

# Fossil and Nuclear Fuels – the Supply Outlook

**March 2013**

**Authors:**

Dr. Werner Zittel

Dipl.-Ing. Jan Zerhusen

Dipl.-Ing. Martin Zerta

Ludwig-Bölkow-Systemtechnik GmbH, Ottobrunn/Germany

Mag. Nikolaus Arnold, MBA, Institut für Sicherheits- und Risikowissenschaften, Universität für Bodenkultur, Wien

**Scientific and parliamentarian advisory board:**

see at [www.energywatchgroup.org](http://www.energywatchgroup.org)

© **Energy Watch Group / Ludwig-Boelkow-Foundation / Reiner-Lemoine-Foundation**

## **About Energy Watch Group**

### **Energy policy needs objective information.**

The Energy Watch Group is an international network of scientists and parliamentarians. The supporting organization is the Ludwig-Bölkow-Foundation. In this project scientists are working on studies independently of government and company interests concerning

- the shortage of fossil and nuclear energy resources,
- development scenarios for regenerative energy sources  
as well as
- strategic deriving from these for a long-term secure energy supply at affordable prices.

The scientists are therefore collecting and analysing not only ecological but above all economical and technological connections. The results of these studies are to be presented not only to experts but also to the politically interested public.

### **Objective information needs independent financing.**

A bigger part of the work in the network is done unsalaried. Furthermore the Energy Watch Group is financed by donations.

More details you can find on our website and here:

Energy Watch Group  
Zinnowitzer Straße 1  
10115 Berlin Germany  
Phone +49 (0)30 3988 9664  
office@energywatchgroup.org  
www.energywatchgroup.org

**CONTENT**

Executive Summary ..... 5

Short Study Version/ Key Findings ..... 13

    Scope ..... 13

    Oil..... 14

    Natural Gas..... 24

    Coal ..... 32

    Uranium and nuclear power ..... 35

    Conclusion..... 39

Acknowledgement..... 41



## **EXECUTIVE SUMMARY**

### **Scope**

Since 1998 when the oil geologists Colin Campbell and Jean Laherrère published a widely discussed survey article “The End of Cheap Oil” in the journal “Scientific American”, the concept of peak oil and the present state of oil depletion are part of any serious analysis of the future oil supply potential. However, recently various publications suggest that oil is still abundantly available and that there is little need to worry about the future oil supply potential.

As in previous years, the International Energy Agency (IEA) in its latest World Energy Outlook 2012 (WEO 2012) projects a rising global oil demand and supply in the coming decades. The IEA explicitly asserts that for the foreseeable future – to 2035 and beyond – no geological or technical restrictions will prevent a continually growing oil supply. The media were echoing this report by emphasising the likelihood of a global oil and gas supply glut triggered by new production technologies in the USA, while ignoring possible geological supply restrictions.

In contrast to the projections put forward by the IEA, in 2008 the Energy Watch Group (EWG) had published a report on the future world oil supply, presenting a scenario projecting a significant decline of global oil supply in the coming decades up to 2030. It is the intention of this new report to update these findings by analysing the developments which took place in the last five years and thereby to arrive at an enhanced understanding of the conditions determining present and future oil supply.

In addition, it is the intention of this study to broaden the perspective of the original study by embedding the oil scenario into a global scenario for all fossil and nuclear fuels by including natural gas and by updating the EWG coal supply scenario of 2006 and the EWG uranium supply scenario of 2007.

In a nutshell, this report gives a short overview on the future availability of fossil and nuclear fuels with an emphasis on critical issues.

### **Oil**

- Empirical data shows that world oil production has not increased anymore but has entered a plateau since about 2005. The production of conventional oil is already in slight decline since about 2008. The peaking of conventional oil is now also accepted by the International Energy Agency. Present and future efforts by the oil industry are directed at upholding this plateau as long as possible while at the same time having to struggle with the growing decline of production in ageing fields. It is becoming

increasingly more difficult to compensate this reduction by developing new fields which are getting harder to find, smaller, and are of poorer quality.

- Recent increases of unconventional oil and gas production in the USA are due to a number of specific conditions, such as a highly developed oil and gas industry and infrastructure, sizeable unconventional oil and gas resources in prospective areas with very low population densities, certain financial incentives for publicly listed companies, and exemptions for the oil and gas industry from environmental restrictions (Energy Policy Act 2005). But most important were the high oil and gas prices reached in 2006. This has led to the fast development of the few hot spots of shale gas and light tight oil while the decline of the conventional oil and gas production is continuing to progress.
- The scenario projections in the WEO 2012 by the International Energy Agency stating that around 2020-2025 unconventional oil and gas production will make the USA independent from imports rest (1) on the assumption that demand declines considerably and (2) on the speculation that huge possible resources will be transformed into proven reserves and then be put into production. In particular the latter is by no means ensured. There is a high probability that light tight oil production in the USA will peak between 2015 and 2017, followed by a steep decline. Light tight oil production will likely turn out to be a bubble, lasting only for about 10 years.
- New field developments in “frontier areas” are disappointing and lagging far behind the hopes raised five to ten years ago:

The *Caspian region* (Kazakhstan, Azerbaijan) is currently producing 3 Mb/day, much less than the expectations raised by the US-EIA in 2000. At that time it was thought that production in the Caspian region might rival the Middle East countries by 2015-2020. The most promising new development since 2000, Azeri-Chirac-Gunashli, has already passed peak and the whole region is now in decline. Only the expensive and delayed development of Kashagan might bring about a production increase in that region.

Oil production in deep water areas in the *Gulf of Mexico*, *West of Africa*, and *East of Brazil* is far behind forecasts from ten years ago for each of the areas. The Gulf of Mexico has already passed peak production; the same is true for Angola. Stagnating oil production in Brazil is standing at 2 Mb/day at the end of 2012. This is far behind Petrobras’ original time schedule and poses huge financial problems for the state company. In contrast to earlier expectations, gasoline imports to Brazil grew over the last years.

Tar Sands in *Canada* and Extra Heavy Oil in *Venezuela* have increased global

reserves by several hundred Gigabarrels. However, production growth from these resources is far behind the goals published five years ago. Synthetic crude oil and bitumen production in Canada amounts to 1.8 Mb/day, while projections in 2007 suggested a production level of about double that (3.5 Mb/day). Extra heavy oil production in Venezuela still stays at 600 kb/day – similar to the year 2000.

*Saudi Arabia*, ten years ago still seen as the most important future oil producer which would raise its production to 12-14 Mb/day and maintain that rate until 2033, struggles with steep decline rates of up to 8 per cent in aging fields. Though Saudi Arabia is reporting huge oil reserves lasting for many decades, empirical evidence casts doubts on the reliability of these data.

- The decline of the European oil production was already predicted in 2001 by ASPO. Production is now below 3 Mb/day, a 60 per cent decline from the peak in 2000, and close to the predicted number by ASPO. In 2004, when the ongoing decline should have been obvious to every neutral observer, the International Energy Agency still predicted a production rate of 4.8 Mb/day for 2010.
- On the other hand, some other regions showed higher production than anticipated several years ago:

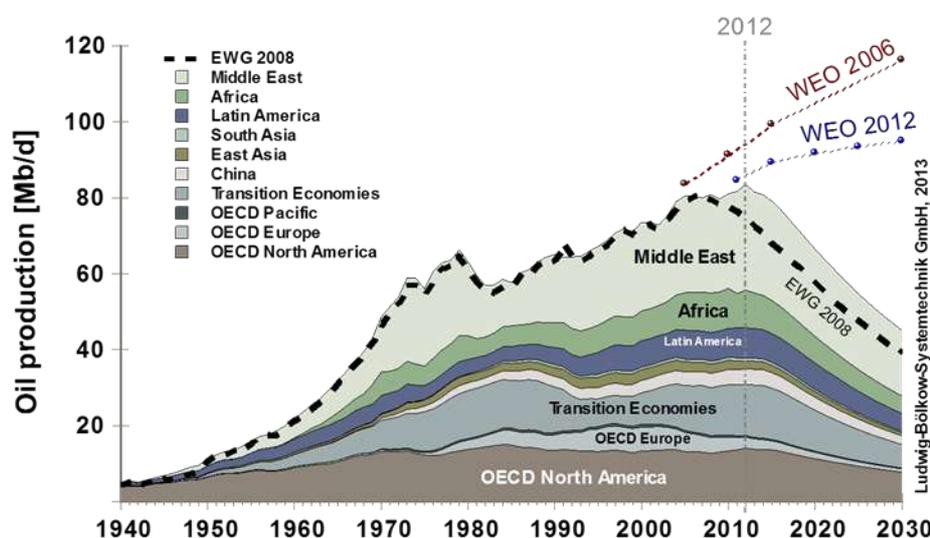
*China* still increased its production to 4 Mb/day in 2011, while EWG and IEA expected a decline to between 3.3-3.5 Mb/day. Declining production of aging fields was more than offset by new offshore developments.

