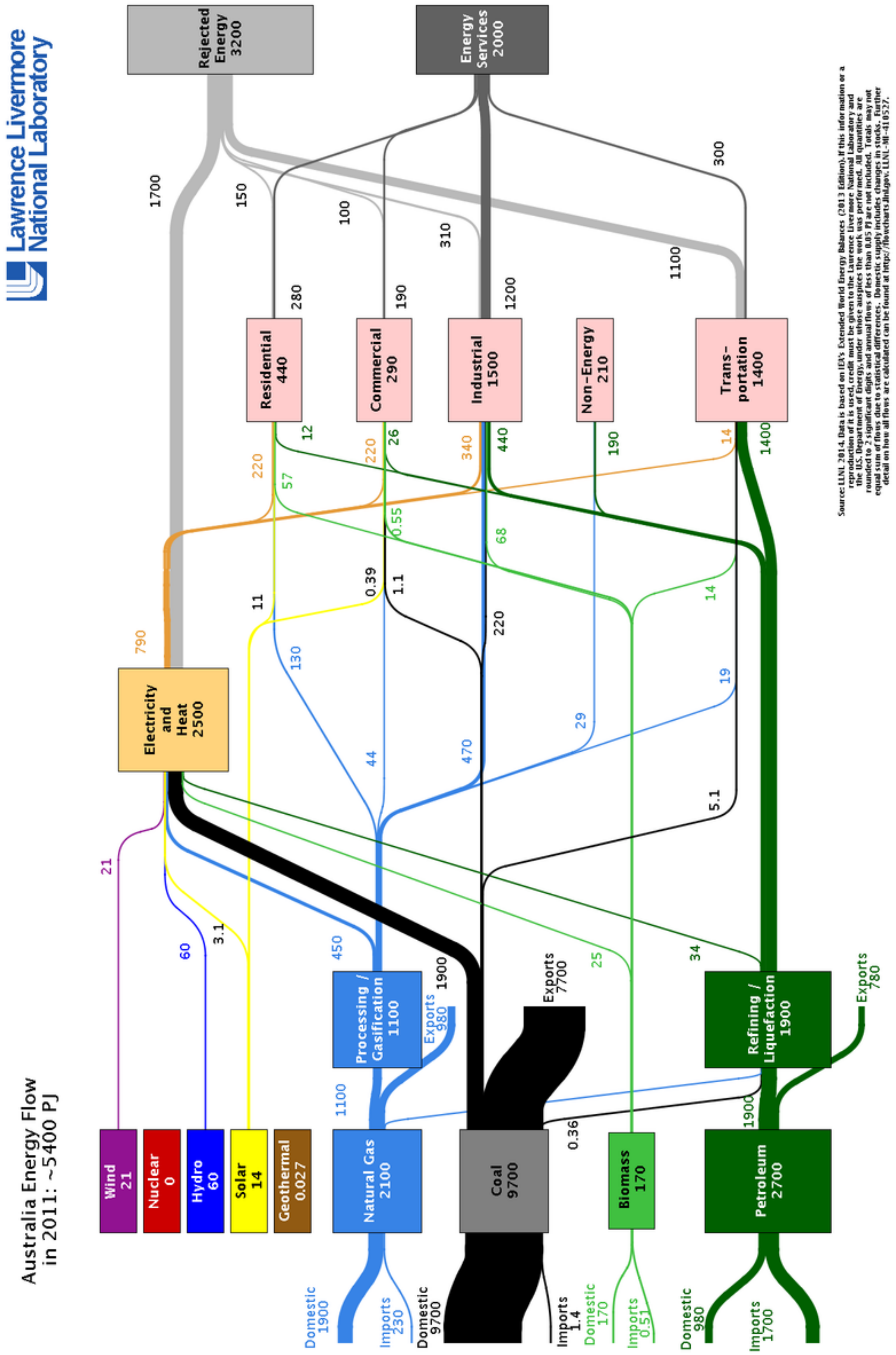

Figure A23. Australia energy flow between energy source and application
(Source: Lawrence Livermore National Laboratory Energy Flow Charts)
(Copyright License: https://creativecommons.org/licenses/by-nc-sa/4.0/)

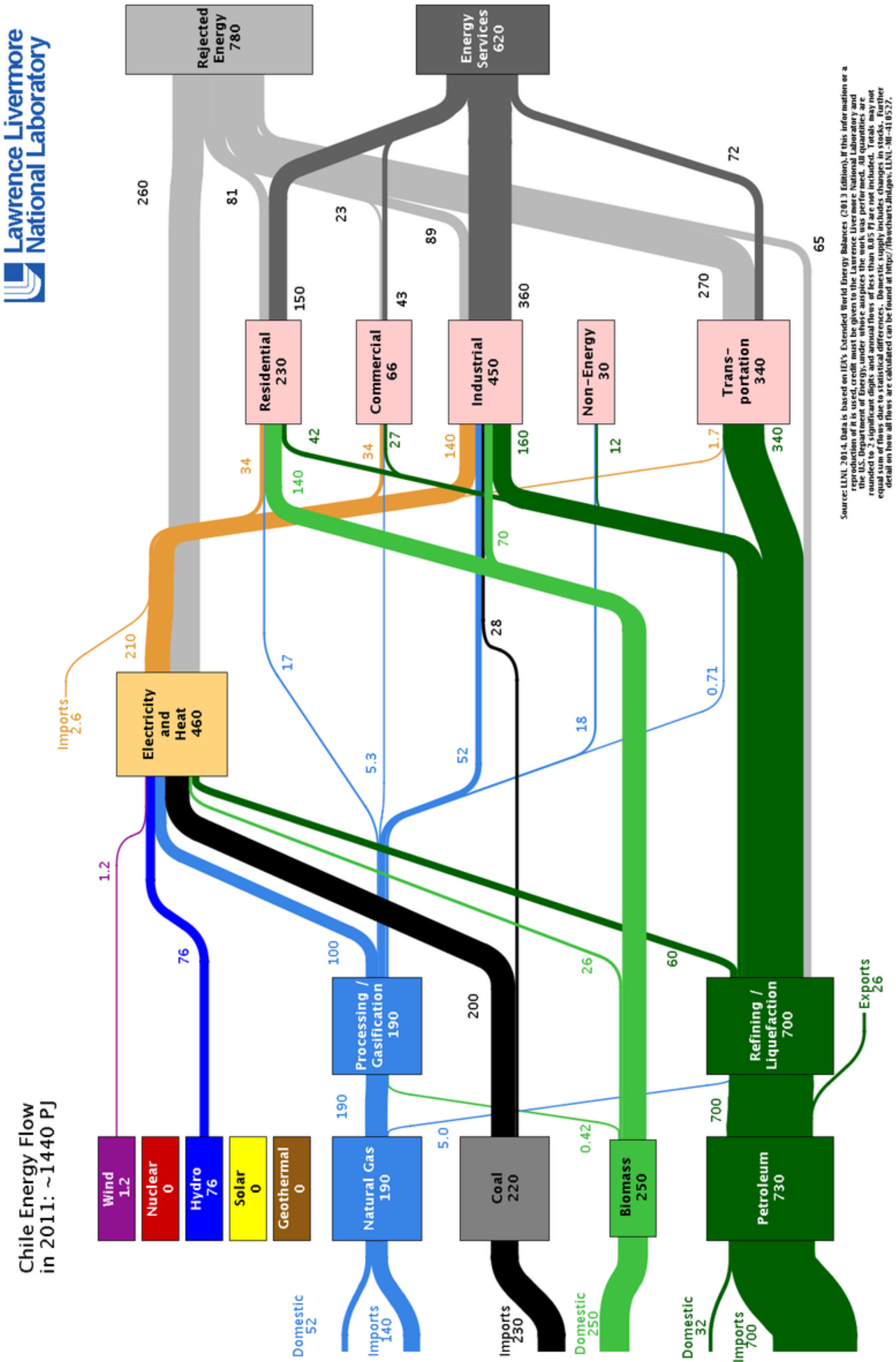

Figure A24. Chile energy flow between energy source and application (Source: Lawrence Livermore National Laboratory Energy Flow Charts) (Copyright License: https://creativecommons.org/licenses/by-nc-sa/4.0/)

25 APPENDIX B - REFINED PETROLEUM PRODUCTS CONSUMPTION

Table B1 (Part 1 of 5). Global refined petroleum products - consumption is the country's total consumption of refined petroleum products, in barrels per day (bbl/day). (Source: Central Intelligence Agnecy - World Fact Book)

(https://www.cia.gov/library/publications/the-world-factbook/rankorder/2246rank.html)

Rank	Nation State	Petroleum Conumption (Barrels/Day)	Global Market Share (%)	Date of estimate according to source
	GLOBAL TOTAL	**109 265 942**		
1	UNITED STATES	19 690 000	18,02 %	2015 EST.
2	EUROPEAN UNION	12 890 000	11,80 %	2015 EST.
3	CHINA	11 750 000	10,75 %	2015 EST.
4	INDIA	4 489 000	4,11 %	2016 EST.
5	JAPAN	4 026 000	3,68 %	2016 EST.
6	RUSSIA	3 594 000	3,29 %	2015 EST.
7	SAUDI ARABIA	3 237 000	2,96 %	2015 EST.
8	BRAZIL	3 018 000	2,76 %	2016 EST.
9	KOREA, SOUTH	2 630 000	2,41 %	2016 EST.
10	GERMANY	2 410 000	2,21 %	2016 EST.
11	CANADA	2 379 000	2,18 %	2016 EST.
12	MEXICO	2 027 000	1,86 %	2016 EST.
13	IRAN	1 922 000	1,76 %	2015 EST.
14	FRANCE	1 661 000	1,52 %	2016 EST.
15	INDONESIA	1 615 000	1,48 %	2016 EST.
16	UNITED KINGDOM	1 586 000	1,45 %	2016 EST.
17	SINGAPORE	1 582 000	1,45 %	2015 EST.
18	SPAIN	1 287 000	1,18 %	2016 EST.
19	THAILAND	1 272 000	1,16 %	2015 EST.
20	ITALY	1 253 000	1,15 %	2016 EST.
21	AUSTRALIA	1 100 000	1,01 %	2016 EST.
22	NETHERLANDS	973 000	0,89 %	2016 EST.
23	TAIWAN	955 300	0,87 %	2015 EST.
24	TURKEY	943 700	0,86 %	2016 EST.
25	UNITED ARAB EMIRATES	901 000	0,82 %	2015 EST.
26	IRAQ	850 000	0,78 %	2015 EST.
27	ARGENTINA	803 000	0,73 %	2015 EST.
28	EGYPT	802 000	0,73 %	2015 EST.
29	MALAYSIA	760 000	0,70 %	2015 EST.
30	VENEZUELA	747 000	0,68 %	2015 EST.
31	BELGIUM	662 400	0,61 %	2016 EST.
32	SOUTH AFRICA	660 000	0,60 %	2015 EST.
33	POLAND	578 200	0,53 %	2016 EST.
34	PAKISTAN	517 000	0,47 %	2015 EST.
35	KUWAIT	500 000	0,46 %	2016 EST.
36	PHILIPPINES	455 500	0,42 %	2017 EST.
37	ALGERIA	428 000	0,39 %	2015 EST.
38	VIETNAM	422 000	0,39 %	2015 EST.
39	HONG KONG	388 500	0,36 %	2015 EST.
40	COLOMBIA	345 000	0,32 %	2015 EST.
41	CHILE	337 400	0,31 %	2016 EST.
42	SWEDEN	320 200	0,29 %	2016 EST.
43	NIGERIA	316 000	0,29 %	2015 EST.
44	GREECE	299 600	0,27 %	2016 EST.
45	MOROCCO	286 000	0,26 %	2015 EST.
46	QATAR	280 000	0,26 %	2015 EST.
47	ECUADOR	274 000	0,25 %	2015 EST.

Table B1 (Part 2 of 5). Global refined petroleum products - consumption is the country's total consumption of refined petroleum products, in barrels per day (bbl/day). (Source: Central Intelligence Agnecy - World Fact Book)

(https://www.cia.gov/library/publications/the-world-factbook/rankorder/2246rank.html)

Rank	Nation State	Petroleum Conumption (Barrels/Day)	Global Market Share (%)	Date of estimate according to source
48	AUSTRIA	267 500	0,24 %	2016 EST.
49	LIBYA	262 000	0,24 %	2015 EST.
50	UKRAINE	248 000	0,23 %	2015 EST.
51	PERU	240 000	0,22 %	2015 EST.
52	PORTUGAL	234 700	0,21 %	2016 EST.
53	NORWAY	227 700	0,21 %	2016 EST.
54	SWITZERLAND	217 400	0,20 %	2016 EST.
55	FINLAND	200 700	0,18 %	2016 EST.
56	ISRAEL	199 900	0,18 %	2016 EST.
57	KAZAKHSTAN	186 300	0,17 %	2016 EST.
58	ROMANIA	182 000	0,17 %	2015 EST.
59	CZECHIA	180 400	0,17 %	2016 EST.
60	CUBA	180 000	0,16 %	2015 EST.
61	OMAN	176 000	0,16 %	2015 EST.
62	BELARUS	172 000	0,16 %	2015 EST.
63	NEW ZEALAND	167 700	0,15 %	2016 EST.
64	JORDAN	160 000	0,15 %	2015 EST.
65	DENMARK	158 200	0,14 %	2016 EST.
66	TURKMENISTAN	158 000	0,14 %	2015 EST.
67	HUNGARY	157 200	0,14 %	2016 EST.
68	PUERTO RICO	155 000	0,14 %	2015 EST.
69	IRELAND	151 700	0,14 %	2016 EST.
70	PANAMA	144 000	0,13 %	2015 EST.
71	LEBANON	143 000	0,13 %	2015 EST.
72	ANGOLA	142 000	0,13 %	2015 EST.
73	YEMEN	140 000	0,13 %	2015 EST.
74	SYRIA	140 000	0,13 %	2015 EST.
75	VIRGIN ISLANDS	132 000	0,12 %	2015 EST.
76	AFGHANISTAN	130 000	0,12 %	2015 EST.
77	DOMINICAN REPUBLIC	114 000	0,10 %	2015 EST.
78	SUDAN	110 000	0,101 %	2015 EST.
79	SRI LANKA	107 000	0,098 %	2015 EST.
80	BANGLADESH	107 000	0,098 %	2015 EST.
81	AZERBAIJAN	101 000	0,092 %	2015 EST.
82	TUNISIA	98 000	0,090 %	2015 EST.
83	GUATEMALA	94 770	0,087 %	2017 EST.
84	KENYA	93 000	0,085 %	2015 EST.
85	BURMA	91 000	0,083 %	2015 EST.
86	BULGARIA	89 000	0,081 %	2015 EST.
87	BOLIVIA	85 580	0,078 %	2017 EST.
88	SLOVAKIA	84 290	0,077 %	2016 EST.
89	SVALBARD	80 250	0,073 %	2013 EST.
90	CURACAO	72 000	0,066 %	2010 EST.
91	GIBRALTAR	70 000	0,064 %	2015 EST.
92	SERBIA	66 230	0,061 %	2016 EST.
93	ETHIOPIA	65 000	0,059 %	2015 EST.
94	GHANA	64 320	0,059 %	2016 EST.
95	CROATIA	63 850	0,058 %	2016 EST.
96	UZBEKISTAN	61 000	0,056 %	2015 EST.
97	TANZANIA	60 000	0,055 %	2015 EST.
98	BAHRAIN	58 000	0,053 %	2015 EST.
99	JAMAICA	57 600	0,053 %	2016 EST.

Table B1 (Part 3 of 5). Global refined petroleum products - consumption is the country's total consumption of refined petroleum products, in barrels per day (bbl/day). (Source: Central Intelligence Agnecy - World Fact Book)

(https://www.cia.gov/library/publications/the-world-factbook/rankorder/2246rank.html)

Rank	Nation State	Petroleum Conumption (Barrels/Day)	Global Market Share (%)	Date of estimate according to source
100	LUXEMBOURG	56 120	0,051 %	2016 EST.
101	URUGUAY	54 000	0,049 %	2015 EST.
102	COSTA RICA	54 000	0,049 %	2015 EST.
103	LITHUANIA	53 000	0,049 %	2015 EST.
104	SLOVENIA	52 300	0,048 %	2016 EST.
105	HONDURAS	52 000	0,048 %	2015 EST.
106	TRINIDAD AND TOBAGO	46 000	0,042 %	2015 EST.
107	CYPRUS	46 000	0,042 %	2015 EST.
108	BENIN	44 000	0,040 %	2015 EST.
109	SENEGAL	44 000	0,040 %	2015 EST.
110	COTE D'IVOIRE	43 000	0,039 %	2015 EST.
111	MALTA	42 000	0,038 %	2015 EST.
112	PAPUA NEW GUINEA	42 000	0,038 %	2015 EST.
113	CAMEROON	42 000	0,038 %	2015 EST.
114	CAMBODIA	39 000	0,036 %	2015 EST.
115	PARAGUAY	38 000	0,035 %	2015 EST.
116	LATVIA	37 680	0,034 %	2016 EST.
117	EL SALVADOR	36 230	0,033 %	2017 EST.
118	KYRGYZSTAN	33 000	0,030 %	2015 EST.
119	NEPAL	32 000	0,029 %	2015 EST.
120	BOSNIA AND HERZEGOVINA	31 000	0,028 %	2015 EST.
121	NICARAGUA	30 000	0,027 %	2015 EST.
122	CONGO, DEMOCRATIC REPUBLIC OF THE	30 000	0,027 %	2015 EST.
123	ESTONIA	29 140	0,027 %	2016 EST.
124	ZIMBABWE	29 000	0,027 %	2015 EST.
125	UGANDA	27 000	0,025 %	2015 EST.
126	ALBANIA	27 000	0,025 %	2014 EST.
127	MAURITIUS	26 000	0,024 %	2015 EST.
128	MONGOLIA	26 000	0,024 %	2015 EST.
129	NAMIBIA	25 000	0,023 %	2015 EST.
130	BAHAMAS, THE	24 000	0,022 %	2015 EST.
131	TAJIKISTAN	23 000	0,021 %	2015 EST.
132	BOTSWANA	23 000	0,021 %	2015 EST.
133	GEORGIA	23 000	0,021 %	2015 EST.
134	MOZAMBIQUE	23 000	0,021 %	2015 EST.
135	ZAMBIA	23 000	0,021 %	2015 EST.
136	BURKINA FASO	22 000	0,020 %	2015 EST.
137	GABON	22 000	0,020 %	2015 EST.
138	MOLDOVA	21 720	0,020 %	2017 EST.
139	MACEDONIA	20 700	0,019 %	2016 EST.
140	ICELAND	19 800	0,018 %	2016 EST.
141	WEST BANK	19 000	0,017 %	2015 EST.
142	HAITI	19 000	0,017 %	2015 EST.
143	BRUNEI	18 000	0,016 %	2015 EST.
144	CONGO, REPUBLIC OF THE	18 000	0,016 %	2015 EST.
145	KOREA, NORTH	18 000	0,016 %	2015 EST.
146	NEW CALEDONIA	17 000	0,016 %	2015 EST.
147	GUINEA	16 000	0,015 %	2015 EST.
148	FIJI	16 000	0,015 %	2015 EST.
149	MAURITANIA	16 000	0,015 %	2015 EST.
150	GUAM	15 400	0,014 %	2015 EST.

Table B1 (Part 4 of 5). Global refined petroleum products - consumption is the country's total consumption of refined petroleum products, in barrels per day (bbl/day). (Source: Central Intelligence Agnecy - World Fact Book)

(https://www.cia.gov/library/publications/the-world-factbook/rankorder/2246rank.html)

Rank	Nation State	Petroleum Conumption (Barrels/Day)	Global Market Share (%)	Date of estimate according to source
151	MADAGASCAR	15 000	0,014 %	2015 EST.
152	TOGO	14 000	0,013 %	2015 EST.
153	SURINAME	14 000	0,013 %	2015 EST.
154	KOSOVO	13 570	0,012 %	2017 EST.
155	NIGER	13 000	0,012 %	2015 EST.
156	GUYANA	13 000	0,012 %	2015 EST.
157	MACAU	12 700	0,012 %	2015 EST.
158	BARBADOS	12 000	0,01098 %	2015 EST.
159	MALDIVES	11 000	0,01007 %	2015 EST.
160	SOUTH SUDAN	11 000	0,01007 %	2015 EST.
161	ARMENIA	8 000	0,00732 %	2015 EST.
162	ARUBA	7 500	0,00686 %	2015 EST.
163	MONTENEGRO	7 500	0,00686 %	2016 EST.
164	MALI	7 500	0,00686 %	2015 EST.
165	SIERRA LEONE	7 500	0,00686 %	2015 EST.
166	MALAWI	7 000	0,00641 %	2015 EST.
167	FRENCH POLYNESIA	7 000	0,00641 %	2015 EST.
168	LIBERIA	6 600	0,00604 %	2015 EST.
169	SEYCHELLES	6 500	0,00595 %	2015 EST.
170	DJIBOUTI	6 000	0,00549 %	2015 EST.
171	GREENLAND	6 000	0,00549 %	2015 EST.
172	RWANDA	6 000	0,00549 %	2015 EST.
173	CABO VERDE	6 000	0,00549 %	2015 EST.
174	SOMALIA	5 700	0,00522 %	2015 EST.
175	EQUATORIAL GUINEA	5 200	0,00476 %	2015 EST.
176	ESWATINI	5 000	0,00458 %	2015 EST.
177	ANTIGUA AND BARBUDA	5 000	0,00458 %	2015 EST.
178	LESOTHO	5 000	0,00458 %	2015 EST.
179	CAYMAN ISLANDS	4 000	0,00366 %	2015 EST.
180	FAROE ISLANDS	3 947	0,00361 %	2015 EST.
181	BELIZE	3 700	0,00339 %	2015 EST.
182	ERITREA	3 600	0,00329 %	2015 EST.
183	GAMBIA, THE	3 600	0,00329 %	2015 EST.
184	LAOS	3 500	0,00320 %	2015 EST.
185	BERMUDA	3 300	0,00302 %	2015 EST.
186	SAINT LUCIA	3 100	0,00284 %	2015 EST.
187	TIMOR-LESTE	3 100	0,00284 %	2015 EST.
188	CENTRAL AFRICAN REPUBLIC	3 000	0,00275 %	2015 EST.
189	BHUTAN	3 000	0,00275 %	2015 EST.
190	GUINEA-BISSAU	2 500	0,00229 %	2015 EST.
191	AMERICAN SAMOA	2 375	0,00217 %	2015 EST.
192	CHAD	2 200	0,00201 %	2015 EST.
193	MARSHALL ISLANDS	2 000	0,00183 %	2015 EST.
194	SAINT KITTS AND NEVIS	1 900	0,00174 %	2015 EST.
195	WESTERN SAHARA	1 700	0,00156 %	2015 EST.
196	SOLOMON ISLANDS	1 600	0,00146 %	2015 EST.
197	SAINT VINCENT AND THE GRENADINES	1 600	0,00146 %	2015 EST.
198	TONGA	1 500	0,00137 %	2015 EST.
199	BURUNDI	1 500	0,00137 %	2015 EST.
200	TURKS AND CAICOS ISLANDS	1 340	0,00123 %	2015 EST.

Table B1 (Part 5 of 5). Global refined petroleum products - consumption is the country's total consumption of refined petroleum products, in barrels per day (bbl/day). (Source: Central Intelligence Agnecy - World Fact Book)

(https://www.cia.gov/library/publications/the-world-factbook/rankorder/2246rank.html)

Rank	Nation State	Petroleum Conumption (Barrels/Day)	Global Market Share (%)	Date of estimate according to source
201	COMOROS	1 300	0,00119 %	2015 EST.
202	BRITISH VIRGIN ISLANDS	1 200	0,00110 %	2015 EST.
203	SAMOA	1 100	0,00101 %	2015 EST.
204	SAO TOME AND PRINCIPE	1 000	0,00092 %	2015 EST.
205	VANUATU	1 000	0,00092 %	2015 EST.
206	DOMINICA	1 000	0,00092 %	2015 EST.
207	GRENADA	860	0,00079 %	2017 EST.
208	SAINT PIERRE AND MIQUELON	630	0,00058 %	2015 EST.
209	MONTSERRAT	570	0,00052 %	2015 EST.
210	COOK ISLANDS	530	0,00049 %	2015 EST.
211	KIRIBATI	400	0,00037 %	2015 EST.
212	NAURU	400	0,00037 %	2015 EST.
213	FALKLAND ISLANDS (ISLAS MALVINAS)	300	0,00027 %	2015 EST.
214	SAINT HELENA, ASCENSION, AND TRISTAN DA CUNHA	80	0,00007 %	2015 EST.
215	NIUE	60	0,00005 %	2015 EST.

Table B2 (Part 1 of 6). Petroleum Products Supplied by Type (Thousand Barrels per Day)
(Source: U.S. Energy Information Administration, July 2019 Monthly Energy Review)

Annual Average (year)	Asphalt and Road Oil Product Supplied ('000 bbls/day)	Aviation Gasoline Product Supplied ('000 bbls/day)	Distillate Fuel Oil Product Supplied ('000 bbls/day)	Propane Product Supplied ('000 bbls/day)	Propylene Product Supplied ('000 bbls/day)
1949	156 679	93 129	902 132	116 202	10 011
1950	179 655	108 266	1 081 877	145 606	12 544
1951	198 011	145 071	1 225 419	172 425	14 854
1952	212 989	169 391	1 303 240	183 927	15 845
1953	215 940	193 732	1 337 192	202 069	17 408
1954	229 570	177 995	1 442 047	218 756	18 845
1955	253 814	192 167	1 592 132	251 300	21 649
1956	271 675	203 833	1 682 667	274 326	23 633
1957	263 277	201 140	1 687 918	281 694	24 267
1958	280 260	223 249	1 790 208	302 598	26 068
1959	297 652	209 384	1 808 173	361 938	31 180
1960	302 120	161 240	1 872 317	385 996	33 253
1961	311 110	157 608	1 902 345	398 322	34 315
1962	331 745	142 693	2 006 589	435 026	37 477
1963	340 460	137 416	2 047 271	470 349	40 520
1964	346 175	127 208	2 050 339	501 144	43 173
1965	367 553	120 266	2 125 518	522 983	45 054
1966	386 252	105 340	2 184 603	551 630	47 522
1967	378 679	90 148	2 241 507	586 565	50 532
1968	405 003	83 672	2 389 451	659 369	47 784
1969	416 564	70 003	2 466 471	738 856	54 030
1970	446 899	54 529	2 540 304	726 791	55 041
1971	457 570	49 019	2 661 140	742 365	58 937
1972	468 104	46 243	2 912 869	832 748	68 372
1973	521 737	45 290	3 092 367	809 860	69 395
1974	481 134	44 425	2 947 715	769 313	68 918
1975	418 732	38 540	2 850 879	730 445	59 934
1976	410 956	36 508	3 133 046	766 733	70 071
1977	436 129	38 170	3 351 584	759 643	73 573
1978	478 759	38 781	3 431 660	714 566	77 156
1979	476 038	38 162	3 310 838	834 045	79 271
1980	396 169	34 828	2 866 052	741 815	71 525
1981	341 759	30 539	2 828 701	769 324	67 825
1982	342 427	25 497	2 670 863	831 017	52 836
1983	373 262	25 873	2 690 210	780 968	61 049
1984	408 475	23 750	2 844 858	766 940	66 396
1985	425 031	27 312	2 868 020	810 260	72 315
1986	448 254	31 981	2 914 358	750 537	80 085
1987	466 534	24 770	2 976 473	839 860	84 252
1988	467 859	26 516	3 121 611	830 228	92 578
1989	452 504	25 827	3 156 779	888 712	101 575
1990	483 123	24 411	3 020 557	811 737	105 184

Table B2 (Part 2 of 6). Petroleum Products Supplied by Type (Thousand Barrels per Day)
(Source: U.S. Energy Information Administration, July 2019 Monthly Energy Review)

Annual Average (year)	Asphalt and Road Oil Product Supplied ('000 bbls/day)	Aviation Gasoline Product Supplied ('000 bbls/day)	Distillate Fuel Oil Product Supplied ('000 bbls/day)	Propane Product Supplied ('000 bbls/day)	Propylene Product Supplied ('000 bbls/day)
1991	444 456	22 644	2 920 770	856 811	124 715
1992	453 817	22 221	2 978 887	896 377	135 929
1993	474 382	20 838	3 041 212	872 643	133 400
1994	484 248	20 699	3 162 239	939 696	142 353
1995	486 419	21 482	3 206 627	938 414	157 153
1996	484 167	20 219	3 365 243	978 366	157 227
1997	505 159	21 545	3 435 447	964 723	205 153
1998	521 255	19 266	3 461 444	929 405	190 296
1999	546 795	21 260	3 571 997	1 038 041	208 038
2000	525 235	19 639	3 722 172	1 010 710	224 098
2001	518 907	18 962	3 846 803	931 529	210 008
2002	511 926	18 307	3 775 907	1 014 964	233 000
2003	503 496	16 403	3 927 048	976 942	237 696
2004	536 833	16 910	4 058 262	1 021 082	254 822
2005	546 309	19 195	4 118 011	985 825	243 449
2006	520 682	18 153	4 169 125	947 181	267 655
2007	494 207	17 145	4 195 911	983 349	251 518
2008	416 659	15 309	3 945 420	923 858	230 347
2009	360 459	14 414	3 631 081	892 966	267 090
2010	362 394	14 679	3 800 314	851 621	308 019
2011	354 847	14 685	3 898 854	851 446	301 227
2012	340 376	13 593	3 741 416	862 377	312 404
2013	323 411	12 134	3 827 465	968 591	306 534
2014	327 246	11 775	4 037 248	869 645	297 178
2015	343 358	11 474	3 995 237	864 761	297 178
2016	351 356	11 077	3 877 252	833 043	296 773
2017	350 591	11 370	3 932 188	802 802	314 419
2018	329 090	12 151	4 133 572	856 660	304 540

Table B2 (Part 3 of 6). Petroleum Products Supplied by Type (Thousand Barrels per Day)
(Source: U.S. Energy Information Administration, July 2019 Monthly Energy Review)

Annual Average (year)	Propane/Propylene Product Supplied ('000 bbls/day)	Total Hydrocarbon Gas Liquids Product Supplied ('000 bbls/day)	Jet Fuel Product Supplied ('000 bbls/day)	Kerosene Product Supplied ('000 bbls/day)	Lubricants Product Supplied ('000 bbls/day)
1949	126 213	186 953	data not availavle	281 293	90 688
1950	158 150	234 260	data not availavle	322 860	106 447
1951	187 280	277 408	data not availavle	337 647	115 868
1952	199 772	295 913	54 989	331 292	104 276
1953	219 477	325 101	94 474	313 608	110 951
1954	237 602	351 948	125 622	324 140	105 581
1955	272 949	404 307	154 208	320 022	116 375
1956	297 959	441 352	197 145	320 557	120 036
1957	305 961	453 205	215 534	279 430	112 918
1958	328 667	486 838	274 630	293 742	108 142
1959	393 118	582 307	325 096	261 608	117 474
1960	419 249	621 014	371 481	271 421	116 601
1961	432 637	640 844	415 405	266 430	113 792
1962	472 503	699 896	489 137	268 584	119 493
1963	510 869	756 726	521 844	265 688	119 455
1964	544 317	806 270	558 068	253 383	125 104
1965	568 037	841 405	601 732	267 348	129 096
1966	599 152	887 496	669 551	277 033	134 107
1967	637 097	943 701	824 027	274 189	120 885
1968	707 153	1 053 937	954 585	281 243	132 423
1969	792 886	1 220 893	991 044	274 981	133 649
1970	781 832	1 224 153	967 063	262 942	136 145
1971	801 302	1 251 375	1 010 200	249 088	135 126
1972	901 119	1 420 355	1 045 055	234 566	144 298
1973	879 255	1 453 781	1 059 252	216 205	162 112
1974	838 231	1 422 441	993 425	176 307	155 260
1975	790 380	1 351 721	1 000 795	158 877	137 449
1976	836 804	1 406 811	987 317	169 180	152 273
1977	833 216	1 421 562	1 039 060	175 238	159 753
1978	791 722	1 412 751	1 056 586	175 458	171 559
1979	913 317	1 664 099	1 075 888	187 863	179 518
1980	813 340	1 590 148	1 067 557	158 388	159 421
1981	837 149	1 582 226	1 007 444	126 865	153 309
1982	883 853	1 599 648	1 012 552	128 666	139 805
1983	842 017	1 537 184	1 045 981	126 992	146 373
1984	833 336	1 701 544	1 175 479	115 259	155 661
1985	882 575	1 721 451	1 218 362	113 882	145 468
1986	830 622	1 628 617	1 307 342	98 251	142 236
1987	924 112	1 749 285	1 384 987	94 556	160 806
1988	922 806	1 779 530	1 448 660	96 173	154 647
1989	990 288	1 789 909	1 489 440	84 256	159 056
1990	916 921	1 704 518	1 522 267	42 530	163 680

Table B2 (Part 4 of 6). Petroleum Products Supplied by Type (Thousand Barrels per Day)
(Source: U.S. Energy Information Administration, July 2019 Monthly Energy Review)

Annual Average (year)	Propane/Propylene Product Supplied ('000 bbls/day)	Total Hydrocarbon Gas Liquids Product Supplied ('000 bbls/day)	Jet Fuel Product Supplied ('000 bbls/day)	Kerosene Product Supplied ('000 bbls/day)	Lubricants Product Supplied ('000 bbls/day)
1991	981 526	1 862 944	1 471 441	46 295	146 429
1992	1 032 306	1 946 032	1 454 292	41 402	148 882
1993	1 006 043	1 931 066	1 469 339	49 627	152 016
1994	1 082 049	2 080 571	1 526 858	48 945	158 887
1995	1 095 568	2 099 778	1 514 422	54 041	156 159
1996	1 135 593	2 221 803	1 577 954	61 735	151 137
1997	1 169 877	2 232 868	1 598 529	65 879	160 096
1998	1 119 701	2 126 447	1 621 934	78 055	167 597
1999	1 246 079	2 411 436	1 672 605	72 937	169 351
2000	1 234 809	2 433 776	1 725 284	67 396	166 355
2001	1 141 537	2 200 386	1 655 401	72 340	152 836
2002	1 247 964	2 295 310	1 613 649	43 340	151 025
2003	1 214 638	2 205 068	1 577 834	54 625	139 625
2004	1 275 904	2 264 030	1 629 964	64 317	141 068
2005	1 229 274	2 146 050	1 678 990	69 809	140 716
2006	1 214 835	2 135 483	1 632 906	53 683	137 096
2007	1 234 866	2 191 323	1 622 386	32 140	141 575
2008	1 154 205	2 044 387	1 538 554	14 229	131 078
2009	1 160 057	2 126 941	1 393 190	17 548	118 171
2010	1 159 640	2 265 268	1 431 649	19 929	131 296
2011	1 152 674	2 241 453	1 425 343	12 241	124 572
2012	1 174 782	2 297 426	1 398 133	5 276	114 299
2013	1 275 125	2 501 189	1 434 398	5 197	121 267
2014	1 166 823	2 442 439	1 469 928	8 996	126 494
2015	1 161 939	2 551 652	1 548 242	6 386	137 753
2016	1 129 817	2 536 162	1 614 227	8 670	130 418
2017	1 117 221	2 642 863	1 682 176	5 177	120 556
2018	1 161 200	2 986 920	1 710 960	5 085	112 212

Table B2 (Part 5 of 6). Petroleum Products Supplied by Type (Thousand Barrels per Day)
(Source: U.S. Energy Information Administration, July 2019 Monthly Energy Review)

Annual Average (year)	Motor Gasoline Product Supplied ('000 bbls/day)	Petroleum Coke Product Supplied ('000 bbls/day)	Residual Fuel Oil Product Supplied ('000 bbls/day)	Other Petroleum Products Supplied ('000 bbls/day)	Total Petroleum Products Supplied ('000 bbls/day)
1949	2 410 195	39 526	1 358 962	243 482	**5 763 038**
1950	2 615 816	41 153	1 517 241	250 342	**6 457 918**
1951	2 840 041	39 674	1 546 293	290 699	**7 016 132**
1952	2 953 525	38 044	1 516 844	289 115	**7 269 617**
1953	3 109 762	48 216	1 535 545	315 107	**7 599 627**
1954	3 193 499	54 181	1 431 005	320 447	**7 756 033**
1955	3 463 189	66 858	1 526 184	366 093	**8 455 348**
1956	3 547 749	67 970	1 537 740	384 475	**8 775 199**
1957	3 615 170	74 044	1 503 564	402 811	**8 809 011**
1958	3 710 715	85 258	1 454 978	409 767	**9 117 789**
1959	3 859 868	97 397	1 543 737	423 805	**9 526 501**
1960	3 969 005	148 831	1 528 522	434 770	**9 797 322**
1961	4 042 866	183 929	1 503 227	438 553	**9 976 110**
1962	4 198 926	193 710	1 495 378	453 929	**10 400 079**
1963	4 334 099	189 926	1 476 504	554 074	**10 743 463**
1964	4 402 590	192 336	1 515 249	645 781	**11 022 503**
1965	4 592 614	201 718	1 608 249	656 937	**11 512 436**
1966	4 808 033	201 863	1 716 247	713 849	**12 084 373**
1967	4 958 310	205 836	1 785 986	737 077	**12 560 345**
1968	5 260 593	208 522	1 825 790	797 648	**13 392 866**
1969	5 526 014	221 452	1 977 874	837 849	**14 136 795**
1970	5 784 518	211 548	2 203 529	865 556	**14 697 186**
1971	6 014 433	218 896	2 296 014	869 633	**15 212 493**
1972	6 376 443	241 191	2 529 090	948 770	**16 366 984**
1973	6 674 400	260 701	2 822 403	999 430	**17 307 679**
1974	6 537 471	238 510	2 638 948	1 017 074	**16 652 710**
1975	6 674 600	246 707	2 461 841	981 819	**16 321 959**
1976	6 977 689	243 418	2 800 951	1 142 915	**17 461 066**
1977	7 176 822	267 764	3 071 033	1 294 304	**18 431 419**
1978	7 411 805	255 679	3 022 556	1 391 027	**18 846 622**
1979	7 034 447	246 197	2 826 184	1 473 307	**18 512 540**
1980	6 578 544	236 560	2 508 268	1 459 926	**17 055 861**
1981	6 587 526	251 693	2 087 753	1 059 881	**16 057 696**
1982	6 539 244	247 930	1 716 463	872 624	**15 295 720**
1983	6 622 149	228 661	1 420 834	1 013 615	**15 231 134**
1984	6 692 515	247 381	1 369 397	991 295	**15 725 615**
1985	6 831 126	264 487	1 202 301	908 978	**15 726 418**
1986	7 034 071	268 346	1 418 402	988 770	**16 280 627**
1987	7 205 722	298 752	1 264 394	1 038 767	**16 665 046**
1988	7 336 462	311 659	1 377 800	1 162 394	**17 283 310**
1989	7 327 861	307 253	1 370 047	1 162 220	**17 325 153**
1990	7 234 907	338 637	1 228 825	1 225 039	**16 988 496**

Table B2 (Part 6 of 6). Petroleum Products Supplied by Type (Thousand Barrels per Day)
(Source: U.S. Energy Information Administration, July 2019 Monthly Energy Review)

Annual Average (year)	Motor Gasoline Product Supplied ('000 bbls/day)	Petroleum Coke Product Supplied ('000 bbls/day)	Residual Fuel Oil Product Supplied ('000 bbls/day)	Other Petroleum Products Supplied ('000 bbls/day)	Total Petroleum Products Supplied ('000 bbls/day)
1991	7 187 518	328 357	1 157 875	1 125 107	**16 713 836**
1992	7 267 522	382 253	1 094 346	1 243 200	**17 032 855**
1993	7 476 302	365 706	1 080 171	1 176 071	**17 236 731**
1994	7 601 368	360 662	1 020 787	1 252 896	**17 718 159**
1995	7 788 644	364 740	851 811	1 180 467	**17 724 589**
1996	7 890 585	379 413	848 363	1 308 287	**18 308 904**
1997	8 016 844	377 077	796 699	1 410 160	**18 620**
1998	8 253 416	446 690	887 121	1 333 916	**18 917 140**
1999	8 430 800	476 803	830 132	1 315 220	**19 519 337**
2000	8 472 060	405 880	908 544	1 254 735	**19 701 077**
2001	8 610 027	437 060	811 173	1 324 815	**19 648 707**
2002	8 847 838	462 762	699 608	1 341 628	**19 761 304**
2003	8 934 896	454 658	772 131	1 447 722	**20 033 507**
2004	9 105 407	524 268	864 708	1 525 380	**20 731 150**
2005	9 159 264	515 212	919 976	1 488 630	**20 802 162**
2006	9 252 533	522 215	688 845	1 556 696	**20 687 418**
2007	9 285 669	490 027	722 906	1 487 089	**20 680 378**
2008	8 989 228	463 654	622 199	1 317 247	**19 497 964**
2009	8 996 521	426 538	511 118	1 175 419	**18 771 400**
2010	8 992 654	375 724	535 099	1 251 118	**19 180 123**
2011	8 752 750	361 209	461 076	1 239 669	**18 886 697**
2012	8 682 206	360 240	368 756	1 164 937	**18 486 659**
2013	8 842 984	353 716	318 555	1 226 551	**18 966 868**
2014	8 920 842	346 797	257 192	1 151 125	**19 100 082**
2015	9 178 372	349 173	259 326	1 152 538	**19 533 511**
2016	9 317 080	345 246	326 225	1 169 522	**19 687 234**
2017	9 326 536	316 227	341 710	1 228 328	**19 957 724**
2018	9 319 219	332 968	321 570	1 189 124	**20 452 870**

26 APPENDIX C – OIL CONSUMPTION DEMAND

Table C1. Global oil consumption (thousand barrels per day) (Source: BP Statistical Review of World Energy 2019)

Oil: Consumption in thousands of barrels per day*

Thousand barrels daily	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Growth rate per annum 2018	Growth rate per annum 2007-17	Share 2018
Canada	2323	2209	2358	2436	2376	2398	2442	2401	2448	2448	**2447**	◆	0.4%	2.5%
Mexico	2080	2021	2040	2065	2083	2034	1960	1939	1950	1883	**1812**	-3.8%	-1.0%	1.8%
US	19490	18771	19180	18882	18490	18961	19106	19531	19687	19958	**20456**	2.5%	-0.4%	20.5%
Total North America	23894	23001	23578	23383	22949	23393	23507	23871	24086	24289	**24714**	1.8%	-0.3%	24.8%
Argentina	540	532	594	609	636	683	673	696	686	684	**648**	-5.3%	2.6%	0.6%
Brazil	2481	2498	2714	2832	2884	3100	3210	3140	2960	3052	**3081**	0.9%	2.8%	3.1%
Chile	390	383	343	371	376	362	353	355	377	369	**379**	2.7%	-0.2%	0.4%
Colombia	248	230	256	275	295	297	316	332	345	340	**342**	0.6%	3.9%	0.3%
Ecuador	188	191	220	226	233	247	260	254	240	237	**255**	7.6%	2.6%	0.3%
Peru	175	182	191	220	215	228	225	247	259	258	**267**	3.4%	5.1%	0.3%
Trinidad & Tobago	45	44	45	42	40	45	41	46	48	42	**42**	-1.2%	-0.1%	◆
Venezuela	716	726	725	737	792	782	720	637	537	463	**409**	-11.7%	-3.2%	0.4%
Other S. & Cent. America	1257	1229	1247	1267	1244	1219	1234	1294	1340	1352	**1373**	1.5%	0.5%	1.4%
Total S. & Cent. America	6041	6016	6335	6579	6715	6964	7034	7001	6792	6798	**6795**	◆	1.7%	6.8%
Austria	272	262	275	259	258	262	255	256	261	265	**272**	2.5%	-0.3%	0.3%
Belgium	731	678	706	662	645	665	665	684	694	696	**703**	1.0%	◆	0.7%
Czech Republic	209	204	195	201	198	190	202	196	182	217	**222**	2.2%	0.6%	0.2%
Finland	225	213	223	213	205	220	214	212	221	217	**229**	5.7%	-0.5%	0.2%
France	1889	1822	1763	1725	1673	1661	1613	1612	1597	1608	**1607**	-0.1%	-1.7%	1.6%
Germany	2502	2409	2441	2365	2352	2404	2344	2336	2374	2443	**2321**	-5.0%	0.3%	2.3%
Greece	440	419	382	362	321	303	302	313	314	324	**323**	-0.3%	-3.6%	0.3%
Hungary	164	154	146	155	143	142	159	168	166	177	**188**	6.5%	0.5%	0.2%
Italy	1661	1563	1532	1475	1384	1274	1204	1257	1266	1279	**1253**	-2.0%	-3.0%	1.3%
Netherlands	979	945	964	971	925	898	866	834	851	829	**860**	3.8%	-2.2%	0.9%
Norway	218	222	229	227	226	230	217	223	217	223	**234**	5.1%	0.1%	0.2%
Poland	567	567	594	592	571	538	538	559	606	662	**685**	3.4%	1.9%	0.7%
Portugal	293	274	272	256	231	241	241	246	240	246	**236**	-4.0%	-2.1%	0.2%
Romania	216	195	184	191	191	174	187	191	202	213	**211**	-1.0%	-0.3%	0.2%
Spain	1559	1474	1447	1383	1300	1203	1199	1243	1288	1301	**1335**	2.7%	-2.1%	1.3%
Sweden	340	325	328	309	309	306	304	302	319	321	**308**	-3.8%	-1.1%	0.3%
Switzerland	256	260	242	235	238	249	224	227	216	222	**215**	-3.2%	-0.8%	0.2%
Turkey	686	709	694	673	704	757	775	912	978	1013	**1003**	-1.0%	3.8%	1.0%
Ukraine	299	282	267	278	267	257	221	194	205	207	**200**	-3.0%	-3.9%	0.2%
United Kingdom	1738	1669	1652	1600	1546	1532	1536	1578	1623	1637	**1618**	-1.2%	-0.7%	1.6%
Other Europe	1313	1231	1216	1189	1140	1124	1123	1169	1214	1253	**1252**	-0.1%	-0.5%	1.3%
Total Europe	16558	15876	15752	15321	14826	14631	14389	14713	15032	15351	**15276**	-0.5%	-0.8%	15.3%
Azerbaijan	74	73	72	89	92	101	99	100	98	99	**98**	-1.0%	0.9%	0.1%
Belarus	160	182	150	173	211	144	164	139	137	135	**136**	1.0%	-1.9%	0.1%
Kazakhstan	240	198	211	243	245	260	262	295	305	317	**357**	12.4%	2.8%	0.4%
Russian Federation	2861	2775	2878	3074	3119	3134	3298	3146	3217	3207	**3228**	0.7%	1.4%	3.2%
Turkmenistan	114	106	118	125	129	137	143	145	143	147	**151**	3.2%	2.8%	0.2%
Uzbekistan	93	89	76	71	63	60	57	53	49	55	**52**	-4.0%	-5.3%	0.1%
Other CIS	60	63	63	65	75	78	76	78	86	73	**76**	3.0%	2.7%	0.1%
Total CIS	3602	3486	3567	3838	3935	3914	4099	3955	4034	4033	**4099**	1.6%	1.3%	4.1%
Iran	1925	1919	1788	1851	1882	2064	1959	1804	1749	1843	**1879**	2.0%	◆	1.9%
Iraq	481	536	570	629	666	716	681	683	760	732	**777**	6.1%	4.1%	0.8%
Israel	254	232	241	254	295	223	214	226	230	247	**242**	-1.9%	-0.6%	0.2%
Kuwait	406	455	470	444	490	508	446	461	453	455	**451**	-0.9%	1.7%	0.5%
Oman	123	119	135	146	157	178	185	184	187	193	**192**	-0.3%	7.9%	0.2%
Qatar	178	173	191	246	257	287	294	317	341	320	**328**	2.6%	8.0%	0.3%
Saudi Arabia	2622	2914	3206	3295	3460	3451	3764	3886	3875	3838	**3724**	-3.0%	4.8%	3.7%
United Arab Emirates	603	606	654	735	773	852	880	957	1023	964	**991**	2.8%	5.3%	1.0%
Other Middle East	795	774	720	701	650	630	631	579	553	547	**551**	0.8%	-3.5%	0.6%
Total Middle East	7386	7727	7974	8301	8631	8910	9053	9099	9172	9138	**9136**	◆	2.7%	9.2%
Algeria	309	327	327	349	370	387	401	425	412	408	**414**	1.6%	3.6%	0.4%
Egypt	686	725	766	720	747	756	806	834	857	806	**760**	-5.7%	2.3%	0.8%
Morocco	231	234	258	275	277	282	272	268	275	290	**286**	-1.6%	3.2%	0.3%
South Africa	511	507	538	542	552	561	555	578	555	556	**533**	-4.1%	0.3%	0.5%
Other Africa	1462	1530	1592	1512	1628	1719	1737	1751	1779	1901	**1996**	3.4%	3.5%	2.0%
Total Africa	3198	3322	3481	3398	3574	3705	3770	3857	3878	3962	**3959**	-0.1%	2.7%	4.0%
Australia	944	950	954	1001	1025	1034	1047	1005	1038	1055	**1094**	3.7%	1.2%	1.1%
Bangladesh	77	72	81	104	110	108	120	127	137	153	**176**	14.8%	7.2%	0.2%
China	7914	8295	9446	9808	10242	10750	11239	11986	12304	12840	**13525**	5.3%	5.1%	13.5%
China Hong Kong SAR	292	332	359	361	344	352	336	368	380	427	**434**	1.6%	2.9%	0.4%
India	3137	3300	3381	3550	3747	3789	3914	4245	4654	4870	**5156**	5.9%	5.0%	5.2%
Indonesia	1288	1321	1415	1590	1646	1677	1708	1571	1628	1696	**1785**	5.2%	2.5%	1.8%
Japan	4847	4390	4442	4442	4702	4516	4303	4151	4019	3975	**3854**	-3.1%	-2.3%	3.9%
Malaysia	672	679	688	724	757	802	796	790	807	793	**814**	2.6%	1.2%	0.8%
New Zealand	154	148	150	150	148	151	154	160	163	175	**173**	-1.2%	1.3%	0.2%
Pakistan	389	415	411	414	402	442	458	505	566	589	**498**	-15.4%	4.4%	0.5%
Philippines	283	300	313	298	309	326	347	397	427	459	**466**	1.5%	4.5%	0.5%
Singapore	973	1049	1157	1208	1202	1225	1268	1338	1385	1419	**1449**	2.1%	4.4%	1.5%
South Korea	2312	2345	2378	2401	2466	2464	2463	2587	2781	2811	**2793**	-0.6%	1.6%	2.8%
Sri Lanka	83	87	87	92	95	82	71	90	105	113	**112**	-1.3%	2.2%	0.1%
Taiwan	1010	1022	1043	950	950	981	1013	1021	1046	1069	**1075**	0.5%	-0.4%	1.1%
Thailand	1016	1075	1121	1184	1250	1299	1309	1360	1396	1444	**1478**	2.3%	3.4%	1.5%
Vietnam	300	305	332	361	368	398	409	445	471	498	**522**	4.9%	5.8%	0.5%
Other Asia Pacific	249	268	285	304	329	364	388	408	436	449	**461**	2.8%	6.0%	0.5%
Total Asia Pacific	25940	26351	28043	28942	30094	30759	31343	32551	33743	34835	**35863**	3.0%	2.9%	35.9%
Total World	**86619**	**85780**	**88730**	**89763**	**90724**	**92276**	**93194**	**95048**	**96737**	**98406**	**99843**	**1.5%**	**1.2%**	**100.0%**
of which: OECD	48187	46217	46776	46253	45752	45782	45455	46086	46688	47199	**47466**	0.6%	-0.5%	47.5%
Non-OECD	38432	39563	41954	43510	44973	46494	47739	48961	50049	51206	**52377**	2.3%	3.2%	52.5%
European Union	14786	14092	14012	13599	13101	12848	12663	12855	13091	13356	**13302**	-0.4%	-1.1%	13.3%

*Inland demand plus international aviation and marine bunkers and refinery fuel and loss. Consumption of biogasoline (such as ethanol), biodiesel and derivatives of coal and natural gas are also included.
◆Less than 0.05%.
Notes: Differences between these world consumption figures and world production statistics are accounted for by stock changes, consumption of non-petroleum additives and substitute fuels, and unavoidable disparities in the definition, measurement or conversion of oil supply and demand data.
Annual changes and shares of total are calculated using thousand barrels daily figures.

Table C2. Global oil consumption (Mtoe) (Source: BP Statistical Review of World Energy 2019)

Oil: Consumption in million tonnes oil equivalent*

												Growth rate per annum		Share
Million tonnes oil equivalent	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	**2018**	2018	2007-17	2018
Canada	105.7	99.8	107.1	110.4	107.5	107.8	109.6	107.0	108.7	108.8	**110.0**	1.1%	0.2%	2.4%
Mexico	96.2	92.9	93.3	94.9	96.4	93.8	89.5	88.5	89.1	85.8	**82.8**	-3.5%	-1.2%	1.8%
US	903.4	860.6	877.5	862.2	843.8	859.8	866.1	884.5	893.3	902.0	**919.7**	2.0%	-0.6%	19.7%
Total North America	1105.3	1053.3	1077.9	1067.4	1047.7	1061.3	1065.3	1080.0	1091.1	1096.6	**1112.5**	1.5%	-0.6%	23.9%
Argentina	25.5	25.0	28.6	28.9	30.1	32.4	31.9	32.9	32.3	32.0	**30.1**	-6.0%	2.6%	0.6%
Brazil	112.6	112.9	122.8	128.4	131.3	140.3	145.7	140.6	132.7	136.1	**135.9**	-0.1%	2.6%	2.9%
Chile	19.2	18.7	16.6	18.1	18.1	17.5	17.0	17.1	18.2	17.7	**18.1**	2.7%	-0.4%	0.4%
Colombia	12.0	11.0	12.3	13.2	14.3	14.4	15.3	16.2	16.8	16.5	**16.6**	0.7%	4.0%	0.4%
Ecuador	9.1	9.2	10.7	10.9	11.3	12.0	12.7	12.3	11.5	11.3	**12.2**	8.2%	2.5%	0.3%
Peru	8.4	8.7	9.1	10.5	10.2	10.7	10.5	11.6	12.2	12.0	**12.4**	3.2%	4.7%	0.3%
Trinidad & Tobago	2.3	2.2	2.3	2.1	2.0	2.3	2.1	2.3	2.4	2.1	**2.1**	-0.9%	-0.1%	◆
Venezuela	34.9	35.3	35.2	35.7	38.5	38.0	34.9	30.7	25.9	22.1	**19.5**	-11.9%	-3.2%	0.4%
Other S. & Cent. America	63.9	62.2	62.9	64.0	63.0	61.2	61.9	64.8	67.1	67.4	**68.3**	1.4%	0.4%	1.5%
Total S. & Cent. America	287.9	285.3	300.4	311.9	318.9	328.8	331.9	328.5	319.1	317.2	**315.3**	-0.6%	1.5%	6.8%
Austria	13.7	13.2	13.7	12.8	12.7	12.9	12.6	12.6	12.9	13.1	**13.4**	2.4%	-0.5%	0.3%
Belgium	36.9	33.4	34.8	32.5	31.5	32.3	32.0	32.9	33.7	33.7	**34.1**	1.0%	-0.4%	0.7%
Czech Republic	10.2	10.0	9.5	9.7	9.5	9.1	9.7	9.5	8.9	10.4	**10.6**	2.4%	0.3%	0.2%
Finland	11.0	10.4	10.9	10.3	9.9	10.4	10.0	10.0	10.5	10.3	**10.7**	4.8%	-0.8%	0.2%
France	93.8	90.3	87.3	85.4	83.0	82.0	79.6	79.2	78.7	79.1	**78.9**	-0.2%	-1.8%	1.7%
Germany	123.7	118.7	119.5	115.8	115.3	117.5	114.5	114.2	116.5	119.0	**113.2**	-4.9%	0.1%	2.4%
Greece	22.2	21.0	19.1	18.0	16.0	15.0	14.9	15.4	15.4	16.0	**16.0**	-0.1%	-3.7%	0.3%
Hungary	7.8	7.4	7.0	7.3	6.8	6.7	7.5	7.9	7.8	8.3	**8.8**	6.3%	0.3%	0.2%
Italy	82.5	77.2	75.3	72.6	67.8	61.9	58.5	61.1	61.6	62.0	**60.8**	-2.0%	-3.2%	1.3%
Netherlands	48.0	46.0	46.7	47.3	45.0	42.7	40.8	39.8	41.0	39.6	**40.9**	3.2%	-2.4%	0.9%
Norway	10.2	10.3	10.6	10.5	10.5	10.6	10.0	10.2	9.9	10.1	**10.4**	3.6%	-0.3%	0.2%
Poland	27.2	27.1	28.5	28.4	27.5	25.6	25.7	26.7	29.1	31.7	**32.8**	3.6%	2.0%	0.7%
Portugal	14.4	13.4	13.3	12.5	11.3	11.7	11.6	11.9	11.7	12.0	**11.5**	-3.4%	-2.2%	0.2%
Romania	10.5	9.5	9.0	9.3	9.3	8.5	9.1	9.3	9.8	10.3	**10.2**	-0.2%	-0.3%	0.2%
Spain	78.7	74.1	72.7	69.6	65.5	60.5	60.3	62.2	64.5	65.0	**66.6**	2.6%	-2.2%	1.4%
Sweden	16.6	15.9	16.1	15.0	14.9	14.7	14.6	14.5	15.3	15.4	**14.8**	-3.6%	-1.3%	0.3%
Switzerland	12.6	12.8	11.9	11.5	11.7	12.3	11.0	11.2	10.6	10.9	**10.5**	-3.3%	-0.8%	0.2%
Turkey	33.1	33.6	32.8	32.1	33.8	36.5	37.2	44.0	47.4	49.2	**48.6**	-1.2%	3.9%	1.0%
Ukraine	14.7	14.0	13.1	13.6	13.1	12.4	10.7	9.4	9.9	9.9	**9.6**	-3.6%	-4.0%	0.2%
United Kingdom	83.4	79.8	79.0	76.7	74.5	73.4	73.5	75.3	77.5	78.0	**77.0**	-1.2%	-0.8%	1.7%
Other Europe	65.9	61.7	61.0	59.5	57.3	56.1	56.0	58.4	60.7	62.5	**62.4**	-0.1%	-0.6%	1.3%
Total Europe	817.1	779.8	771.5	750.6	727.0	712.8	699.7	715.7	733.3	746.2	**742.0**	-0.6%	-1.0%	15.9%
Azerbaijan	3.7	3.5	3.4	4.2	4.4	4.8	4.7	4.7	4.7	4.7	**4.6**	-2.1%	0.3%	0.1%
Belarus	8.0	9.3	7.5	8.5	10.4	7.2	8.2	7.0	6.9	6.7	**6.8**	1.1%	-1.8%	0.1%
Kazakhstan	11.9	9.6	10.2	11.9	12.0	12.6	12.6	14.1	14.5	15.0	**16.4**	9.5%	2.3%	0.4%
Russian Federation	138.1	132.5	137.9	147.0	149.6	149.5	157.4	149.4	153.1	151.5	**152.3**	0.5%	1.2%	3.3%
Turkmenistan	5.4	5.2	5.7	6.0	6.2	6.4	6.7	6.8	6.7	6.9	**7.1**	2.8%	2.7%	0.2%
Uzbekistan	4.7	4.4	3.7	3.5	3.1	3.0	2.8	2.6	2.4	2.7	**2.6**	-3.9%	-5.3%	0.1%
Other CIS	2.9	3.1	3.1	3.2	3.5	3.7	3.6	3.7	4.0	3.6	**3.7**	3.1%	2.6%	0.1%
Total CIS	174.7	167.5	171.6	184.4	189.3	187.1	196.0	188.2	192.3	191.1	**193.5**	1.3%	1.1%	4.2%
Iran	94.7	93.9	85.6	89.3	90.7	99.9	93.9	85.6	81.8	84.5	**86.2**	2.0%	-0.7%	1.8%
Iraq	23.0	26.1	27.8	30.5	32.6	34.9	33.1	33.2	37.0	35.6	**38.4**	7.7%	4.4%	0.8%
Israel	12.3	11.1	11.5	12.2	14.3	10.6	10.1	10.7	10.9	11.7	**11.5**	-1.7%	-0.8%	0.2%
Kuwait	19.4	20.9	21.5	19.9	22.3	23.2	19.9	20.8	20.5	20.4	**20.0**	-1.9%	1.2%	0.4%
Oman	6.0	5.8	6.6	6.9	7.5	8.7	8.9	9.0	9.2	9.2	**9.2**	-0.4%	7.6%	0.2%
Qatar	6.8	6.5	7.0	8.8	9.0	10.2	10.7	11.7	12.8	11.8	**12.2**	3.5%	7.6%	0.3%
Saudi Arabia	118.6	130.2	141.3	144.4	151.8	152.2	167.0	173.5	171.5	168.8	**162.6**	-3.6%	4.5%	3.5%
United Arab Emirates	30.8	30.2	32.2	34.9	36.4	40.3	40.8	43.8	46.6	43.8	**45.1**	2.9%	4.1%	1.0%
Other Middle East	39.5	38.2	35.5	34.6	32.1	30.8	30.8	28.3	27.0	26.6	**26.8**	0.8%	-3.6%	0.6%
Total Middle East	351.1	362.8	368.9	381.5	396.8	410.8	415.2	416.6	417.4	412.5	**412.1**	-0.1%	2.2%	8.8%
Algeria	14.6	15.5	15.5	16.5	17.6	18.4	19.1	20.3	19.7	19.4	**19.6**	1.2%	3.7%	0.4%
Egypt	33.6	35.4	37.4	34.8	36.5	36.9	39.5	41.1	42.1	39.2	**36.7**	-6.4%	2.3%	0.8%
Morocco	11.0	11.1	12.3	13.2	13.3	13.4	12.8	12.5	12.8	13.5	**13.2**	-2.5%	3.1%	0.3%
South Africa	25.3	25.0	26.6	26.7	27.4	27.7	27.5	28.6	27.5	27.5	**26.3**	-4.5%	0.3%	0.6%
Other Africa	72.0	75.1	78.1	74.0	79.9	84.1	84.9	85.4	86.8	92.4	**95.5**	3.3%	3.3%	2.0%
Total Africa	156.5	162.2	169.9	165.3	174.5	180.4	183.7	187.9	189.0	192.1	**191.3**	-0.4%	2.6%	4.1%
Australia	45.2	45.4	45.6	48.2	49.6	49.9	50.6	48.5	50.3	51.1	**53.3**	4.4%	1.4%	1.1%
Bangladesh	3.9	3.6	4.1	5.2	5.6	5.5	6.1	6.5	7.1	7.9	**9.0**	14.6%	7.4%	0.2%
China	384.7	400.6	455.5	472.4	495.3	517.3	539.3	573.3	587.0	610.7	**641.2**	5.0%	4.9%	13.8%
China Hong Kong SAR	14.9	16.9	18.3	18.4	17.6	18.0	17.1	18.7	19.4	21.9	**22.2**	1.3%	2.9%	0.5%
India	149.3	157.0	160.6	168.3	178.3	179.5	184.7	199.8	219.5	227.1	**239.1**	5.3%	4.8%	5.1%
Indonesia	62.6	63.5	67.6	76.0	78.4	79.5	80.7	73.8	76.4	79.3	**83.4**	5.2%	2.1%	1.8%
Japan	232.4	208.2	210.5	211.0	224.9	214.7	204.0	196.5	191.0	187.8	**182.4**	-2.9%	-2.4%	3.9%
Malaysia	31.0	30.8	30.9	33.0	34.6	36.8	36.5	36.2	36.4	36.0	**36.9**	2.6%	1.1%	0.8%
New Zealand	7.5	7.2	7.3	7.3	7.2	7.4	7.5	7.8	7.9	8.5	**8.4**	-1.3%	1.4%	0.2%
Pakistan	19.8	21.2	21.0	21.1	20.5	22.4	23.2	25.3	28.3	29.2	**24.3**	-16.6%	4.1%	0.5%
Philippines	13.8	14.5	15.2	14.4	15.0	15.8	16.7	19.1	20.5	21.7	**22.0**	1.0%	4.2%	0.5%
Singapore	51.7	55.8	61.3	64.0	63.8	64.6	66.3	70.0	72.9	74.8	**75.8**	1.4%	4.4%	1.6%
South Korea	108.1	109.0	110.5	111.4	114.7	114.3	114.1	120.2	129.3	130.0	**128.9**	-0.8%	1.4%	2.8%
Sri Lanka	4.1	4.3	4.3	4.6	4.7	4.0	3.5	4.3	5.1	5.4	**5.3**	-1.6%	1.9%	0.1%
Taiwan	47.8	48.0	49.0	44.5	44.5	45.5	47.1	47.5	48.7	50.1	**50.0**	-0.1%	-0.6%	1.1%
Thailand	46.4	48.6	50.2	52.4	55.1	57.2	57.6	60.2	62.5	64.4	**65.8**	2.2%	3.1%	1.4%
Vietnam	14.6	14.8	16.0	17.4	17.6	19.0	19.5	21.2	22.5	23.6	**24.9**	5.1%	5.5%	0.5%
Other Asia Pacific	12.4	13.2	14.0	14.9	16.2	17.8	19.0	20.0	21.3	21.9	**22.5**	2.8%	5.8%	0.5%
Total Asia Pacific	1250.2	1262.6	1341.7	1384.7	1443.6	1469.1	1493.4	1548.9	1606.2	1651.3	**1695.4**	2.7%	2.8%	36.4%
Total World	**4142.9**	**4073.4**	**4201.9**	**4245.7**	**4297.8**	**4350.3**	**4385.3**	**4465.8**	**4548.3**	**4607.0**	**4662.1**	**1.2%**	**1.0%**	**100.0%**
of which: OECD	2288.9	2177.5	2198.5	2172.9	2151.9	2139.3	2120.1	2147.8	2180.5	2196.5	**2204.8**	0.4%	-0.7%	47.3%
Non-OECD	1853.9	1896.0	2003.4	2072.8	2145.8	2211.0	2265.3	2317.9	2367.7	2410.5	**2457.3**	1.9%	3.0%	52.7%
European Union	730.5	693.2	687.5	667.2	643.1	626.4	616.3	625.7	639.0	649.5	**646.8**	-0.4%	-1.2%	13.9%

*Inland demand plus international aviation and marine bunkers and refinery fuel and loss. Consumption of biogasoline (such as ethanol), biodiesel and derivatives of coal and natural gas are also included.
◆Less than 0.05%.
Notes: Differences between these world consumption figures and world production statistics are accounted for by stock changes, consumption of non-petroleum additives and substitute fuels, and unavoidable disparities in the definition, measurement or conversion of oil supply and demand data.
Annual changes and shares of total are calculated using million tonnes oil equivalent figures.
Oil consumption data expressed in million tonnes is available at *bp.com/statisticalreview.*

Table C2. Regional oil consumption by product group (Source: BP Statistical Review of World Energy 2019)

Oil: Regional consumption – by product group

Thousand barrels daily	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Growth rate per annum 2018	Growth rate per annum 2007-17	Share 2018
North America														
Light distillates	10859	10839	10950	10697	10572	10778	10841	11092	11287	11229	**11195**	-0.3%	◆	45.3%
Middle distillates	6934	6281	6567	6694	6409	6519	6792	6814	6757	6927	**7212**	4.1%	-0.5%	29.2%
Fuel oil	941	801	810	745	662	576	447	418	474	519	**498**	-4.1%	-7.1%	2.0%
Others	5160	5080	5251	5248	5306	5520	5427	5547	5567	5613	**5810**	3.5%	0.1%	23.5%
Total North America	23894	23001	23578	23383	22949	23393	23507	23871	24086	24289	**24714**	1.8%	-0.3%	100.0%
of which: US														
Light distillates	9253	9257	9263	9022	8932	9125	9164	9413	9547	9566	**9556**	-0.1%	◆	46.7%
Middle distillates	5801	5241	5464	5518	5278	5371	5632	5657	5603	5742	**5961**	3.8%	-0.8%	29.1%
Fuel oil	609	508	532	459	367	317	256	258	325	341	**321**	-5.9%	-7.2%	1.6%
Others	3827	3766	3921	3883	3913	4147	4054	4203	4212	4309	**4618**	7.2%	0.3%	22.6%
Total US	19490	18771	19180	18882	18490	18961	19106	19531	19687	19958	**20456**	2.5%	-0.4%	100.0%
S. & Cent. America														
Light distillates	1678	1768	1868	1946	1989	2091	2152	2212	2184	2246	**2245**	◆	3.5%	33.0%
Middle distillates	2178	2144	2367	2485	2602	2725	2744	2726	2645	2640	**2679**	1.4%	2.2%	39.4%
Fuel oil	833	783	763	739	739	712	736	724	665	610	**582**	-4.6%	-2.7%	8.6%
Others	1352	1320	1336	1409	1385	1435	1403	1339	1298	1302	**1290**	-1.0%	0.6%	19.0%
Total S. & Cent. America	6041	6016	6335	6579	6715	6964	7034	7001	6792	6798	**6795**	◆	1.7%	100.0%
Europe														
Light distillates	3648	3585	3533	3323	3173	3083	3010	2937	2948	2985	**2955**	-1.0%	-2.6%	19.3%
Middle distillates	8060	7767	7869	7749	7624	7684	7636	7987	8144	8404	**8399**	-0.1%	0.7%	55.0%
Fuel oil	1633	1481	1338	1291	1166	1041	969	923	965	967	**953**	-1.5%	-5.5%	6.2%
Others	3217	3044	3012	2958	2864	2823	2775	2866	2976	2995	**2970**	-0.9%	-0.8%	19.4%
Total Europe	16558	15876	15752	15321	14826	14631	14389	14713	15032	15351	**15276**	-0.5%	-0.8%	100.0%
CIS														
Light distillates	1118	1104	1161	1172	1204	1246	1254	1245	1246	1268	**1292**	1.9%	1.8%	31.5%
Middle distillates	1152	1051	1149	1250	1256	1244	1221	1173	1195	1248	**1326**	6.3%	1.4%	32.4%
Fuel oil	376	343	336	358	354	363	432	346	365	311	**330**	6.1%	-2.6%	8.0%
Others	957	989	921	1058	1121	1062	1192	1191	1228	1206	**1151**	-4.6%	2.1%	28.1%
Total CIS	3602	3486	3567	3838	3935	3914	4099	3955	4034	4033	**4099**	1.6%	1.3%	100.0%
Middle East														
Light distillates	1565	1627	1665	1757	1838	1911	1981	2026	2067	2181	**2239**	2.6%	4.1%	24.5%
Middle distillates	2303	2301	2279	2411	2497	2631	2537	2465	2371	2301	**2272**	-1.3%	0.2%	24.9%
Fuel oil	1747	1901	1937	1989	2021	2120	2164	2206	2094	1975	**1920**	-2.8%	2.3%	21.0%
Others	1772	1898	2093	2144	2275	2248	2370	2402	2639	2681	**2705**	0.9%	4.8%	29.6%
Total Middle East	7386	7727	7974	8301	8631	8910	9053	9099	9172	9138	**9136**	◆	2.7%	100.0%
Africa														
Light distillates	761	802	838	819	872	886	906	970	1029	1078	**1097**	1.7%	4.4%	27.7%
Middle distillates	1460	1514	1616	1611	1682	1797	1836	1865	1843	1896	**1922**	1.4%	3.2%	48.6%
Fuel oil	435	446	461	395	438	433	435	422	403	380	**320**	-15.9%	-1.1%	8.1%
Others	542	561	567	572	582	589	593	599	603	607	**621**	2.2%	1.4%	15.7%
Total Africa	3198	3322	3481	3398	3574	3705	3770	3857	3878	3962	**3959**	-0.1%	2.7%	100.0%
Asia Pacific														
Light distillates	7424	7711	8331	8537	8966	9489	9780	10571	10944	11251	**11636**	3.4%	4.3%	32.4%
Middle distillates	9394	9403	9926	10341	10800	11021	11146	11339	11585	11925	**12268**	2.9%	2.5%	34.2%
Fuel oil	3360	3043	3046	3113	3218	2983	2823	2805	2852	2791	**2646**	-5.2%	-2.5%	7.4%
Others	5762	6194	6740	6951	7110	7265	7594	7836	8362	8868	**9313**	5.0%	4.3%	26.0%
Total Asia Pacific	25940	26351	28043	28942	30094	30759	31343	32551	33743	34835	**35863**	3.0%	2.9%	100.0%
of which: China														
Light distillates	1941	2055	2416	2605	2787	3117	3338	3781	3952	4072	**4368**	7.3%	8.4%	32.3%
Middle distillates	3085	3134	3452	3667	3963	4070	4130	4206	4154	4287	**4386**	2.3%	4.1%	32.4%
Fuel oil	724	662	666	588	560	564	592	591	556	576	**587**	1.8%	-4.4%	4.3%
Others	2164	2443	2912	2948	2932	2998	3179	3408	3642	3906	**4185**	7.1%	5.9%	30.9%
Total China	7914	8295	9446	9808	10242	10750	11239	11986	12304	12840	**13525**	5.3%	5.1%	100.0%
of which: India														
Light distillates	581	569	573	607	644	665	688	797	868	887	**976**	10.1%	4.9%	18.9%
Middle distillates	1350	1439	1519	1601	1686	1685	1694	1774	1848	1879	**1955**	4.0%	4.1%	37.9%
Fuel oil	226	222	199	178	147	117	107	113	136	122	**118**	-3.0%	-6.2%	2.3%
Others	981	1070	1089	1163	1271	1322	1425	1560	1802	1982	**2106**	6.3%	7.4%	40.9%
Total India	3137	3300	3381	3550	3747	3789	3914	4245	4654	4870	**5156**	5.9%	5.0%	100.0%
of which: Japan														
Light distillates	1614	1634	1696	1635	1614	1631	1575	1621	1570	1578	**1518**	-3.8%	-0.9%	39.4%
Middle distillates	1502	1381	1391	1343	1361	1345	1319	1281	1291	1296	**1280**	-1.2%	-2.2%	33.2%
Fuel oil	707	450	442	577	824	646	532	433	371	284	**269**	-5.6%	-8.0%	7.0%
Others	1025	925	913	887	903	895	876	816	788	817	**787**	-3.7%	-2.0%	20.4%
Total Japan	4847	4390	4442	4442	4702	4516	4303	4151	4019	3975	**3854**	-3.1%	-2.3%	100.0%
World														
Light distillates	27053	27435	28346	28252	28614	29484	29923	31052	31705	32237	**32658**	1.3%	1.7%	32.7%
Middle distillates	31480	30462	31772	32542	32869	33620	33912	34370	34540	35342	**36078**	2.1%	1.2%	36.1%
Fuel oil	9324	8797	8691	8630	8598	8230	8006	7844	7820	7554	**7249**	-4.0%	-2.3%	7.3%
Others	18761	19086	19920	20340	20643	20942	21354	21781	22674	23272	**23859**	2.5%	2.0%	23.9%
Total World	**86619**	**85780**	**88730**	**89763**	**90724**	**92276**	**93194**	**95048**	**96737**	**98406**	**99843**	**1.5%**	**1.2%**	**100.0%**
OECD														
Light distillates	17388	17390	17568	17115	16919	17058	17052	17353	17561	17645	**17502**	-0.8%	-0.3%	36.9%
Middle distillates	17373	16301	16727	16720	16389	16562	16775	17175	17343	17775	**18094**	1.8%	◆	38.1%
Fuel oil	3528	2921	2786	2791	2846	2444	2091	1922	1984	1903	**1857**	-2.4%	-6.5%	3.9%
Others	9898	9605	9695	9626	9597	9718	9536	9636	9801	9875	**10014**	1.4%	-0.4%	21.1%
Total OECD	48187	46217	46776	46253	45752	45782	45455	46086	46688	47199	**47466**	0.6%	-0.5%	100.0%
Non-OECD														
Light distillates	9665	10045	10779	11136	11695	12425	12871	13699	14144	14592	**15156**	3.9%	4.8%	28.9%
Middle distillates	14108	14161	15045	15821	16480	17058	17136	17195	17197	17567	**17984**	2.4%	2.6%	34.3%
Fuel oil	5797	5877	5905	5839	5752	5786	5915	5922	5836	5651	**5392**	-4.6%	-0.3%	10.3%
Others	8863	9481	10225	10714	11046	11225	11817	12145	12872	13397	**13845**	3.3%	4.3%	26.4%
Total Non-OECD	38432	39563	41954	43510	44973	46494	47739	48961	50049	51206	**52377**	2.3%	3.2%	100.0%

◆Less than 0.05%.
Notes: 'Light distillates' consists of aviation and motor gasolines and light distillate feedstock (LDF).
'Middle distillates' consists of jet and heating kerosenes, and gas and diesel oils (including marine bunkers).
'Fuel oil' includes marine bunkers and crude oil used directly as fuel.
'Others' consists of refinery gas, liquefied petroleum gas (LPG), solvents, petroleum coke, lubricants, bitumen, wax, other refined products and refinery fuel and loss.
Annual changes and shares of total are calculated using thousand barrels daily figures
An extended breakdown of oil consumption by product group is available at *bp.com/statisticalreview*.

Table C4 (1 of 6). Oil consumption by country
(Source: BP Statistical Review of World Energy 2019 & BP Statistical Review of World Energy 2011)

Year	United States (kbbls/day)	China (kbbls/day)	European Union E-28 (kbbls/day)	Germany (kbbls/day)	India (kbbls/day)	Japan (kbbls/day)
1965	11522	216	7792	1714	253	1704
1966	12100	277	8563	1922	282	1944
1967	12567	274	9298	2005	290	2387
1968	13405	299	10177	2241	325	2764
1969	14153	402	11413	2530	393	3282
1970	14710	556	12636	2774	391	3874
1971	15223	755	13238	2899	417	4283
1972	16381	867	14154	3048	448	4568
1973	17318	1061	15168	3262	474	5262
1974	16631	1220	14255	2970	465	5066
1975	16334	1346	13752	2887	477	4786
1976	17461	1539	14653	3111	503	4974
1977	18443	1630	14531	3085	543	5126
1978	18756	1823	15227	3234	589	5389
1979	18438	1831	15600	3342	634	5449
1980	17062	1690	14542	3020	644	4900
1981	16060	1612	13619	2759	698	4657
1982	15295	1597	12958	2614	728	4363
1983	15235	1638	12665	2569	766	4359
1984	15725	1695	12756	2561	824	4577
1985	15726	1820	12982	2649	897	4397
1986	16281	1934	13372	2784	945	4457
1987	16665	2055	13421	2725	975	4466
1988	17283	2203	13546	2728	1071	4766
1989	17325	2338	13632	2576	1165	4964
1990	16988	2320	13807	2689	1213	5234
1991	16713	2520	13908	2815	1234	5339
1992	17033	2736	13925	2832	1298	5454
1993	17236	3047	13808	2886	1314	5380
1994	17719	3115	13829	2864	1413	5673
1995	17725	3394	14048	2865	1581	5725
1996	18309	3722	14338	2905	1701	5754
1997	18621	4120	14479	2900	1832	5707
1998	18917	4216	14765	2902	1968	5478
1999	19519	4452	14743	2810	2141	5573
2000	19701	4766	14585	2746	2261	5530

Table C4 (2 of 6). Oil consumption by country
(Source: BP Statistical Review of World Energy 2019 & BP Statistical Review of World Energy 2011)

Year	United States (kbbls/day)	China (kbbls/day)	European Union E-28 (kbbls/day)	Germany (kbbls/day)	India (kbbls/day)	Japan (kbbls/day)
2001	19649	4859	14754	2787	2288	5394
2002	19761	5262	14679	2697	2376	5320
2003	20033	5771	14769	2648	2420	5413
2004	20732	6738	14953	2619	2574	5238
2005	20802	6944	15101	2592	2567	5334
2006	20687	7437	15103	2609	2571	5203
2007	20680	7817	14801	2380	2835	5029
2008	19490	7914	14786	2502	3137	4847
2009	18771	8295	14092	2409	3300	4390
2010	19180	9446	14012	2441	3381	4442
2011	18882	9808	13599	2365	3550	4442
2012	18490	10242	13101	2352	3747	4702
2013	18961	10750	12848	2404	3789	4516
2014	19106	11239	12663	2344	3914	4303
2015	19531	11986	12855	2336	4245	4151
2016	19687	12304	13091	2374	4654	4019
2017	19958	12840	13356	2443	4870	3975
2018	20456	13525	13302	2321	5156	3854

Table C4 (3 of 6). Oil consumption by country
(Source: BP Statistical Review of World Energy 2019 & BP Statistical Review of World Energy 2011)

Year	Saudi Arabia (kbbls/day)	Russian Federation (kbbls/day)	Brazil (kbbls/day)	United Kingdom (kbbls/day)	Norway (kbbls/day)	Iran (kbbls/day)
1965	391		307	1449	101	200
1966	394		336	1556	114	221
1967	397		347	1676	120	245
1968	400		415	1782	131	269
1969	404		461	1922	145	298
1970	408		522	2030	163	330
1971	411		581	2038	163	364
1972	438		667	2157	169	402
1973	466		822	2226	172	471
1974	488		887	2071	154	501
1975	366		918	1819	162	568
1976	428		983	1809	179	597
1977	500		1015	1831	178	636
1978	537		1123	1895	191	643
1979	653		1194	1917	196	689
1980	607		1155	1647	197	621
1981	727		1117	1538	187	568
1982	805		1151	1559	178	617
1983	878		1133	1516	176	746
1984	929		1160	1824	186	809
1985	955	4944	1213	1615	195	891
1986	949	5006	1355	1640	199	860
1987	990	5051	1395	1604	212	888
1988	1004	5001	1434	1698	200	771
1989	986	5111	1472	1744	195	878
1990	1175	5049	1432	1754	200	947
1991	1252	4921	1461	1753	190	991
1992	1178	4525	1516	1771	194	1015
1993	1216	3816	1570	1788	208	1048
1994	1340	3305	1668	1778	209	1112
1995	1271	3122	1744	1759	209	1214
1996	1332	2752	1853	1798	215	1264
1997	1395	2759	1968	1754	220	1254
1998	1489	2613	2036	1743	219	1198
1999	1503	2713	2089	1729	218	1227
2000	1578	2698	2018	1704	204	1304

Table C4 (4 of 6). Oil consumption by country
(Source: BP Statistical Review of World Energy 2019 & BP Statistical Review of World Energy 2011)

Year	Saudi Arabia (kbbls/day)	Russian Federation (kbbls/day)	Brazil (kbbls/day)	United Kingdom (kbbls/day)	Norway (kbbls/day)	Iran (kbbls/day)
2001	1622	2688	2047	1704	216	1322
2002	1668	2730	2030	1700	211	1423
2003	1780	2755	2010	1723	229	1509
2004	1913	2767	2020	1766	219	1578
2005	2001	2777	2078	1806	221	1641
2006	2074	2893	2094	1788	226	1728
2007	2200	2913	2234	1716	235	1718
2008	2622	2861	2481	1738	218	1925
2009	2914	2775	2498	1669	222	1919
2010	3206	2878	2714	1652	229	1788
2011	3295	3074	2832	1600	227	1851
2012	3460	3119	2884	1546	226	1882
2013	3451	3134	3100	1532	230	2064
2014	3764	3298	3210	1536	217	1959
2015	3886	3146	3140	1578	223	1804
2016	3875	3217	2960	1623	217	1749
2017	3838	3207	3052	1637	223	1843
2018	3724	3228	3081	1618	234	1879

Table C4 (5 of 6). Oil consumption by country
(Source: BP Statistical Review of World Energy 2019 & BP Statistical Review of World Energy 2011)

Year	Iraq (kbbls/day)	Venezuela (kbbls/day)	UAE (kbbls/day)	Kuwait (kbbls/day)	Canada (kbbls/day)	Mexico (kbbls/day)	Kazakhstan (kbbls/day)	Qatar (kbbls/day)
1965	81	182		104	1108	296		1,0
1966	84	185		101	1167	309		1,0
1967	88	187		98	1246	331		1,6
1968	92	196	1	94	1322	361		2,0
1969	96	198	1	92	1380	383		2,3
1970	100	206	3	89	1472	412		2,0
1971	104	211	3	88	1512	434		1,9
1972	108	238	4	95	1589	481		2,3
1973	116	257	6	90	1682	515		2,9
1974	118	263	8	82	1713	589		4,0
1975	122	281	13	63	1682	663		4,8
1976	129	278	19	75	1789	730		6,6
1977	136	357	28	73	1812	755		8,7
1978	145	374	31	78	1849	874		8,5
1979	160	382	42	88	1931	951		9,2
1980	157	427	100	86	1898	1048		16,9
1981	160	435	111	114	1788	1172		18,5
1982	155	433	123	130	1609	1228		27,3
1983	147	423	125	145	1518	1203		30,2
1984	138	394	143	160	1540	1280		33,5
1985	132	407	175	162	1556	1345	421	43,8
1986	137	427	211	168	1559	1371	384	50,4
1987	153	409	231	166	1627	1421	372	53,5
1988	168	423	275	162	1710	1407	373	38,2
1989	172	411	289	161	1771	1503	382	42,2
1990	177	417	304	106	1747	1580	442	43,1
1991	182	401	369	75	1659	1660	446	39,0
1992	193	473	371	112	1689	1683	416	40,4
1993	198	439	391	102	1697	1687	321	41,2
1994	220	480	410	125	1726	1821	248	43,7
1995	248	472	412	131	1761	1690	243	45,6
1996	248	391	397	127	1804	1720	206	47,9
1997	245	437	405	146	1873	1770	208	50,6
1998	261	479	403	218	1898	1868	173	51,9
1999	278	559	397	246	1911	1887	144	51,3
2000	279	559	396	249	1922	1950	162	60,4

Table C4 (6 of 6). Oil consumption by country
(Source: BP Statistical Review of World Energy 2019 & BP Statistical Review of World Energy 2011)

Year	Iraq (kbbls/day)	Venezuela (kbbls/day)	UAE (kbbls/day)	Kuwait (kbbls/day)	Canada (kbbls/day)	Mexico (kbbls/day)	Kazakhstan (kbbls/day)	Qatar (kbbls/day)
2001	260	622	400	253	2008	1939	179	72,8
2002	260	660	439	273	2051	1864	191	84,3
2003	267	535	488	296	2115	1909	209	94,8
2004	251	582	515	327	2231	1985	223	106,8
2005	257	628	553	359	2229	2032	236	121,7
2006	251	661	584	333	2246	2021	239	136,4
2007	264	682	617	338	2323	2070	247	153,0
2008	481	716	603	406	2323	2080	240	178,0
2009	536	726	606	455	2209	2021	198	173,0
2010	570	725	654	470	2358	2040	211	191,0
2011	629	737	735	444	2436	2065	243	246
2012	666	792	773	490	2376	2083	245	257
2013	716	782	852	508	2398	2034	260	287
2014	681	720	880	446	2442	1960	262	294
2015	683	637	957	461	2401	1939	295	317
2016	760	537	1023	453	2448	1950	305	341
2017	732	463	964	455	2448	1883	317	320
2018	777	409	991	451	2447	1812	357	328

27 APPENDIX D – OIL PRODUCTION

Table D1. Global oil production (thousands of barrels a day) (Source: BP Statistical Review of World Energy 2019)