In 2008, the EWG expected the peak of *Russian production* around 2010. Now it seems that the production plateau is coming to an end and 2012 is probably the peak year.

Major *Middle East* producers still increased their production to a joint volume of 25.8 Mb in 2011 which is close to the 26.5 Mb/day projected in the WEO 2002.

- Most important, the development of light tight oil resources in the USA reversed the decline of the US production which has been rising again since 2010 as a result. This production increase in the US was not expected and has fuelled speculations that the USA will become the world leading oil producer by 2020 with 11.1 Mb/day. This would require a doubling of present crude production.
- According to our analysis, it is quite likely that in 2030 world oil production will have declined by 40 percent compared to 2012. The figure below shows the updated scenario of world oil production 1940 - 2030.

- The oil consumption in OECD countries has already passed peak – in favour of non-OECD countries which could still increase their consumption, while total world oil demand stayed almost flat.



*World oil production according to the present study; the comparison to some other studies is also given*

## Natural Gas

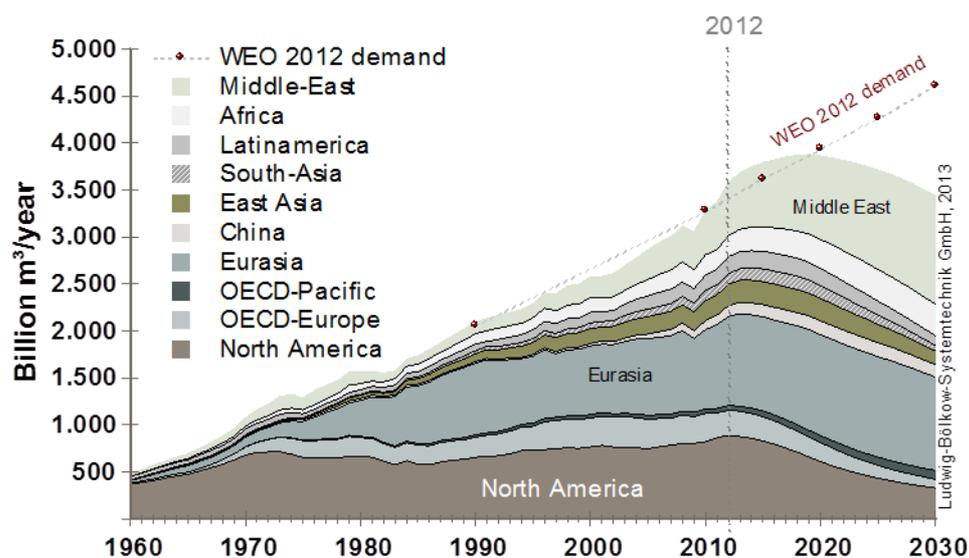
This report also contains scenario projections for the future supply of natural gas. These are performed in similar depth as the projections of future oil supply. Important findings are:

- Conventional gas production is in decline in Europe and North America which together hold almost 35 per cent of world gas production.
- Unconventional gas production, predominantly shale gas production, has increased US production in the last years since the exemption of the gas industry from environmental regulations of the Safe Drinking Water Act (SDWA). Now shale gas has a U.S. market share of 30 percent.
- Shale gas production in the USA is unlikely to see a significant further expansion. Due to the particular production dynamics of shale gas it will decline as soon as new wells are not being developed any more at an adequate rate. The decline of shale gas production from 2015 onward will add to the decline of conventional gas production. In 2030 gas production in the US probably will be far below present production levels.
- Gas production in Europe has been in decline since the turn of the century and will continue to follow that trend. Shale gas production will not play a role comparable to the one in U.S., since geological, geographical, and industrial conditions are much less

favourable. In order to keep gas consumption in Europe flat or rising, imports will need to increase by at least additionally 200 billion m<sup>3</sup>/yr.

- Russia, the second largest natural gas producer closely behind the U.S., faces a struggle between declining production from ageing fields and new expensive and time consuming developments in Northern Siberia and offshore. Russian gas production reached a first peak in 1989 when the largest fields passed peak production. Gazprom production never reached that level again. Ageing fields force Russia to speed up the development of new fields. The developments of Shtokmanskoye in the Barents Sea and of other fields in Yamal are delayed. If the gas fields in the Yamal Peninsula would be developed in time, they would have produced 310-360 bcm in 2030 according to Gazprom. But even this will not be sufficient to compensate for the decline of ageing current fields.
- Domestic consumption in Russia and growing demand from Asia will put increasing pressure on volumes available for export from Eurasia to Europe in the coming years.
- The Middle Eastern countries Iran and Qatar are expected to feed the rising demand for liquefied natural gas over the next decades. Though these countries have large reserves, it is highly probable that reported reserves are exaggerated.

The following figure shows the gas supply scenario projections until 2030.

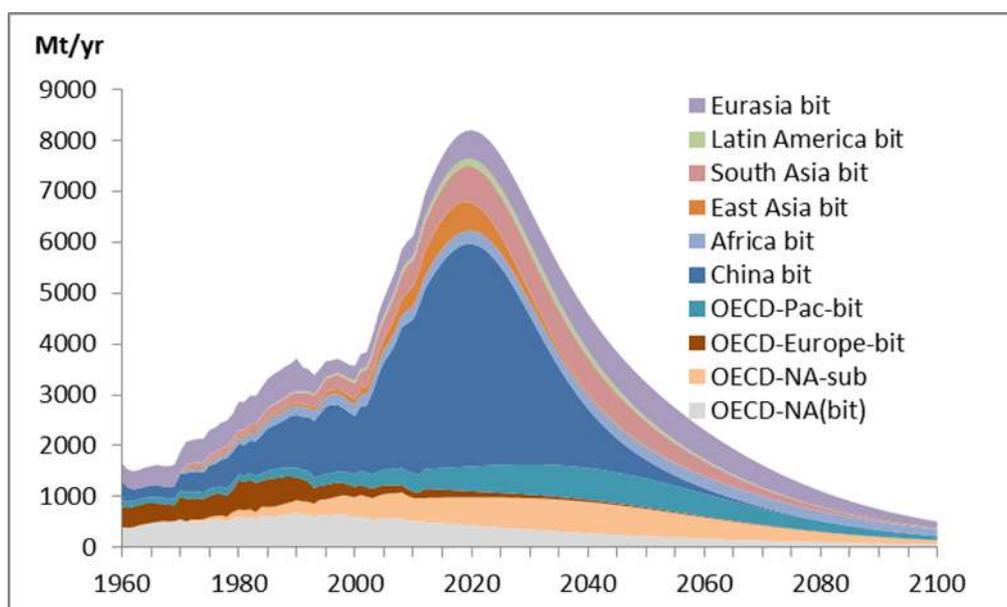


*World supply of natural gas according to the present study; the projection of the WEO 2012 by the International Energy Agency is also shown*

## Coal

Coal still is widely regarded to be an abundant resource. However, internationally coal is only available from few countries having large export capacities. This signals a supply risk that is actually greater than it seems at first glance:

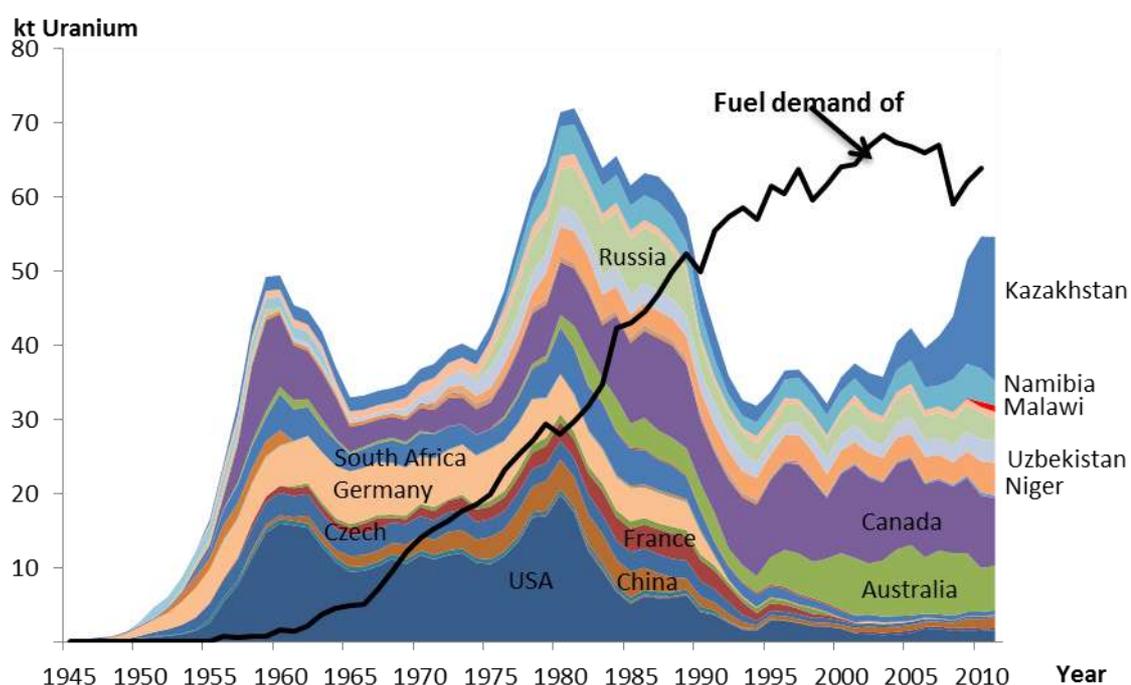
- The USA has passed peak production of bituminous coal 25 years ago.
- China is reporting the second largest reserves; notwithstanding, it switched within a few years from being one of the largest coal exporters to being the largest coal importer comparable in volume to Japan.
- India is among the largest reserve holders, but also its coal imports are rising, due to the low quality of domestic coal reserves which contain up to 70 percent of ash.
- Only about 10-15 per cent of world coal production is sea-traded. Trade volumes more than doubled over the last decade. This rising demand predominantly was supplied by two nations: Australia, the world's largest exporter of coking coal for steel production, and Indonesia, the world's largest exporter of steam coal for power generation.
- Future world coal trade volumes will predominantly depend on these two nations.
- The quality of mined coal will gradually decrease.
- Coal production is expected to peak within the next decade.



*World coal production according to the updated scenario*

## Uranium

World uranium production has already peaked around 1980. The recent increase of production is driven by mining extensions in Kazakhstan. The size of reported remaining resources would be sufficient to fuel the present number of nuclear reactors for several decades. However, the ore concentration of new mining projects in Africa has declined to below 0.02 per cent, which in turn raises the necessary effort for mining including the energy needed. As a consequence, most new projects are in delay while the production from old mines is declining. Therefore, according to our analysis, the risk of a uranium supply gap for nuclear reactors within the present decade is high.



*World supply of uranium from mining*

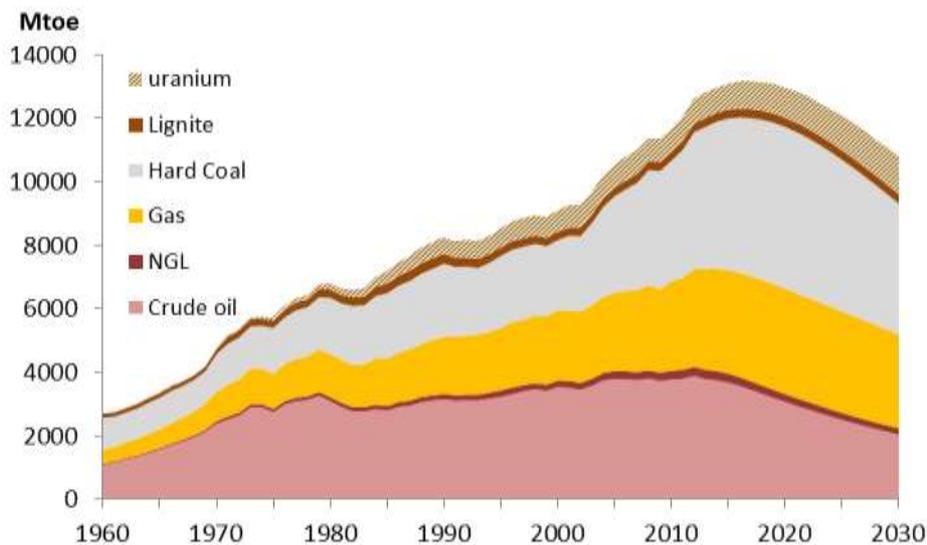
## Conclusion

The figure below shows the supply scenario for all fossil and nuclear fuels. Fuel supply for all fuels is measured in energy units (1Mtoe = 1 million tons of oil equivalent).

According to our study, coal and gas production will reach their respective production peaks around 2020. The combined peak of all fossil fuels will occur a few years earlier than the peaking of coal and gas and will almost coincide with the beginning decline of oil production.

Therefore, the decline of oil production – which is expected to start soon – will lead to a rising energy gap which will become too large to be filled by natural gas and/or coal. Substituting oil by other fossil fuels will also not be possible in case gas and coal production would continue to grow at the present rate. Moreover, a further rise of gas and coal production soon will deplete these resources in a way similar to oil.

The energy contribution of nuclear fuels is too low in order to have any significant influence at global level, though this might be different for some countries. Moreover, like with fossil fuels, easy and cheap to develop mines are also being depleted in uranium production and production effort and cost will continuously increase as a consequence.



*Scenario of world supply of fossil fuels and uranium*

Total world fossil fuel supply is close to peak, driven by the peak of oil production. Declining oil production in the coming years will create a rising gap which other fossil fuels will be unable to compensate for.

## **SHORT STUDY VERSION/ KEY FINDINGS**

### **Scope**

The main purpose of this paper is to project the future availability of fossil and nuclear fuels until 2030. For crude oil, coal and uranium such a report was already published by the Energy Watch Group in 2007 (EWG 2007) and 2008 (EWG), respectively. It is the intention of this report to compare recent developments with the basic assumptions taken five years ago in order to check whether they are still valid today or must be revised according to new findings. This is particularly relevant since recent publications by the International Energy Agency (WEO 2012), the US-Energy Information Agency (AEO 2013), several oil companies (see for instance BP World Energy Outlook 2013) and others claim that the “peak oil theory” has to be revised in face of new discoveries and supposed new technologies enabling the production of unconventional oil and gas.

“At present, widely diverging projections exist in parallel which would require completely different actions by politics, business and individuals.” This observation from the EWG-report in 2008 is still true today.