Oil: Production in thousands of barrels per day*

												Growth rate per annum		Share
Thousand barrels daily	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	**2018**	2018	2007-17	2018
Canada	3207	3202	3332	3515	3740	4000	4271	4388	4451	4798	**5208**	8.5%	3.8%	5.5%
Mexico	3165	2978	2959	2940	2911	2875	2784	2587	2456	2224	**2068**	-7.0%	-4.4%	2.2%
US	6783	7259	7552	7870	8910	10073	11773	12773	12340	13135	**15311**	16.6%	6.7%	16.2%
Total North America	13156	13440	13843	14326	15561	16948	18828	19748	19247	20157	**22587**	12.1%	4.0%	23.8%
Argentina	802	730	712	667	657	645	638	647	610	591	**592**	0.2%	-3.2%	0.6%
Brazil	1887	2019	2125	2173	2132	2096	2341	2525	2591	2721	**2683**	-1.4%	4.1%	2.8%
Colombia	588	671	786	915	944	1010	990	1006	886	854	**866**	1.4%	4.9%	0.9%
Ecuador	507	488	488	501	505	527	557	543	548	531	**517**	-2.7%	0.3%	0.5%
Peru	122	155	165	159	157	171	175	153	141	137	**154**	12.4%	1.6%	0.2%
Trinidad & Tobago	149	150	145	136	117	116	114	109	97	99	**87**	-11.5%	-4.4%	0.1%
Venezuela	3228	3038	2842	2755	2704	2680	2692	2631	2347	2096	**1514**	-27.8%	-4.3%	1.6%
Other S. & Cent. America	143	136	144	144	147	152	155	146	135	132	**124**	-5.6%	-1.2%	0.1%
Total S. & Cent. America	7426	7387	7407	7450	7362	7397	7663	7759	7355	7160	**6537**	-8.7%	-0.2%	6.9%
Denmark	287	265	249	225	204	178	167	158	142	138	**116**	-15.9%	-7.8%	0.1%
Italy	108	95	106	110	112	114	120	113	78	86	**97**	12.9%	-3.4%	0.1%
Norway	2458	2342	2132	2033	1911	1832	1881	1940	1991	1963	**1844**	-6.0%	-2.6%	1.9%
Romania	99	94	90	89	83	86	84	83	79	76	**74**	-2.2%	-2.7%	0.1%
United Kingdom	1549	1469	1356	1112	946	864	852	963	1013	999	**1085**	8.6%	-4.9%	1.1%
Other Europe	374	357	342	335	335	344	339	329	313	303	**306**	1.1%	-2.6%	0.3%
Total Europe	4876	4621	4274	3903	3592	3419	3443	3587	3616	3565	**3523**	-1.2%	-3.6%	3.7%
Azerbaijan	916	1027	1037	932	882	888	861	851	838	792	**795**	0.4%	-1.0%	0.8%
Kazakhstan	1485	1609	1676	1684	1664	1737	1710	1695	1655	1838	**1927**	4.8%	2.7%	2.0%
Russian Federation	9965	10152	10379	10533	10656	10807	10860	11007	11269	11255	**11438**	1.6%	1.1%	12.1%
Turkmenistan	208	205	210	223	234	254	257	262	244	232	**222**	-4.7%	1.9%	0.2%
Uzbekistan	102	95	78	77	68	63	61	59	58	61	**64**	5.0%	-5.2%	0.1%
Other CIS	37	36	36	36	35	35	35	36	36	37	**38**	2.6%	-0.1%	♦
Total CIS	12712	13125	13415	13485	13539	13784	13784	13909	14099	14215	**14483**	1.9%	1.1%	15.3%
Iran	4415	4285	4421	4452	3810	3609	3714	3853	4586	5024	**4715**	-6.1%	1.4%	5.0%
Iraq	2428	2446	2469	2773	3079	3103	3239	3986	4423	4533	**4614**	1.8%	7.8%	4.9%
Kuwait	2781	2495	2556	2909	3164	3125	3097	3061	3141	3001	**3049**	1.6%	1.2%	3.2%
Oman	757	813	865	885	918	942	943	981	1004	971	**978**	0.8%	3.2%	1.0%
Qatar	1432	1415	1630	1824	1928	1991	1975	1933	1938	1874	**1879**	0.3%	4.0%	2.0%
Saudi Arabia	10665	9709	9865	11079	11622	11393	11519	11998	12406	11892	**12287**	3.3%	1.5%	13.0%
Syria	406	401	385	353	171	59	33	27	25	25	**24**	-2.2%	-24.4%	♦
United Arab Emirates	3113	2795	2937	3303	3440	3577	3603	3898	4038	3910	**3942**	0.8%	2.4%	4.2%
Yemen	316	308	306	220	178	197	153	63	43	60	**68**	12.8%	-15.9%	0.1%
Other Middle East	193	192	192	201	184	209	214	213	214	208	**207**	-0.7%	0.7%	0.2%
Total Middle East	26506	24859	25626	28001	28493	28205	28490	30012	31818	31497	**31762**	0.8%	2.2%	33.5%
Algeria	1951	1775	1689	1642	1537	1485	1589	1558	1577	1540	**1510**	-2.0%	-2.5%	1.6%
Angola	1876	1754	1812	1670	1734	1738	1701	1796	1745	1676	**1534**	-8.5%	0.1%	1.6%
Chad	127	118	122	114	101	91	89	111	103	104	**101**	-3.1%	-3.2%	0.1%
Republic of Congo	237	276	314	301	280	243	253	234	232	269	**333**	23.6%	1.9%	0.4%
Egypt	715	730	725	714	715	710	714	726	691	660	**670**	1.4%	-0.6%	0.7%
Equatorial Guinea	369	332	306	301	320	282	284	260	223	195	**190**	-2.6%	-6.3%	0.2%
Gabon	240	241	233	236	221	213	211	214	221	210	**194**	-7.6%	-1.5%	0.2%
Libya	1875	1739	1799	516	1539	1048	518	437	412	929	**1010**	8.7%	-6.9%	1.1%
Nigeria	2172	2211	2533	2461	2412	2279	2276	2201	1900	1991	**2051**	3.0%	-1.0%	2.2%
South Sudan	n/a	n/a	n/a	n/a	31	100	155	148	117	111	**131**	17.5%	n/a	0.1%
Sudan	457	475	462	291	103	118	120	109	104	95	**100**	5.7%	-15.0%	0.1%
Tunisia	96	91	83	77	82	76	71	64	60	48	**50**	4.3%	-7.4%	0.1%
Other Africa	184	181	149	198	196	225	234	276	259	304	**320**	5.4%	4.7%	0.3%
Total Africa	10299	9923	10227	8520	9270	8607	8216	8133	7643	8133	**8193**	0.7%	-2.3%	8.6%
Australia	538	507	548	483	479	407	436	384	361	348	**356**	2.2%	-4.5%	0.4%
Brunei	175	168	172	165	159	135	126	127	121	113	**112**	-1.5%	-5.3%	0.1%
China	3814	3805	4077	4074	4155	4216	4246	4309	3999	3846	**3798**	-1.3%	0.3%	4.0%
India	818	838	901	937	926	926	905	893	874	884	**869**	-1.7%	1.2%	0.9%
Indonesia	1006	994	1003	952	917	883	847	838	876	838	**808**	-3.5%	-1.5%	0.9%
Malaysia	727	688	733	659	663	627	649	696	704	683	**682**	-0.1%	-0.6%	0.7%
Thailand	368	383	391	428	468	462	461	478	486	483	**485**	0.3%	3.3%	0.5%
Vietnam	309	341	323	327	358	359	336	365	333	298	**275**	-7.9%	-1.1%	0.3%
Other Asia Pacific	341	330	315	299	287	272	307	308	292	281	**249**	-11.2%	-1.3%	0.3%
Total Asia Pacific	8095	8055	8463	8324	8411	8287	8313	8399	8044	7774	**7633**	-1.8%	-0.2%	8.1%
Total World	**83069**	**81410**	**83255**	**84009**	**86228**	**86647**	**88736**	**91547**	**91822**	**92502**	**94718**	**2.4%**	**1.2%**	**100.0%**
of which: OECD	18417	18424	18531	18571	19487	20621	22565	23583	23090	23940	**26329**	10.0%	2.3%	27.8%
Non-OECD	64652	62986	64724	65438	66742	66026	66171	67964	68731	68561	**68389**	-0.3%	0.8%	72.2%
OPEC	37290	34999	35894	36724	38292	37293	37228	38601	39736	39673	**39338**	-0.8%	0.9%	41.5%
Non-OPEC	45779	46412	47361	47285	47936	49354	51508	52946	52086	52828	**55380**	4.8%	1.3%	58.5%
European Union	2258	2119	1981	1712	1518	1425	1405	1499	1483	1464	**1533**	4.7%	-4.9%	1.6%

*Includes crude oil, shale oil, oil sands, condensates (both lease condensate and gas plant condensate) and NGLs (natural gas liquids – ethane, LPG and naphtha separated from the production of natural gas). Excludes liquid fuels from other sources such as biomass and derivatives of coal and natural gas.
♦Less than 0.05%.
n/a not available.
Note: Annual changes and shares of total are calculated using thousand barrels daily figures.

Table D2. Global oil production (million tonnes) (Source: BP Statistical Review of World Energy 2019)

Oil: Production in million tonnes*

Million tonnes	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Growth rate per annum 2018	Growth rate per annum 2007-17	Share 2018
Canada	152.9	152.8	160.3	169.8	182.6	195.1	209.4	215.6	218.0	235.4	**255.5**	8.5%	4.2%	5.7%
Mexico	156.9	146.7	145.6	144.5	143.9	141.8	137.1	127.5	121.4	109.5	**102.3**	-6.6%	-4.4%	2.3%
US	302.2	322.2	332.8	345.4	394.2	447.2	523.0	566.6	541.9	573.9	**669.4**	16.6%	6.5%	15.0%
Total North America	612.0	621.7	638.7	659.8	720.6	784.1	869.5	909.7	881.3	918.7	**1027.1**	11.8%	3.8%	23.0%
Argentina	37.8	34.0	33.3	31.2	30.8	30.2	29.8	30.1	28.7	27.3	**27.6**	1.1%	-3.3%	0.6%
Brazil	98.8	105.7	111.3	113.8	111.9	109.7	122.5	132.2	136.2	142.3	**140.3**	-1.4%	4.1%	3.1%
Colombia	31.0	35.3	41.4	48.2	49.9	53.2	52.2	53.0	46.8	45.0	**45.6**	1.4%	4.9%	1.0%
Ecuador	27.2	26.1	26.1	26.8	27.1	28.2	29.8	29.1	29.5	28.5	**27.7**	-2.7%	0.4%	0.6%
Peru	5.7	6.9	7.3	7.0	6.9	7.3	7.5	6.5	5.8	5.7	**6.4**	12.2%	0.4%	0.1%
Trinidad & Tobago	6.9	6.8	6.2	5.9	5.2	5.1	5.1	4.8	4.3	4.4	**3.9**	-10.9%	-4.8%	0.1%
Venezuela	165.8	155.9	145.8	141.5	139.3	137.8	138.5	135.4	121.0	107.6	**77.3**	-28.1%	-4.2%	1.7%
Other S. & Cent. America	7.3	6.9	7.3	7.3	7.4	7.6	7.8	7.3	6.8	6.6	**6.2**	-5.5%	-1.2%	0.1%
Total S. & Cent. America	380.5	377.6	378.7	381.7	378.6	379.2	393.1	398.4	379.2	367.3	**335.1**	-8.8%	-0.2%	7.5%
Denmark	14.0	12.9	12.2	10.9	10.0	8.7	8.1	7.7	6.9	6.7	**5.7**	-15.9%	-7.8%	0.1%
Italy	5.2	4.6	5.1	5.3	5.4	5.5	5.8	5.5	3.8	4.1	**4.7**	12.9%	-3.4%	0.1%
Norway	114.2	108.1	98.4	93.2	86.9	82.8	84.8	87.5	90.2	88.6	**83.1**	-6.2%	-2.8%	1.9%
Romania	4.7	4.5	4.3	4.2	4.0	4.1	4.1	4.0	3.8	3.6	**3.6**	-2.0%	-2.6%	0.1%
United Kingdom	72.0	68.3	63.2	52.1	44.7	40.7	40.0	45.4	47.5	46.6	**50.8**	9.0%	-4.9%	1.1%
Other Europe	18.5	17.6	16.9	16.6	16.7	17.1	16.9	16.4	15.6	15.0	**15.2**	1.0%	-2.6%	0.3%
Total Europe	228.7	216.0	200.0	182.3	167.6	158.9	159.7	166.5	167.8	164.7	**162.9**	-1.1%	-3.7%	3.6%
Azerbaijan	45.3	50.9	51.3	46.1	43.7	43.8	42.5	42.0	41.4	39.1	**39.2**	0.3%	-1.0%	0.9%
Kazakhstan	70.7	76.5	79.7	80.1	79.3	82.3	81.1	80.2	78.6	87.0	**91.2**	4.9%	2.6%	2.0%
Russian Federation	494.3	501.4	512.3	519.5	526.7	532.2	535.1	541.8	555.9	554.3	**563.3**	1.6%	1.1%	12.6%
Turkmenistan	10.2	10.0	10.3	10.9	11.5	12.4	12.5	12.8	11.9	11.2	**10.6**	-5.3%	1.7%	0.2%
Uzbekistan	4.8	4.5	3.6	3.6	3.2	2.9	2.8	2.7	2.6	2.8	**2.9**	4.5%	-5.6%	0.1%
Other CIS	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	**1.9**	2.6%	-0.1%	◆
Total CIS	627.2	645.0	659.1	662.0	666.1	675.4	675.8	681.3	692.2	696.1	**709.1**	1.9%	1.1%	15.8%
Iran	215.4	207.2	212.0	212.5	180.5	169.7	174.0	180.2	216.3	235.6	**220.4**	-6.5%	1.0%	4.9%
Iraq	119.3	119.7	120.8	135.8	151.3	152.0	158.8	195.6	217.6	222.2	**226.1**	1.8%	7.8%	5.1%
Kuwait	136.0	120.9	123.2	140.7	153.8	151.2	150.0	148.1	152.5	144.8	**146.8**	1.4%	1.1%	3.3%
Oman	37.1	39.7	42.2	43.2	45.0	46.1	46.2	48.0	49.3	47.6	**47.8**	0.5%	3.2%	1.1%
Qatar	64.5	62.4	70.9	77.7	82.2	84.2	83.5	81.2	81.6	78.5	**78.5**	◆	3.2%	1.8%
Saudi Arabia	510.0	459.0	463.3	522.7	549.2	538.4	543.8	568.0	586.7	559.3	**578.3**	3.4%	1.4%	12.9%
Syria	19.6	19.3	18.5	16.9	8.1	2.7	1.5	1.2	1.1	1.1	**1.1**	-2.5%	-25.1%	◆
United Arab Emirates	145.2	129.3	135.2	150.6	156.9	163.3	163.4	176.1	182.4	176.2	**177.7**	0.8%	2.1%	4.0%
Yemen	14.8	14.4	14.3	10.2	8.1	9.0	6.9	2.6	1.6	2.4	**2.8**	14.7%	-17.2%	0.1%
Other Middle East	9.5	9.4	9.4	9.9	9.0	10.3	10.5	10.5	10.6	10.3	**10.2**	-1.0%	0.7%	0.2%
Total Middle East	1271.5	1181.4	1210.0	1320.3	1344.2	1326.9	1338.7	1411.6	1499.8	1477.9	**1489.7**	0.8%	2.0%	33.3%
Algeria	84.8	77.2	73.8	71.7	67.2	64.8	68.8	67.2	68.4	66.6	**65.3**	-2.0%	-2.6%	1.5%
Angola	92.3	86.0	88.9	82.0	85.3	85.2	83.3	88.2	85.8	81.9	**74.6**	-8.8%	0.1%	1.7%
Chad	6.7	6.2	6.4	6.0	5.3	4.8	4.7	5.8	5.4	5.4	**5.3**	-3.1%	-3.2%	0.1%
Republic of Congo	12.2	14.1	16.0	15.3	14.2	12.3	12.9	11.9	11.8	13.8	**17.0**	23.9%	1.8%	0.4%
Egypt	34.7	35.3	35.0	34.6	34.7	34.4	35.1	35.4	33.8	32.2	**32.7**	1.6%	-0.5%	0.7%
Equatorial Guinea	17.6	15.6	14.5	14.2	15.2	13.2	13.3	12.1	10.4	9.0	**8.7**	-3.1%	-6.6%	0.2%
Gabon	12.0	12.0	11.6	11.8	11.1	10.7	10.5	10.7	11.0	10.5	**9.7**	-7.6%	-1.5%	0.2%
Libya	88.2	81.7	84.6	24.3	72.6	49.4	24.4	20.5	19.3	43.8	**47.5**	8.7%	-6.9%	1.1%
Nigeria	105.8	106.9	122.1	118.4	116.4	109.5	109.3	105.7	91.3	95.5	**98.4**	3.0%	-1.1%	2.2%
South Sudan	n/a	n/a	n/a	n/a	1.5	4.9	7.7	7.3	5.8	5.5	**6.4**	17.5%	n/a	0.1%
Sudan	22.6	23.4	22.8	14.3	5.1	5.8	5.9	5.4	5.1	4.7	**4.9**	5.7%	-15.0%	0.1%
Tunisia	4.5	4.2	3.9	3.6	3.8	3.5	3.3	2.9	2.8	2.2	**2.3**	3.4%	-7.5%	0.1%
Other Africa	9.2	9.1	7.4	9.8	9.8	11.2	11.6	13.7	12.9	15.0	**15.7**	5.1%	4.6%	0.4%
Total Africa	490.4	471.8	487.0	406.0	442.2	409.5	390.6	386.8	363.9	386.0	**388.7**	0.7%	-2.3%	8.7%
Australia	24.1	22.4	24.5	21.5	21.4	17.8	19.1	17.0	15.6	14.9	**15.2**	1.5%	-4.8%	0.3%
Brunei	8.6	8.2	8.4	8.1	7.8	6.6	6.2	6.2	5.9	5.5	**5.4**	-1.4%	-5.3%	0.1%
China	190.4	189.5	203.0	202.9	207.5	210.0	211.4	214.6	199.7	191.5	**189.1**	-1.3%	0.3%	4.2%
India	37.8	38.0	41.3	42.9	42.5	42.5	41.6	41.2	40.2	40.4	**39.5**	-2.2%	1.0%	0.9%
Indonesia	49.4	48.4	48.6	46.3	44.6	42.7	41.0	40.6	42.8	41.0	**39.5**	-3.5%	-1.5%	0.9%
Malaysia	33.6	31.8	33.1	29.7	30.1	28.7	29.8	32.2	32.6	31.5	**31.5**	-0.2%	-0.6%	0.7%
Thailand	14.4	14.9	15.1	15.8	17.2	17.0	16.8	17.5	18.0	17.5	**17.3**	-1.0%	2.6%	0.4%
Vietnam	15.2	16.7	15.6	15.8	17.4	17.3	16.2	17.6	16.0	14.3	**13.0**	-9.1%	-1.3%	0.3%
Other Asia Pacific	14.9	14.4	13.8	13.1	12.6	12.0	13.7	13.8	13.1	12.5	**11.1**	-11.1%	-1.1%	0.2%
Total Asia Pacific	388.4	384.3	403.5	396.0	401.0	394.6	395.8	400.6	383.9	369.1	**361.6**	-2.0%	-0.3%	8.1%
Total World	**3998.7**	**3897.8**	**3976.9**	**4008.0**	**4120.3**	**4128.5**	**4223.2**	**4354.8**	**4368.0**	**4379.9**	**4474.3**	**2.2%**	**1.0%**	**100.0%**
of which: OECD	857.4	853.0	856.5	856.6	902.3	953.2	1041.2	1086.4	1058.1	1092.0	**1198.6**	9.8%	2.1%	26.8%
Non-OECD	3141.3	3044.8	3120.4	3151.4	3217.9	3175.3	3182.0	3268.5	3309.8	3287.9	**3275.8**	-0.4%	0.7%	73.2%
OPEC	1796.3	1674.2	1709.0	1746.2	1822.4	1769.8	1764.4	1830.1	1885.8	1873.7	**1854.3**	-1.0%	0.8%	41.4%
Non-OPEC	2202.3	2223.6	2267.9	2261.9	2297.9	2358.7	2458.8	2524.8	2482.2	2506.2	**2620.1**	4.5%	1.2%	58.6%
European Union	106.6	100.0	93.6	81.3	72.7	68.1	67.0	71.6	70.6	69.3	**72.7**	4.9%	-4.9%	1.6%

*Includes crude oil, shale oil, oil sands, condensates (both lease condensate and gas plant condensate) and NGLs (natural gas liquids – ethane, LPG and naphtha separated from the production of natural gas). Excludes liquid fuels from other sources such as biomass and derivatives of coal and natural gas.
◆Less than 0.05%.
n/a not available.
Note: Annual changes and shares of total are calculated using million tonnes figures.

Table D3. Global crude oil and condensate production (Source: BP Statistical Review of World Energy 2019)

Oil: Crude oil and condensate production in thousands of barrels per day*

Thousand barrels daily	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Growth rate per annum 2018	Growth rate per annum 2007-17	Share 2018
Canada	2581	2576	2724	2900	3131	3358	3610	3679	3678	3977	**4302**	8.2%	4.3%	5.2%
Mexico	2792	2601	2577	2553	2548	2522	2429	2267	2154	1948	**1833**	-5.9%	-4.5%	2.2%
US	5000	5349	5478	5654	6502	7467	8759	9431	8831	9352	**10962**	17.2%	6.3%	13.2%
Total North America	10372	10527	10779	11106	12180	13348	14797	15376	14662	15277	**17097**	11.9%	3.6%	20.6%
Argentina	679	604	589	553	549	540	532	532	511	480	**489**	2.1%	-3.6%	0.6%
Brazil	1812	1950	2055	2105	2061	2024	2255	2437	2510	2622	**2587**	-1.3%	4.1%	3.1%
Colombia	588	671	786	915	944	1010	990	1006	886	854	**866**	1.4%	4.9%	1.0%
Ecuador	505	486	486	500	504	526	557	543	548	531	**517**	-2.7%	0.4%	0.6%
Peru	98	117	123	117	112	118	121	104	91	88	**98**	11.2%	-0.7%	0.1%
Trinidad & Tobago	114	107	98	92	82	81	81	79	71	72	**63**	-11.6%	-5.1%	0.1%
Venezuela	3064	2879	2695	2623	2580	2564	2578	2514	2242	1992	**1425**	-28.4%	-4.2%	1.7%
Other S. & Cent. America	129	121	125	126	131	135	140	133	122	117	**111**	-5.6%	-0.9%	0.1%
Total S. & Cent. America	6988	6935	6957	7031	6963	6998	7255	7347	6982	6756	**6157**	-8.9%	-0.2%	7.4%
Denmark	287	265	249	225	204	178	167	158	142	138	**116**	-15.9%	-7.8%	0.1%
Italy	108	95	106	110	112	114	120	113	78	86	**97**	12.9%	-3.4%	0.1%
Norway	2175	2057	1871	1758	1612	1532	1562	1608	1648	1617	**1515**	-6.3%	-3.3%	1.8%
Romania	93	90	86	84	79	83	82	80	76	73	**71**	-1.8%	-2.5%	0.1%
United Kingdom	1404	1344	1245	1036	891	815	796	909	940	917	**1005**	9.5%	-4.9%	1.2%
Other Europe	347	331	319	315	317	327	324	315	297	284	**287**	1.1%	-2.6%	0.3%
Total Europe	4416	4182	3876	3527	3215	3050	3050	3183	3180	3116	**3092**	-0.8%	-4.0%	3.7%
Azerbaijan	895	1014	1023	919	872	877	849	840	826	781	**783**	0.2%	-0.9%	0.9%
Kazakhstan	1483	1609	1676	1684	1662	1720	1701	1672	1637	1813	**1900**	4.8%	2.5%	2.3%
Russian Federation	9784	9927	10150	10287	10395	10528	10595	10758	11003	11017	**11201**	1.7%	1.1%	13.5%
Turkmenistan	198	194	199	212	220	237	240	245	224	209	**196**	-6.3%	1.2%	0.2%
Uzbekistan	102	95	78	77	68	63	61	59	58	61	**64**	5.0%	-5.2%	0.1%
Other CIS	37	36	36	36	35	35	35	36	36	37	**38**	2.6%	-0.1%	◆
Total CIS	12498	12876	13162	13214	13252	13461	13481	13610	13785	13918	**14181**	1.9%	1.1%	17.1%
Iran	4173	4015	4068	4048	3398	3192	3273	3392	4090	4471	**4156**	-7.0%	0.7%	5.0%
Iraq	2394	2405	2424	2728	3037	3058	3198	3945	4375	4469	**4550**	1.8%	7.8%	5.5%
Kuwait	2574	2278	2307	2645	2890	2847	2830	2782	2860	2704	**2737**	1.2%	0.9%	3.3%
Oman	757	813	865	885	918	942	943	981	1004	971	**978**	0.8%	3.2%	1.2%
Qatar	1211	1151	1307	1399	1491	1520	1508	1463	1465	1416	**1408**	-0.6%	2.6%	1.7%
Saudi Arabia	9453	8411	8423	9566	9987	9875	9941	10420	10688	10175	**10534**	3.5%	1.2%	12.7%
Syria	371	366	350	319	146	45	23	19	17	17	**16**	-3.3%	-26.7%	◆
United Arab Emirates	2819	2495	2603	2856	2961	3095	3063	3284	3384	3280	**3301**	0.6%	1.7%	4.0%
Yemen	295	286	284	197	154	173	128	38	16	33	**40**	21.3%	-20.3%	◆
Other Middle East	183	182	182	191	173	199	204	203	204	199	**196**	-1.5%	0.8%	0.2%
Total Middle East	24230	22402	22813	24834	25155	24944	25113	26527	28104	27733	**27916**	0.7%	1.8%	33.6%
Algeria	1643	1517	1461	1416	1320	1275	1329	1290	1316	1287	**1258**	-2.2%	-2.7%	1.5%
Angola	1855	1734	1793	1656	1714	1716	1672	1780	1722	1637	**1483**	-9.5%	◆	1.8%
Chad	127	118	122	114	101	91	89	111	103	104	**101**	-3.1%	-3.2%	0.1%
Republic of Congo	235	269	307	292	268	234	245	227	225	263	**327**	24.3%	1.8%	0.4%
Egypt	651	665	663	649	649	643	667	662	631	603	**615**	2.0%	-0.6%	0.7%
Equatorial Guinea	349	310	286	280	299	261	266	242	204	174	**169**	-2.9%	-6.8%	0.2%
Gabon	240	241	233	236	221	213	211	214	221	210	**194**	-7.6%	-1.5%	0.2%
Libya	1808	1687	1748	508	1499	1025	510	422	397	909	**988**	8.7%	-6.8%	1.2%
Nigeria	2100	2138	2455	2373	2330	2193	2188	2119	1822	1912	**1967**	2.9%	-1.1%	2.4%
South Sudan	n/a	n/a	n/a	n/a	31	100	155	148	117	111	**131**	17.5%	n/a	0.2%
Sudan	457	475	462	291	103	118	120	109	104	95	**100**	5.7%	-15.0%	0.1%
Tunisia	87	82	79	70	70	64	59	54	51	43	**42**	-3.5%	-7.6%	0.1%
Other Africa	184	181	149	198	196	225	234	276	259	304	**319**	5.2%	4.7%	0.4%
Total Africa	9735	9418	9759	8083	8802	8158	7744	7653	7170	7651	**7693**	0.5%	-2.3%	9.3%
Australia	455	423	471	411	405	335	353	322	292	284	**295**	3.8%	-4.7%	0.4%
Brunei	161	155	159	153	146	122	114	115	109	101	**100**	-1.1%	-5.6%	0.1%
China	3814	3805	4077	4074	4155	4216	4246	4309	3999	3846	**3798**	-1.3%	0.3%	4.6%
India	703	690	762	793	786	789	778	771	744	744	**719**	-3.3%	0.5%	0.9%
Indonesia	977	949	945	902	859	825	789	786	831	801	**772**	-3.6%	-1.7%	0.9%
Malaysia	688	659	653	583	598	588	610	662	667	648	**646**	-0.2%	-0.5%	0.8%
Thailand	229	238	242	224	239	241	233	248	258	240	**228**	-4.8%	1.2%	0.3%
Vietnam	301	332	304	308	338	337	315	342	307	275	**243**	-11.6%	-1.6%	0.3%
Other Asia Pacific	289	279	267	253	242	235	272	276	262	249	**224**	-10.2%	-0.9%	0.3%
Total Asia Pacific	7617	7530	7880	7701	7769	7688	7711	7832	7469	7187	**7024**	-2.3%	-0.5%	8.4%
Total World	**75857**	**73869**	**75226**	**75498**	**77336**	**77647**	**79152**	**81528**	**81351**	**81639**	**83161**	**1.9%**	**0.8%**	**100.0%**
of which: OECD	15098	14990	14988	14904	15653	16578	18058	18745	18005	18551	**20352**	9.7%	1.7%	24.5%
Non-OECD	60759	58879	60238	60594	61683	61069	61094	62783	63346	63089	**62809**	-0.4%	0.6%	75.5%
OPEC	34423	32017	32597	33126	34499	33594	33370	34636	35558	35430	**35014**	-1.2%	0.6%	42.1%
Non-OPEC	41435	41852	42629	42371	42837	44053	45782	46892	45793	46209	**48147**	4.2%	1.0%	57.9%
European Union	2088	1971	1851	1617	1447	1361	1336	1432	1397	1369	**1441**	5.3%	-4.9%	1.7%

*Includes crude oil, shale oil, oil sands and condensates (both lease condensate and gas plant condensate). Excludes liquid fuels from other sources such as natural gas liquids, biomass and derivatives of coal and natural gas.
◆Less than 0.05%.
n/a not available.
Note: Annual changes and shares of total are calculated using thousand barrels daily figures.

Table D4. Global natural gas liquids production (Source: BP Statistical Review of World Energy 2019)

Oil: Natural gas liquids production in thousands of barrels per day*

Thousand barrels daily	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Growth rate per annum 2018	Growth rate per annum 2007-17	Share 2018
Canada	626	626	608	615	610	642	661	709	773	822	**906**	10.3%	1.9%	7.8%
Mexico	374	377	382	388	363	353	355	320	302	276	**235**	-14.8%	-3.7%	2.0%
US	1784	1910	2074	2216	2408	2606	3015	3342	3509	3783	**4349**	15.0%	7.8%	37.6%
Total North America	2783	2913	3064	3219	3381	3600	4031	4371	4584	4880	**5490**	12.5%	5.5%	47.5%
Argentina	123	126	123	114	107	105	106	114	100	111	**102**	-7.8%	-1.2%	0.9%
Brazil	74	69	70	68	70	72	87	88	81	99	**96**	-3.3%	3.3%	0.8%
Colombia	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a
Ecuador	2	2	2	1	1	1	–	–	–	–	**–**	n/a	-100.0%	–
Peru	24	38	42	42	45	54	54	49	50	49	**56**	14.7%	8.3%	0.5%
Trinidad & Tobago	35	44	47	44	35	34	33	30	25	27	**24**	-11.3%	-2.3%	0.2%
Venezuela	165	159	147	132	124	116	114	117	105	104	**88**	-15.0%	-5.1%	0.8%
Other S. & Cent. America	14	15	19	19	16	17	14	13	12	14	**13**	-5.0%	-3.2%	0.1%
Total S. & Cent. America	438	453	451	419	399	399	408	411	373	404	**379**	-6.0%	-1.1%	3.3%
Denmark	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a
Italy	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a
Norway	283	285	261	275	300	300	318	332	343	345	**329**	-4.7%	2.2%	2.8%
Romania	6	4	4	5	4	3	3	3	4	3	**3**	-11.5%	-7.2%	◆
United Kingdom	144	125	110	76	55	49	56	55	73	82	**80**	-1.8%	-5.1%	0.7%
Other Europe	27	25	23	20	19	17	15	14	16	19	**19**	1.4%	-3.4%	0.2%
Total Europe	460	439	398	375	377	369	392	404	436	449	**431**	-3.9%	◆	3.7%
Azerbaijan	21	12	13	13	10	11	12	11	11	10	**12**	9.9%	-6.2%	0.1%
Kazakhstan	2	†	†	†	2	17	9	23	18	25	**27**	9.2%	30.5%	0.2%
Russian Federation	180	225	228	247	260	278	265	249	266	238	**237**	-0.2%	2.3%	2.1%
Turkmenistan	10	10	10	10	14	17	17	17	20	23	**26**	10.0%	11.3%	0.2%
Uzbekistan	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a
Other CIS	–	–	–	–	–	–	–	–	–	–	**–**	n/a	n/a	–
Total CIS	214	248	252	271	286	323	303	299	315	296	**301**	1.7%	3.1%	2.6%
Iran	242	270	352	404	412	418	441	461	496	553	**559**	1.1%	11.5%	4.8%
Iraq	34	41	45	45	42	45	40	41	48	64	**64**	-0.1%	9.1%	0.6%
Kuwait	207	217	249	264	275	278	267	279	281	297	**312**	5.0%	4.7%	2.7%
Oman	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a
Qatar	222	264	323	426	437	471	466	470	473	458	**471**	2.8%	10.9%	4.1%
Saudi Arabia	1211	1298	1442	1513	1635	1518	1577	1578	1718	1717	**1753**	2.1%	3.7%	15.2%
Syria	35	35	35	34	25	14	10	8	8	8	**8**	–	-13.7%	0.1%
United Arab Emirates	294	300	334	447	479	482	539	614	654	631	**641**	1.7%	7.3%	5.5%
Yemen	21	22	23	23	24	24	25	26	26	27	**28**	2.4%	2.1%	0.2%
Other Middle East	10	10	10	11	10	10	10	10	10	10	**11**	14.4%	◆	0.1%
Total Middle East	2275	2457	2812	3167	3338	3260	3377	3485	3714	3764	**3847**	2.2%	5.8%	33.3%
Algeria	308	258	228	225	216	210	260	268	261	254	**252**	-0.8%	-1.8%	2.2%
Angola	22	20	19	14	20	22	30	16	23	39	**51**	31.8%	6.0%	0.4%
Chad	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a
Republic of Congo	2	7	7	9	12	9	8	7	7	6	**6**	-5.6%	7.7%	0.1%
Egypt	65	65	61	65	66	67	47	64	60	57	**55**	-3.9%	-0.6%	0.5%
Equatorial Guinea	21	22	20	21	20	21	19	17	19	21	**21**	-0.3%	-0.4%	0.2%
Gabon	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a
Libya	67	51	50	8	40	22	8	15	15	20	**21**	5.9%	-11.2%	0.2%
Nigeria	72	73	78	88	82	86	88	82	78	80	**85**	6.0%	1.3%	0.7%
South Sudan	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a
Sudan	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a
Tunisia	8	9	4	7	13	12	12	10	9	5	**8**	74.4%	-5.4%	0.1%
Other Africa	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	**1**	n/a	n/a	◆
Total Africa	564	506	468	437	468	449	471	480	472	482	**500**	3.7%	-1.4%	4.3%
Australia	82	84	77	71	73	72	83	62	69	64	**61**	-4.7%	-3.4%	0.5%
Brunei	14	14	13	13	13	13	12	11	12	13	**12**	-4.8%	-1.6%	0.1%
China	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	**n/a**	n/a	n/a	n/a
India	115	148	140	144	140	136	128	122	129	141	**150**	6.7%	6.0%	1.3%
Indonesia	29	45	58	50	58	58	58	52	45	37	**36**	-1.6%	7.8%	0.3%
Malaysia	39	29	79	76	65	39	39	35	37	35	**36**	1.9%	-2.0%	0.3%
Thailand	139	145	149	204	229	222	228	230	228	244	**257**	5.4%	6.1%	2.2%
Vietnam	8	10	19	19	20	22	21	23	25	23	**32**	35.8%	7.9%	0.3%
Other Asia Pacific	52	51	48	46	45	37	35	32	30	31	**25**	-19.3%	-4.0%	0.2%
Total Asia Pacific	478	526	583	623	643	599	603	567	576	587	**609**	3.6%	3.0%	5.3%
Total World	**7212**	**7541**	**8029**	**8511**	**8892**	**9000**	**9584**	**10018**	**10471**	**10862**	**11557**	**6.4%**	**4.3%**	**100.0%**
of which: OECD	3319	3434	3543	3668	3834	4043	4507	4838	5086	5390	**5977**	10.9%	4.7%	51.7%
Non-OECD	3893	4107	4486	4843	5058	4956	5077	5181	5385	5473	**5580**	2.0%	4.0%	48.3%
OPEC	2867	2982	3296	3597	3793	3699	3858	3964	4178	4243	**4325**	1.9%	4.5%	37.4%
Non-OPEC	4345	4559	4733	4914	5099	5300	5726	6054	6293	6619	**7233**	9.3%	4.2%	62.6%
European Union	169	147	130	94	71	63	69	67	87	95	**92**	-3.3%	-5.2%	0.8%

*Includes ethane, LPG and naphtha separated from the production of natural gas. Excludes condensates.
†Less than 0.05.
◆Less than 0.05%.
n/a not available.
Note: Annual changes and shares of total are calculated using thousand barrels daily figures.

Source: Includes data from ICIS.

Table D5 (1 of 6). Crude oil production by country
(Source: BP Statistical Review of World Energy 2019 and BP Statistical Review of World Energy 2011)

Year	United States (kbbls/day)	Saudi Arabia (kbbls/day)	Russian Federation (kbbls/day)	Canada (kbbls/day)	Iran (kbbls/day)
1965	9014,0	2219,0		920,0	1908,0
1966	9579,0	2615,0		1012,0	2132,0
1967	10219	2825		1106	2603
1968	10600	3081		1194	2840
1969	10828	3262		1306	3376
1970	11297	3851		1473	3848
1971	11156	4821		1582	4572
1972	11185	6070		1829	5059
1973	10946	7693		2114	5907
1974	10461	8618		1993	6060
1975	10008	7216		1735	5387
1976	9736	8762		1598	5918
1977	9863	9419		1608	5714
1978	10274	8554		1597	5302
1979	10136	9841		1835	3218
1980	10170	10270		1764	1479
1981	10181	10256		1610	1321
1982	10199	6961		1590	2397
1983	10247	4951		1661	2454
1984	10509	4534		1775	2043
1985	10580	3601	10904	1812	2205
1986	10231	5208	11306	1803	2054
1987	9944	4599	11484	1907	2342
1988	9765	5720	11444	2000	2349
1989	9159	5635	11135	1958	2894
1990	8914	7105	10405	1965	3270
1991	9076	8820	9326	1980	3500
1992	8868	9098	8038	2062	3523
1993	8583	8962	7173	2184	3712
1994	8389	9084	6419	2276	3730
1995	8322	9145	6288	2402	3744
1996	8295	9299	6114	2480	3759
1997	8269	9482	6227	2588	3776
1998	8011	9502	6169	2672	3855
1999	7731	8853	6178	2604	3603

Table D5 (2 of 6). Crude oil production by country
(Source: BP Statistical Review of World Energy 2019 and BP Statistical Review of World Energy 2011)

Year	United States (kbbls/day)	Saudi Arabia (kbbls/day)	Russian Federation (kbbls/day)	Canada (kbbls/day)	Iran (kbbls/day)
2000	7733	9491	6536	2721	3855
2001	7669	9209	7056	2677	3892
2002	7626	8928	7698	2858	3709
2003	7400	10164	8544	3004	4183
2004	7228	10638	9287	3085	4248
2005	6895	11114	9552	3041	4234
2006	6841	10853	9769	3208	4286
2007	6847	10449	9978	3297	4322
2008	6783	10665	9965	3207	4415
2009	7259	9709	10152	3202	4285
2010	7552	9865	10379	3332	4421
2011	7870	11079	10533	3515	4452
2012	8910	11622	10656	3740	3810
2013	10073	11393	10807	4000	3609
2014	11773	11519	10860	4271	3714
2015	12773	11998	11007	4388	3853
2016	12340	12406	11269	4451	4586
2017	13135	11892	11255	4798	5024
2018	15311	12287	11438	5208	4715

Table D5 (3 of 6). Crude oil production by country
(Source: BP Statistical Review of World Energy 2019 and BP Statistical Review of World Energy 2011)

Year	Iraq (kbbls/day)	China (kbbls/day)	United Arab Emirates (kbbls/day)	Kuwait (kbbls/day)	Brazil (kbbls/day)	Nigeria (kbbls/day)	Mexico (kbbls/day)
1965	1313,0	226,8	282,0	2371,0	96	274	362
1966	1392,0	291,8	360,0	2505,0	117	418	370
1967	1228	278	382	2522	147	319	411
1968	1503	320	498	2656	161	141	439
1969	1521	436	599	2819	176	540	461
1970	1549	615	762	3036	167	1084	487
1971	1694	790	1106	3253	175	1531	486
1972	1466	913	1300	3339	171		506
1973	2018	1075	1456	3080	174	2056	525
1974	1977	1301	1631	2603	181	2256	653
1975	2271	1545	1696	2132	178	1785	806
1976	2422	1743	1937	2199	173	2071	894
1977	2358	1878	1998	2024	167	2098	1085
1978	2574	2087	1829	2182	166	1897	1327
1979	3489	2129	1831	2623	172	2306	1607
1980	2658	2119	1745	1757	188	2059	2129
1981	907	2030	1540	1187	220	1440	2553
1982	988	2048	1375	862	268	1290	3001
1983	1106	2127	1296	1117	340	1236	2930
1984	1228	2292	1283	1229	473	1388	2942
1985	1425	2505	1260	1127	560	1499	2912
1986	1899	2621	1594	1210	591	1467	2758
1987	2391	2690	1603	1072	589	1353	2879
1988	2782	2741	1620	1286	573	1496	2877
1989	2838	2760	2024	1408	613	1775	2897
1990	2149	2774	2283	964	650	1870	2977
1991	285	2828	2639	185	643	1960	3126
1992	531	2841	2510	1077	652	2020	3120
1993	455	2888	2443	1945	664	2024	3132
1994	505	2930	2482	2085	693	1991	3142
1995	530	2989	2401	2130	718	1998	3065
1996	580	3170	2519	2129	807	2145	3277
1997	1166	3211	2620	2137	868	2316	3410
1998	2121	3212	2687	2232	1003	2167	3499
1999	2610	3213	2583	2085	1133	2066	3343

Table D5 (4 of 6). Crude oil production by country
(Source: BP Statistical Review of World Energy 2019 and BP Statistical Review of World Energy 2011)

Year	Iraq (kbbls/day)	China (kbbls/day)	United Arab Emirates (kbbls/day)	Kuwait (kbbls/day)	Brazil (kbbls/day)	Nigeria (kbbls/day)	Mexico (kbbls/day)
2000	2614	3252	2620	2206	1268	2155	3450
2001	2523	3306	2551	2148	1337	2274	3560
2002	2116	3346	2390	1995	1499	2103	3585
2003	1344	3401	2695	2329	1555	2238	3789
2004	2030	3481	2847	2475	1542	2431	3824
2005	1833	3637	2983	2618	1716	2499	3760
2006	1999	3705	3149	2690	1809	2420	3683
2007	2143	3737	3053	2636	1833	2305	3471
2008	2428	3814	3113	2781	1887	2172	3165
2009	2446	3805	2795	2495	2019	2211	2978
2010	2469	4077	2937	2556	2125	2533	2959
2011	2773	4074	3303	2909	2173	2461	2940
2012	3079	4155	3440	3164	2132	2412	2911
2013	3103	4216	3577	3125	2096	2279	2875
2014	3239	4246	3603	3097	2341	2276	2784
2015	3986	4309	3898	3061	2525	2201	2587
2016	4423	3999	4038	3141	2591	1900	2456
2017	4533	3846	3910	3001	2721	1991	2224
2018	4614	3798	3942	3049	2683	2051	2068

Table D5 (5 of 6). Crude oil production by country
(Source: BP Statistical Review of World Energy 2019 and BP Statistical Review of World Energy 2011)

Year	Kazakhstan (kbbls/day)	Qatar (kbbls/day)	Venezuela (kbbls/day)	Libya (kbbls/day)	United Kingdom (kbbls/day)	Norway (kbbls/day)
1965		233	3503,0	1220,0	1,7	
1966		291	3402,0	1508,0	1,6	
1967		324	3576	1733	2	
1968		340	3639	2599	2	
1969		356	3631	3108	2	
1970		363	3754	3357	4	
1971		430	3615	2750	5	6
1972		482	3301	2248	8	33
1973		570	3455	2211	9	32
1974		518	3060	1558	10	35
1975		437	2422	1514	34	189
1976		487	2371	1972	253	279
1977		435	2314	2108	792	287
1978		484	2227	2023	1119	356
1979		506	2425	2139	1611	407
1980		476	2228	1862	1663	528
1981		421	2163	1253	1853	512
1982		345	1954	1176	2150	532
1983		316	1852	1151	2404	661
1984		353	1853	1022	2632	752
1985	466	315	1744	1025	2675	823
1986	484	355	1886	1064	2671	907
1987	504	315	1910	1003	2593	1054
1988	526	360	1998	1051	2396	1196
1989	536	403	2012	1164	1929	1567
1990	551	434	2244	1424	1918	1716
1991	569	420	2501	1439	1919	1955
1992	549	495	2499	1473	1981	2217
1993	490	460	2592	1402	2119	2377
1994	430	451	2752	1431	2675	2693
1995	434	461	2959	1439	2749	2903
1996	474	568	3137	1452	2735	3232
1997	536	692	3321	1491	2702	3280
1998	537	701	3480	1480	2807	3138
1999	631	723	3126	1425	2909	3139