The scope and structure of these projections is similar to those put forward in the periodic World Energy Outlooks by the International Energy Agency (IEA). However, in this report no assumptions or projections regarding prices are made. The report concentrates on supply scenarios for each world region and their major countries. The results are aggregated for ten world regions. The definition of these regions follows the definition used by the International Energy Agency in 2008:

- OECD North America, including Canada, Mexico and the USA.
- OECD Europe, including Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, The Netherlands, Norway, Poland, Slovak Republic, Spain, Sweden, Switzerland, Turkey, and the UK.
- OECD Pacific, including
  - OECD Oceania with Australia, and New Zealand,
  - OECD Asia with Japan and Korea.
- Transition Economies, including Albania, Armenia, Azerbaijan, Belarus, Bosnia-Herzegovina, Bulgaria, Croatia, Estonia, Yugoslavia, Macedonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Romania, Russia, Slovenia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan, Cyprus, and Malta.
- China, including China and Hong Kong.

- East Asia, including Afghanistan, Bhutan, Brunei, Chinese Taipei, Fiji, Polynesia, Indonesia, Kiribati, The Democratic Republic of Korea, Malaysia, Maldives, Myanmar, New Caledonia, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Island, Thailand, Vietnam, and Vanuatu.
- South Asia, including Bangladesh, India, Nepal, Pakistan, and Sri Lanka.
- Latin America, including Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Bermuda, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, French Guyana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, St. Kitts-Nevis-Antigua, Saint Lucia, St. Vincent Grenadines and Suriname, Trinidad and Tobago, Uruguay, and Venezuela.
- Middle East, including Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, the United Arab Emirates, Yemen, and the neutral zone between Saudi Arabia, and Iraq.
- Africa, including Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, the Central African Republic, Chad, Congo, the Democratic Republic of Congo, Côte d'Ivoire, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, the United Republic of Tanzania, Togo, Tunisia, Uganda, Zambia, and Zimbabwe.

However, for many regions the scenario results presented in this paper are very different to the scenarios presented by the IEA in their periodic editions of the World Energy Outlook (WEO). The IEA projects a continuing growth of oil supply and as a consequence a continuation of business as usual for decades to come is deemed possible.

The report is divided into different chapters individually covering the four fuels oil, natural gas, coal, and uranium.

## **Oil**

### **Methodology**

The analysis in this paper is an update of the 2008 scenario calculations which were based on data up to 2006. The actual development from 2006 to 2012 is compared with the projections of 2008 and adjustments and revisions are made where necessary. However, it is the intention to stick to the original approach. Therefore, the basic methodological approach is similar to that of the 2008 report: The projections do not primarily rely on data of proved reserves

(1P reserves) which are difficult to assess and verify and in the past have frequently turned out to be unreliable. The history of proved plus probable discoveries (2P reserves) is a better indicator though also here the individual data are of varying quality. Rather, this analysis is based primarily on production data which can be observed more easily and are also more reliable. Historical discovery and production patterns allow for projecting future discoveries and – where peak production is close or has already been reached – future production patterns.

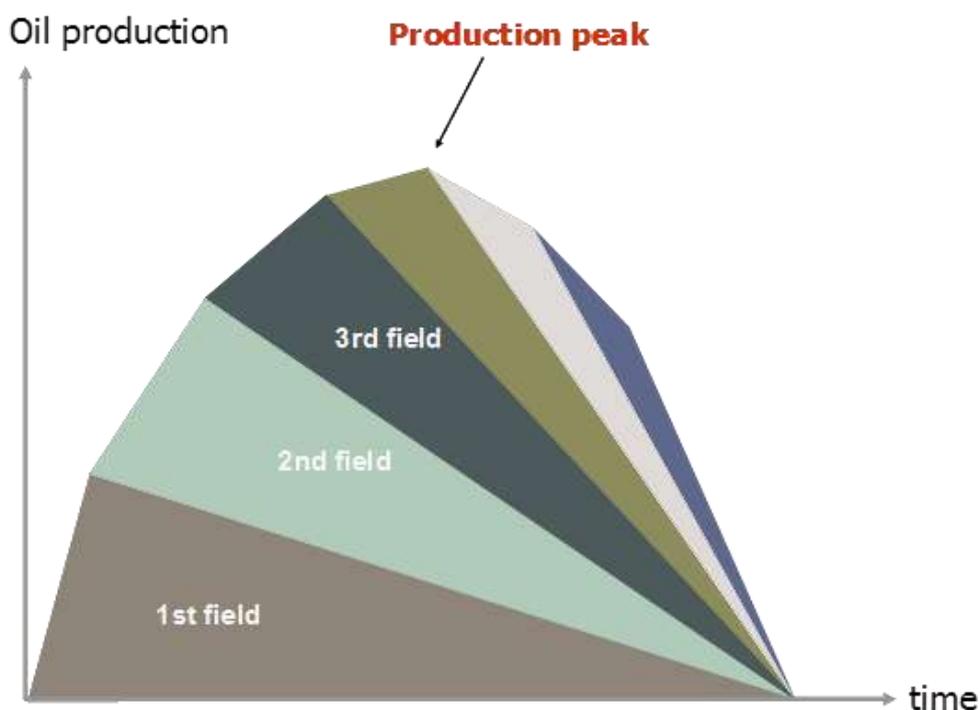
The detailed analysis in 2008 was based on an industry database for past production data and partly also for reserve data for certain regions. As reserve data vary widely and as there is no audited reference, the authors had in some cases made their own reserve estimates based on various sources and own assessments. Generally, future production in regions which are already in decline can be predicted fairly accurately relying solely on past production data.

The projections are based also on published development plans of new fields, on the observation of industry behaviour and on “soft” indicators.

The present report restricts a more detailed analysis to a few key regions, mainly the USA and Middle East.

### **Oil – Understanding the future of oil**

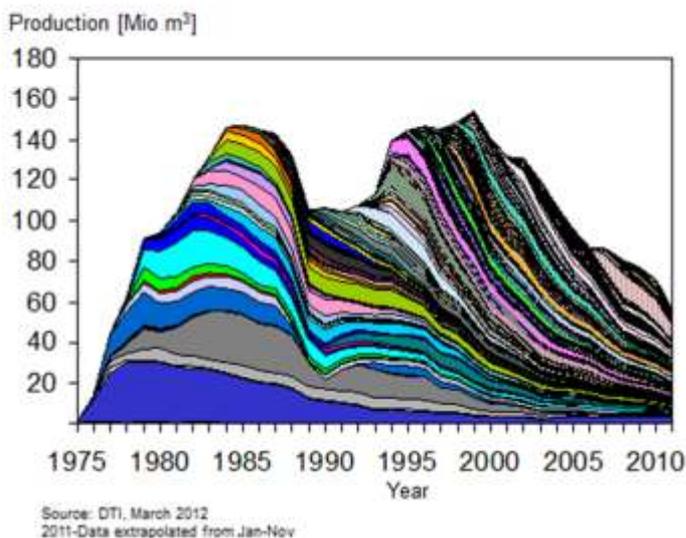
In every oil province the big fields will be usually developed first and only afterwards the smaller ones. As soon as the first big fields of a region have passed their production peak, an increasing number of new and generally smaller fields have to be developed in order to compensate the decline of the existing production base. From there on, it becomes increasingly difficult to sustain the rate of the production growth. A race begins which can be described as follows: More and more large oil fields show declining production rates. The resulting gap has to be filled by bringing an increasingly larger number of smaller fields into production. But once the rate of discoveries has fallen, this is not possible anymore at a sufficient rate. Eventually, these smaller fields reach their individual peak much faster and then add to the aggregate production decline. As a consequence, the production profile of the region which results from the aggregation of the production profiles of the individual fields, becomes more and more “skewed”, the aggregate decline of the producing fields becomes steeper and steeper. This scheme is sketched in Figure 1.

**Figure 1: Typical production pattern for an oil region**

So, the production pattern over time of an oil province can be characterised as follows: increasing the supply of oil will become more and more difficult, the growth rate will slow down and costs will increase up to the point is reached where the industry is not able anymore to quickly enough bring a sufficient number of new fields into production. At that point, production will first stagnate and then eventually start to decline.