Table D5 (6 of 6). Crude oil production by country
(Source: BP Statistical Review of World Energy 2019 and BP Statistical Review of World Energy 2011)

Year	Kazakhstan (kbbls/day)	Qatar (kbbls/day)	Venezuela (kbbls/day)	Libya (kbbls/day)	United Kingdom (kbbls/day)	Norway (kbbls/day)
2000	744	757	3239	1475	2667	3346
2001	836	754	3142	1427	2476	3418
2002	1018	764	2895	1375	2463	3333
2003	1111	879	2554	1485	2257	3264
2004	1297	992	2907	1623	2028	3189
2005	1356	1028	2937	1745	1809	2969
2006	1426	1110	2808	1815	1636	2779
2007	1484	1197	2613	1820	1638	2551
2008	1485	1432	3228	1875	1549	2458
2009	1609	1415	3038	1739	1469	2342
2010	1676	1630	2842	1799	1356	2132
2011	1684	1824	2755	516	1112	2033
2012	1664	1928	2704	1539	946	1911
2013	1737	1991	2680	1048	864	1832
2014	1710	1975	2692	518	852	1881
2015	1695	1933	2631	437	963	1940
2016	1655	1938	2347	412	1013	1991
2017	1838	1874	2096	929	999	1963
2018	1927	1879	1514	1010	1085	1844

28 APPENDIX E – OIL RESERVES

Table E1. Global total proved oil reserves (Billion tonnes) (Source: BP Statistical Review of World Energy 2019)

Total proved reserves

	At end 1998 Thousand million barrels	At end 2008 Thousand million barrels	At end 2017 Thousand million barrels	At end 2018 Thousand million barrels	Thousand million tonnes	Share of total	R/P ratio
Canada	49.8	176.3	168.9	**167.8**	**27.1**	9.7%	88.3
Mexico	21.6	11.9	7.7	**7.7**	**1.1**	0.4%	10.2
US	28.6	28.4	61.2	**61.2**	**7.3**	3.5%	11.0
Total North America	100.0	216.6	237.8	**236.7**	**35.4**	13.7%	28.7
Argentina	2.8	2.5	2.0	**2.0**	**0.3**	0.1%	9.3
Brazil	7.4	12.8	12.8	**13.4**	**2.0**	0.8%	13.7
Colombia	2.5	1.4	1.7	**1.8**	**0.3**	0.1%	5.6
Ecuador	4.1	4.3	3.0	**2.8**	**0.4**	0.2%	14.8
Peru	0.9	1.1	1.0	**1.0**	**0.1**	0.1%	17.6
Trinidad & Tobago	0.7	0.8	0.2	**0.2**	†	◆	7.6
Venezuela	76.1	172.3	302.8	**303.3**	**48.0**	17.5%	*
Other S. & Cent. America	1.1	0.8	0.5	**0.5**	**0.1**	◆	11.5
Total S. & Cent. America	95.6	196.0	324.0	**325.1**	**51.1**	18.8%	136.2
Denmark	0.9	0.8	0.4	**0.4**	**0.1**	◆	10.1
Italy	0.6	0.5	0.6	**0.6**	**0.1**	◆	16.2
Norway	11.7	7.5	7.9	**8.6**	**1.1**	0.5%	12.8
Romania	1.2	0.5	0.6	**0.6**	**0.1**	◆	22.2
United Kingdom	5.1	3.1	2.5	**2.5**	**0.3**	0.1%	6.3
Other Europe	1.9	1.9	1.6	**1.6**	**0.2**	0.1%	14.1
Total Europe	21.4	14.2	13.7	**14.3**	**1.9**	0.8%	11.1
Azerbaijan	1.2	7.0	7.0	**7.0**	**1.0**	0.4%	24.1
Kazakhstan	5.4	30.0	30.0	**30.0**	**3.9**	1.7%	42.7
Russian Federation	113.1	106.4	106.3	**106.2**	**14.6**	6.1%	25.4
Turkmenistan	0.5	0.6	0.6	**0.6**	**0.1**	◆	7.4
Uzbekistan	0.6	0.6	0.6	**0.6**	**0.1**	◆	25.4
Other CIS	0.3	0.3	0.3	**0.3**	†	◆	18.1
Total CIS	121.1	144.8	144.7	**144.7**	**19.6**	8.4%	27.4
Iran	93.7	137.6	155.6	**155.6**	**21.4**	9.0%	90.4
Iraq	112.5	115.0	147.2	**147.2**	**19.9**	8.5%	87.4
Kuwait	96.5	101.5	101.5	**101.5**	**14.0**	5.9%	91.2
Oman	5.4	5.6	5.4	**5.4**	**0.7**	0.3%	15.0
Qatar	13.5	26.8	25.2	**25.2**	**2.6**	1.5%	36.8
Saudi Arabia	261.5	264.1	296.0	**297.7**	**40.9**	17.2%	66.4
Syria	2.3	2.5	2.5	**2.5**	**0.3**	0.1%	284.8
United Arab Emirates	97.8	97.8	97.8	**97.8**	**13.0**	5.7%	68.0
Yemen	1.9	2.7	3.0	**3.0**	**0.4**	0.2%	121.4
Other Middle East	0.2	0.1	0.1	**0.2**	†	◆	2.1
Total Middle East	685.2	753.7	834.3	**836.1**	**113.2**	48.3%	72.1
Algeria	11.3	12.2	12.2	**12.2**	**1.5**	0.7%	22.1
Angola	4.0	9.5	8.4	**8.4**	**1.1**	0.5%	15.0
Chad	–	1.5	1.5	**1.5**	**0.2**	0.1%	40.9
Republic of Congo	1.7	1.6	1.6	**1.6**	**0.2**	0.1%	13.2
Egypt	3.8	4.2	3.3	**3.3**	**0.4**	0.2%	13.6
Equatorial Guinea	0.6	1.7	1.1	**1.1**	**0.1**	0.1%	15.8
Gabon	2.6	2.0	2.0	**2.0**	**0.3**	0.1%	28.2
Libya	29.5	44.3	48.4	**48.4**	**6.3**	2.8%	131.3
Nigeria	22.5	37.2	37.5	**37.5**	**5.1**	2.2%	50.0
South Sudan	n/a	n/a	3.5	**3.5**	**0.5**	0.2%	73.4
Sudan	0.3	5.0	1.5	**1.5**	**0.2**	0.1%	41.1
Tunisia	0.3	0.6	0.4	**0.4**	**0.1**	◆	23.2
Other Africa	0.7	0.7	3.9	**3.9**	**0.5**	0.2%	33.7
Total Africa	77.2	120.4	125.3	**125.3**	**16.6**	7.2%	41.9
Australia	4.8	4.2	4.0	**4.0**	**0.4**	0.2%	30.8
Brunei	1.0	1.1	1.1	**1.1**	**0.1**	0.1%	27.0
China	17.4	21.2	25.9	**25.9**	**3.5**	1.5%	18.7
India	5.4	5.8	4.5	**4.5**	**0.6**	0.3%	14.1
Indonesia	5.1	3.7	3.2	**3.2**	**0.4**	0.2%	10.7
Malaysia	3.4	5.5	3.0	**3.0**	**0.4**	0.2%	12.1
Thailand	0.4	0.5	0.3	**0.3**	†	◆	1.8
Vietnam	1.9	4.7	4.4	**4.4**	**0.6**	0.3%	43.9
Other Asia Pacific	1.3	1.3	1.2	**1.2**	**0.2**	0.1%	12.9
Total Asia Pacific	40.8	48.0	47.7	**47.6**	**6.3**	2.8%	17.1
Total World	**1141.2**	**1493.8**	**1727.5**	**1729.7**	**244.1**	**100.0%**	**50.0**
of which: OECD	124.5	234.0	254.4	**254.0**	**37.6**	14.7%	26.4
Non-OECD	1016.7	1259.8	1473.1	**1475.8**	**206.6**	85.3%	59.1
OPEC	827.9	1027.9	1240.2	**1242.2**	**174.8**	71.8%	86.5
Non-OPEC	313.3	465.9	487.3	**487.5**	**69.4**	28.2%	24.1
European Union	8.7	5.7	4.9	**4.8**	**0.6**	0.3%	8.6
Canadian oil sands: Total	43.1	170.3	163.4	**162.3**	**26.4**	9.4%	
of which: Under active development	8.4	27.0	22.0	**20.9**	**3.4**	1.2%	
Venezuela: Orinoco Belt	–	94.2	260.9	**261.4**	**41.9**	15.1%	

†Less than 0.05.
◆Less than 0.05%.
n/a not available.
*More than 500 years.

Notes: Total proved reserves of oil – Generally taken to be those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known reservoirs under existing economic and operating conditions. The data series for total proved oil reserves does not necessarily meet the definitions, guidelines and practices used for determining proved reserves at company level, for instance as published by the US Securities and Exchange Commission, nor does it necessarily represent BP's view of proved reserves by country.
Reserves-to-production (R/P) ratio – If the reserves remaining at the end of any year are divided by the production in that year, the result is the length of time that those remaining reserves would last if production were to continue at that rate.
Source of data – The estimates in this table have been compiled using a combination of primary official sources, third-party data from the OPEC Secretariat, World Oil, Oil & Gas Journal and Chinese reserves based on official data and information in the public domain.
Canadian oil sands 'under active development' are an official estimate. Venezuelan Orinoco Belt reserves are based on the OPEC Secretariat and government announcements.
Reserves include gas condensate and natural gas liquids (NGLs) as well as crude oil. Saudi Arabia's oil reserves include NGLs from 2017.
Shares of total and R/P ratios are calculated using thousand million barrels figures.

Table E2. Global Net Inventory Contribution
(Source: BP Statistical World Energy Review 2019, 2018, 2016, 2015, 2013, 2012, 2011, 2010)

Year	Oil: Proved reserves Billion barrels (Thousand million barrels)	New Reserves (Thousand barrels)	Oil: Daily Consumption (Thousand barrels daily)	Oil: Annual Consumption (Thousand barrels)	Global Net Inventory Contribution (Thousand barrels)
1980	668		61177	22 329 610	
1981	688	20 055 346	59309	21 647 638	-1 592 292
1982	717	29 780 489	57667	21 048 406	8 732 083
1983	728	10 901 050	57445	20 967 560	-10 066 510
1984	762	33 339 743	58728	21 435 694	11 904 050
1985	771	9 685 496	59090	21 568 005	-11 882 508
1986	878	106 665 813	60936	22 241 779	84 424 033
1987	910	32 045 828	62168	22 691 438	9 354 389
1988	999	89 022 377	63953	23 342 966	65 679 411
1989	1 006	7 393 313	65292	23 831 465	-16 438 152
1990	1 003	-3 176 502	66503	24 273 685	-27 450 187
1991	1 008	4 310 142	66656	24 329 280	-20 019 138
1992	1 013	5 783 341	67349	24 582 563	-18 799 222
1993	1 014	974 427	67125	24 500 680	-23 526 253
1994	1 019	5 178 866	68525	25 011 560	-19 832 694
1995	1 029	9 496 455	69861	25 499 377	-16 002 922
1996	1 051	21 611 409	71342	26 039 922	-4 428 514
1997	1 069	18 687 313	73477	26 819 166	-8 131 854
1998	1 070	297 256	74001	27 010 301	-26 713 045
1999	1 085	15 370 898	75726	27 639 941	-12 269 043
2000	1 105	19 942 427	76605	27 960 851	-8 018 423
2001	1 129	24 085 849	77304	28 215 858	-4 130 009
2002	1 190	60 656 341	78268	28 567 782	32 088 559
2003	1 203	13 528 059	79823	29 135 419	-15 607 361
2004	1 209	6 104 746	82827	30 231 938	-24 127 192
2005	1 220	10 384 424	84126	30 706 063	-20 321 639
2006	1 234	14 403 313	84958	31 009 788	-16 606 476
2007	1 254	19 467 556	86428	31 546 388	-12 078 831
2008	1 335	81 101 336	86619	31 615 935	49 485 401
2009	1 377	41 936 858	85780	31 309 700	10 627 158
2010	1 622	245 538 117	88730	32 386 450	213 151 667
2011	1 654	32 000 000	89 763	32 763 495	-763 495
2012	1 669	14 800 000	90 724	33 114 260	-18 314 260
2013	1 701	32 100 000	92 276	33 680 740	-1 580 740
2014	1 700	-1 000 000	93 194	34 015 810	-35 015 810
2015	1 698	-2 400 000	95 048	34 692 520	-37 092 520
2016	1 697	-500 000	96 737	35 309 005	-35 809 005
2017	1 697	-500 000	98 406	35 918 190	-36 418 190
2018	1 730	33 100 000	99 843	36 442 695	-3 342 695

Table E3 (1 of 3). Stated Reserves by Country 1980 to 2010
(Source: BP Statistical World Energy Review 2019, 2018, 2016, 2015, 2013, 2012, 2011, 2010)

Year	Iran (billion barrels)	Iraq (billion barrels)	Kuwait (billion barrels)	Oman (billion barrels)	Qatar (billion barrels)
1980	58,3	30,0	67,9	2,5	3,6
1981	57,0	32,0	67,7	2,9	3,5
1982	56,1	59,0	67,2	3,4	3,4
1983	55,3	65,0	67,0	3,5	3,3
1984	58,9	65,0	92,7	3,9	4,5
1985	59,0	65,0	92,5	4,1	4,5
1986	92,9	72,0	94,5	4,0	4,5
1987	92,9	100,0	94,5	4,1	4,5
1988	92,9	100,0	94,5	4,1	4,5
1989	92,9	100,0	97,1	4,3	4,5
1990	92,9	100,0	97,0	4,4	3,0
1991	92,9	100,0	96,5	4,4	3,0
1992	92,9	100,0	96,5	4,7	3,1
1993	92,9	100,0	96,5	5,0	3,1
1994	94,3	100,0	96,5	5,1	3,5
1995	93,7	100,0	96,5	5,2	3,7
1996	92,6	112,0	96,5	5,3	3,7
1997	92,6	112,5	96,5	5,4	12,5
1998	93,7	112,5	96,5	5,4	13,5
1999	93,1	112,5	96,5	5,7	13,1
2000	99,5	112,5	96,5	5,8	16,9
2001	99,1	115,0	96,5	5,9	16,8
2002	130,7	115,0	96,5	5,7	27,6
2003	133,3	115,0	99,0	5,6	27,0
2004	132,7	115,0	101,5	5,6	26,9
2005	137,5	115,0	101,5	5,6	27,9
2006	138,4	115,0	101,5	5,6	27,4
2007	138,2	115,0	101,5	5,6	27,3
2008	137,6	115,0	101,5	5,6	26,8
2009	137,0	115,0	101,5	5,5	25,9
2010	137,0	115,0	101,5	5,5	25,9
2018	155,6	147,2	101,5		

Table E3 (2 of 3). Stated Reserves by Country 1980 to 2010
(Source: BP Statistical World Energy Review 2019, 2018, 2016, 2015, 2013, 2012, 2011, 2010)

Year	Saudi Arabia (billion barrels)	United Kingdom (billion barrels)	Norway (billion barrels)	China (billion barrels)	US (billion barrels)
1980	168,0	8,4	4,0	13,3	36,5
1981	167,9	7,9	4,0	13,3	36,5
1982	165,5	7,5	3,8	13,2	35,1
1983	168,8	6,9	4,9	14,9	35,6
1984	171,7	6,0	5,0	16,3	36,1
1985	171,5	5,6	5,9	17,1	36,4
1986	169,7	5,3	6,5	17,1	35,1
1987	169,6	5,2	6,6	17,4	35,4
1988	255,0	4,3	8,2	17,3	35,1
1989	260,1	3,8	8,4	16,0	34,3
1990	260,3	4,0	8,6	16,0	33,8
1991	260,9	4,2	8,8	15,5	32,1
1992	261,2	4,6	9,7	15,2	31,2
1993	261,4	4,5	9,6	16,4	30,2
1994	261,4	4,3	9,7	16,2	29,6
1995	261,5	4,5	10,8	16,3	29,8
1996	261,4	5,0	11,7	16,4	29,8
1997	261,5	5,2	12,0	17,0	30,5
1998	261,5	5,1	11,7	17,4	28,6
1999	262,8	5,0	10,9	15,1	29,7
2000	262,8	4,7	11,4	15,2	30,4
2001	262,7	4,5	11,6	15,4	30,4
2002	262,8	4,5	10,4	15,5	30,7
2003	262,7	4,3	10,1	15,5	29,4
2004	264,3	4,0	9,7	15,5	29,3
2005	264,2	3,9	9,7	15,6	29,9
2006	264,3	3,6	8,5	15,6	29,4
2007	264,2	3,4	8,2	15,5	30,5
2008	264,1	3,1	7,5	14,8	28,4
2009	264,6	2,8	7,1	14,8	30,9
2010	264,5	2,8	6,7	14,8	30,9
2018	297,7	2,5	8,6	25,9	61,2

Table E3 (3 of 3). Stated Reserves by Country 1980 to 2010
(Source: BP Statistical World Energy Review 2019, 2018, 2016, 2015, 2013, 2012, 2011, 2010)

Year	Canada (billion barrels)	Libya (billion barrels)	Nigeria (billion barrels)	Venezuela (billion barrels)	Russian Federation (billion barrels)
1980	8,7	20,3	16,7	19,5	
1981	9,3	22,6	16,5	19,9	
1982	9,1	22,2	16,8	24,9	
1983	9,6	21,8	16,6	25,9	
1984	9,7	21,4	16,7	28,0	
1985	10,0	21,3	16,6	54,5	
1986	11,7	22,8	16,1	55,5	
1987	11,7	22,8	16,0	58,1	
1988	11,9	22,8	16,0	58,5	
1989	11,6	22,8	16,0	59,0	
1990	11,2	22,8	17,1	60,1	55,0
1991	10,9	22,8	20,0	62,6	
1992	10,3	22,8	21,0	63,3	
1993	10,0	22,8	21,0	64,4	
1994	10,4	22,8	21,0	64,9	
1995	10,5	29,5	20,8	66,3	
1996	11,0	29,5	20,8	72,7	
1997	10,7	29,5	20,8	74,9	
1998	15,1	29,5	22,5	76,1	55,2
1999	18,3	29,5	29,0	76,8	58,6
2000	18,3	36,0	29,0	76,8	59,0
2001	17,8	36,0	31,5	77,7	63,5
2002	17,6	36,0	34,3	77,3	72,9
2003	16,8	39,1	35,3	77,2	75,2
2004	16,6	39,1	35,9	79,7	74,7
2005	17,1	41,5	36,2	80,0	75,5
2006	27,6	41,5	37,2	87,3	72,4
2007	28,2	43,7	37,2	99,4	73,0
2008	33,0	44,3	37,2	172,3	76,0
2009	32,1	46,4	37,2	211,2	76,7
2010	32,1	46,4	37,2	211,2	77,4
2018	167,8	48,7	37,5	303,3	106,2

29 APPENDIX F – U.S. TIGHT OIL FRACKING SECTOR

The following charts describe each of the major tight oil plays in the United States

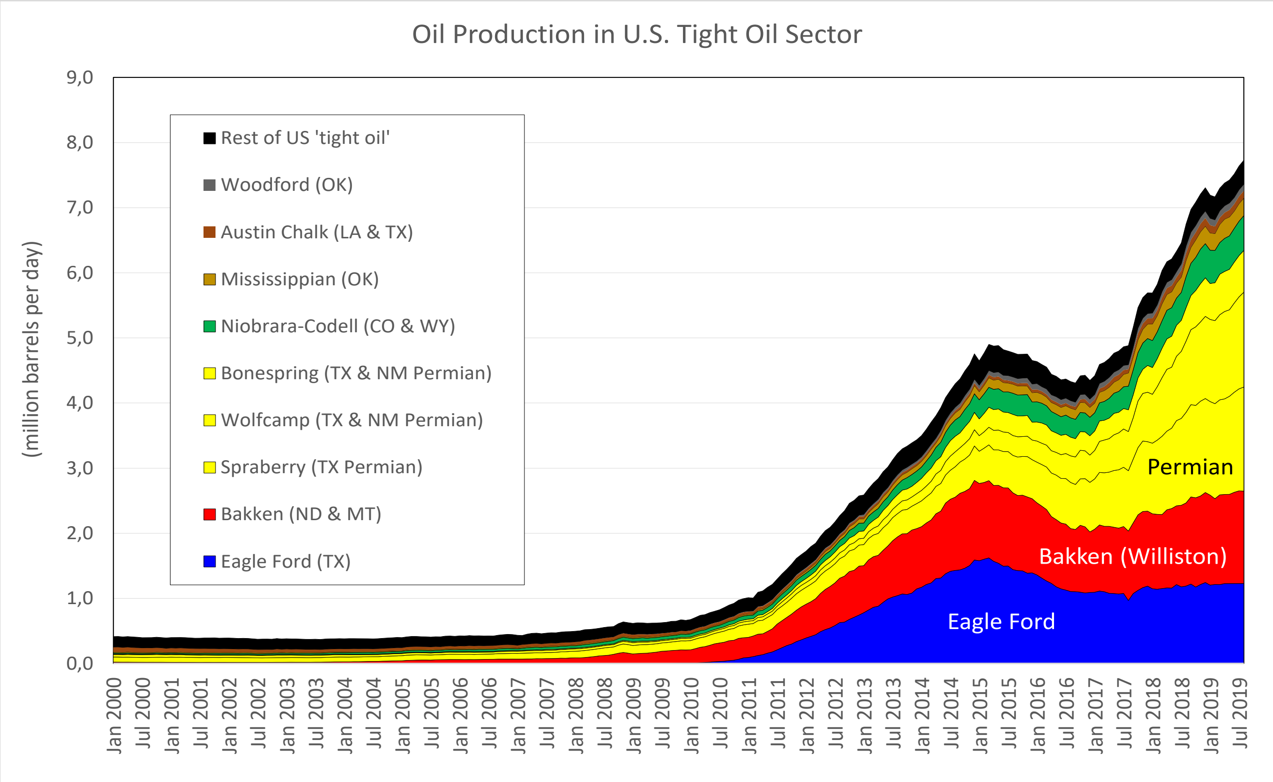

Figure F1. Oil production of the United States tight oil sector by Basin
(Source: EIA Tight Oil estimates, Shaleprofile.com)

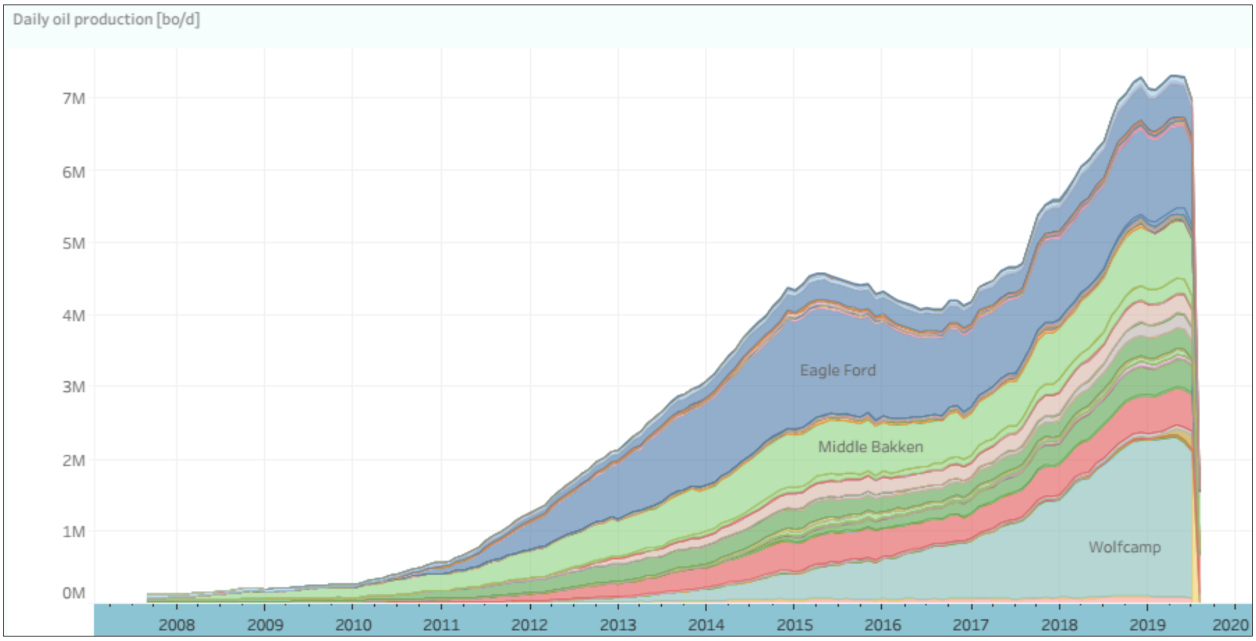

Figure F2. Oil production of the United States tight oil sector by Basin
(Source: EIA Tight Oil estimates, Shaleprofile.com)

Figure F3. Annual decline of well production, All Basin Play's
(Source: EIA Tight Oil estimates, Shaleprofile.com)

29.1 Permian Basin Play

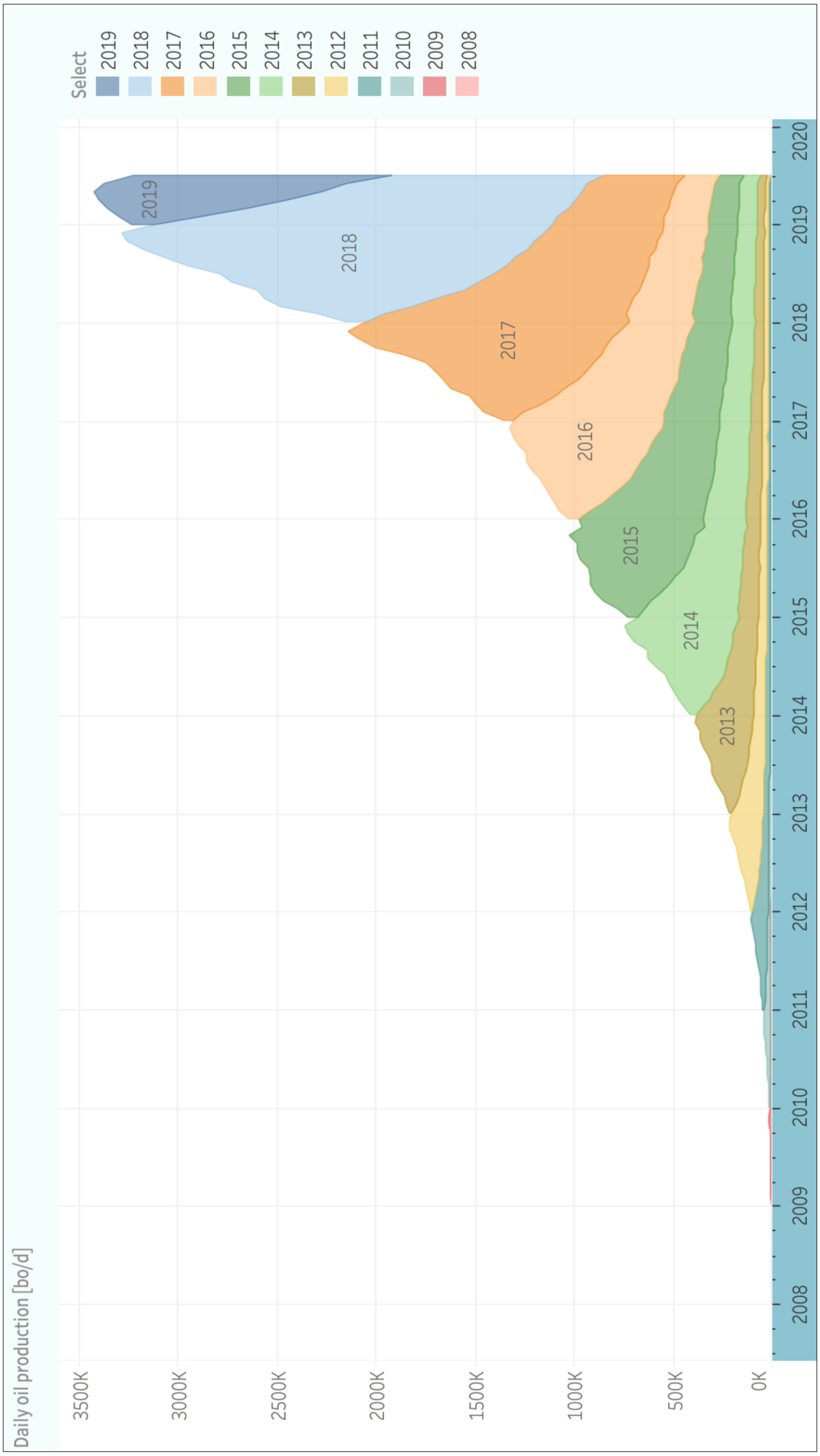

Figure F4. Permian Basin Play production by year
(Source: Shaleprofile.com)

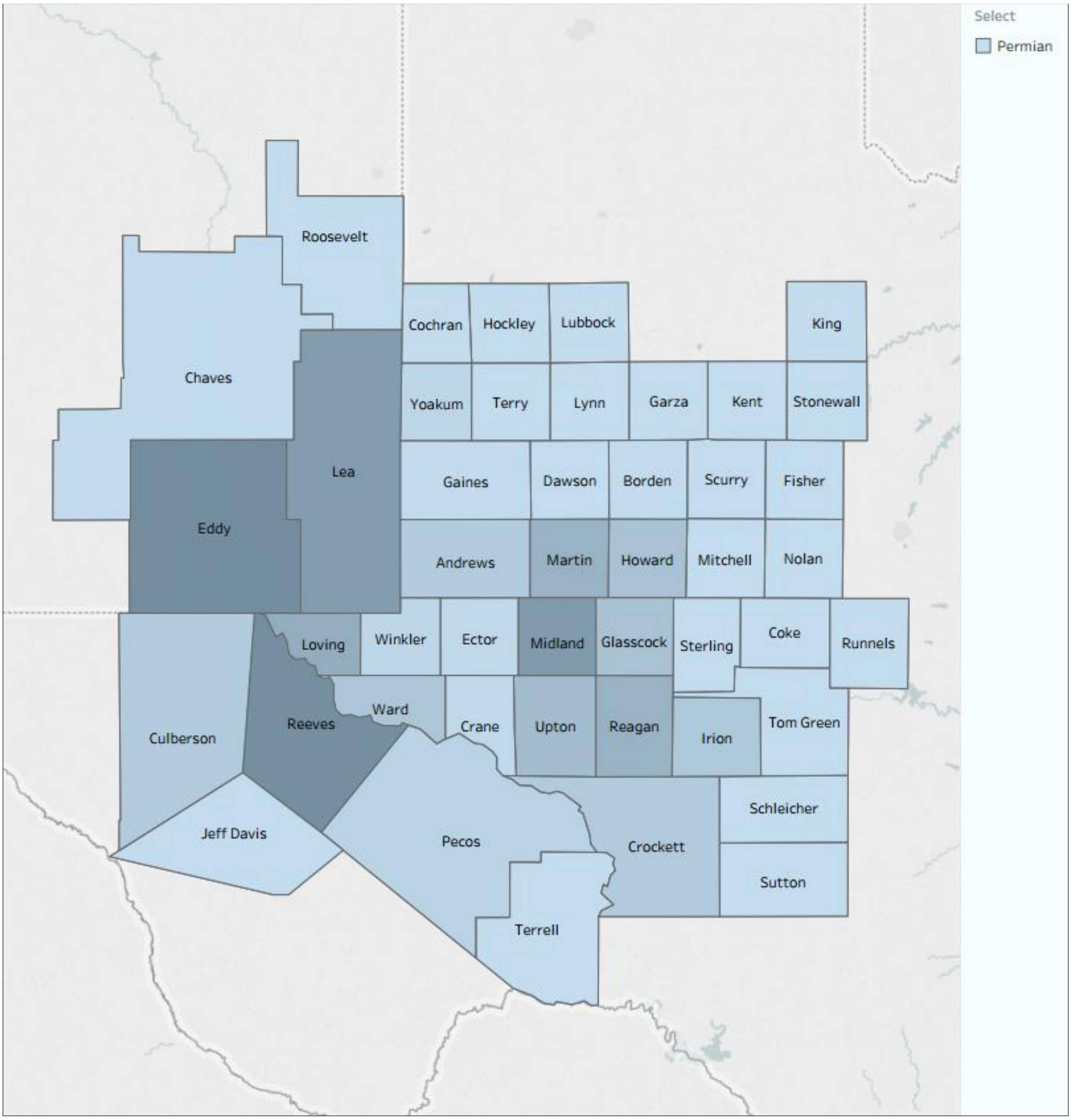

Figure F5. Permian Basin Play geographical map by county in the United States
(Source: Shaleprofile.com)

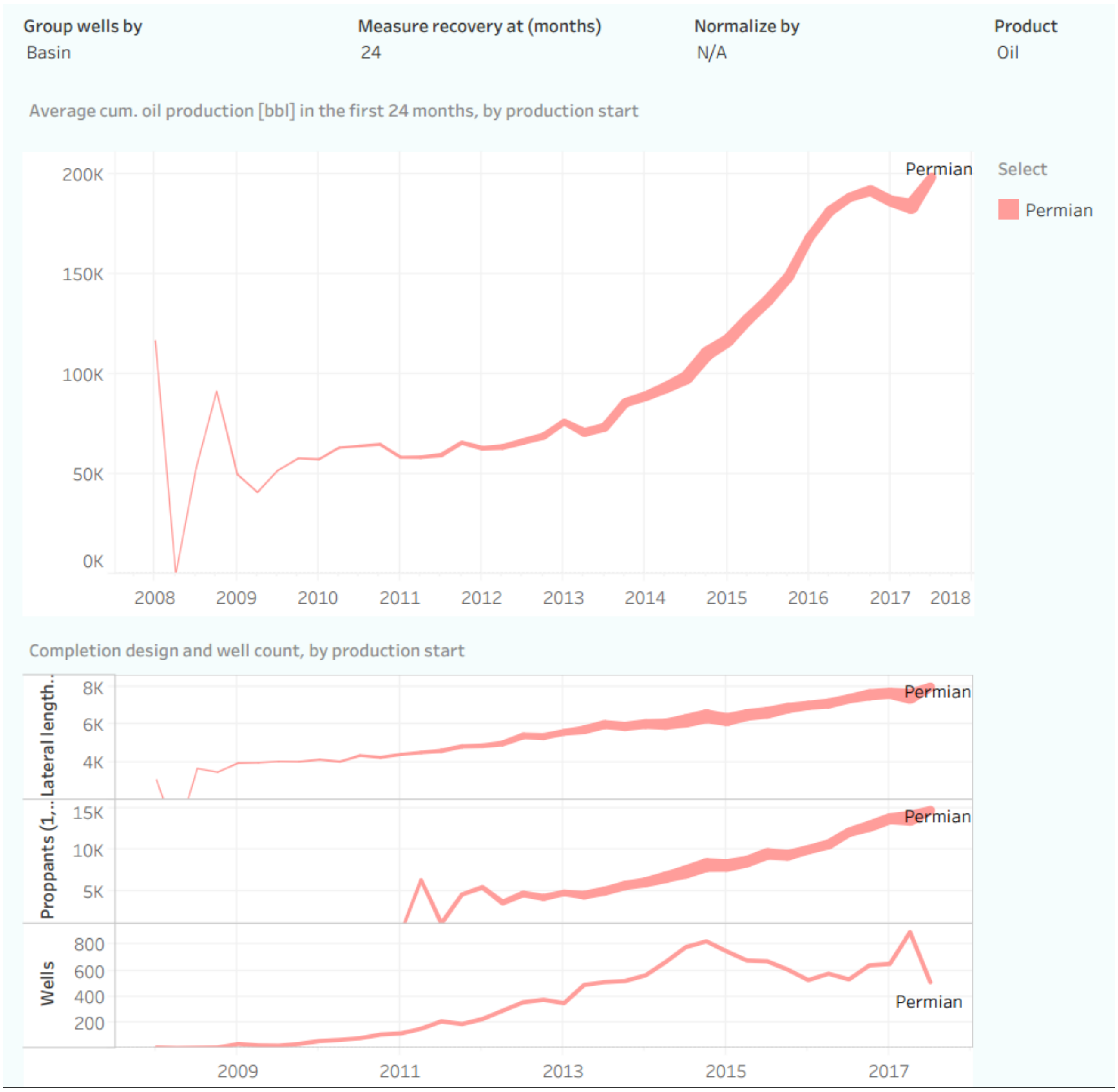

Figure F6. Permian Basin Play Productivity
(Source: Shaleprofile.com)

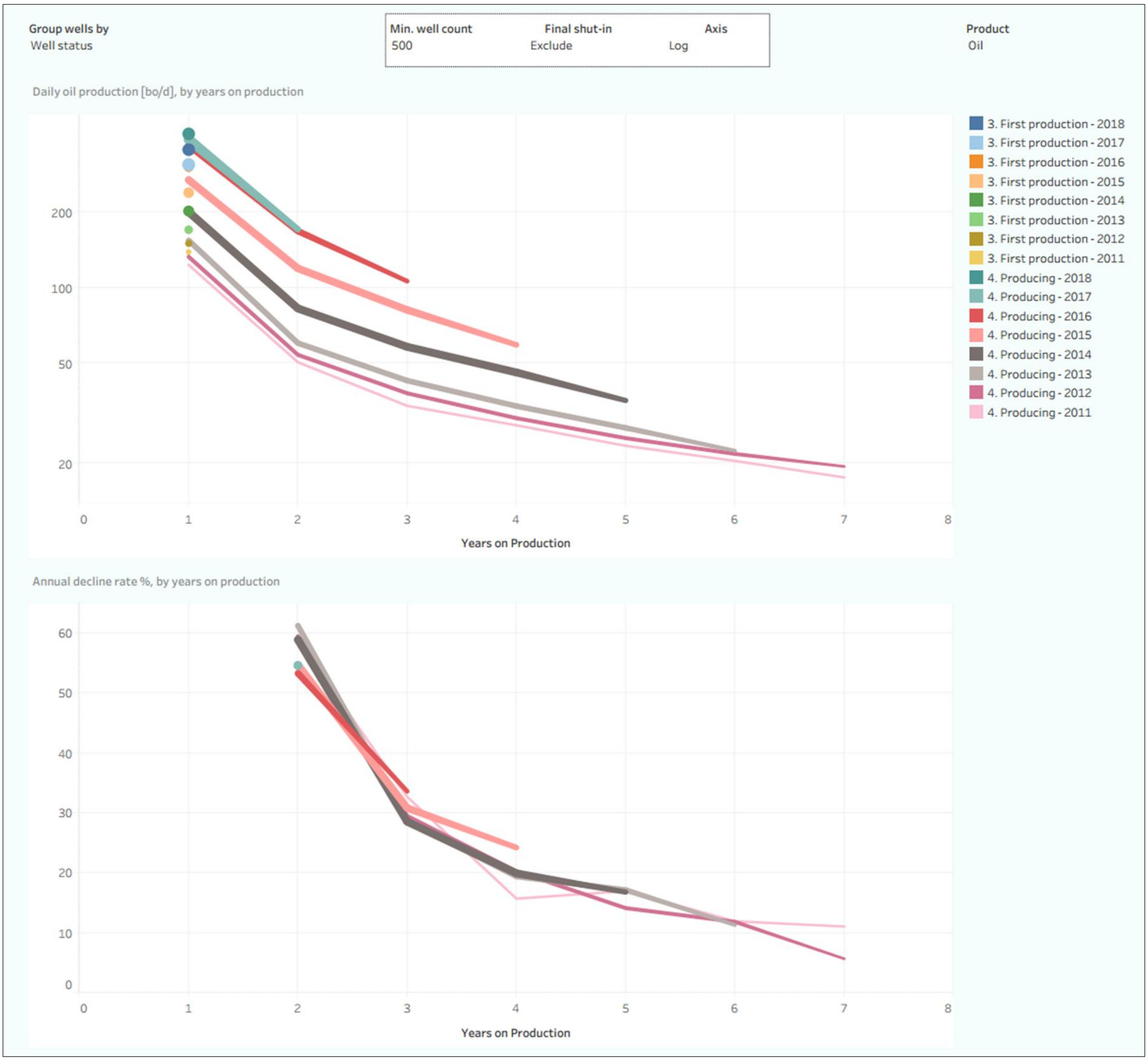

Figure F7. Annual decline of well production, Permian Basin Play
(Source: Shaleprofile.com)

29.2 Eagle Ford Basin Play

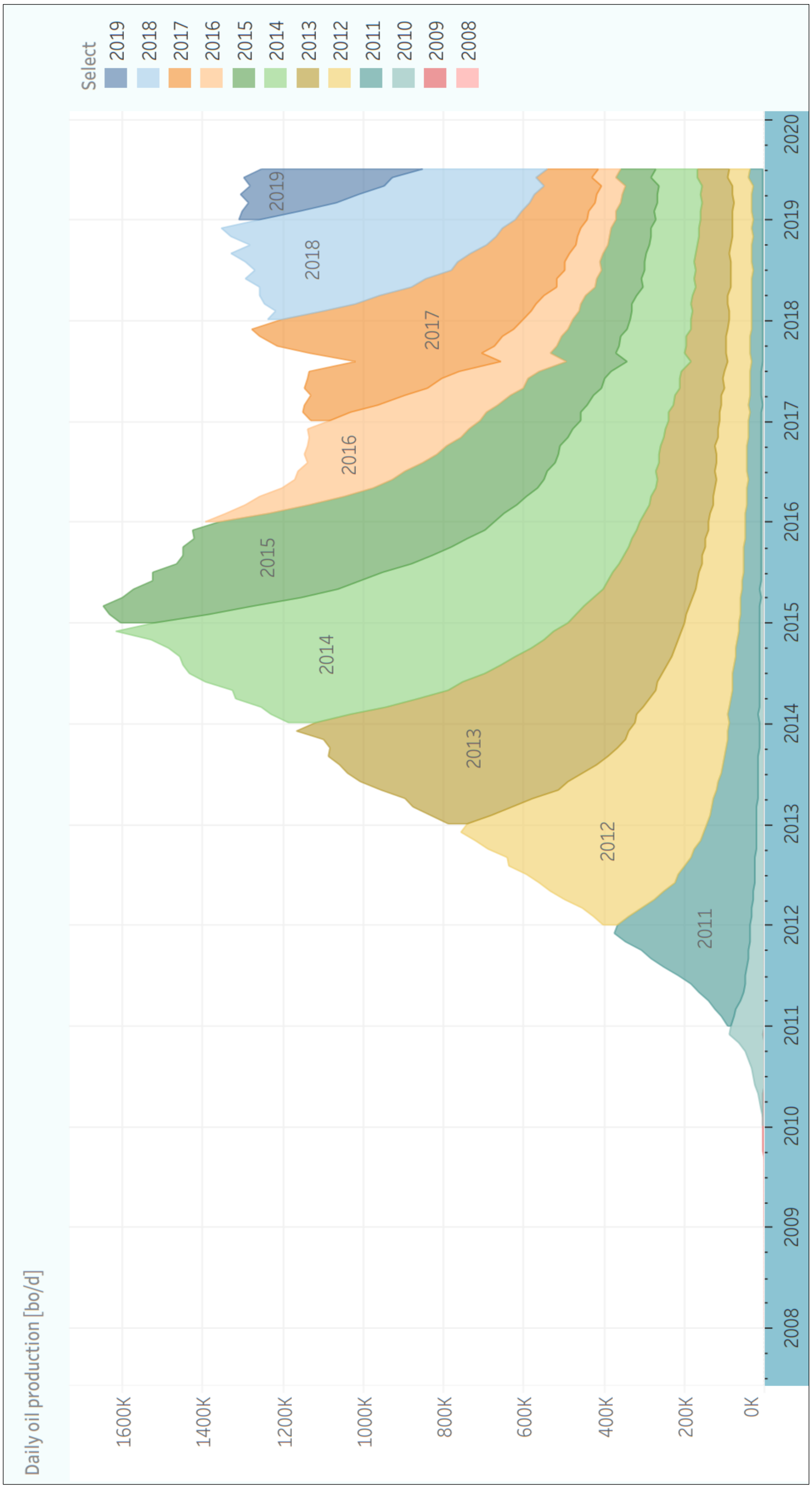

Figure F8. Eagle Ford Basin Play production by year
(Source: Shaleprofile.com)

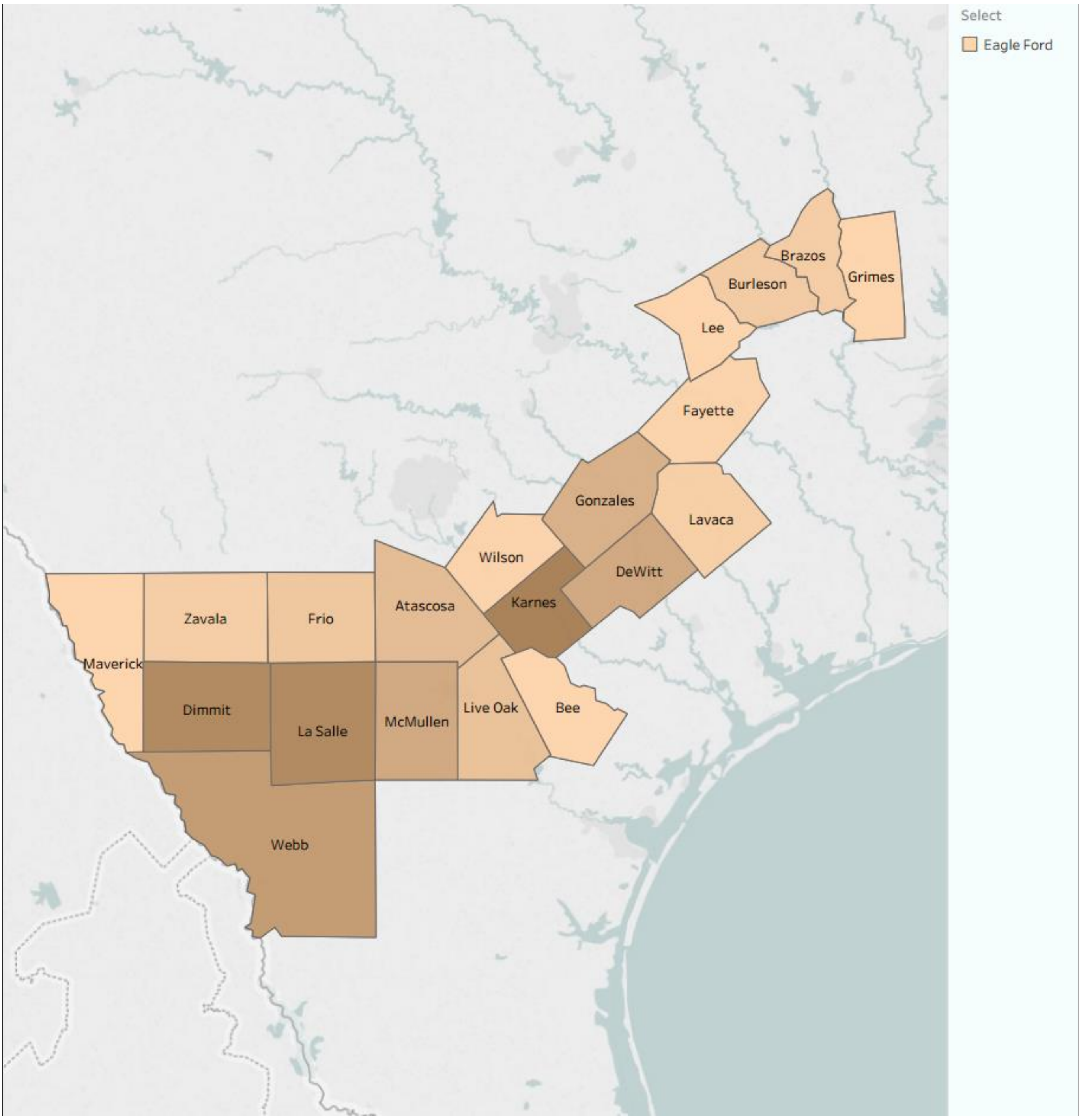

Figure F9. Eagle Ford Basin Play geographical map by county in the United States
(Source: Shaleprofile.com)

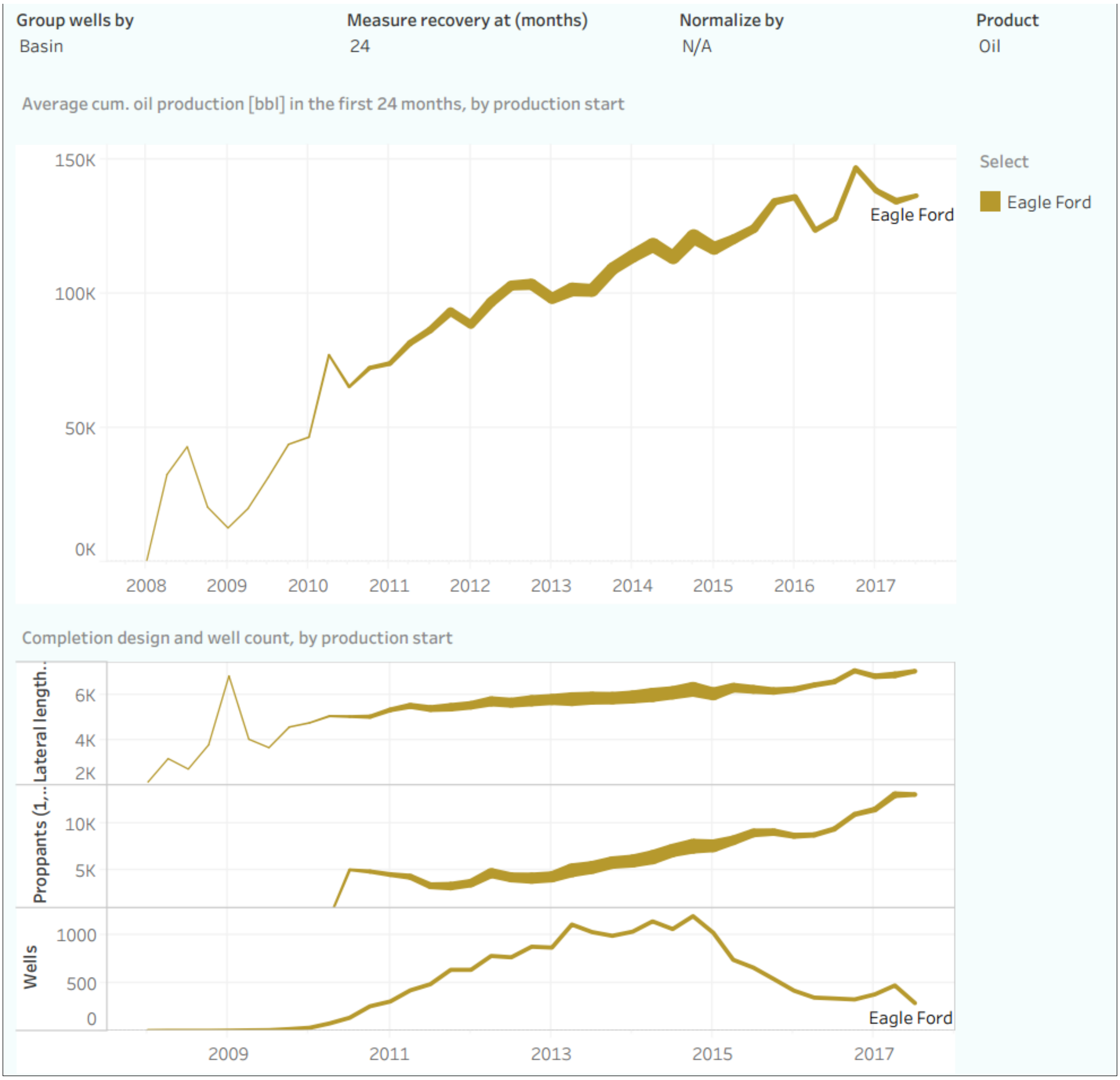

Figure F10. Eagle Ford Basin Play Productivity
(Source: Shaleprofile.com)

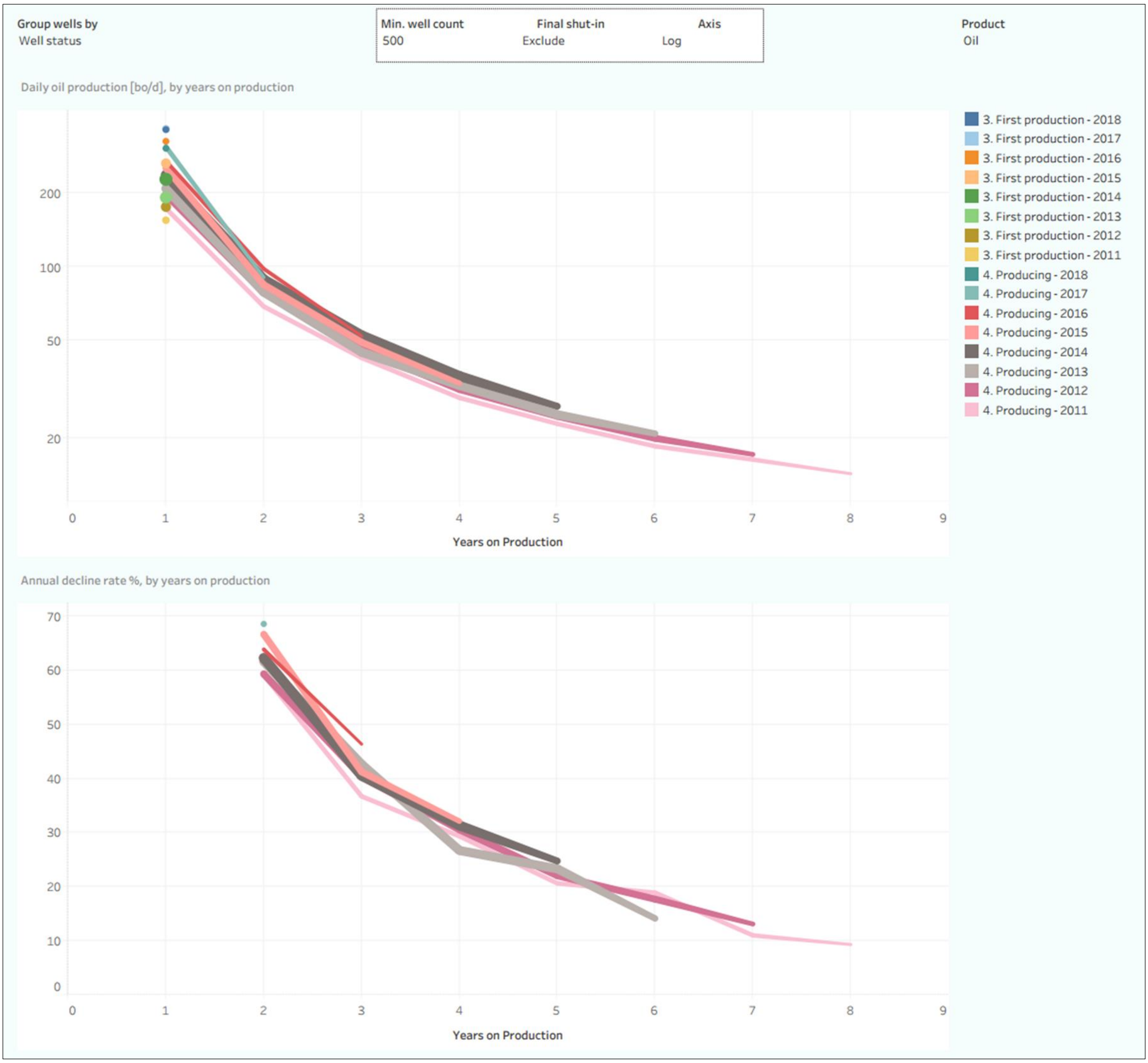

Figure F11. Annual decline of well production, Eagle Ford Basin Play
(Source: Shaleprofile.com)

29.3 Bakken Basin Play (Williston)

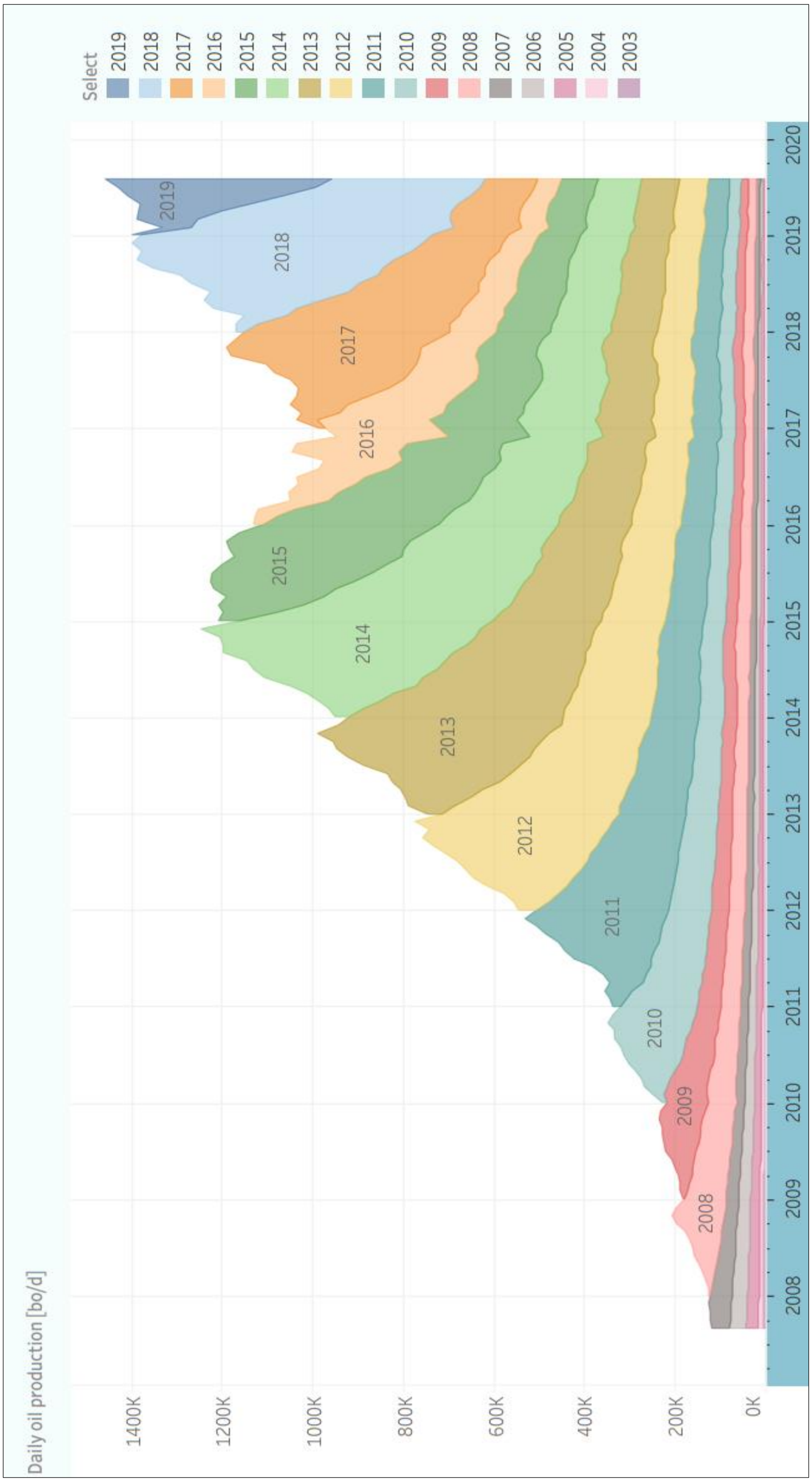

Figure F12. Bakken (Williston) Basin Play production by year
(Source: Shaleprofile.com)

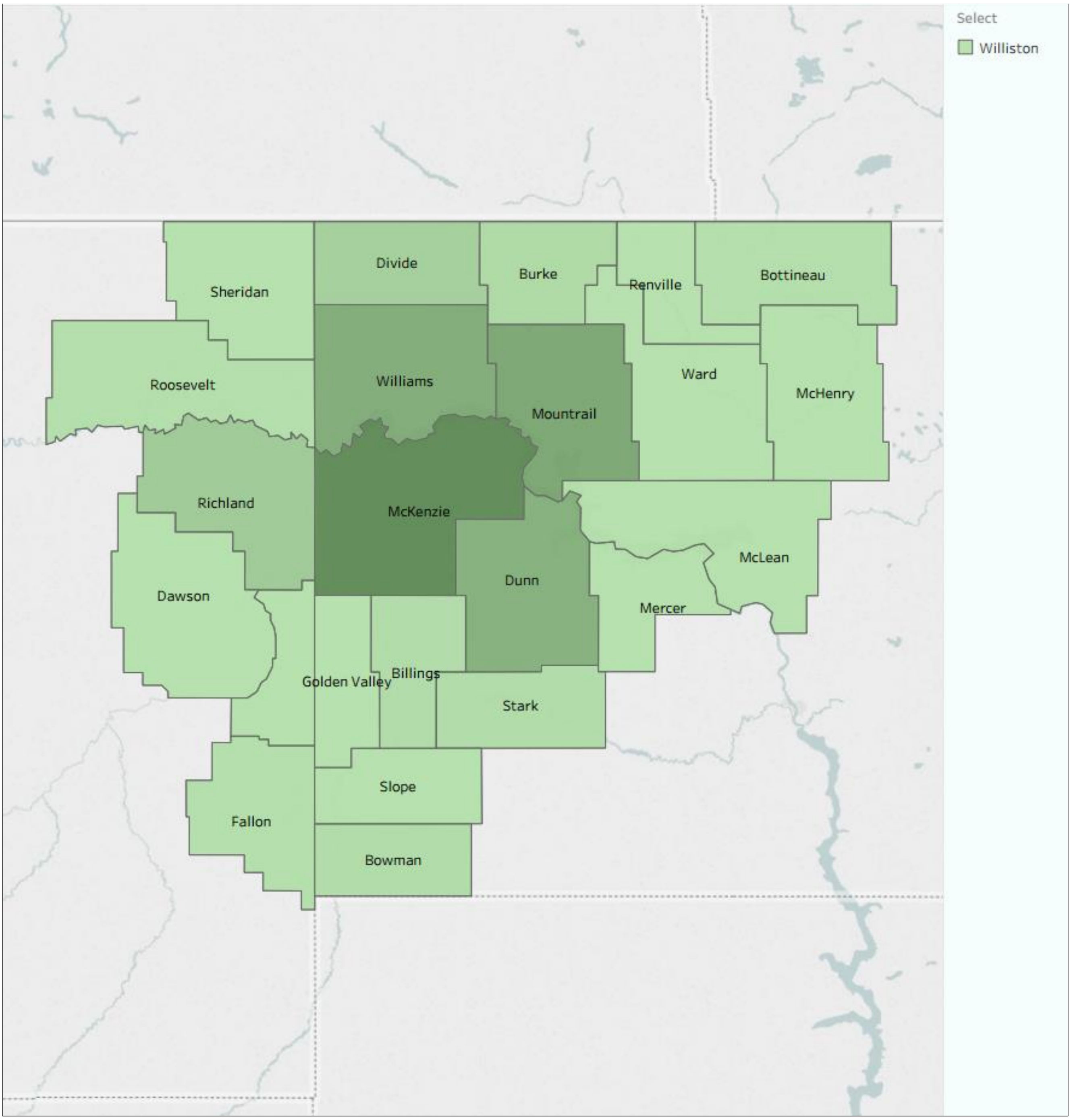

Figure F13. Bakken (Williston) Basin Play geographical map by county in the United States (Source: Shaleprofile.com)

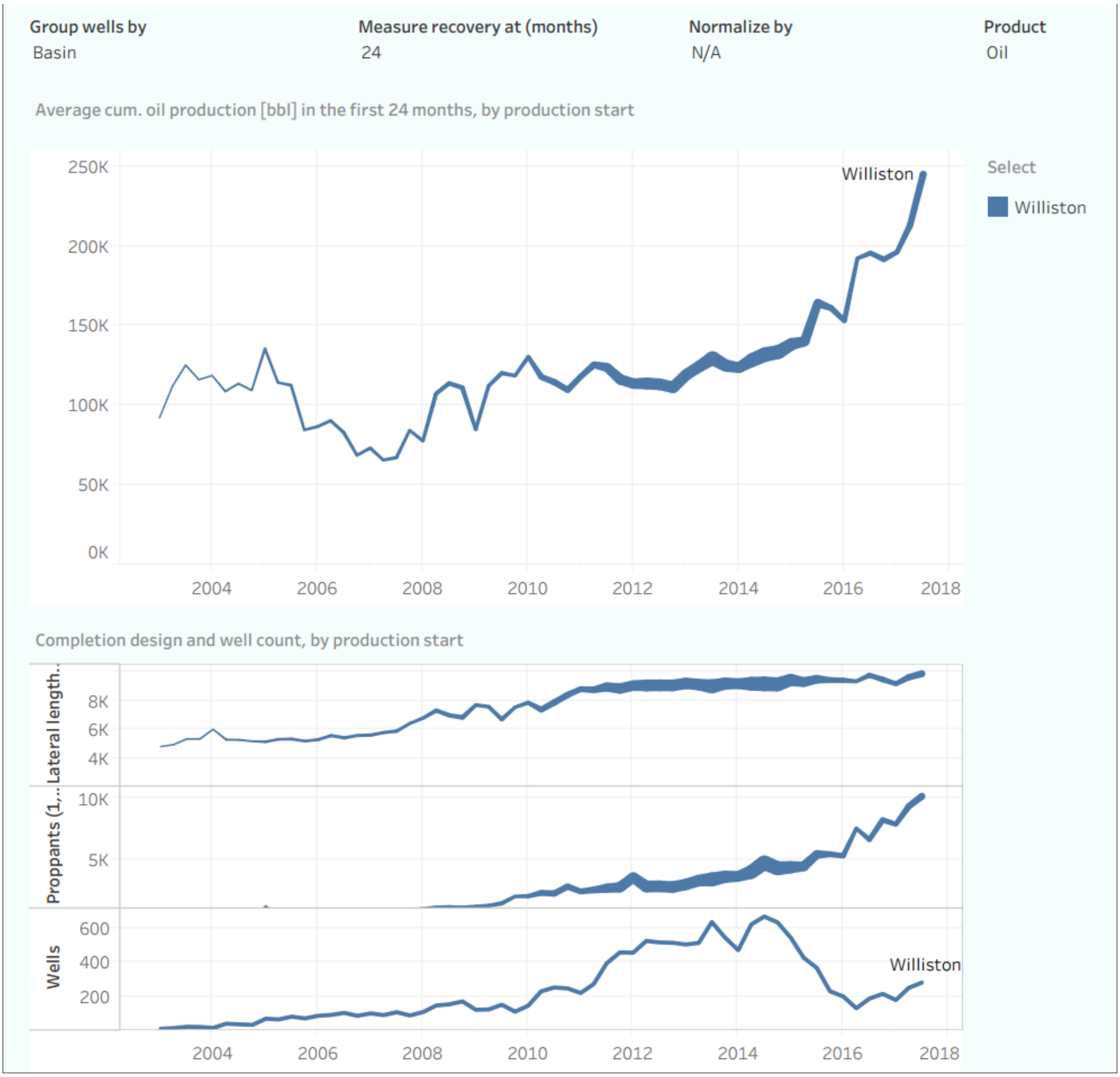

Figure F14. Bakken (Williston) Basin Play Productivity
(Source: Shaleprofile.com)

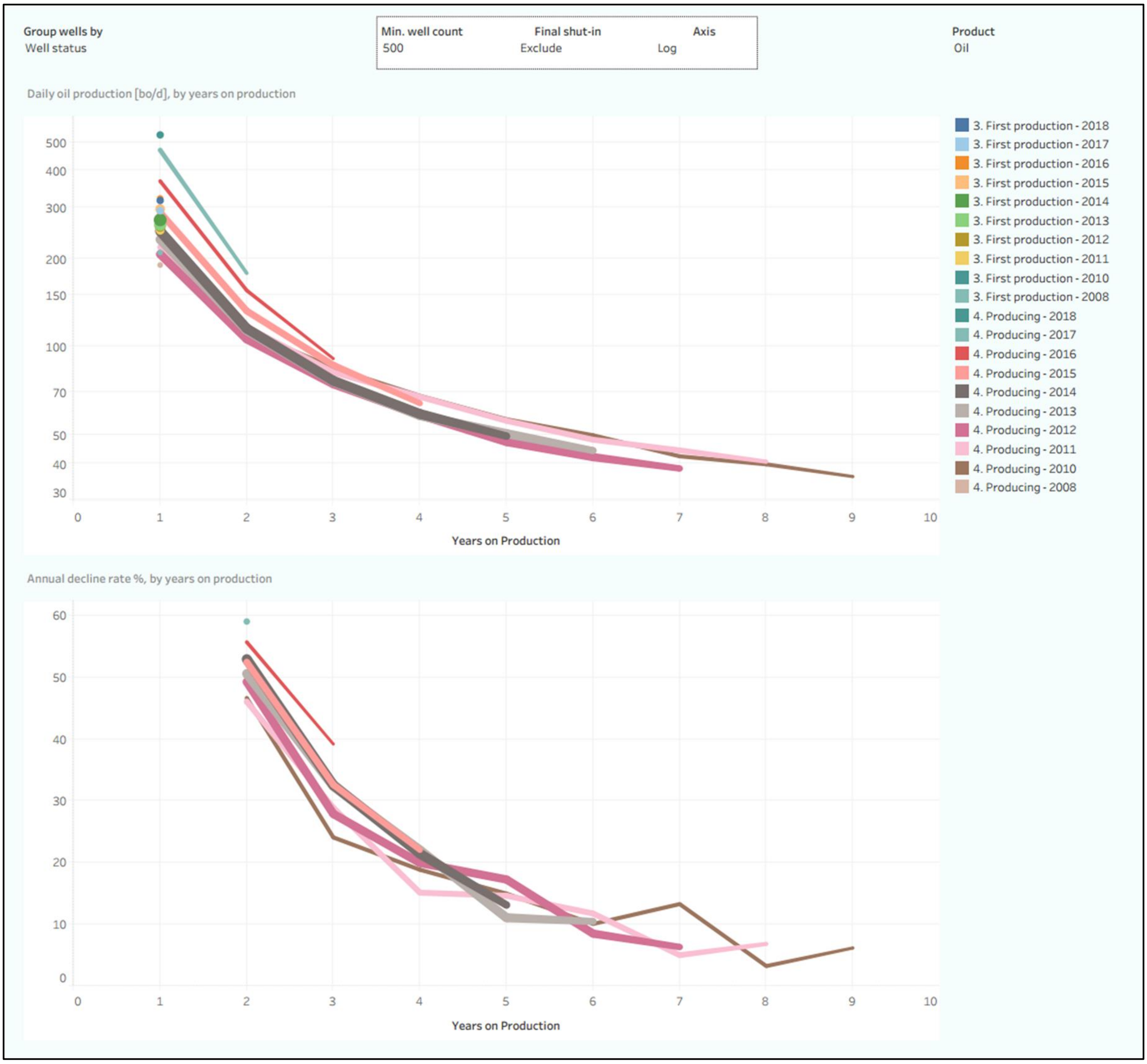

Figure F15. Annual decline of well production, Bakken (Williston) Basin Play (Source: Shaleprofile.com)

29.4 DJ Niobrara Basin Play

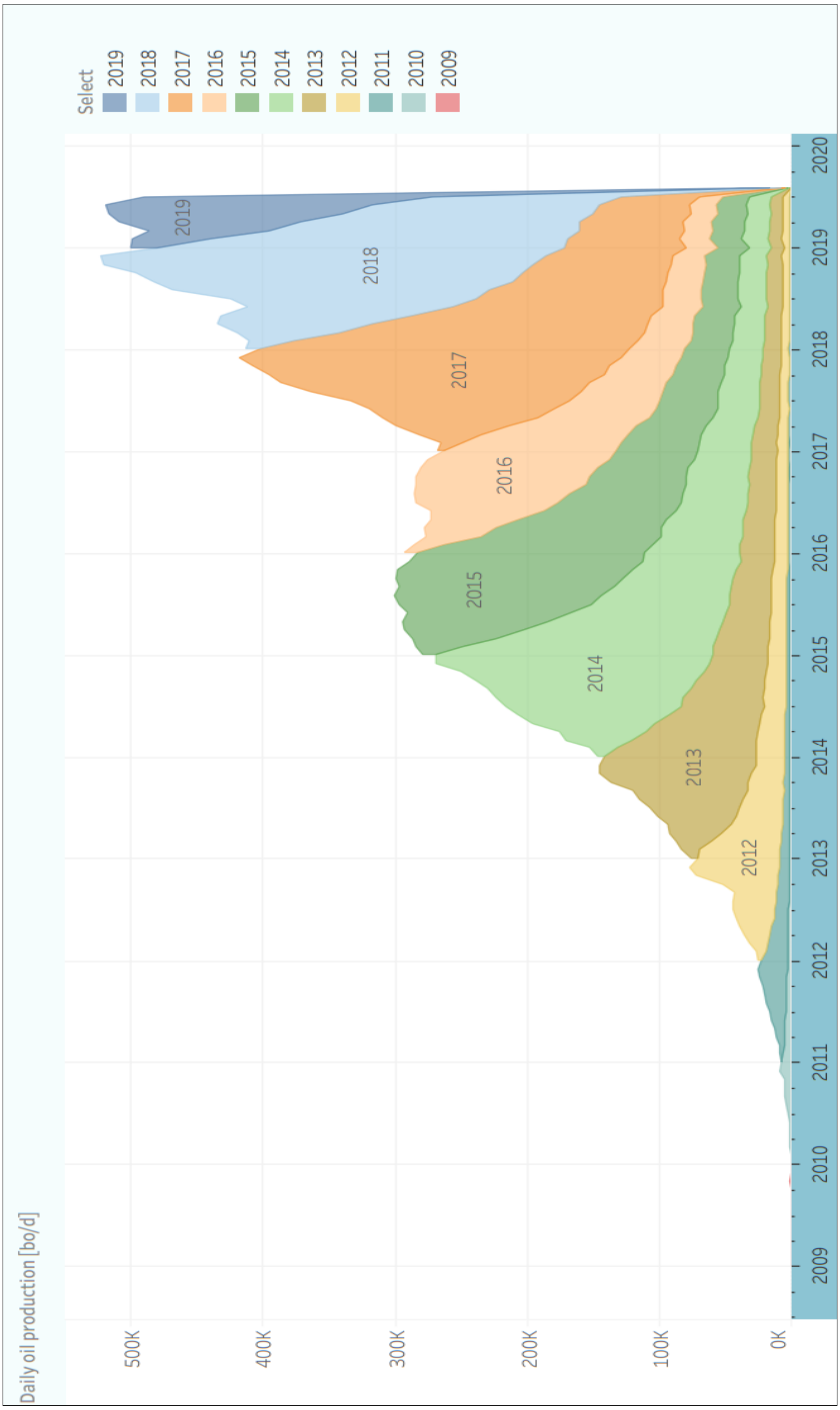

Figure F16. DJ Niobrara Basin Play production by year
(Source: Shaleprofile.com)

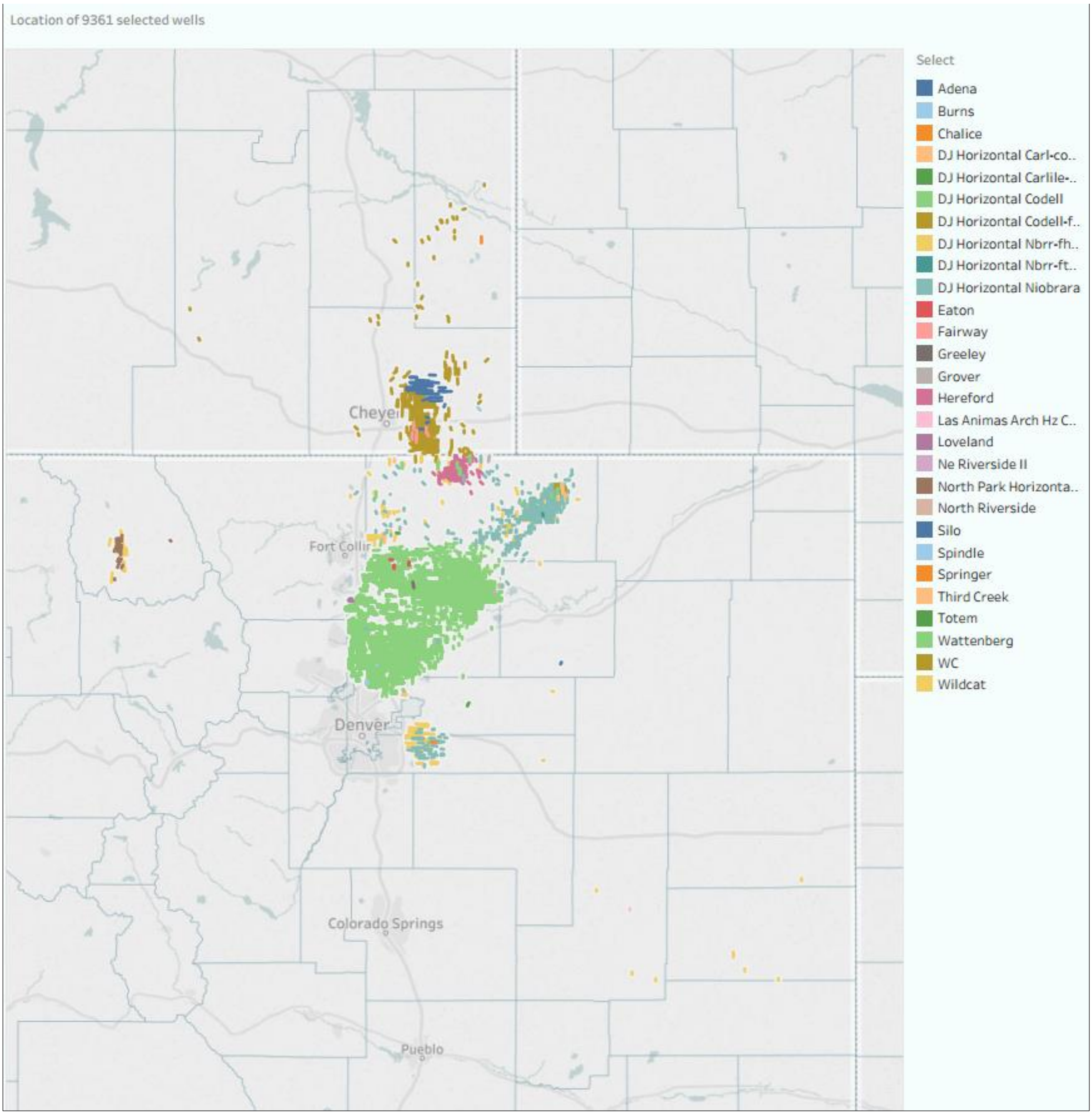

Figure F17. DJ Niobrara Basin Play geographical map by county in the United States (Source: Shaleprofile.com)

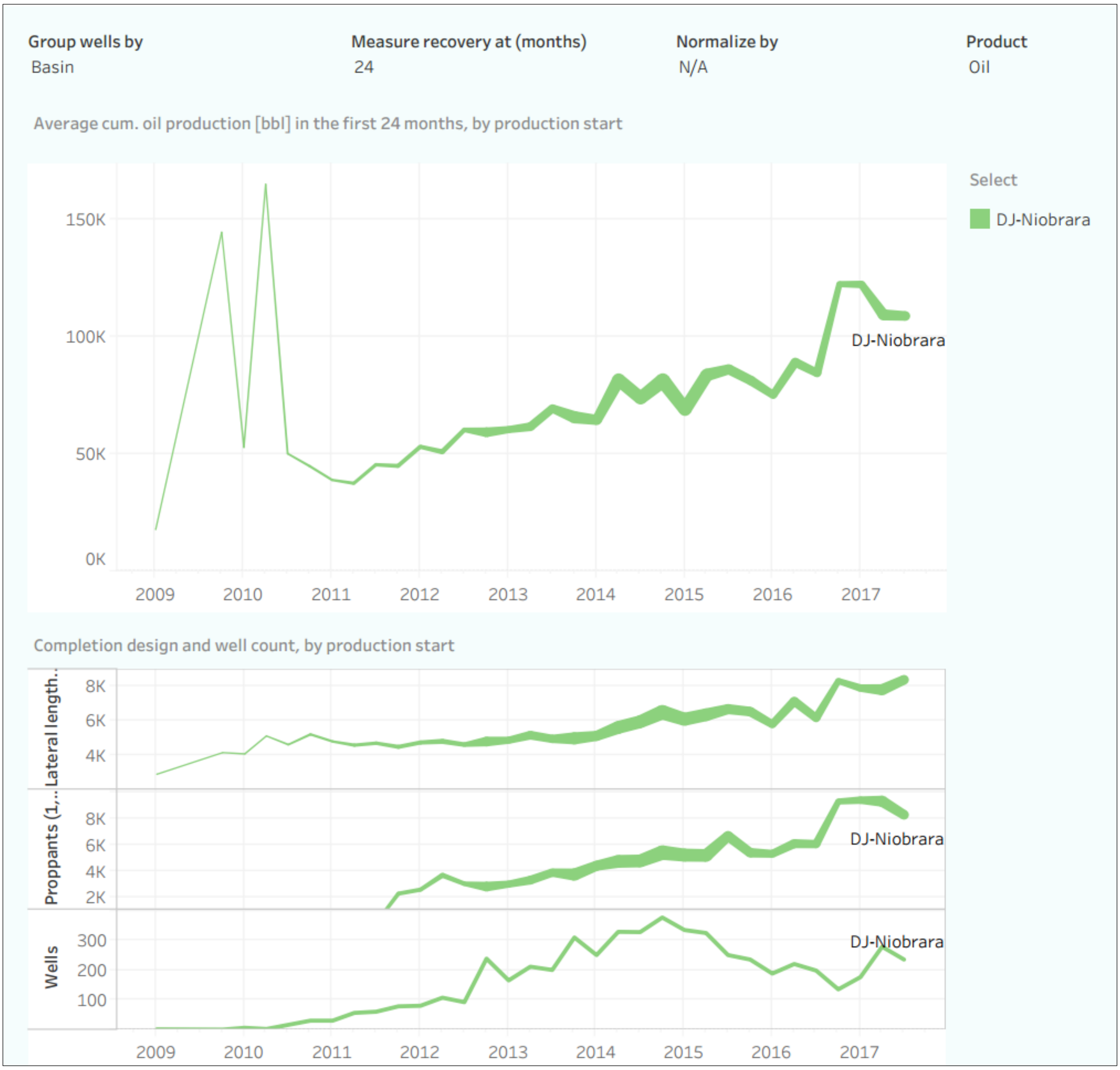

Figure F18. DJ Niobrara Basin Play Productivity
(Source: Shaleprofile.com)

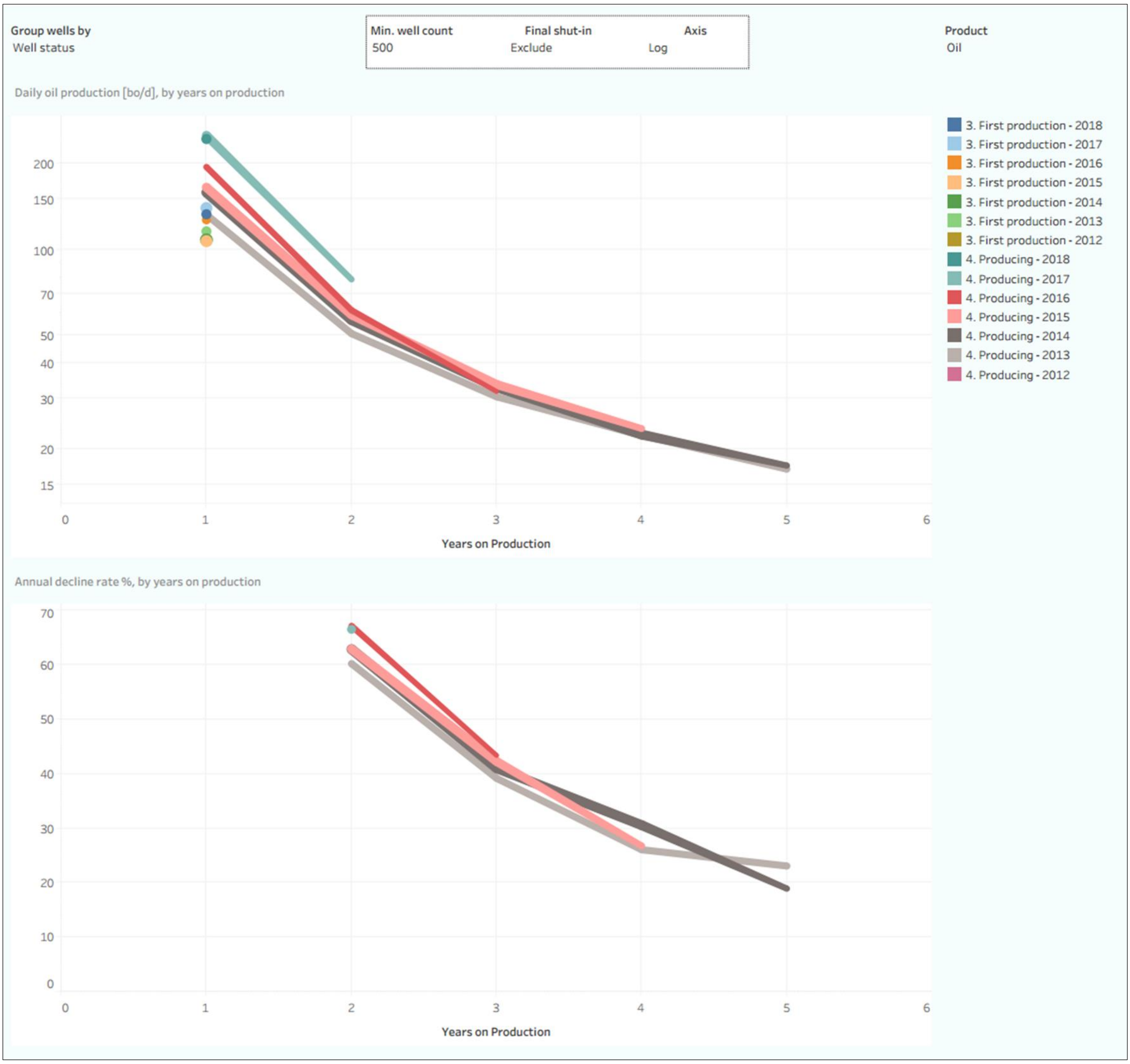

Figure F19. Annual decline of well production, DJ Niobrara Basin Play
(Source: Shaleprofile.com)