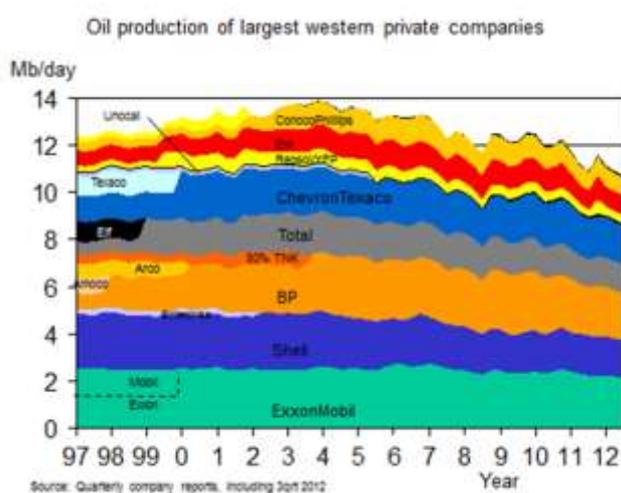
This pattern can be observed when e.g. looking at the oil production in the UK. The production decline in the late 1980s was the result of adapting the safety regime on the platforms following the severe accident at the platform Piper-Alpha. New field developments even in 2006 and later were not sufficient to compensate for the declining base production, having an almost negligible effect on the overall trend. Within one decade UK oil production declined by 60 per cent. This corresponds to an average decline rate of 5 per cent per year.

**Figure 2: Oil production in the United Kingdom**



The difficulties of expanding oil production can also be demonstrated by looking at the performance of the big international oil companies. In aggregate, they were not able to increase their production in the last ten years. In spite of the tripling of oil prices (Nymex) between January 2004 and July 2008, the production of the oil majors declined. Actually, at year end 2012 their production was almost 30 per cent below their 2004 peak production and even below their production in 1997. Obviously, rising prices were not sufficient to reverse the declining production. Western oil majors have passed peak production and are struggling against the continuing decline – without any success so far.

**Figure 3: Oil production of the oil majors from 1997 to 2012**



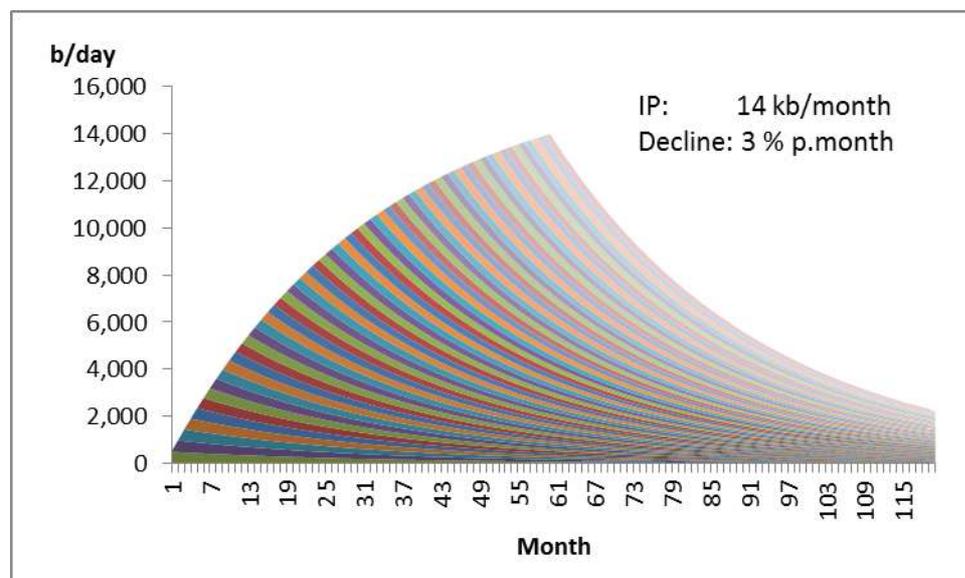
The peaking of oil production of major private western oil companies coincides with the time when oil prices started to rise to levels not seen before. Between end of July 2004 and end of July 2008 the Nymex oil price rose from 43.8 \$/bbl to 124.08 \$/bbl. It is equally remarkable

that oil export volumes available on the world market peaked in 2005 – long before the breakdown of oil prices in 2008 due to financial disruptions and the onset of a worldwide recession. Different to the 1960s, when rising demand could be met by a rising supply at still low prices, this time rising prices could not boost production. Obviously, the price increase since 2005 was driven by supply restrictions.

### Oil – Understanding the potential of unconventional oil production

The described decline pattern is even more relevant for the production of unconventional light tight oil. The average decline rate of the producing oil wells in the Bakken formation, one of the world’s most prolific tight oil fields underlying parts of Montana, North Dakota, and Saskatchewan in North America, is in the order of 30 per cent per year and must be compensated by the fast development of new wells. The speed and quality of these developments determines whether production in the region can still grow, or will be flat for some time, or whether the decline of production wells cannot be compensated anymore, thereby initiating the production decline of the whole region. Figure 4 explains this behaviour. In this example, for a period of 60 month each month 150 new wells with similar production properties are developed. The decline pattern has it that saturation sets in as each new well must spend a larger share to compensate for the aggregated decline. As soon as no new wells are developed, the whole region turns into decline.

**Figure 4: Hypothetical production profile of a tight oil field with initial well production rate of 14 kb/month, 3 per cent monthly decline rate and a development speed of 150 wells per month, which is typical for Bakken wells**



### Oil – Key findings

- “Peak oil is now”.

In our 2008 report we stated that oil production had peaked in 2006. This view still

holds and is also shared by the International Energy Agency and EIA when unconventional synthetic crude oil is excluded. WEO 2012 sees conventional crude oil production in 2005 at 70 Mb/day and in 2011 at 68.5 Mb/day (WEO 2012). Peak of conventional oil now is “common sense” in the energy community.

In 2008 we expected that total world oil production will start to decline soon. Based on present data it is obvious that global oil production has not increased since 2005 and reached a plateau, which was almost not influenced by the oil price variations since then. As the supply was almost unchanged it seems that the demand variations have been the primary driver for price changes and not vice versa. Even when oil prices shortly collapsed to 40\$/bbl in Summer 2008, this did not lead to an increase in demand. OECD countries consume today about 10 per cent less oil than in 2005 (BP 2012).

For quite some time, the notion of peaking oil production has been surrounded by a hot debate. In the last years almost all “hopes” for a growing oil supply in the future turned out to be illusions. Almost all announced large new discoveries have not lived up to their promise. This holds e.g. for the deep water production in the Gulf of Mexico, the deep water developments offshore Brazil or West Africa, the giant field-complex “Azeri-Chirac-Guneshli” in Azerbaijan, the 10 Gb discovery Kashagan in Kazakhstan in the year 2000 (and the enthusiastic hopes that the Caspian Sea producers might become the world’s top producer in 2015 rivalling Saudi Aramco), the development of the huge tar sand deposits in Alberta/Canada, or the huge production increases projected for Saudi Arabia. In its WEO 2012, even the International Energy Agency accepts that Saudi Arabia will not be able to expand its production substantially until 2030.

- *Tight oil will not become a “game changer” turning the USA into a net exporting country.*

The new focus now in the debate is the acceptance of the fact that conventional oil may have peaked and in future is about to decline somewhat. This is countered by the assertion that the recent success in the development of unconventional tight oil will more than offset this decline. Oil supply is no longer perceived as a problem by the media. However, this is in striking disagreement with the facts:

Conventional oil is the backbone of world oil production and will remain being so at least for the next decades. But new field developments are rare, the development of unconventional oil deposits like bitumen and heavy oil is very slow and cost intensive. And as always, the best deposits are already under development. The expansion of bitumen and synthetic crude oil production lags far behind plans developed five years ago.