29.5 Marcellus Basin Play

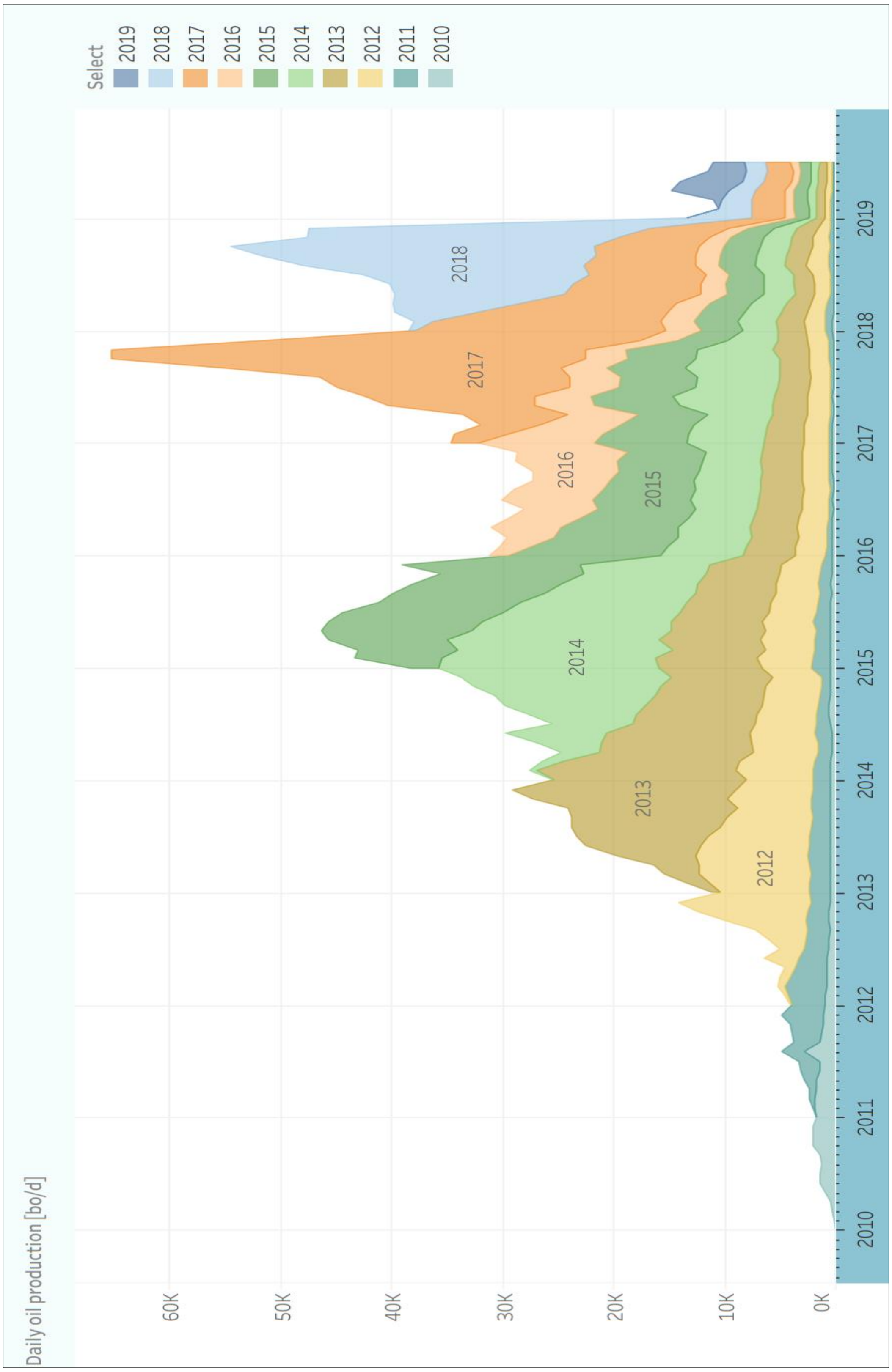

Figure F20. Marcellus Basin Play production by year
(Source: Shaleprofile.com)

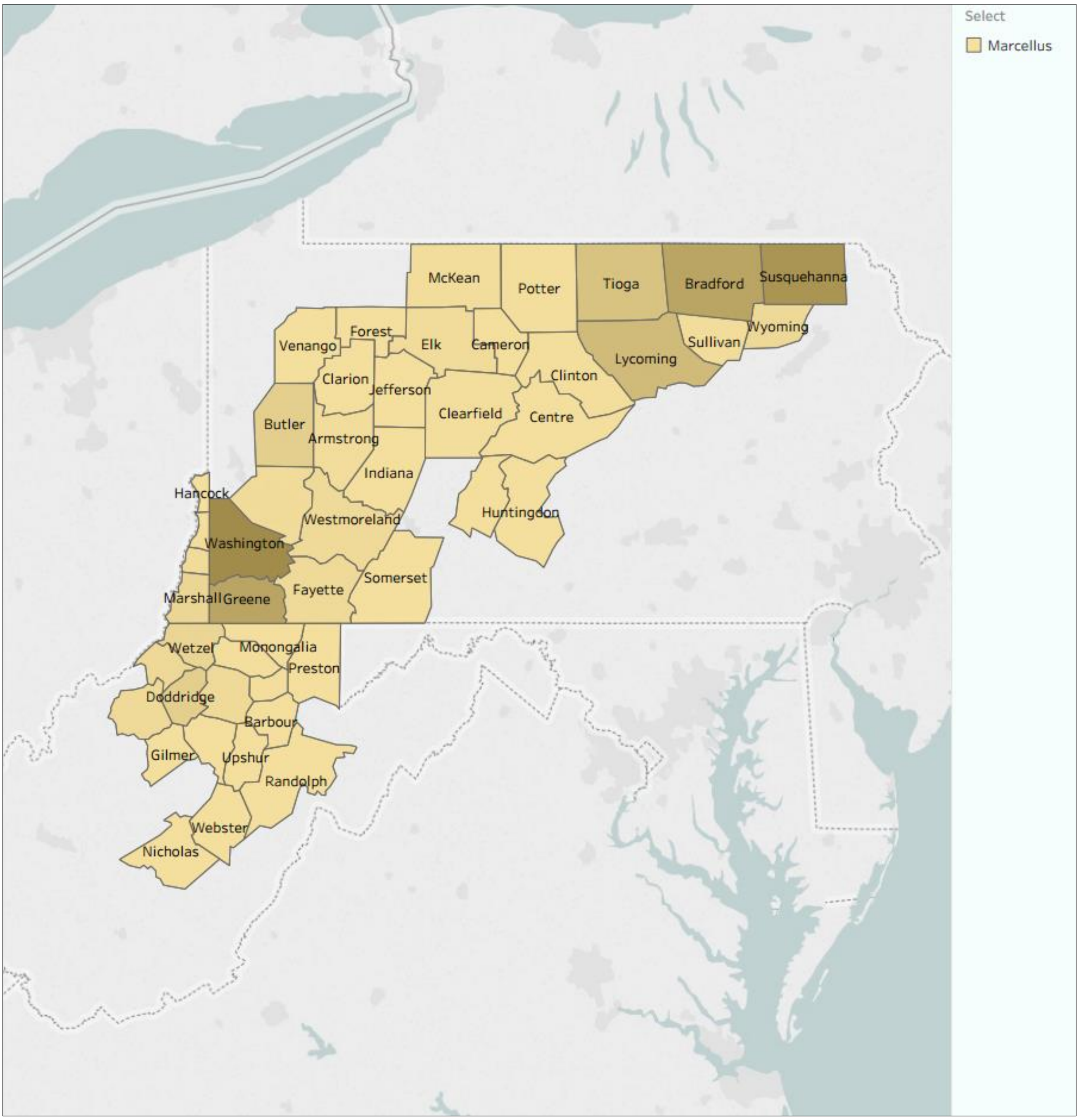

Figure F21. Marcellus Basin Play geographical map by county in the United States
(Source: Shaleprofile.com)

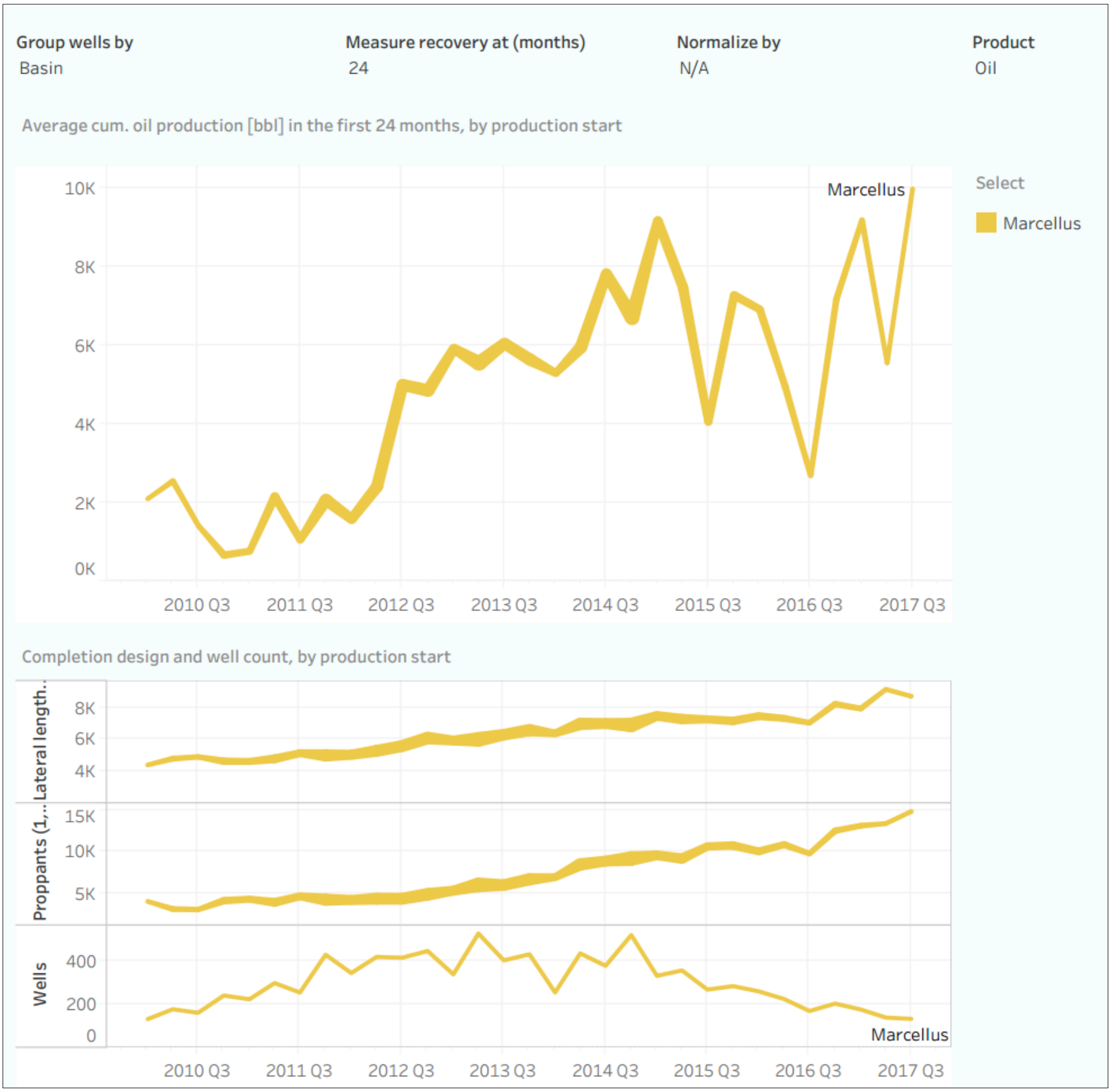

Figure F22. Marcellus Basin Play Productivity
(Source: Shaleprofile.com)

29.6 Granite Wash Basin Play

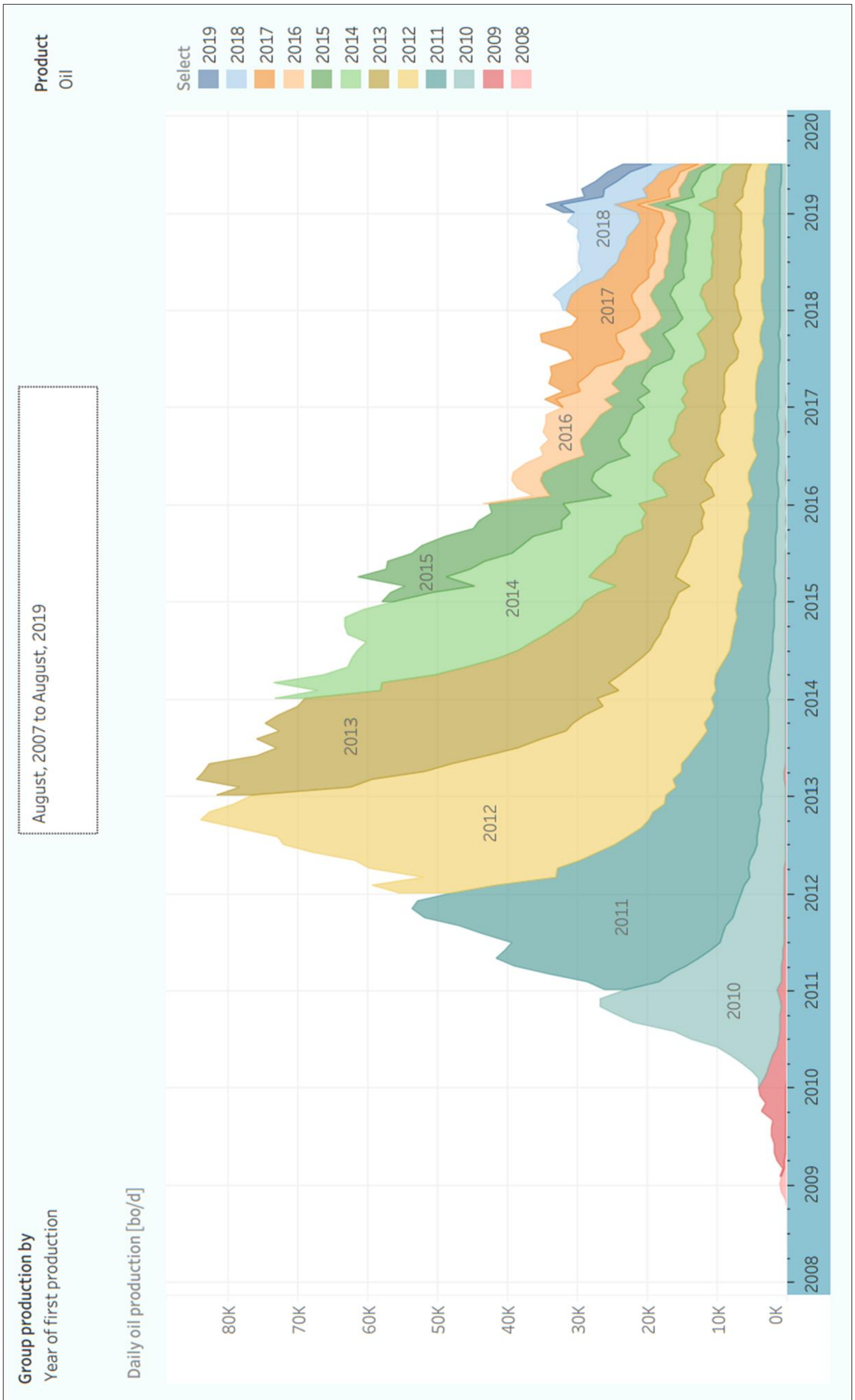

Figure F23. Granite Wash Basin Play production by year
(Source: Shaleprofile.com)

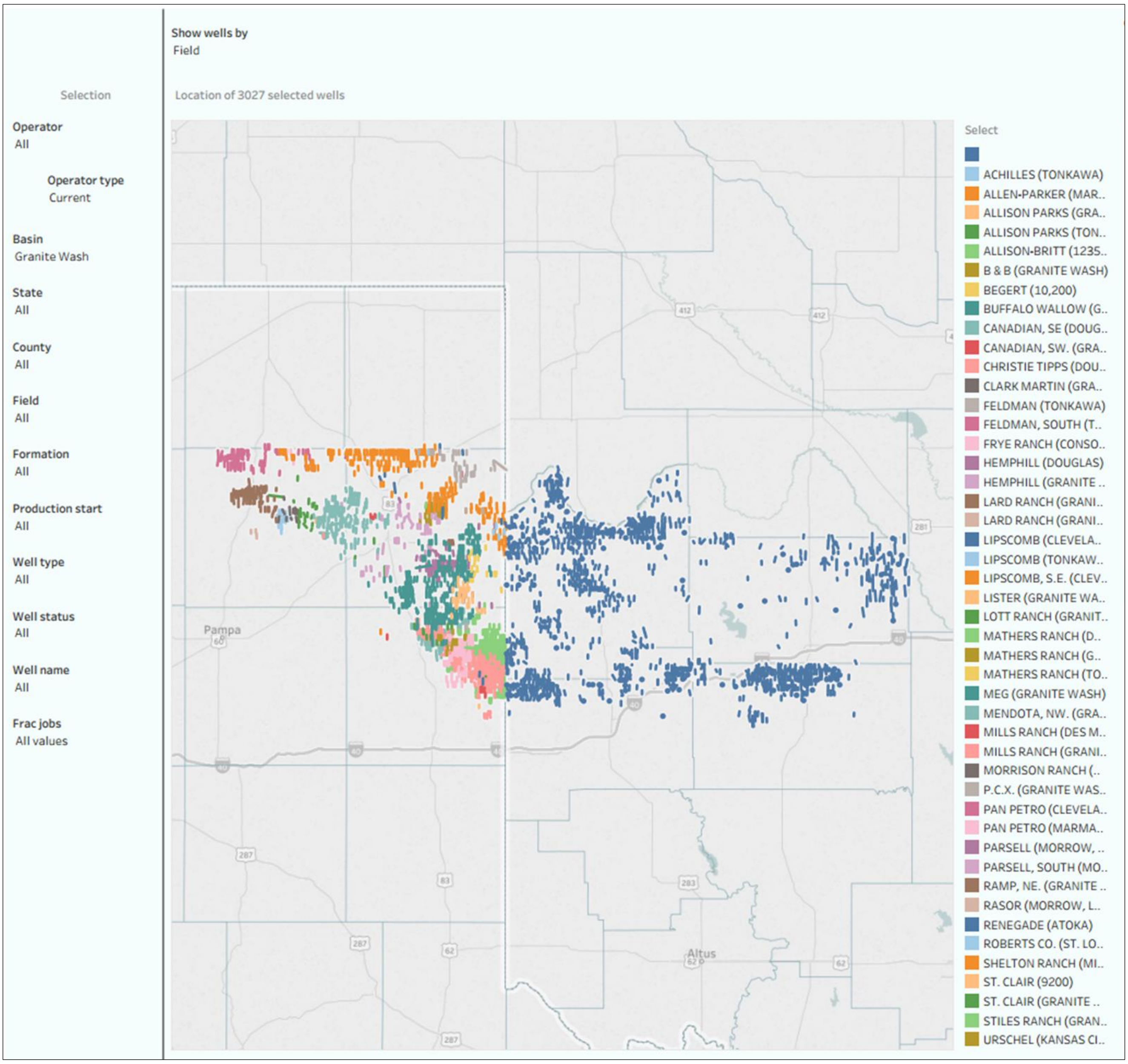

Figure F24. Granite Wash Basin Play geographical map by county in the United States (Source: Shaleprofile.com)

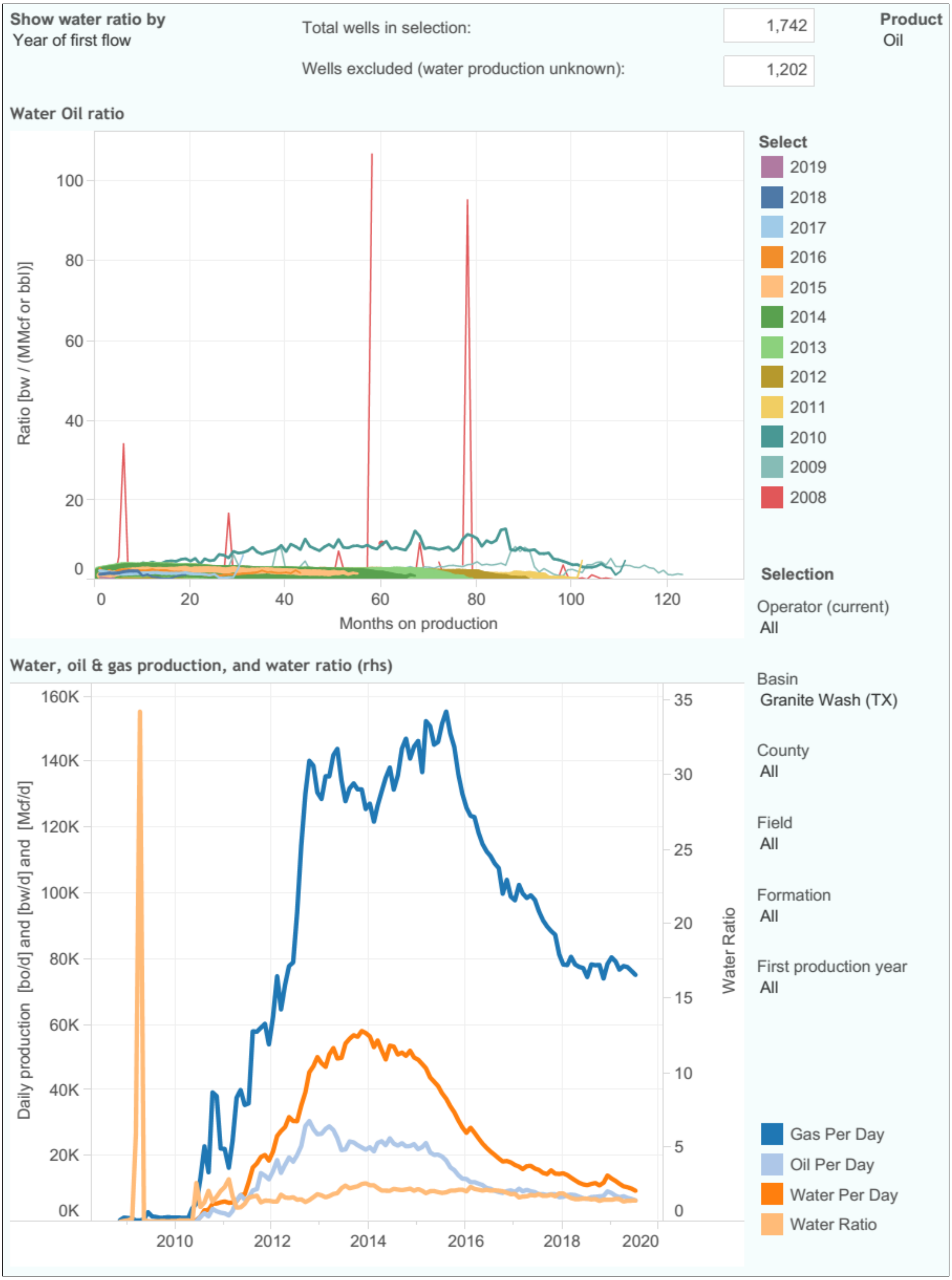

Figure F25. Granite Wash water ratio
(Source: Shaleprofile.com)

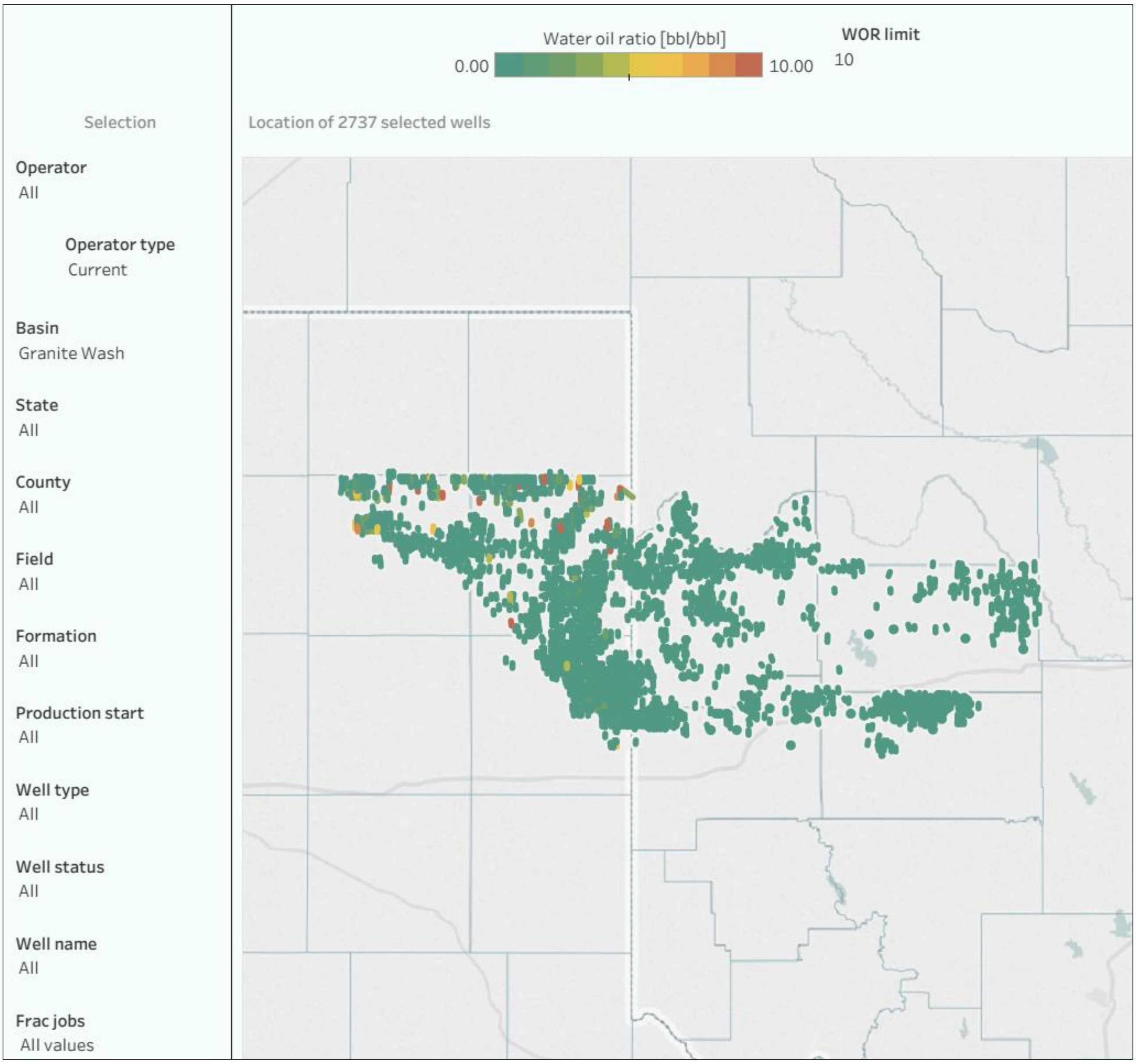

Figure F26. Granite Wash water/oil ratio
(Source: Shaleprofile.com)

29.7 Barnett Basin Play

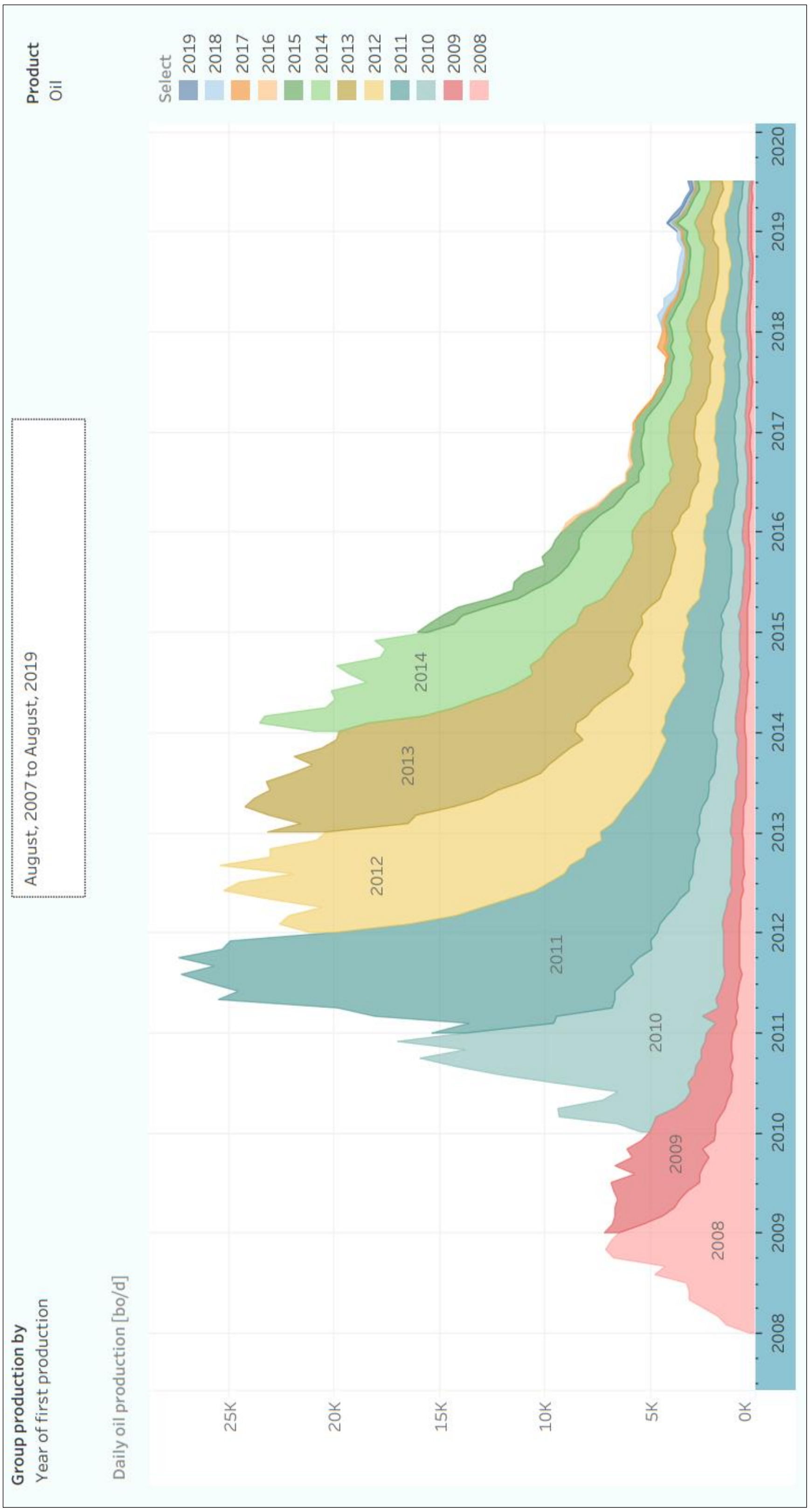

Figure F27. Barnett Basin Play production by year
(Source: Shaleprofile.com)

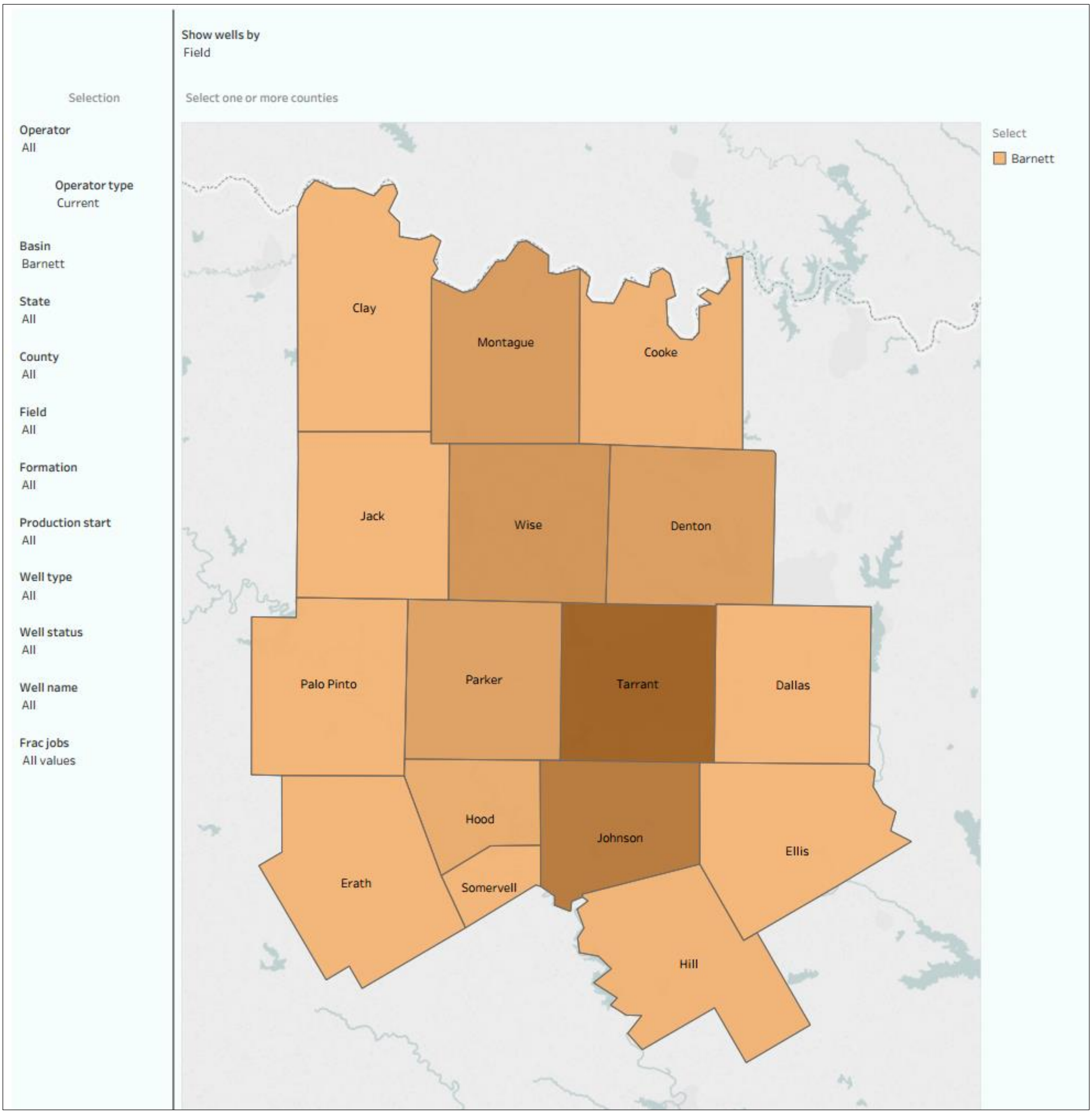

Figure F28. Barnett Basin Play geographical map by county in the United States (Source: Shaleprofile.com)

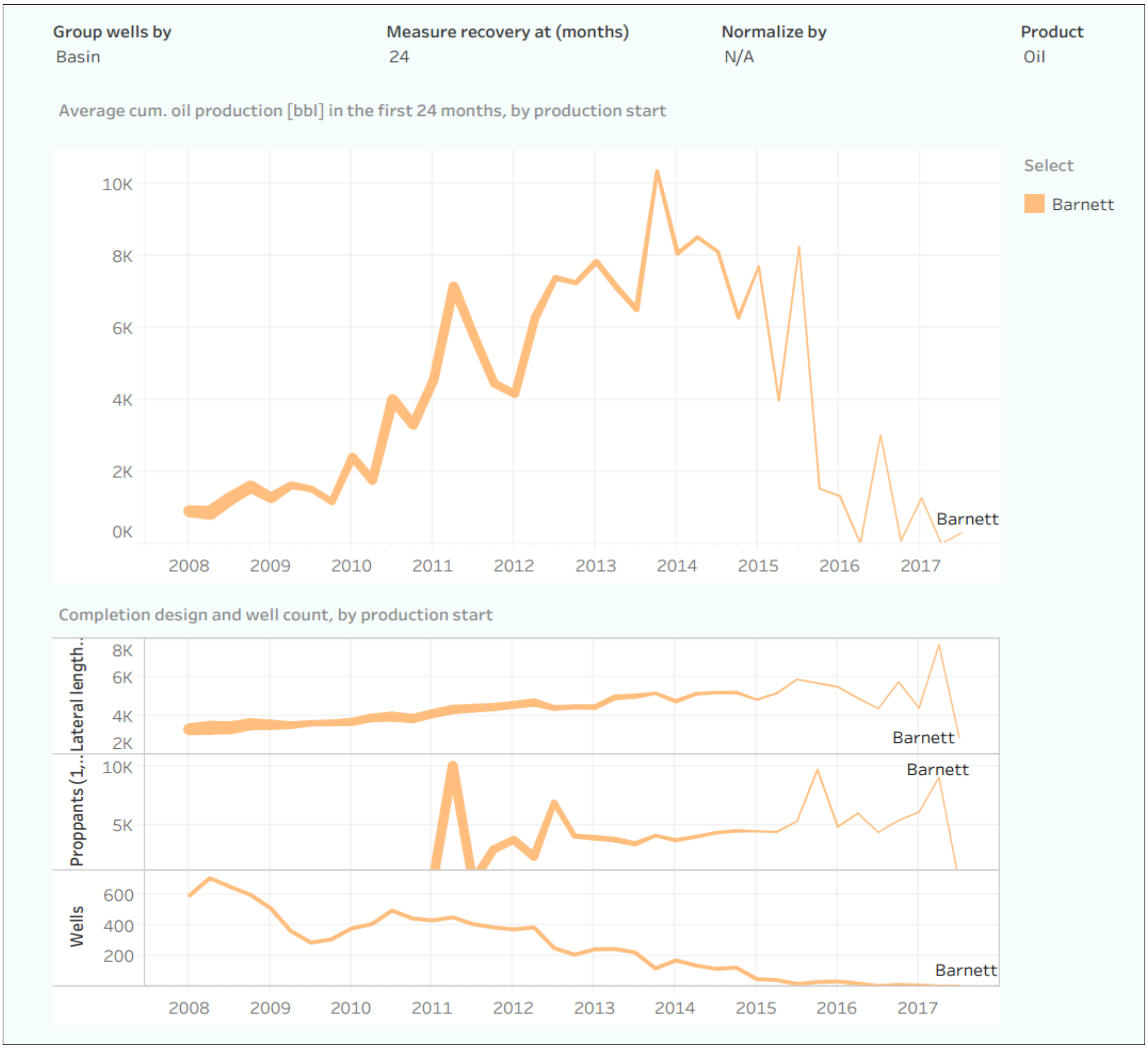

Figure F29. Barnett Basin Play Productivity
(Source: Shaleprofile.com)

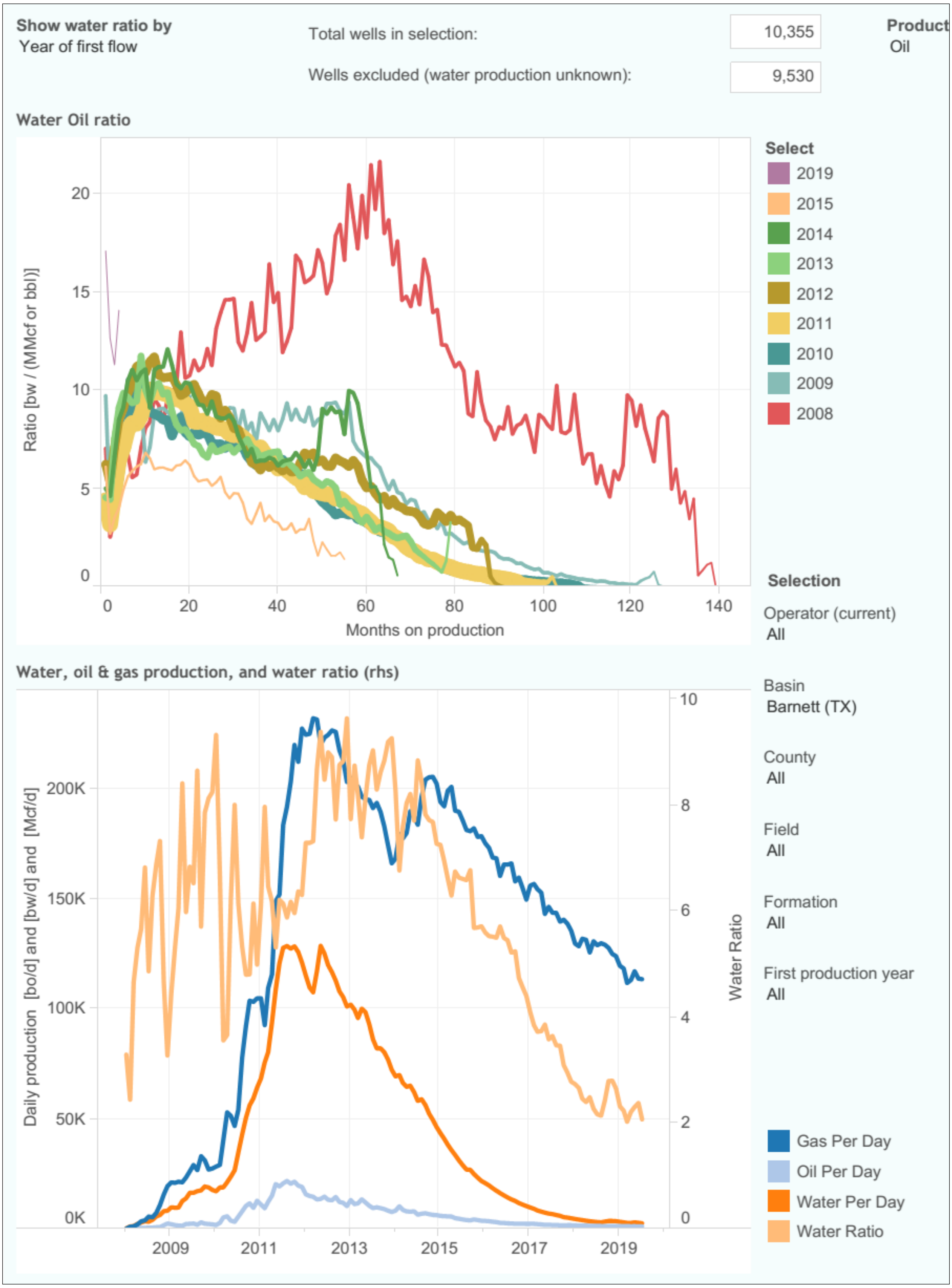

Figure F30. Barnett Basin Play water ratio
(Source: Shaleprofile.com)

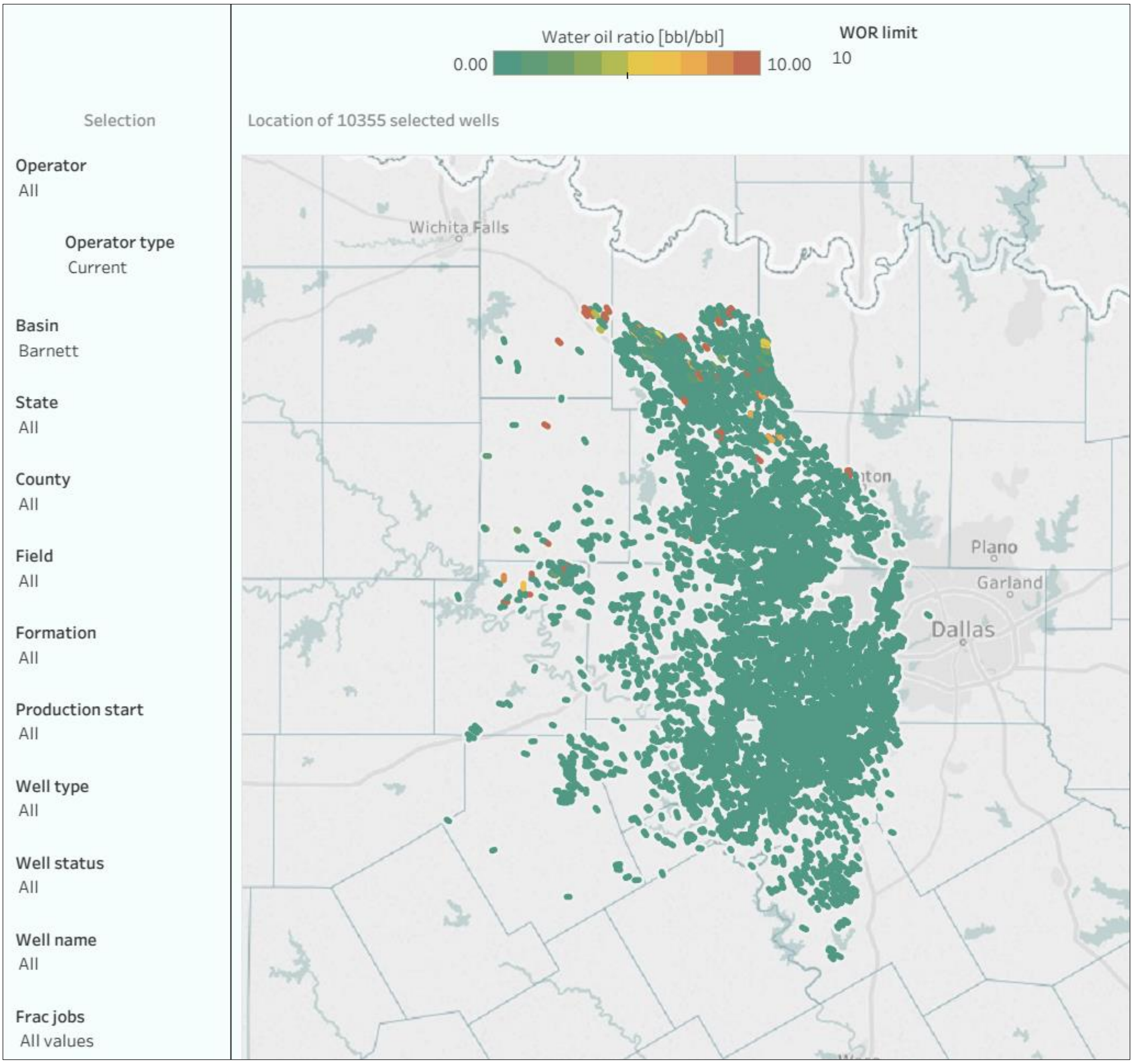

Figure F31. Barnett Basin Play water/oil ratio
(Source: Shaleprofile.com)

29.8 Utica Basin Play

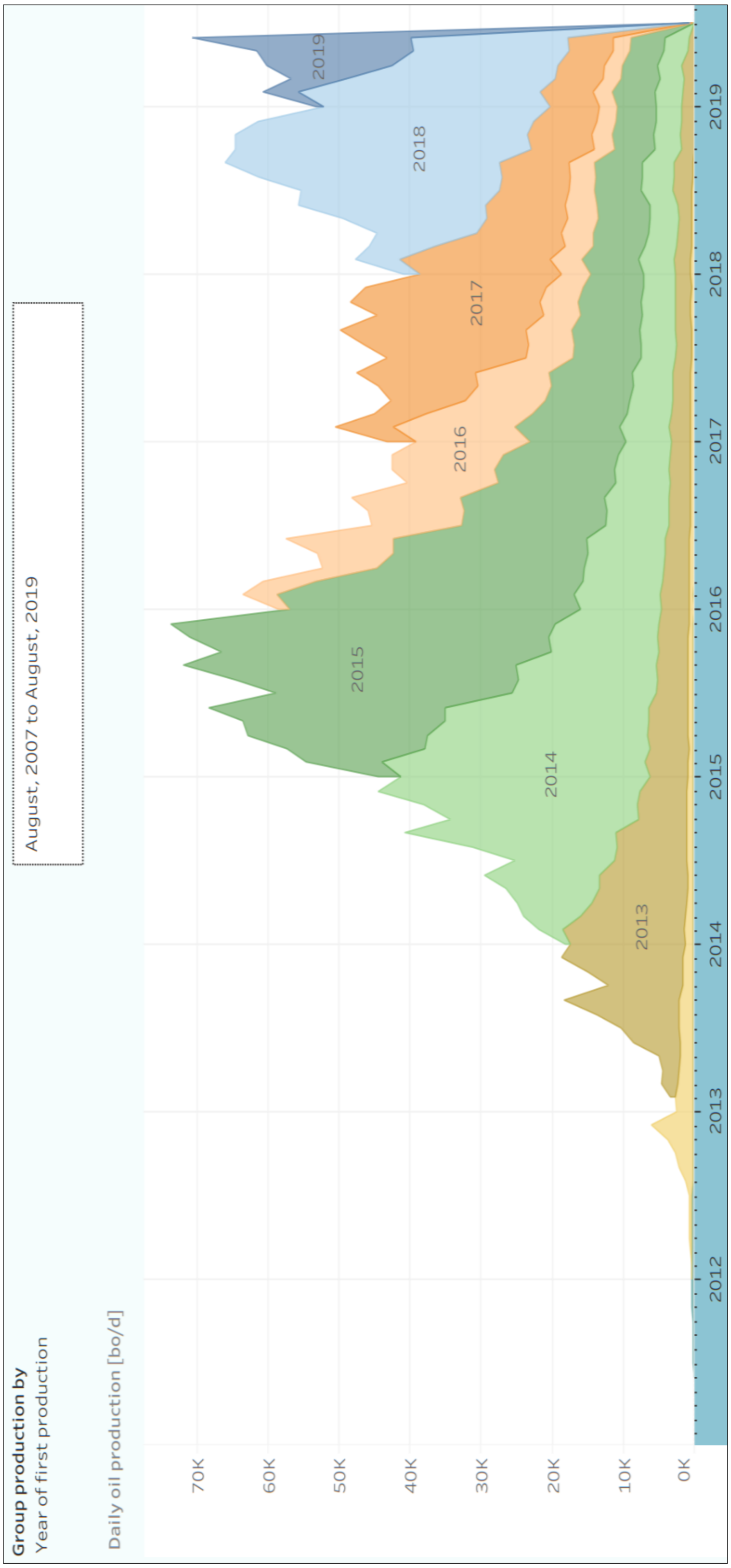

Figure F32. Utica Basin Play production by year
(Source: Shaleprofile.com)

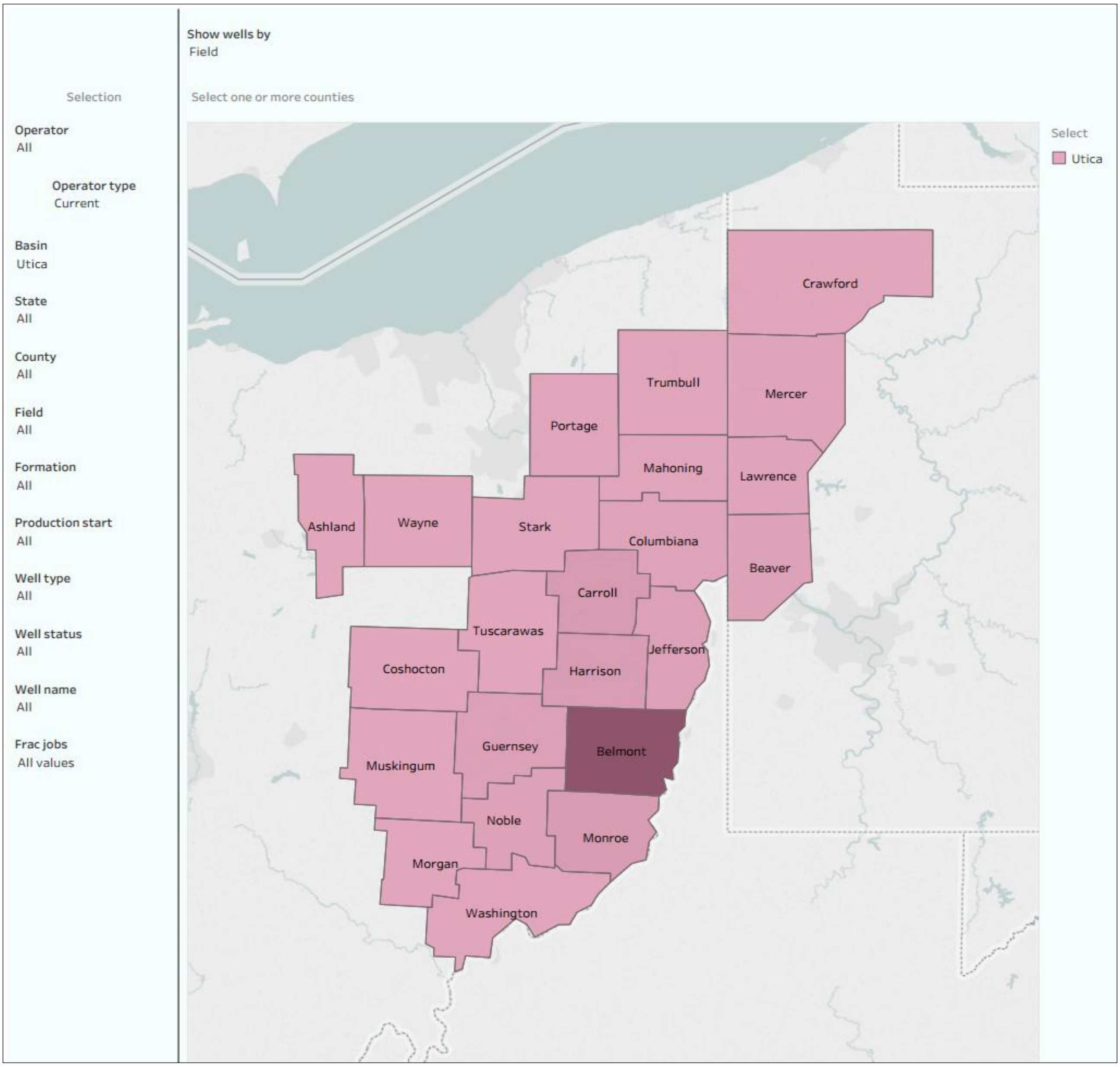

Figure F33. Utica Basin Play geographical map by county in the United States (Source: Shaleprofile.com)

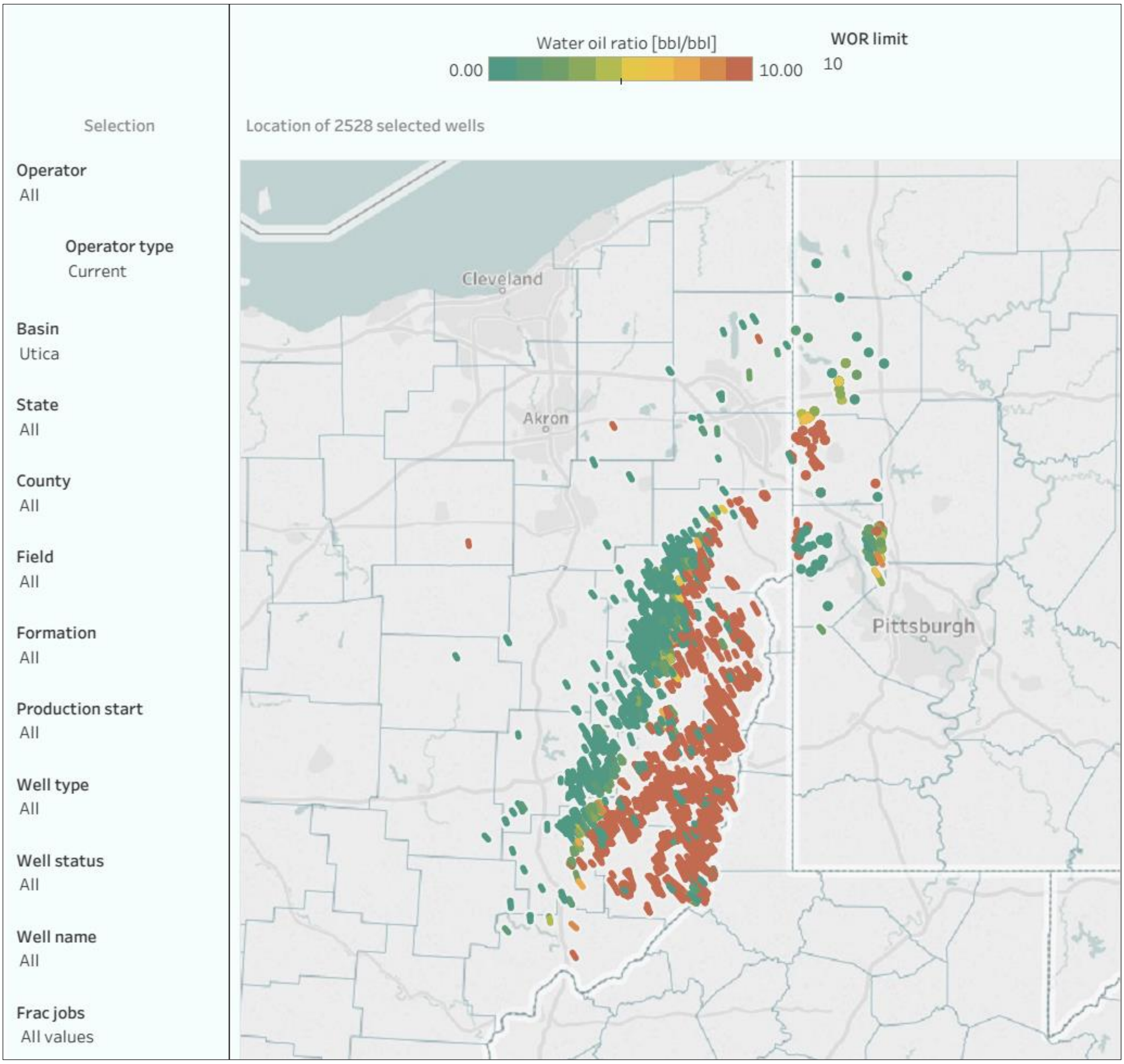

Figure F34. Utica Basin Play, Water oil ratio
(Source: Shaleprofile.com)

29.9 Haynesville Basin Play

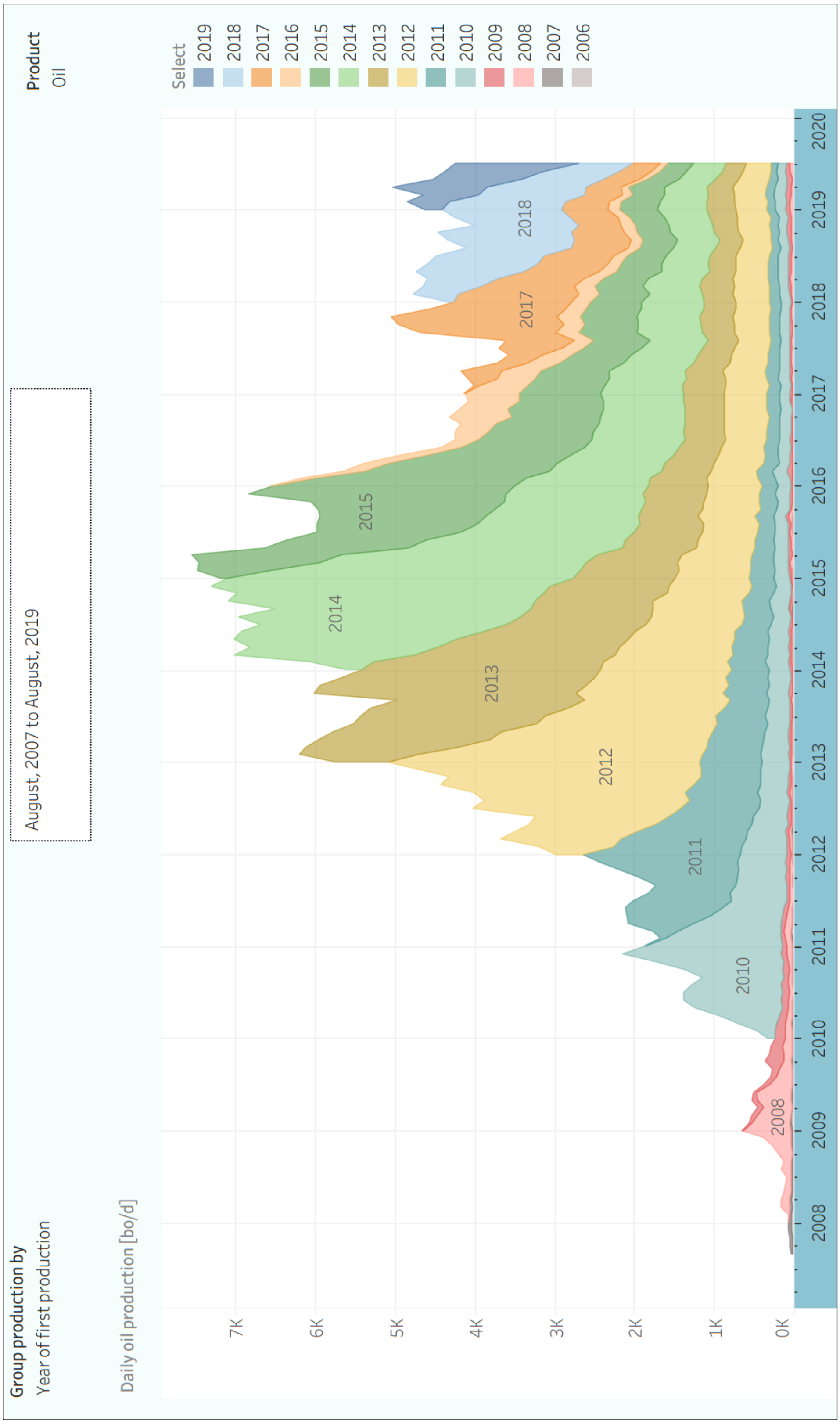

Figure F35. Haynesville Basin Play production by year
(Source: Shaleprofile.com)

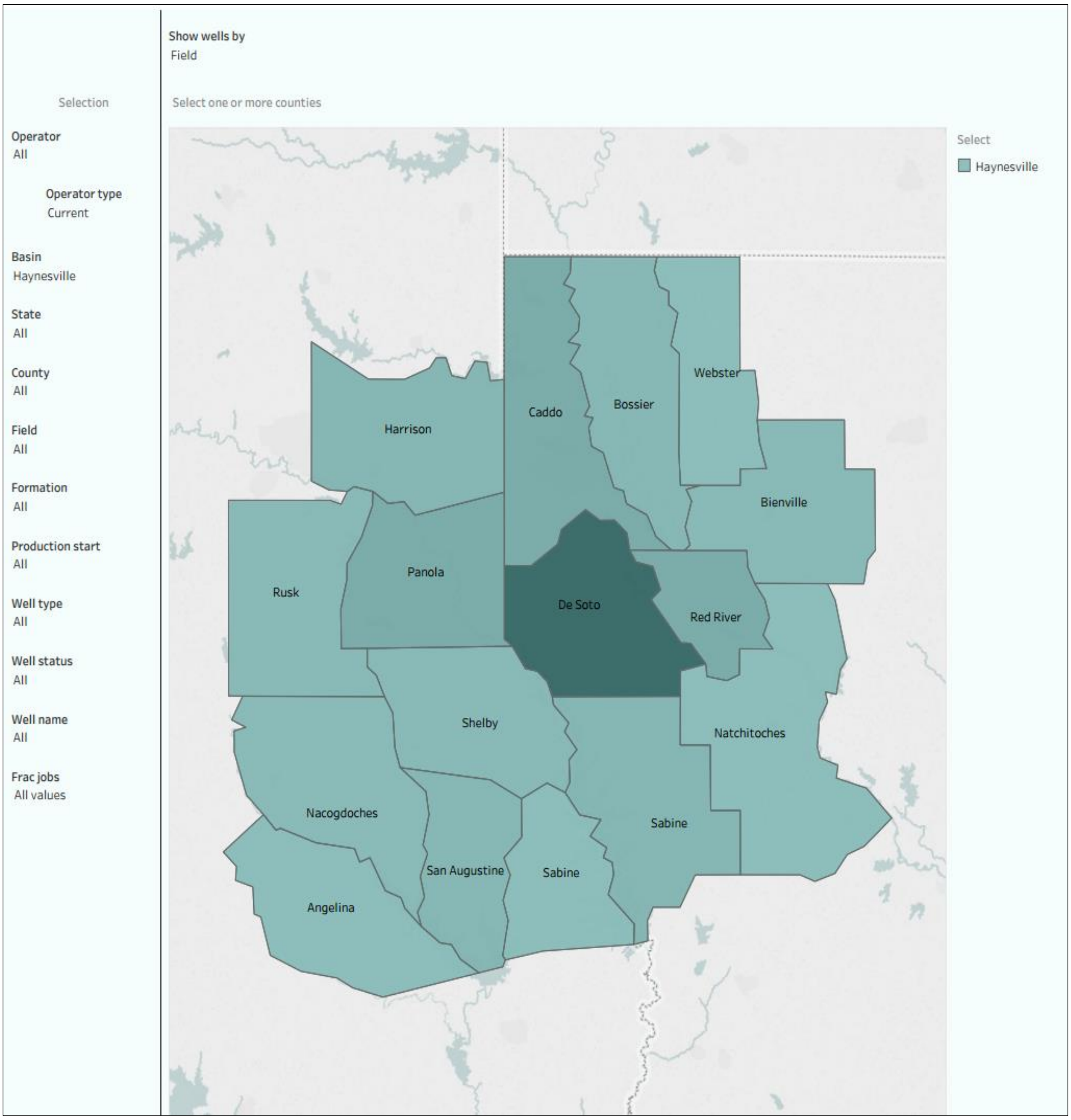

Figure F36. Haynesville Basin Play geographical map by county in the United States (Source: Shaleprofile.com)

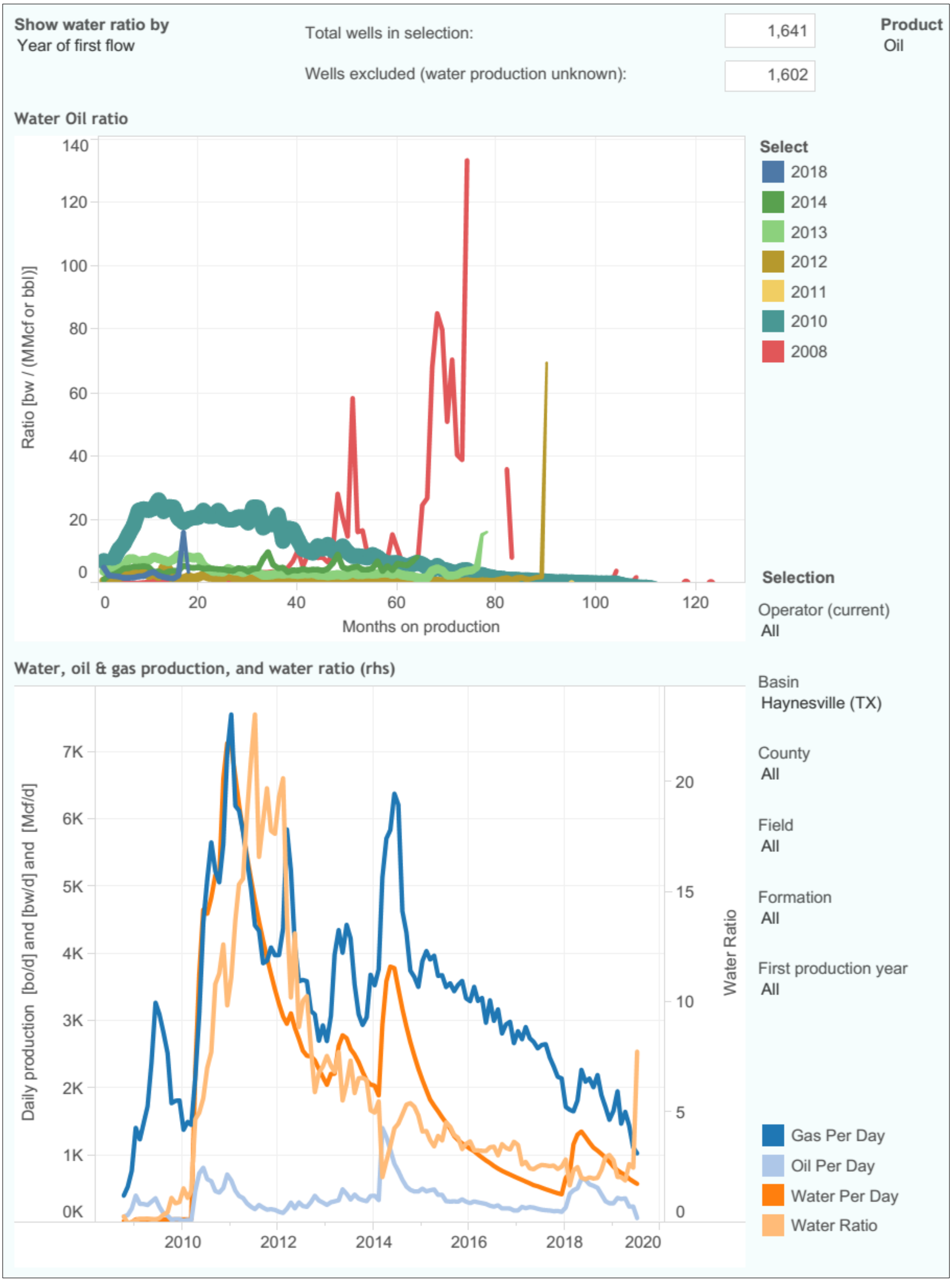

Figure F37. Haynesville Basin Play water ratio
(Source: Shaleprofile.com)

29.10 Cana Woodford Basin Play

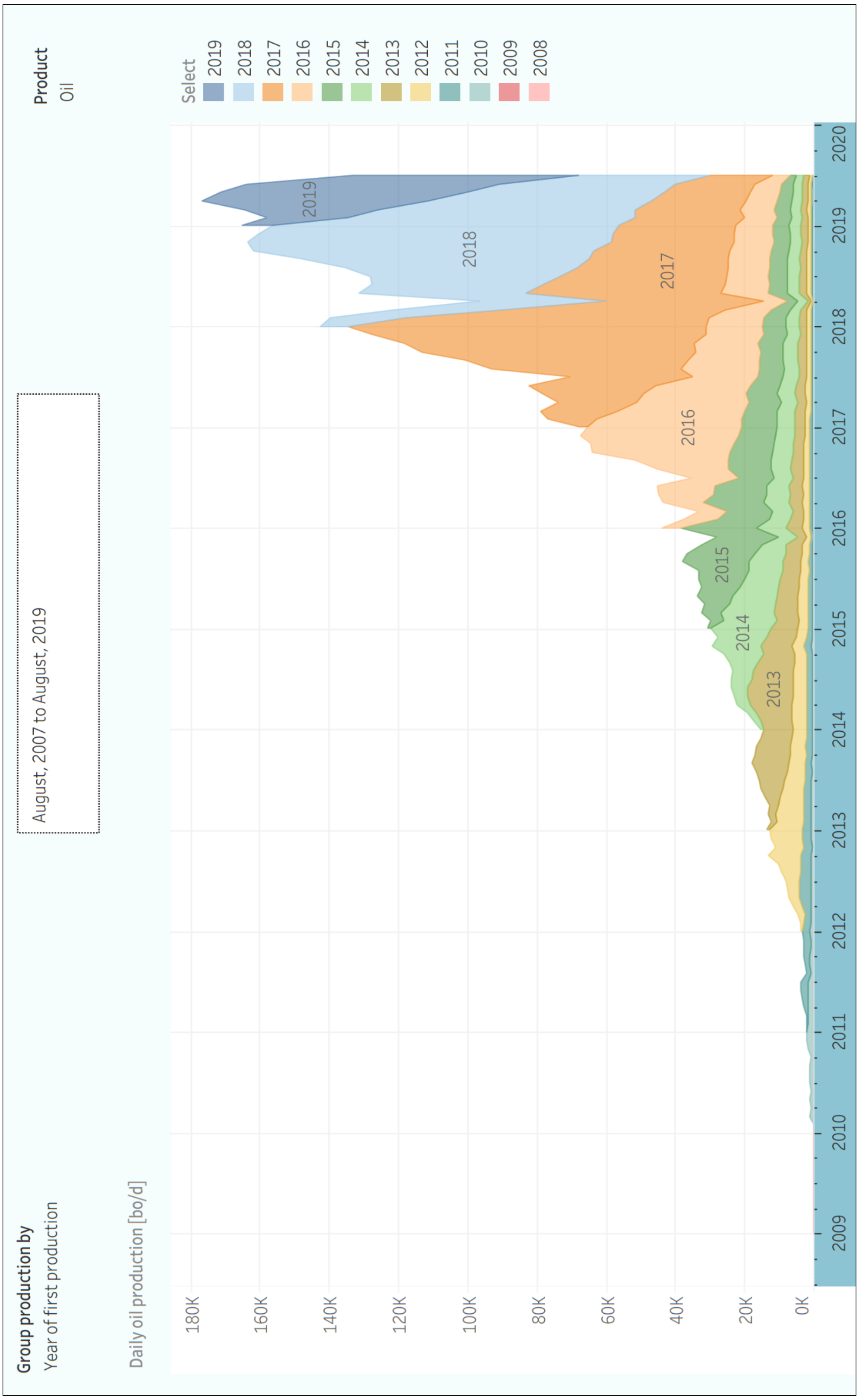

Figure F38. Cana Woodford Basin Play production by year
(Source: Shaleprofile.com)

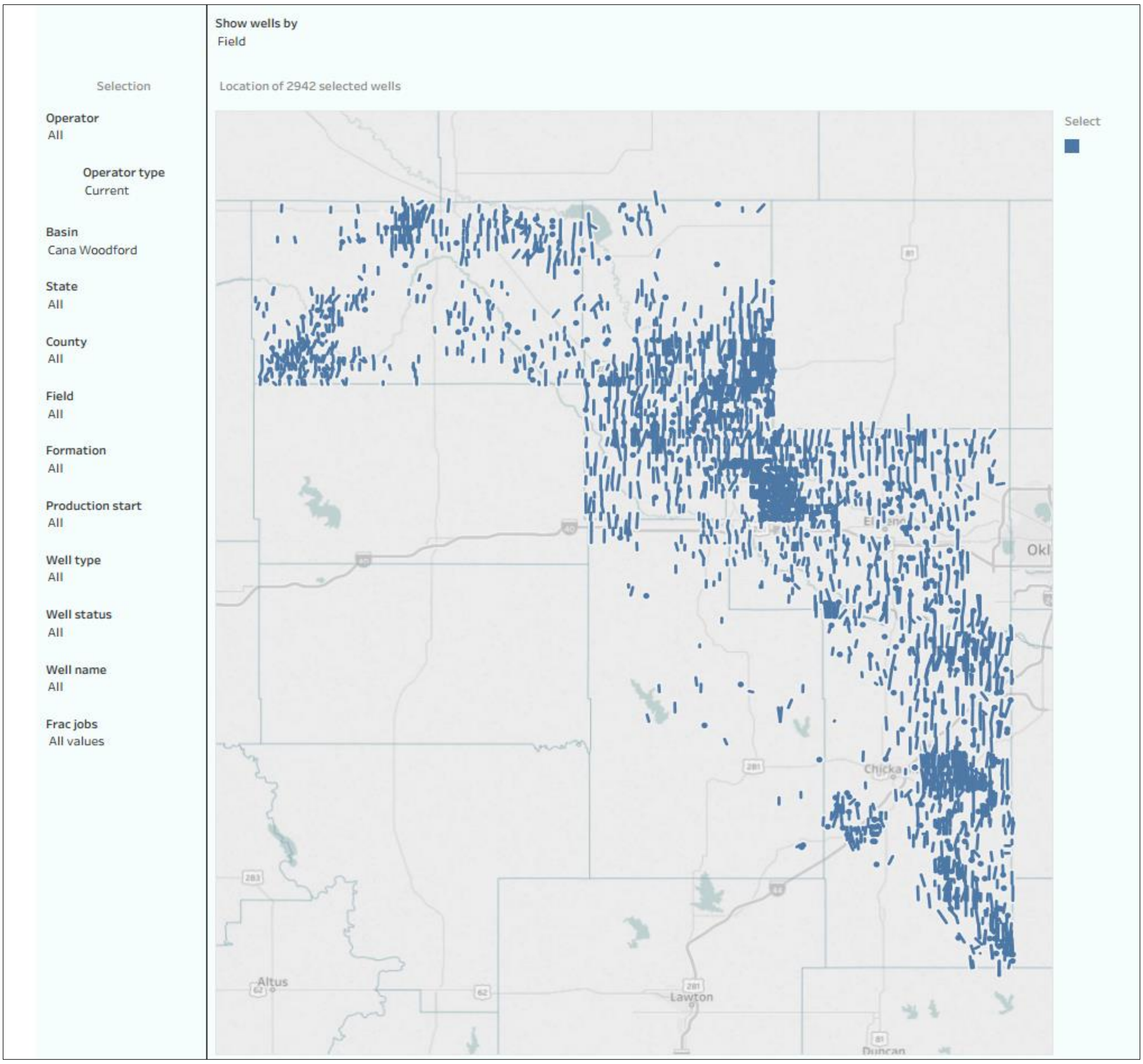

Figure F39. Cana Woodford Basin Play geographical map by county in the United States (Source: Shaleprofile.com)

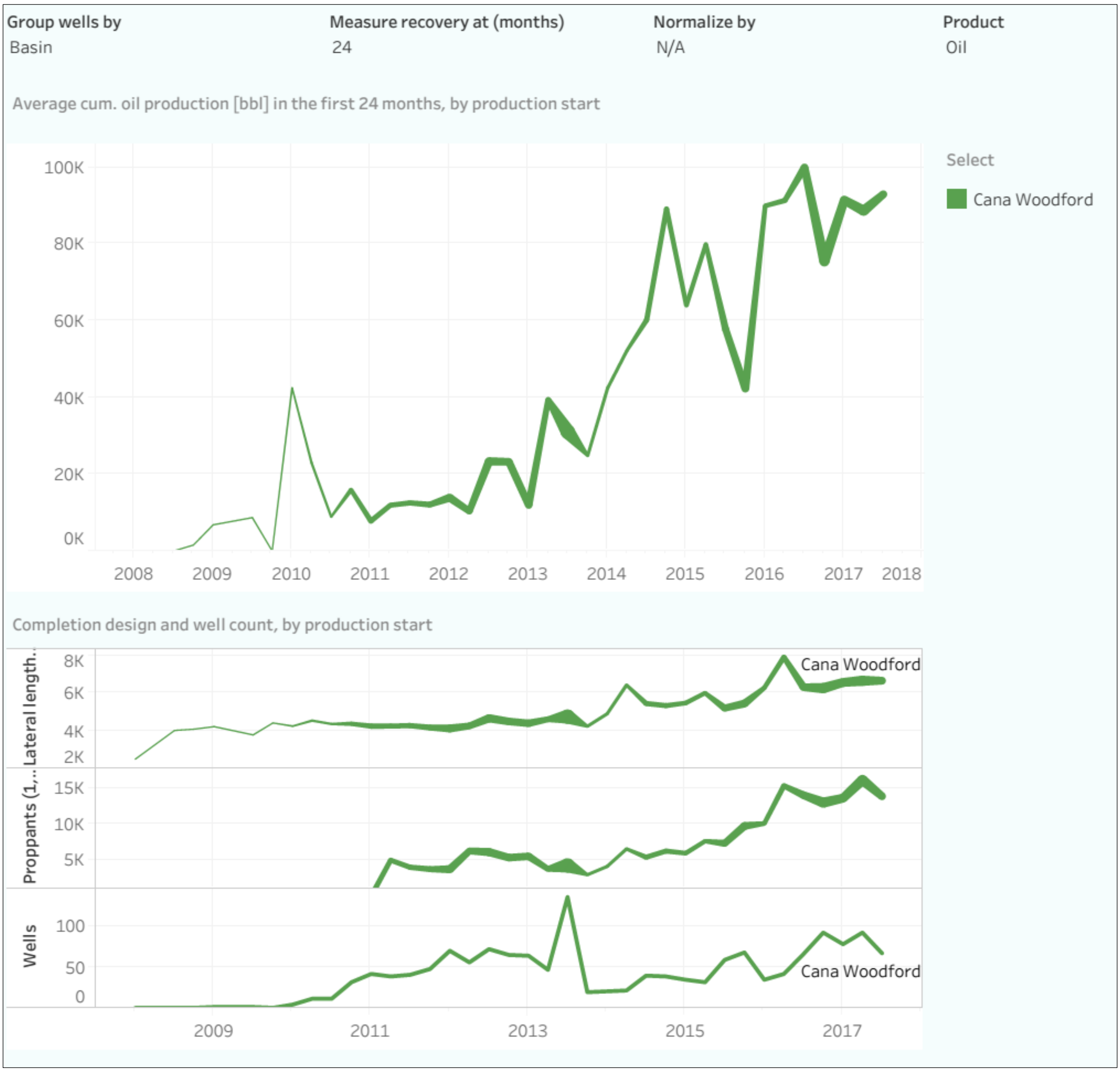

Figure F40. Cana Woodford Basin Play Productivity
(Source: Shaleprofile.com)

29.11 Arkoma Woodford Basin Play

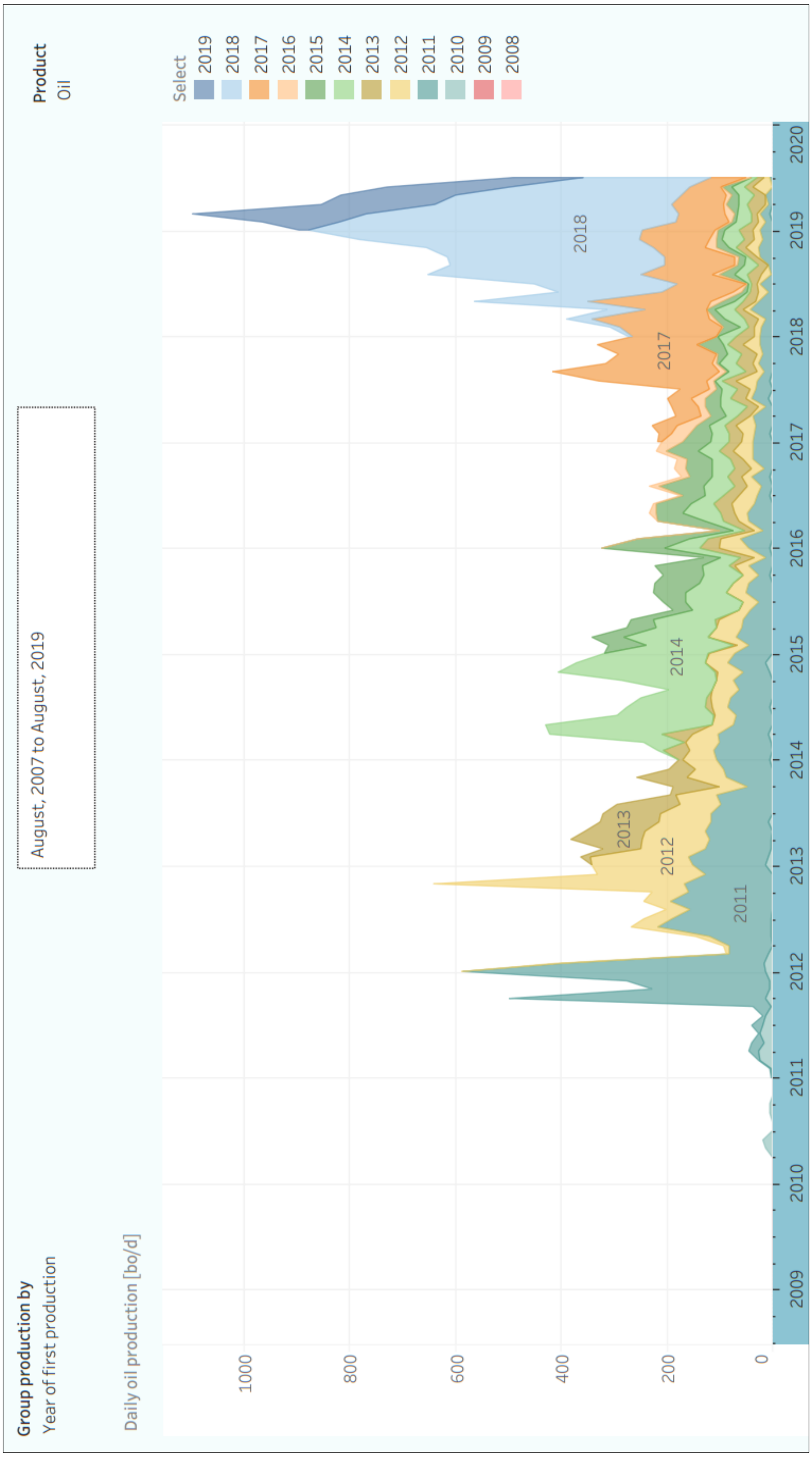

Figure F41. Arkoma Woodford Basin Play production by year
(Source: Shaleprofile.com)

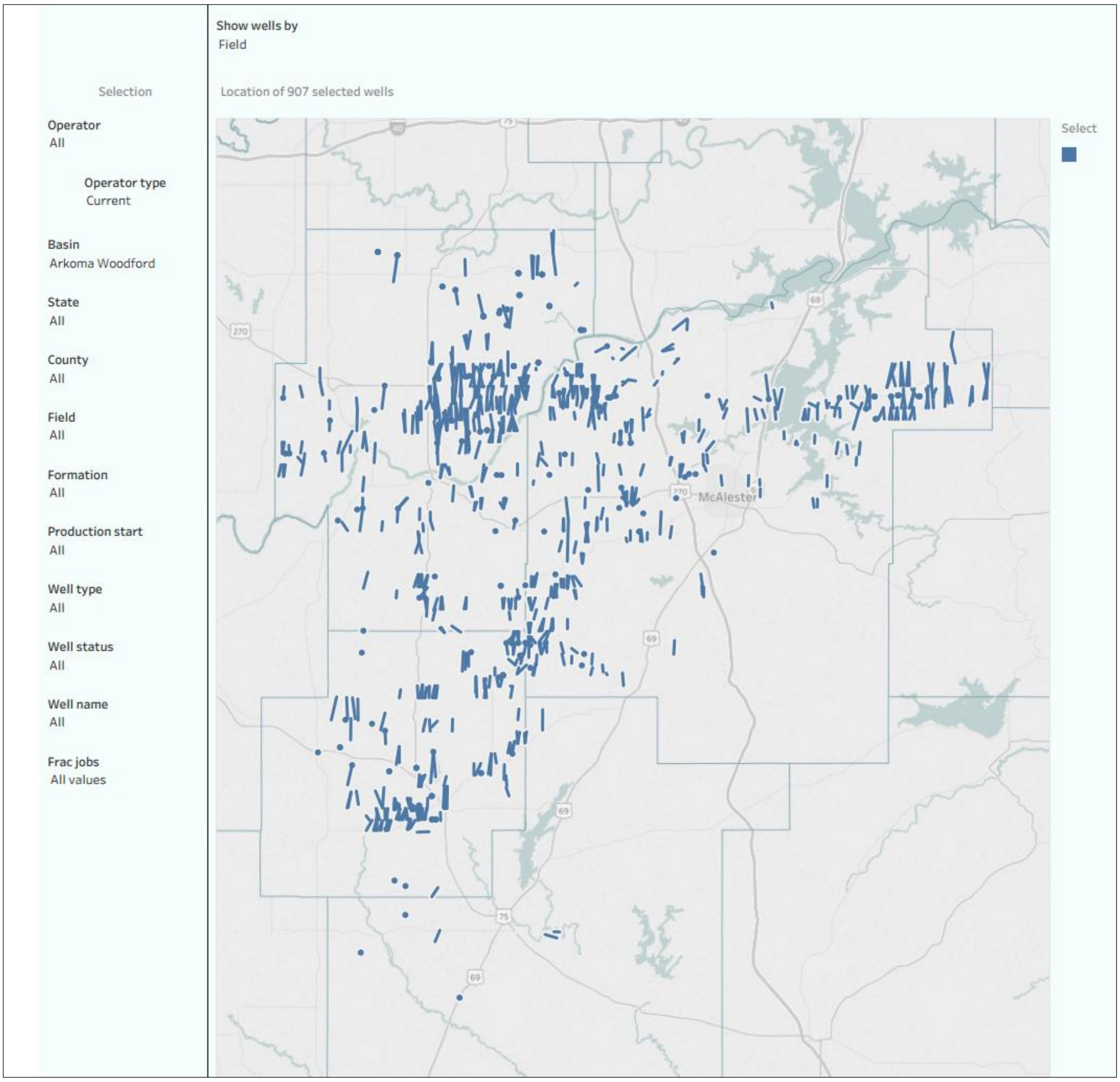

Figure F42. Arkoma Woodford Basin Play geographical map by county in the United States (Source: Shaleprofile.com)