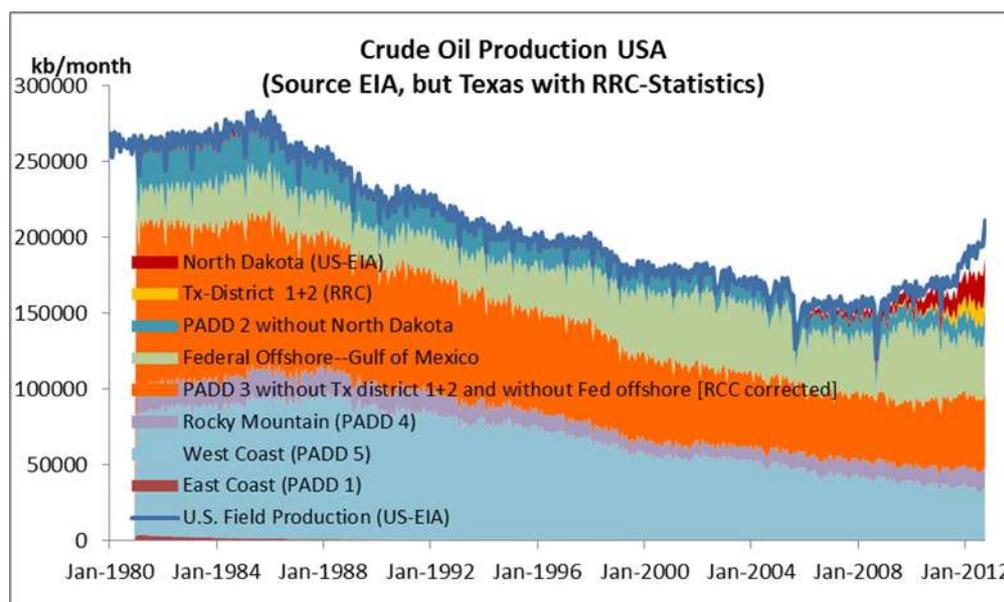
On the other hand, the development of unconventional light tight oil wells has increased oil production in the USA over the last few years. This was the main driver of increasing US oil production in 2010, 2011 and 2012. But light tight oil reserves and resources even in the USA are small compared to conventional oil. More and more exaggerated reports are launched claiming a huge resource potential of light tight oil which will make the USA the largest oil producer in a few years allowing it to become a net exporting country. However, a critical analysis reveals that the production of light tight oil is and most likely will remain restricted to very small geographical areas in and outside the USA where adequate conditions prevail. For instance, the Energy Policy Act in 2005 – which exempted the oil and gas industry from the Safe Drinking Water Act (SDWA) and from reporting to the Environmental Protection Agency (EPA) – was one important prerequisite.

Yet without the steeply rising oil price to more than 80 \$/bbl, there would be no drilling for light tight oil in the USA. Average well drilling cost exploded by a factor of 4 to 8 during the last few years.

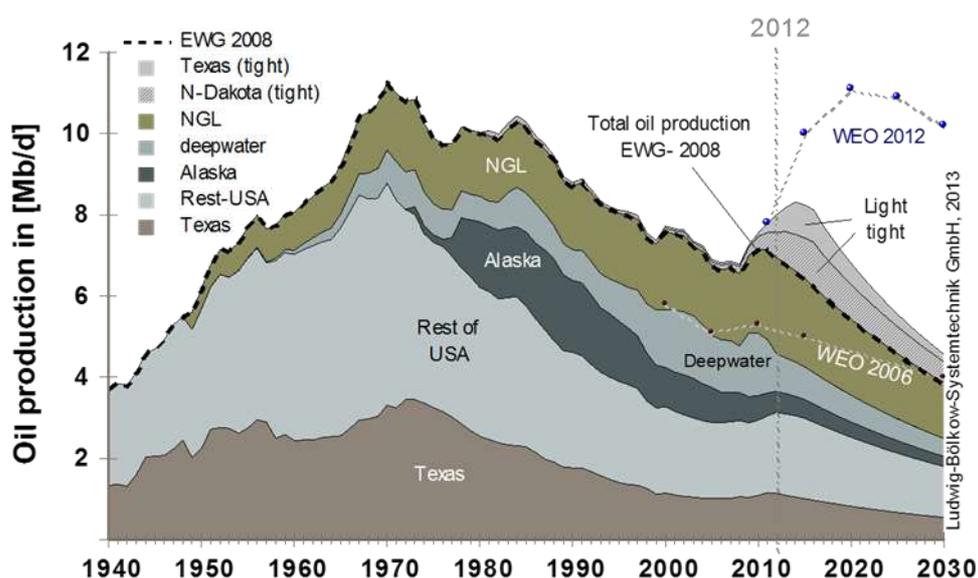
Figure 5 shows the oil production in the USA for individual regions. Such a disaggregation exhibits that 80 per cent of US oil production comes from mature regions which are in decline. This trend is superimposed by rising contributions from very restricted areas in North Dakota (Bakken) and two districts in Texas (Eagle Ford). Further analysis shows that the production dynamics of the many small light tight oil wells cannot compensate for the basic decline for a very long period. A probable US oil production scenario until 2030 is shown in Figure 6.

But Figure 5 also exhibits discrepancies between statistical data of US-EIA and Texas Railroad commission for Texas. The blue line (US-EIA) shows a steep production increase over the last month which is not confirmed by detailed regional data for Texas. The gap between the blue line and the coloured areas shows the data difference.

**Figure 5: Oil production in the USA**



**Figure 6: Oil production in USA according to present findings**



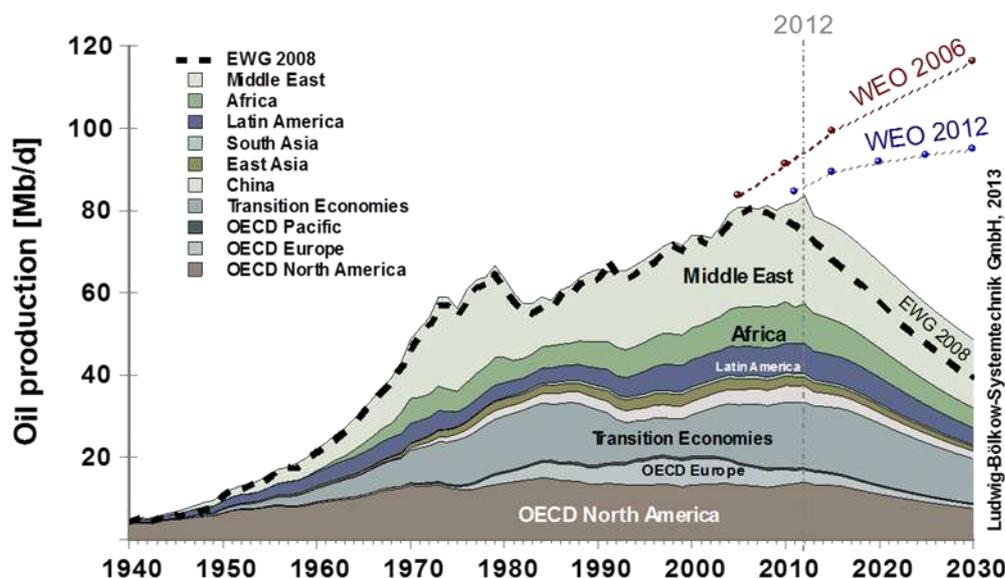
- *World oil production is flat and will soon start to decline*

In contrast to our 2008 study, we see that due to the development of light tight oil and the development of the Khurais field and some smaller fields in Saudi Arabia, the world oil production is still on a plateau which has now been holding for 8 years. In that situation the rising oil consumption in non-OECD countries only became possible because OECD countries – voluntarily or not –reduced their consumption since 2005 by about 10 per cent. It is not unlikely that this reduction is due to “demand destruction” by high oil price. Probably this is a major reason for various economic problems which started around 2005 with the collapse of General Motors (although

the company was eventually rescued by the US government), with many collapses and mergers of US airlines, then leading to a first culmination in the financial crises and the following recessions. High oil prices still might be responsible for the economic weakness of various economies. Further growing oil demand in non-OECD may require continued demand reduction in OECD-countries partly enabled by a more efficient energy use, which however is becoming increasingly difficult.

- *The most important finding is the steep decline of the oil supply after peak.*  
This result – together with the timing of the peak – is obviously in sharp contrast to all projections by the IEA so far. Even in the WEO 2012 only the “450 Scenario” shows a peak in demand, which is driven by political decisions to combat global warming, but not necessitated by supply restrictions. The global scenario for the future oil supply is shown in the following Figure 7.

**Figure 7: Oil production world summary**

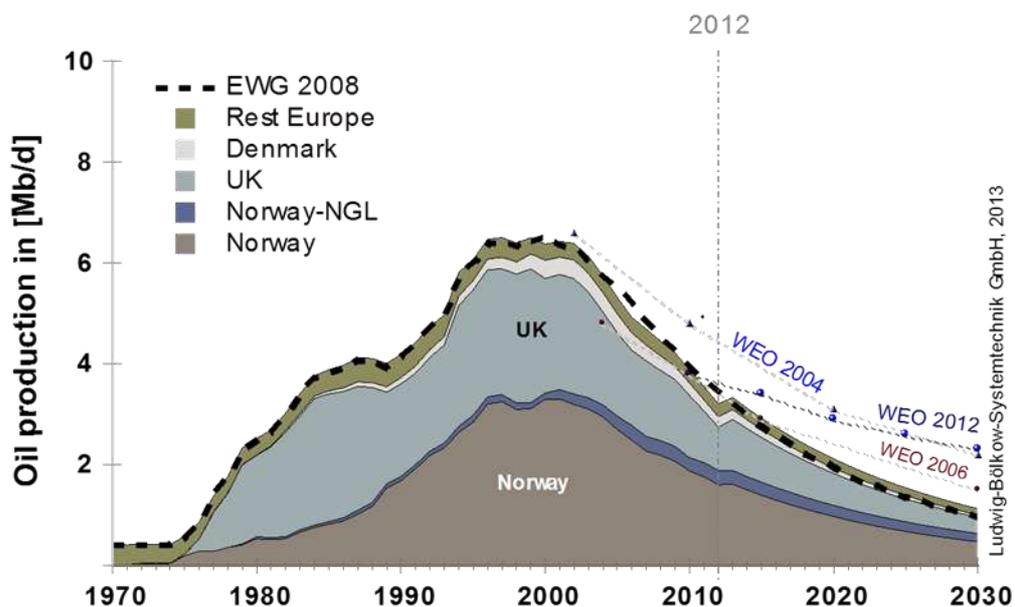


- *Oil volumes available for international trading will decrease significantly by 2030*  
Very often, in past years oil exporting countries increased their domestic oil consumption faster than their production. Even during phases of declining production the domestic demand increased thereby reducing the available volumes for export even further. It can be expected that around 2030 crude oil will be available on the world market only at unprecedented high prices.

Three examples for regional results for key producing regions are given next:

OECD Europe

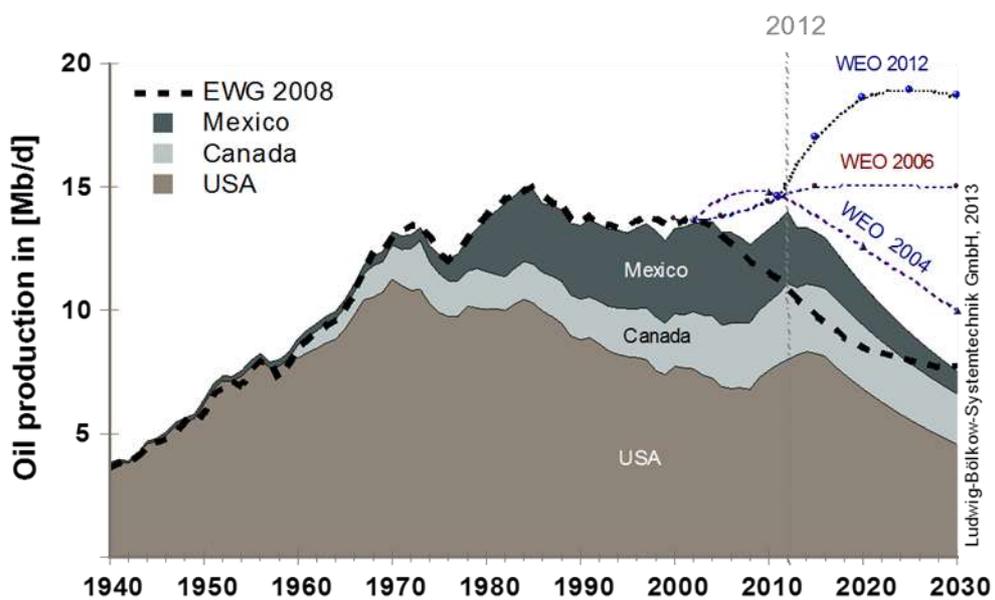
Figure 8: Oil production in OECD Europe

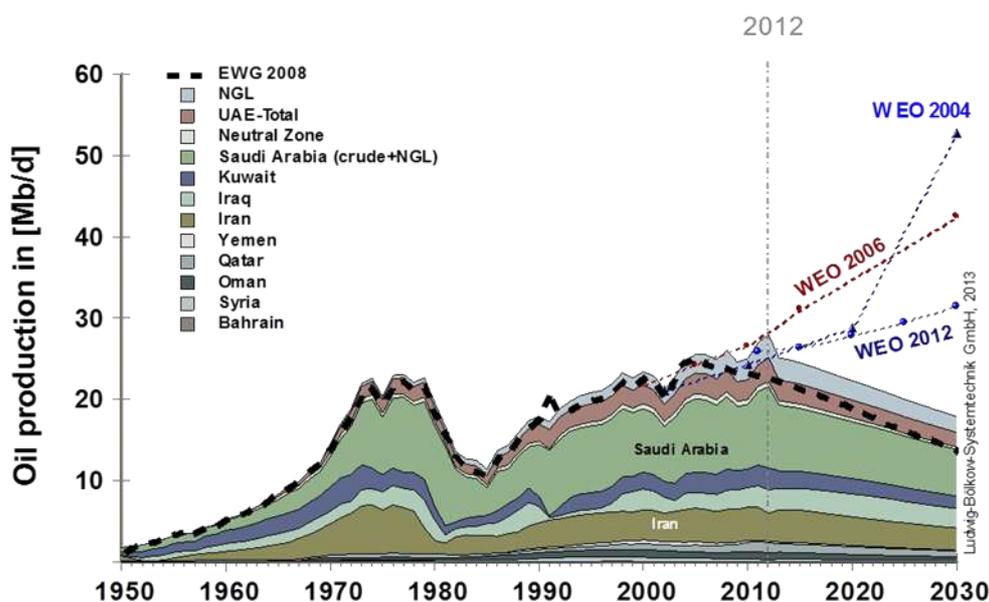


The projections for the oil supply in OECD Europe are as follows:

OECD North America

Figure 9: Oil production in OECD North America



*Middle East***Figure 10: Oil production in the Middle East****Natural Gas**

The International Energy Agency in June 2011 published a special edition of its World Energy Outlook which was dedicated to the future of natural gas with the title: “Are we entering a golden age of gas?”. In contrast to many observers we believe that the most important message of this report is the prominent question mark in the title. This was also underlined by the report “Golden rules for the golden age” by the International Energy Agency which put the bottlenecks of shale gas developments into focus. Even in the WEO 2012 shale gas plays a minor role outside the USA, giving it a production share of less than 10 per cent of global gas production in 2035. Only for North America and China the share of unconventional gas production in 2035 is projected at 60 – 70 per cent.

Conventional gas production is in decline in many parts of the world, most significantly in North America and Europe.