29.12 Ardmore Woodford Basin Play

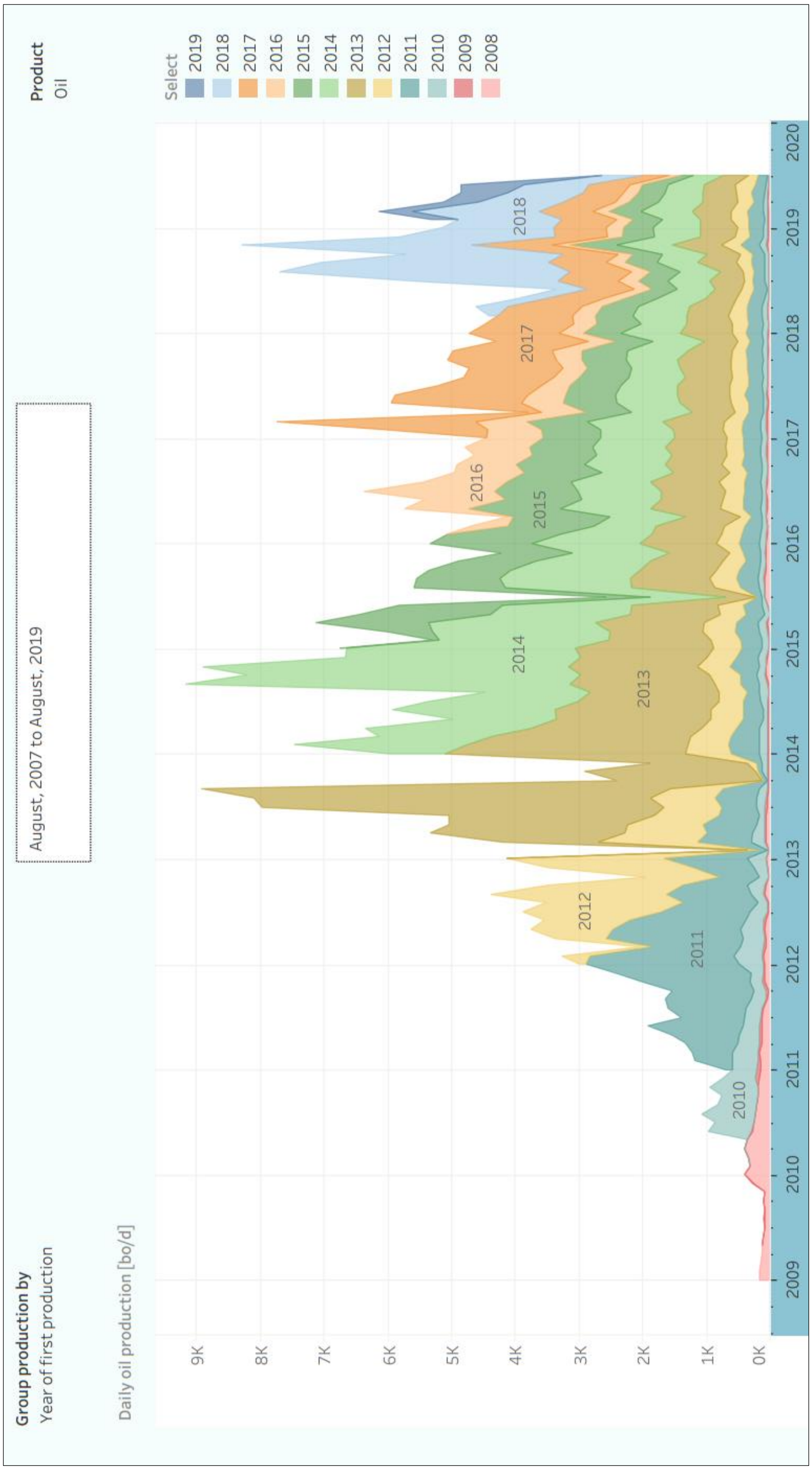

Figure F43. Ardmore Woodford Basin Play production by year
(Source: Shaleprofile.com)

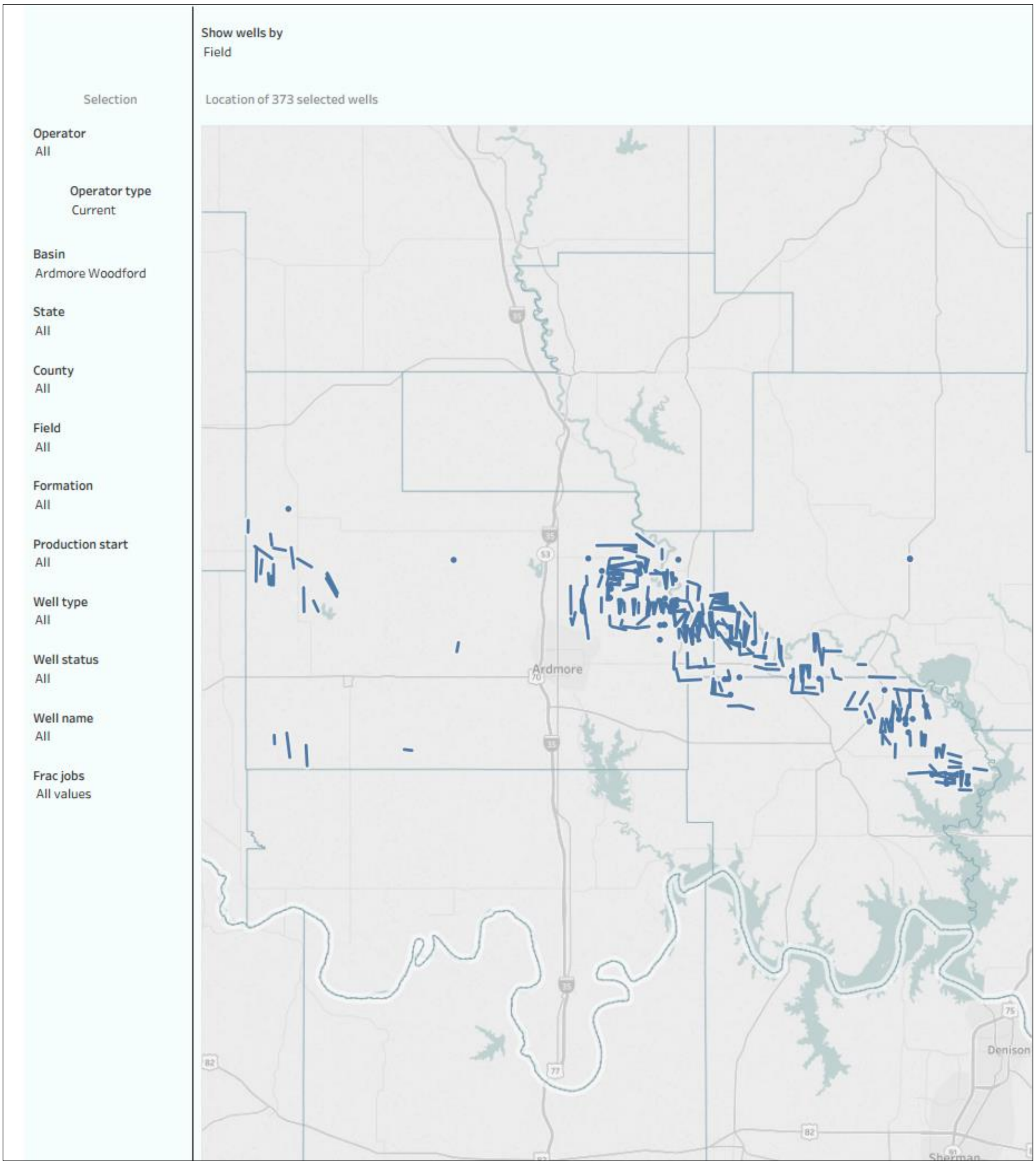

Figure F44. Ardmore Woodford Basin Play geographical map by county in the United States (Source: Shaleprofile.com)

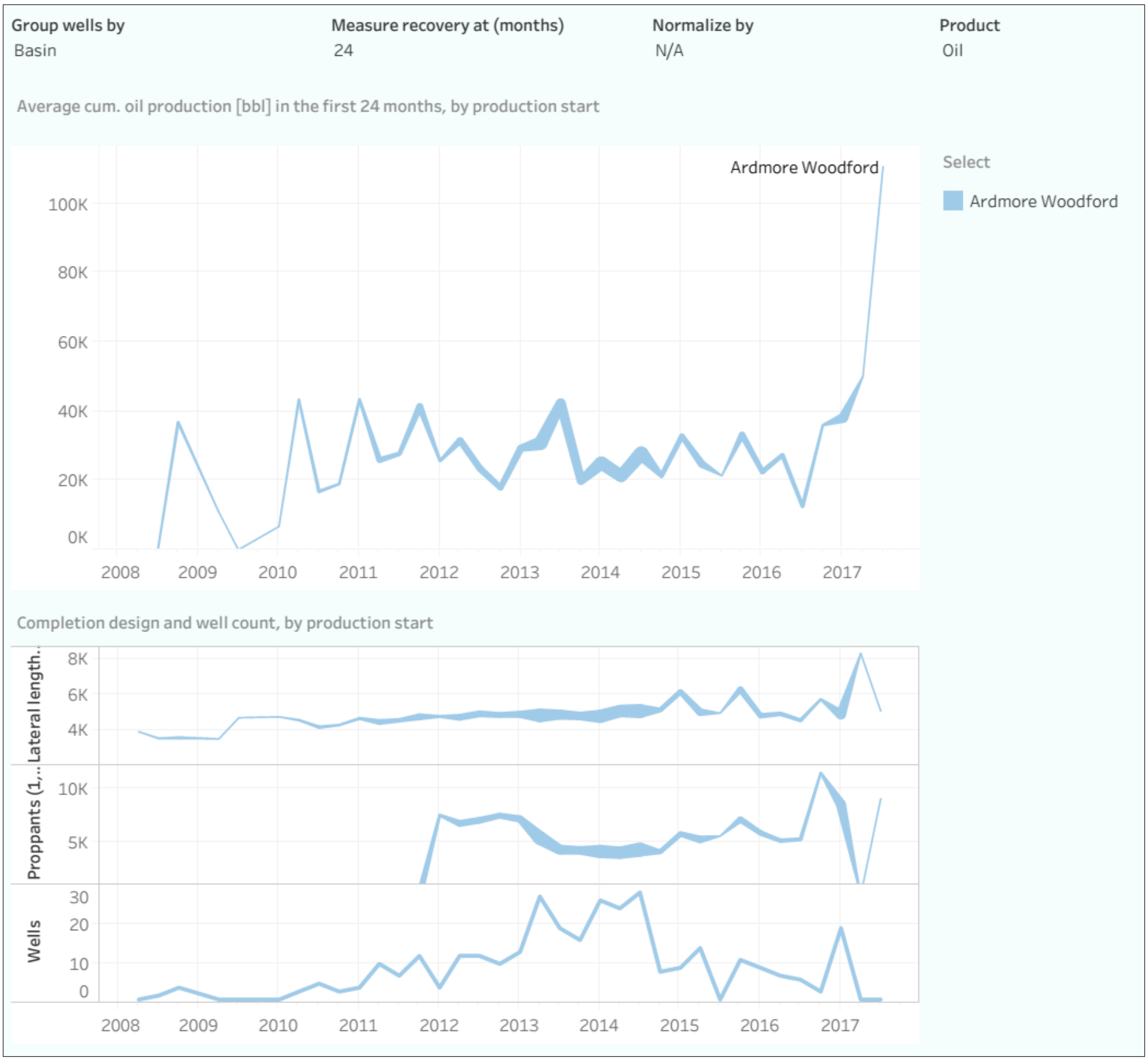

Figure F45. Ardmore Woodford Basin Play Productivity
(Source: Shaleprofile.com)

30 APPENDIX G - COMPOUNDS HAVE BEEN LISTED AS ADDITIVES FOR HYDRAULIC FRACTURING IN THE UNITED STATES

In the US, about 750 compounds have been listed as additives for hydraulic fracturing, also known as ingredients of pressurized fracking fluid, (reference 9) in an industry report to the US Congress in 2011 after originally being kept secret for "commercial reasons" (reference 10 and 11). The following is a partial list of the chemical constituents in additives that are used or have been used in fracturing operations, as based on the report of the New York State Department of Environmental Conservation, some are known to be carcinogenic (reference 12).

30.1 Appendix G References used to compile tables

1. Soraghan, M. (2010 Nov): "Halliburton Announces Ecofriendly Fracking Fluid, More Disclosure". The New York Times. Retrieved 13 April 2017. Halliburton Co., which is fighting U.S. EPA about disclosure of its hydraulic fracturing fluid, today announced that it will publicly disclose detailed information on its website about the chemicals used in its fracturing fluids. The Houston-based oilfield services company announced the creation of a new fracturing fluid that uses chemicals "sourced entirely from the food industry."

2. Healy, D., (2012 July): "Hydraulic Fracturing or 'Fracking': A Short Summary of Current Knowledge and Potential Environmental Impacts"(PDF). Department of Geology & Petroleum Geology, University of Aberdeen: 18–19. Retrieved 12 November 2015.

3. United Kingdom Government (2010):"The Environmental Permitting (England and Wales) Regulations 2010". Retrieved 2016-08-28.

4. Scottosh Regulation (2012): "The Pollution Prevention and Control (Scotland) Regulations 2012". www.legislation.gov.uk. Queen's Printer for Scotland (QPS). Retrieved 1 April 2017.

5. European Commison (2006): "DIRECTIVE 2006/118/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 12 December 2006 on the protection of groundwater against pollution and deterioration". eur-lex.europa.eu. EUR-Lex - 32006L0118 - EN - EUR-Lex. 12 December 2006. Retrieved 18 October 2014. It is necessary to distinguish between hazardous substances, inputs of which should be prevented, and other pollutants, inputs of which should be limited. Annex VIII to Directive 2000/60/EC, listing the main pollutants relevant for the water environment, should be used to identify hazardous and non-hazardous substances which present an existing or potential risk of pollution.

6. "Onshore oil and gas exploration in the UK: regulation and best practice" (PDF). DECC/BEIS. p. 46. Retrieved 13 April 2017. Operators will disclose the chemical additives of fracturing fluids on a well-by-well basis.

7. Mair, R., (2012 June): Shale gas extraction in the UK: A review of hydraulic fracturing (PDF) (Report). The Royal Society and the Royal Academy of Engineering. Retrieved 3 April 2017.

8. US Dept of Health and Human Services (2015 Aug). "Household Products Database". Health and Safety Information on Household Products. U.S. Department of Health and Human Services. Retrieved 11 November 2015.

9. GWPC & IOGCC (2015). "What chemicals are used in a hydraulic fracturing job". Chemical Disclosure Registry. FracFocus. Retrieved 11 November 2015.

10. Kusnetz, N. (April 8, 2011). "Fracking Chemicals Cited in Congressional Report Stay Underground". ProPublica. Retrieved July 11, 2011.

11. Chemicals Used in Hydraulic Fracturing (PDF) (Report). Committee on Energy and Commerce U.S. House of Representatives. April 18, 2011. Archived from the original (PDF) on October 4, 2013.

12. "Natural Gas Development Activities and High-volume Hydraulic Fracturing" (PDF). New York State Department of Environmental Conservation. 30 September 2009. pp. 45–51.

Table G1 (1 of 6). Compounds have been listed as additives for hydraulic fracturing in the United States

CAS Number	Chemical Constituent	Commercial use (ref 8)
2634-33-5	1,2-Benzisothiazolin-2-one / 1,2-benzisothiazolin-3-one	Insecticide Spray, Stain Remover
95-63-6	1,2,4-trimethylbenzene	Automatic Transmission Sealer
123-91-1	1,4-Dioxane	Wood Parquet Adhesive
567040	1-eicosene	No record
629-73-2	1-hexadecene	No record
112-88-9	1-octadecene	No record
1120-36-1	1-tetradecene	Stain Remover
10222-01-2	2,2 Dibromo-3-nitrilopropionamide, a biocide	No record
27776-21-2	2,2'-azobis-{2-(imidazlin-2-yl)propane}-dihydrochloride	No record
73003-80-2	2,2-Dibromomalonamide	No record
15214-89-8	2-Acrylamido-2-methylpropane sulphonic acid sodium salt polymer	No record
46830-22-2	2-acryloyloxyethyl(benzyl)dimethylammonium chloride	No record
52-51-7	2-Bromo-2-nitro-1,3-propanediol	Deodorant, Conditioner
111-76-2	2-Butoxy ethanol	Engine Cleaner
1113-55-9	2-Dibromo-3-Nitriloprionamide (2-Monobromo-3-nitriilopropionamide)	No record
104-76-7	2-Ethyl Hexanol	Diesel Fuel Treatment
67-63-0	2-Propanol / Isopropyl Alcohol / Isopropanol / Propan-2-ol	Damar Varnish, Gloss
26062-79-3	2-Propen-1-aminium, N,N-dimethyl-N-2-propenyl-chloride, homopolymer	Volumizing Conditioner
2594383	2-propenoic acid, homopolymer, ammonium salt	Moisturizer, Sunscreen
25987-30-8	2-Propenoic acid, polymer with 2 p-propenamide, sodium salt / Copolymer of acrylamide and sodium acrylate	No record
71050-62-9	2-Propenoic acid, polymer with sodium phosphinate (1:1)	No record
66019-18-9	2-propenoic acid, telomer with sodium hydrogen sulfite	No record
107-19-7	2-Propyn-1-ol / Propargyl alcohol	No record
51229-78-8	3,5,7-Triaza-1-azoniatricyclo[3.3.1.13,7]decane, 1-(3-chloro-2-propenyl)-chloride,	Clean Pressed Powder
115-19-5	3-methyl-1-butyn-3-ol	No record
127087-87-0	4-Nonylphenol Polyethylene Glycol Ether Branched / Nonylphenol ethoxylated / Oxyalkylated Phenol	Chrome Wheel Cleaner
64-19-7	Acetic acid	Silicone Sealant
68442-62-6	Acetic acid, hydroxy-, reaction products with triethanolamine	No record
108-24-7	Acetic Anhydride	No record
67-64-1	Acetone	Solvent, Clear Finish Gloss
38193-60-1	Acrylamide – sodium 2-acrylamido-2-methylpropane sulfonate copolymer	Moisture, Lotion
25085-02-3	Acrylamide – Sodium Acrylate Copolymer or Anionic Polyacrylamide	No record
25987-30-8	2-Propenoic acid, polymer with 2-propenamide, sodium salt	No record
69418-26-4	Acrylamide polymer with N,N,N-trimethyl-2[1-oxo-2-propenyl]oxy Ethanaminium chloride	No record
15085	–02-3 Acrylamide-sodium acrylate copolymer	No record
68551-12-2	Alcohols, C12-C16, Ethoxylated (a.k.a. Ethoxylated alcohol)	Floor Cleaner, Stain Remover
64742-47-8	Aliphatic Hydrocarbon / Hydrotreated light distillate / Petroleum Distillates / Isoparaffinic Solvent / Paraffin Solvent / Napthenic Solvent	Tar Remover, Lubricant
64743-02-8	Alkenes	No record
68439-57-6	Alkyl (C14-C16) olefin sulfonate, sodium salt	Car Wash, Dog Shampoo
9016-45-9	Alkylphenol ethoxylate surfactants	Engine Cleaner, Rubber Sealant
1327-41-9	Aluminum chloride	Antiperspirant
73138-27-9	Amines, C12-14-tert-alkyl, ethoxylated	No record
71011-04-6	Amines, Ditallow alkyl, ethoxylated	No record
68551-33-7	Amines, tallow alkyl, ethoxylated, acetates	No record
1336-21-6	Ammonia	Stripper, Glue, Tire Repair
631-61-8	Ammonium acetate	Haircolor Shine
68037-05-8	Ammonium Alcohol Ether Sulfate	No record
7783-20-2	Ammonium bisulfate	Ant Killer, Weed & Moss Control

Table G1 (2 of 6). Compounds have been listed as additives for hydraulic fracturing in the United States

CAS Number	Chemical Constituent	Commercial use (ref 8)
10192-30-0	Ammonium bisulfite	No record
12125-02-9	Ammonium chloride	Brass & Copper Polish, Bleach
7632-50-0	Ammonium citrate	No record
37475-88-0	Ammonium Cumene Sulfonate	No record
1341-49-7	Ammonium hydrogen-difluoride	Wheel Cleaner, Glass Etching
6484-52-2	Ammonium nitrate	Moisture Control, Ink Cartridge
7727-54-0	Ammonium Persulfate / Diammonium peroxidisulphate	Latex Paint, Maximizing Powder
1762-95-4	Ammonium Thiocyanate	Liquid Hide Glue
7664-41-7	Aqueous ammonia	Paint Stripper, Caulk
121888-68-4	Bentonite, benzyl(hydrogenated tallow alkyl) dimethylammonium stearate complex / organophilic clay	Wine clearing agent, "Detox" Product
71-43-2	Benzene	Fuel System Cleaner, Degreaser
119345-04-9	Benzene, 1,1'-oxybis, tetratpropylene derivatives, sulfonated, sodium salts	Toilet Cleaner, Rust Neutralizer
74153-51-8	Benzenemethanaminium, N,N-dimethyl-N-[2-[(1-oxo-2-propenyl)oxy]ethyl]-, chloride, polymer with 2-propenamide	No record
10043-35-3	Boric acid	Roach Killer, Stain Remover
1303-86-2	Boric oxide / Boric Anhydride	Carpenters Glue
71-36-3	Butan-1-ol	Interior/Exterior Paint
68002-97-1	C10 – C16 Ethoxylated Alcohol	Floor Finish Remover, Degreaser
68131-39-5	C12-15 Alcohol, Ethoxylated	Graffiti Remover, Radiator Flush
10043-52-4	Calcium chloride	Chlorinating Sanitizer, Ice Melt
124-38-9	Carbon dioxide	Penetrant, Lubricator
68130-15-4	Carboxymethylhydroxypropyl guar	No record
9012-54-8	Cellulase / Hemicellulase Enzyme	
9004-34-6	Cellulose	
10049-04-4	Chlorine dioxide	
77-92-9	Citric Acid	
94266-47-4	Citrus Terpenes	
61789-40-0	Cocamidopropyl betaine	
68155-09-9	Cocamidopropylamine Oxide	
68424-94-2	Coco-betaine	
7758-98-7	Copper(II) sulfate	
31726-34-8	Crissanol A-55	
14808-60-7	Crystalline Silica (Quartz)	
7447-39-4	Cupric chloride dihydrate	
1120-24-7	Decyldimethyl Amine	
2605-79-0	Decyl-dimethyl Amine Oxide	
3252-43-5	Dibromoacetonitrile	
25340-17-4	Diethylbenzene	
111-46-6	Diethylene glycol	
22042-96-2	Diethylenetriamine penta (methylenephonic acid) sodium salt	
28757-00-8	Diisopropyl naphthalenesulfonic acid	
68607-28-3	Dimethylcocoamine, bis(chloroethyl) ether, diquaternary ammonium salt	
7398-69-8	Dimethyldiallylammonium chloride	
25265-71-8	Dipropylene glycol	
139-33-3	Disodium Ethylene Diamine Tetra Acetate	
5989-27-5	D-Limonene	
123-01-3	Dodecylbenzene	
27176-87-0	Dodecylbenzene sulfonic acid	
42504-46-1	Dodecylbenzenesulfonate isopropanolamine	
50-70-4	D-Sorbitol / Sorbitol	

Table G1 (3 of 6). Compounds have been listed as additives for hydraulic fracturing in the United States

CAS Number	Chemical Constituent	Commercial use (ref 8)
37288-54-3	Endo-1,4-beta-mannanase, or Hemicellulase	
149879-98-1	Erucic Amidopropyl Dimethyl Betaine	
89-65-6	Erythorbic acid, anhydrous	
54076-97-0	Ethanaminium, N,N,N-trimethyl-2-[(1-oxo-2-propenyl)oxy]-, chloride, homopolymer	
107-21	–1 Ethane-1,2-diol / Ethylene Glycol	
9002-93-1	Ethoxylated 4-tert-octylphenol	
68439-50-9	Ethoxylated alcohol	
126950-60-5	Ethoxylated alcohol	
67254-71-1	Ethoxylated alcohol (C10-12)	
68951-67-7	Ethoxylated alcohol (C14-15)	
68439-46-3	Ethoxylated alcohol (C9-11)	
66455-15-0	Ethoxylated Alcohols	
84133-50-6	Ethoxylated Alcohols (C12-14 Secondary)	
68439-51-0	Ethoxylated Alcohols (C12-14)	
78330-21-9	Ethoxylated branch alcohol	
34398-01-1	Ethoxylated C11 alcohol	
61791-12-6	Ethoxylated Castor Oil	
61791-29-5	Ethoxylated fatty acid, coco	
61791-08-0	Ethoxylated fatty acid, coco, reaction product with ethanolamine	
68439-45-2	Ethoxylated hexanol	
9036-19-5	Ethoxylated octylphenol	
9005-67-8	Ethoxylated Sorbitan Monostearate	
9004-70-3	Ethoxylated Sorbitan Trioleate	
64-17-5	Ethyl alcohol / ethanol	
100-41-4	Ethyl Benzene	
97-64-3	Ethyl lactate	
2594628	Ethylene Glycol-Propylene Glycol Copolymer (Oxirane, methyl-, polymer with oxirane)	
75-21-8	Ethylene oxide	
5877-42-9	Ethyloctynol	
68526-86-3	Exxal 13	
61790-12-3	Fatty Acids	
68188-40-9	Fatty acids, tall oil reaction products w/ acetophenone, formaldehyde & thiourea	
9043-30-5	Fatty alcohol polyglycol ether surfactant	
7705-08-0	Ferric chloride	
7782-63-0	Ferrous sulfate, heptahydrate	
50-00-0	Formaldehyde	
29316-47-0	Formaldehyde polymer with 4,1,1-dimethylethyl phenolmethyl oxirane	
153795-76-7	Formaldehyde, polymers with branched 4-nonylphenol, ethylene oxide and propylene oxide	
75-12-7	Formamide	
64-18-6	Formic acid	
110-17-8	Fumaric acid	
65997-17-3	Glassy calcium magnesium phosphate	
111-30-8	Glutaraldehyde	
56-81-5	Glycerol / glycerine	
9000-30-0	Guar Gum	
64742-94-5	Heavy aromatic petroleum naphtha	
9025-56-3	Hemicellulase	
7647-01-0	Hydrochloric Acid / Hydrogen Chloride / muriatic acid	Toilet Bowl Cleaner
7722-84-1	Hydrogen peroxide	

Table G1 (4 of 6). Compounds have been listed as additives for hydraulic fracturing in the United States

CAS Number	Chemical Constituent	Commercial use (ref 8)
79-14-1	Hydroxy acetic acid	
35249-89-9	Hydroxyacetic acid ammonium salt	
9004-62-0	Hydroxyethyl cellulose	
1304222	Hydroxylamine hydrochloride	
39421-75-5	Hydroxypropyl guar	
35674-56-7	Isomeric Aromatic Ammonium Salt	
64742-88-7	Isoparaffinic Petroleum Hydrocarbons, Synthetic	
64-63-0	Isopropanol	
98-82-8	Isopropylbenzene (cumene)	
68909-80-8	Isoquinoline, reaction products with benzyl chloride and quinoline	
8008-20-6	Kerosene	
64742-81-0	Kerosine, hydrodesulfurized	
63-42-3	Lactose	
64742-95-6	Light aromatic solvent naphtha	
1120-21-4	Light Paraffin Oil	
14807-96-6	Magnesium Silicate Hydrate (Talc)	
1184-78-7	methanamine, N,N-dimethyl-, N-oxide	
67-56-1	Methanol	
68891-11-2	Methyloxirane polymer with oxirane, mono (nonylphenol) ether, branched	
8052-41-3	Mineral spirits / Stoddard Solvent	
141-43-5	Monoethanolamine	
44992-01-0	N,N,N-trimethyl-2[1-oxo-2-propenyl]oxy Ethanaminium chloride	
64742-48-9	Naphtha (petroleum), hydrotreated heavy	
91-20-3	Naphthalene	
38640-62-9	Naphthalene bis(1-methylethyl)	
93-18-5	Naphthalene, 2-ethoxy-	
68909-18-2	N-benzyl-alkyl-pyridinium chloride	
68139-30-0	N-Cocoamidopropyl-N,N-dimethyl-N-2-hydroxypropylsulfobetaine	
7727-37-9	Nitrogen, Liquid form	
68412-54-4	Nonylphenol Polyethoxylate	
121888-66-2	Organophilic Clays	
64742-65-0	Petroleum Base Oil	
64741-68-0	Petroleum naphtha	
70714-66-8	Phosphonic acid, (phosphonomethyl)iminobis2,1-ethanediylnitrilobis(methylene)tetrakis-, ammonium salt	
8000-41-7	Pine Oil	
60828-78-6	Poly(oxy-1,2-ethanediyl), a-[3,5-dimethyl-1-(2-methylpropyl)hexyl]-w-hydroxy-	
25322-68-3	Poly(oxy-1,2-ethanediyl), a-hydro-w-hydroxy / Polyethylene Glycol	
24938-91-8	Poly(oxy-1,2-ethanediyl), α-tridecyl-ω-hydroxy-	
51838-31-4	Polyepichlorohydrin, trimethylamine quaternized	
56449-46-8	Polyethlene glycol oleate ester	
62649-23-4	Polymer with 2-propenoic acid and sodium 2-propenoate	
9005-65-6	Polyoxyethylene Sorbitan Monooleate	
61791-26-2	Polyoxylated fatty amine salt	
127-08-2	Potassium acetate	
12712-38-8	Potassium borate	
1332-77-0	Potassium borate	
20786-60-1	Potassium Borate	
584-08-7	Potassium carbonate	
7447-40-7	Potassium chloride	

Table G1 (5 of 6). Compounds have been listed as additives for hydraulic fracturing in the United States

CAS Number	Chemical Constituent	Commercial use (ref 8)
590-29-4	Potassium formate	
1310-58-3	Potassium Hydroxide	
13709-94-9	Potassium metaborate	
24634-61-5	Potassium sorbate	
112926-00-8	Precipitated silica / silica gel	
57-55-6	Propane-1,2-diol, or Propylene glycol	
107-98-2	Propylene glycol monomethyl ether	
68953-58-2	Quaternary Ammonium Compounds	
62763-89-7	Quinoline,2-methyl-, hydrochloride	
15619-48-4	Quinolinium, 1-(phenylmethl),chloride	
7631-86-9	Silica, Dissolved	
5324-84-5	Sodium 1-octanesulfonate	
127-09-3	Sodium acetate	
95371-16-7	Sodium Alpha-olefin Sulfonate	
532-32-1	Sodium benzoate	
144-55-8	Sodium bicarbonate	
7631-90-5	Sodium bisulfate	
7647-15-6	Sodium bromide	
497-19-8	Sodium carbonate	
7647-14-5	Sodium Chloride	
7758-19-2	Sodium chlorite	
3926-62-3	Sodium chloroacetate	
68-04-2	Sodium citrate	
6381-77-7	Sodium erythorbate / isoascorbic acid, sodium salt	
2836-32-0	Sodium Glycolate	
1310-73-2	Sodium Hydroxide	
7681-52-9	Sodium hypochlorite	
7775-19-1	Sodium Metaborate .8H2O	
10486-00-7	Sodium perborate tetrahydrate	
7775-27-1	Sodium persulfate	
2594415	Sodium polyacrylate	
7757-82-6	Sodium sulfate	
1303-96-4	Sodium tetraborate decahydrate	
7772-98-7	Sodium thiosulfate	
1338-43-8	Sorbitan Monooleate	
57-50-1	Sucrose	
5329-14-6	Sulfamic acid	
112945-52-5	Synthetic Amorphous / Pyrogenic Silica / Amorphous Silica	
68155-20-4	Tall Oil Fatty Acid Diethanolamine	
8052-48-0	Tallow fatty acids sodium salt	
72480-70-7	Tar bases, quinoline derivs., benzyl chloride-quaternized	
68647-72-3	Terpene and terpenoids	
68956-56-9	Terpene hydrocarbon byproducts	
533-74-4	Tetrahydro-3,5-dimethyl-2H-1,3,5-thiadiazine-2-thione (a.k.a. Dazomet)	
55566-30-8	Tetrakis(hydroxymethyl)phosphonium sulfate (THPS)	
75-57-0	Tetramethyl ammonium chloride	
64-02-8	Tetrasodium Ethylenediaminetetraacetate	
68-11-1	Thioglycolic acid	
62-56-6	Thiourea	

Table G1 (6 of 6). Compounds have been listed as additives for hydraulic fracturing in the United States

CAS Number	Chemical Constituent	Commercial use (ref 8)
68527-49-1	Thiourea, polymer with formaldehyde and 1-phenylethanone	
108-88-3	Toluene	
81741-28-8	Tributyl tetradecyl phosphonium chloride	
68299-02-5	Triethanolamine hydroxyacetate	
112-27-6	Triethylene glycol	
52624-57-4	Trimethylolpropane, Ethoxylated, Propoxylated	
150-38-9	Trisodium Ethylenediaminetetraacetate	
5064-31-3	Trisodium Nitrilotriacetate	
7601-54-9	Trisodium orthophosphate	
57-13-6	Urea	
25038-72-6	Vinylidene Chloride/Methylacrylate Copolymer	
7732-18-5	Water	Deionized water
1330-20-7	Xylene	Carburetor Cleaner, Asphalt Primer
068604-95-5	Aliphatic acids	Wall & Trim Enamel
078330-20-8	Aliphatic Ethoxylated Alcohols	Leather Cleaner
000000-33-9	Alkyl aryl polyethoxy alcohols	Coppersmiths Polish
000000-17-6	Alkylaryl Sulfonate	Detergent, Stain Remover
064742-47-8	Distillates, petroleum, hydrotreated light	Tar Remover, Sealant
000110-43-0	Methyl n-amyl & ethyl ketones	Hobby Cement, Sealant
	Oxyalkylated alkylphenol	
	Petroleum distillate blend	
	Polyethoxylated alkanol	
	Polymeric Hydrocarbons	
	Salt of amine-carbonyl condensate	
	Salt of fatty acid/polyamine reaction product	
	Sugar	
	Surfactant blend	

31 APPENDIX H – ENERGY UNITS AND CONVERSIONS

31.1 Energy Units and Conversions

- 1 Joule (J) is the MKS unit of energy, equal to the force of one Newton acting through one meter.
- 1 MJ/kg = 1000 J/g = 1 GJ/t = 238.85 kcal/kg = 429.9 Btu(IT)/lb = 0.2778 kWh/kg
- 1 MJ/m^3 = 26.839 Btu(IT)/ft^3 = 3.5879 Btu(IT)/gal(US liq) = 0.94782 Btu(IT)/l = 239.01 kcal/m^3
- 1 Watt is the power of a Joule of energy per second
- Power = Current x Voltage (P = I V)
- 1 Watt is the power from a current of 1 Ampere flowing through 1 Volt.
- 1 kilowatt is a thousand Watts.
- 1 kilowatt-hour is the energy of one kilowatt power flowing for one hour. (E = P t).
- 1 kilowatt-hour (kWh) = 3.6 x 106 J = 3.6 million Joules
- 1 kWh/kg = 1547.7 Btu(IT)/lb = 3.597 GJ/t = 3597.1 kJ/kg = 860.421 kcal/kg
- 1 calorie of heat is the amount needed to raise 1 gram of water 1 degree Centigrade.
- 1 calorie (cal) = 4.184 J (The Calories in food ratings are actually kilocalories.)
- 1 kcal/kg = 1 cal/g = 4.1868 MJ/t = 4186.8 J/kg = 1.8 Btu(IT)/lb = 0.001162 kWh/kg
- 1 kcal/m^3 = 0.11237 Btu(IT)/ft^3 = 0.01501 Btu(IT)/gal(US liq) = 0.003966 Btu(IT)/l = 4186.8 J/m^3
- A BTU (British Thermal Unit) is the amount of heat necessary to raise one pound of water by 1 degree Farenheit (F).
- 1 British Thermal Unit (BTU) = 1055 J (The Mechanical Equivalent of Heat Relation)
- 1 Btu(IT)/lb = 2.3278 MJ/t = 2327.8 J/kg = 0.55598 kcal/kg = 0.000646 kWh/kg
- 1 Btu(IT)/ft^3 = 0.1337 Btu(IT)/gal(US liq) = 0.03531 Btu(IT)/l = 8.89915 kcal/m^3 = 3.7259x10^4 J/m^3
- 1 Btu(IT)/gal(US liq) = 0.2642 Btu(IT)/l = 7.4805 Btu(IT)/ft^3 = 66.6148 kcal/m^3 = 2.7872x10^5 J/m^3
- 1 BTU = 252 cal = 1.055 kJ
- 1 Quad = 1015 BTU (World energy usage is about 300 Quads/year, US is about 100 Quads/year in 1996.)
- 1 therm = 100,000 BTU
- 1,000 kWh = 3.41 million BTU

31.2 Power Conversion

- horsepower (hp) = 745.7 watts

31.3 Gas Volume to Energy Conversion

- One thousand cubic feet of gas (Mcf) -> 1.027 million BTU = 1.083 billion J = 301 kWh
- One therm = 100,000 BTU = 105.5 MJ = 29.3 kWh
- Mcf -> 10.27 therms

31.4 Energy Content of Fuels

- Coal 25 million BTU/ton
- Crude Oil 5.6 million BTU/barrel
- Oil 5.78 million BTU/barrel = 1700 kWh / barrel
- Gasoline 5.6 million BTU/barrel (a barrel is 42 gallons) = 1.33 therms / gallon
- Natural gas liquids 4.2 million BTU/barrel
- Natural gas 1030 BTU/cubic foot
- Wood 20 million BTU/cord

31.5 CO^2 Pollution of Fossil Fuels

- Pounds of CO^2 per billion BTU of energy::
- Coal 208,000 pounds
- Oil 164,000 pounds
- Natural Gas 117,000 pounds

- Ratios of CO^2 pollution:
- Oil / Natural Gas = 1.40
- Coal / Natural Gas = 1.78

- Pounds of CO^2 per 1,000 kWh, at 100% efficiency:
- Coal 709 pounds
- Oil 559 pounds
- Natural Gas 399 pounds

Table H1. Scaling labels

SI Unit	Watt-hour (Wh) equivalent
Watt-hour (Wh)	-
Kilowatt-hour (kWh)	One thousand watt-hours (10^3 Wh)
Megawatt-hour (MWh)	One million watt-hours (10^6 Wh)
Gigawatt-hour (GWh)	One billion watt-hours (10^9 Wh)
Terawatt-hour (TWh)	One trillion watt-hours (10^{12} Wh)

Table H2. Approximate conversion factors (BP Statistical Review of World Energy 2019).

Crude oil*

From	To: tonnes (metric)	kilolitres	barrels	US gallons	tonnes per year
	Multiply by				
Tonnes (metric)	1	1.165	7.33	307.86	–
Kilolitres	0.8581	1	6.2898	264.17	–
Barrels	0.1364	0.159	1	42	–
US gallons	0.00325	0.0038	0.0238	1	–
Barrels per day	–	–	–	–	49.8

*Based on worldwide average gravity.

Products

	To convert: barrels to tonnes	tonnes to barrels	kilolitres to tonnes	tonnes to kilolitres
	Multiply by			
Liquefied petroleum gas (LPG)	0.086	11.60	0.542	1.844
Gasoline	0.120	8.35	0.753	1.328
Kerosene	0.127	7.88	0.798	1.253
Gas oil/diesel	0.134	7.46	0.843	1.186
Residual fuel oil	0.157	6.35	0.991	1.010
Product basket	0.125	7.98	0.788	1.269

Natural gas (NG) and liquefied natural gas (LNG)

From	To: billion cubic metres NG	billion cubic feet NG	million tonnes oil equivalent	million tonnes LNG	trillion British thermal units	million barrels oil equivalent
	Multiply by					
1 billion cubic metres NG	1.000	35.315	0.860	0.735	34.121	5.883
1 billion cubic feet NG	0.028	1.000	0.024	0.021	0.966	0.167
1 million tonnes oil equivalent	1.163	41.071	1.000	0.855	39.683	6.842
1 million tonnes LNG	1.360	48.028	1.169	1.000	46.405	8.001
1 trillion British thermal units	0.029	1.035	0.025	0.022	1.000	0.172
1 million barrels oil equivalent	0.170	6.003	0.146	0.125	5.800	1.000

Units

1 metric tonne	= 2204.62lb = 1.1023 short tons
1 kilolitre	= 6.2898 barrels = 1 cubic metre
1 kilocalorie (kcal)	= 4.1868kJ = 3.968Btu
1 kilojoule (kJ)	= 0.239kcal = 0.948Btu
1 British thermal unit (Btu)	= 0.252kcal = 1.055kJ
1 kilowatt-hour (kWh)	= 860kcal = 3600kJ = 3412Btu

Calorific equivalents

One tonne of oil equivalent equals approximately:

Heat units	10 million kilocalories 42 gigajoules 40 million British thermal units
Solid fuels	1.5 tonnes of hard coal 3 tonnes of lignite and sub-bituminous coal
Gaseous fuels	See Natural gas and liquefied natural gas table
Electricity	12 megawatt-hours

One million tonnes of oil or oil equivalent produces about 4400 gigawatt-hours (= 4.4 terawatt-hours) of electricity in a modern power station.

1 barrel of ethanol = 0.58 barrels of oil equivalent
1 barrel of biodiesel = 0.86 barrels of oil equivalent
1 tonne of ethanol = 0.68 tonnes of oil equivalent
1 tonne of biodiesel = 0.88 tonnes of oil equivalent

Definitions

Statistics published in this review are taken from government sources and published data. No use is made of confidential information obtained by BP in the course of its business.

Country, regions and geographic groupings

Country and geographic groupings are made purely for statistical purposes and are not intended to imply any judgement about political or economic standings.

North America
US (excluding US territories), Canada, Mexico.

South & Central America
Caribbean (including Puerto Rico and US Virgin Islands), Bermuda, Central and South America.

Europe
European members of the OECD plus Albania, Bosnia-Herzegovina, Bulgaria, Croatia, Cyprus, Georgia, Gibraltar, Latvia, Lithuania, Malta, Montenegro, North Macedonia, Romania, Serbia and Ukraine.

Commonwealth of Independent States (CIS)
Armenia, Azerbaijan, Belarus, Kazakhstan, Kyrgyzstan, Moldova, Russian Federation, Tajikistan, Turkmenistan, Uzbekistan.

Middle East
Arabian Peninsula, Iran, Iraq, Israel, Jordan, Lebanon, Syria.

North Africa
Territories on the north coast of Africa from Egypt to Western Sahara.

West Africa
Territories on the west coast of Africa from Mauritania to Angola, including Cape Verde, Chad.

East and Southern Africa
Territories on the east coast of Africa from Sudan to Republic of South Africa. Also Botswana, Madagascar, Malawi, Namibia, Uganda, Zambia, Zimbabwe.

Asia Pacific
Brunei, Cambodia, China†, China Hong Kong SAR*, China Macau SAR*, Indonesia, Japan, Laos, Malaysia, Mongolia, North Korea, Philippines, Singapore, South Asia (Afghanistan, Bangladesh, India, Myanmar, Nepal, Pakistan, Sri Lanka), South Korea, Taiwan, Thailand, Vietnam, Australia, New Zealand, Papua New Guinea, Oceania.
†Mainland China.
*Special Administrative Region.

Australasia
Australia, New Zealand.

OECD members
Europe: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, UK.
Other member countries: Australia, Canada, Chile, Israel, Japan, Mexico, New Zealand, South Korea, US.

OPEC members
Middle East: Iran, Iraq, Kuwait, Qatar, Saudi Arabia, United Arab Emirates.
North Africa: Algeria, Libya.
West Africa: Angola, Equatorial Guinea, Gabon, Nigeria, Republic of Congo.
South America: Ecuador, Venezuela.

European Union members
Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, UK.

Non-OECD
All countries that are not members of the OECD.

Methodology

Primary energy consumption is reported in net terms. The gross calorific value to net calorific value adjustment is fuel-specific.

The primary energy values of nuclear and hydroelectric power generation, as well as electricity from renewable sources, have been derived by calculating the equivalent amount of fossil fuel required to generate the same volume of electricity in a thermal power station, assuming a conversion efficiency of 38% (the average for OECD thermal power generation).

Fuels used as inputs for conversion technologies (gas-to-liquids, coal-to-liquids and coal-to-gas) are counted as production for the source fuel and the outputs are counted as consumption for the converted fuel.

Percentages
Calculated before rounding of actuals.

Rounding differences
Because of rounding, some totals may not agree exactly with the sum of their component parts.

Tonnes
Metric equivalent of tons.