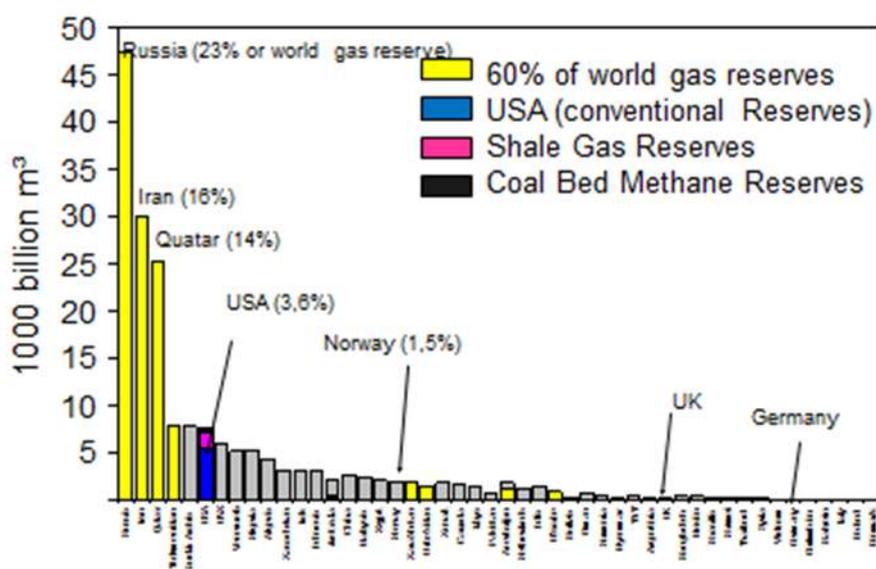
Actually, a certain “gas rush” set in a few years ago due to the fast development of unconventional gas sources in the US. Publications by USGS and US EIA identified huge shale gas deposits almost all over the world which are believed to have the potential to double or even triple world gas reserves. However, we do not share the optimism often associated with these resource studies – at least not in the mid and long term.

First of all, one should clearly distinguish between resources, reserves and production dynamics:

- Resource estimates very often contain a large speculative element. Therefore they have no clear correlation to possible production volumes. Resource estimates are not a useful indicator, neither regarding the actual existence of these resources, nor in case they do exist, regarding their quality of becoming economically producible one day.
- Reserves have a closer correlation to potential future production volumes. However, the quality of reserve estimates still varies, and there is no certainty that reserves one day will be or can be produced. Figure 11 shows reported proved reserves worldwide.

**Figure 11: Proven natural gas reserves (BP 2012; DERA/BGR 2012)**

Geographical distribution of world gas reserves



Source: DERA/BGR 2012, BP 2012

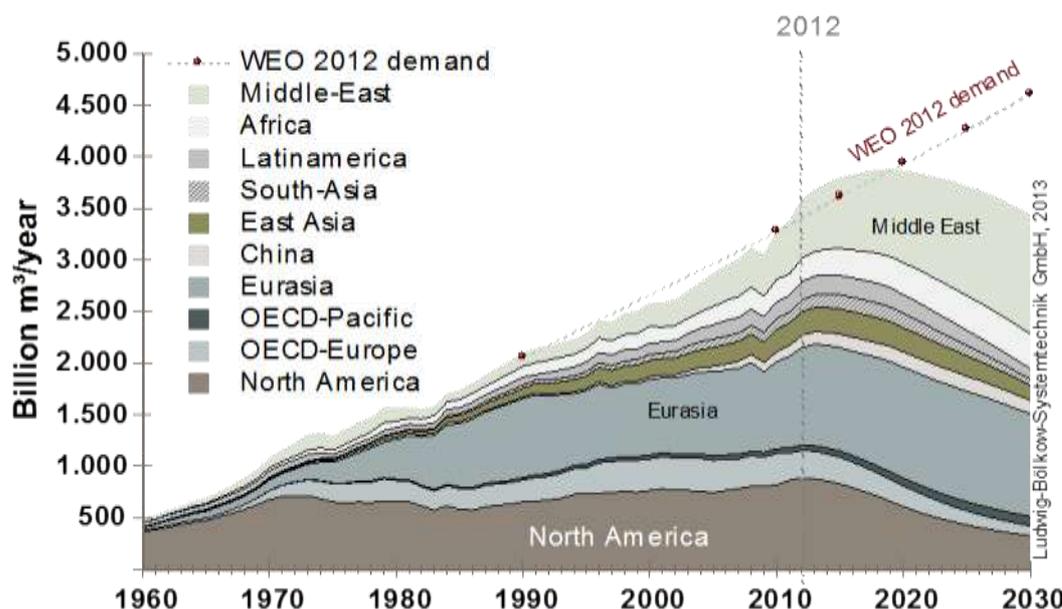
The only reliable data are production volumes. Especially the dynamics of current production from producing fields in decline and possible future production from discovered but still undeveloped new fields determines the balance whether on a regional or world scale gas production will decline or grow.

Despite the recent enthusiasm about rising gas resources it is a matter of fact that about half of the present world gas production comes from regions where production of conventional gas has already peaked: Europe, North America, and Russia.

Figure 12 shows the scenario calculation until 2030. These data are based on historical production trends, the history of discoveries and the extrapolation for future discoveries for

each region individually. According to present data, it is very likely that world gas production will peak around or even before 2020.

**Figure 12: Gas production scenario until 2030**



In contrast to oil, natural gas is volatile. Therefore separate markets have developed which are supplied by regional pipelines. Though trade between different regions takes place via the transport of LNG, pipeline connections still dominate the world supply with a share of 90 per cent.

In the following some key regions are shortly discussed.

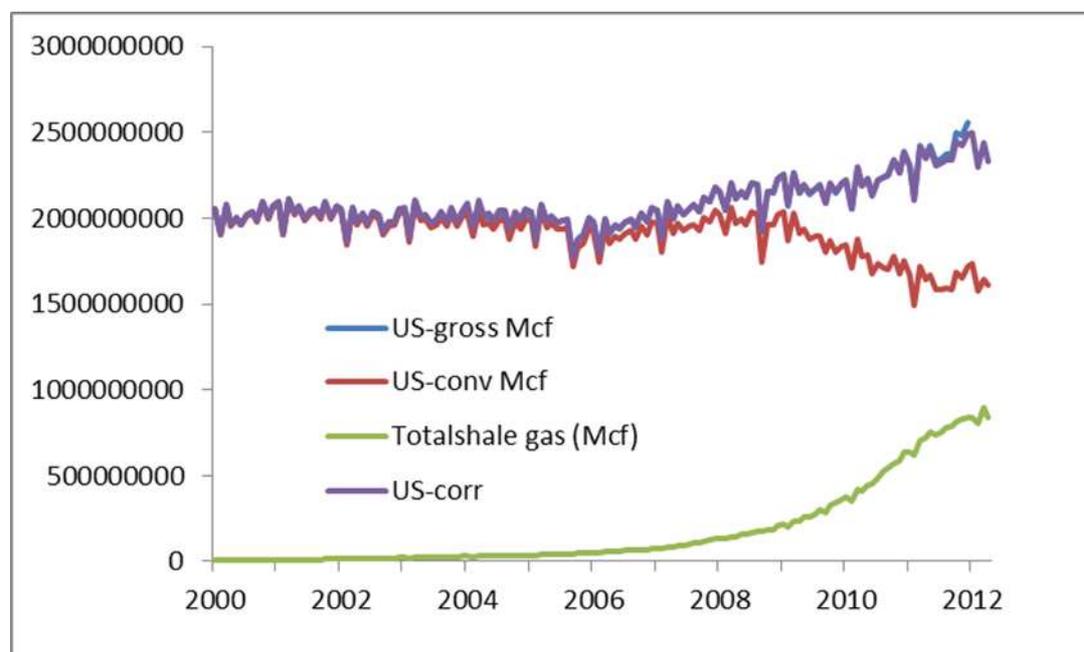
#### *Natural Gas in the USA*

Around 1970, conventional natural gas production peaked in the USA in parallel to oil production. The development of tight gas formations – which very often are not distinguished from conventional production as the transition is continuous – helped to soften the decline. In 2010, gas production from tight gas had a share of about 30 per cent of total gas production. A further 10 per cent are contributed by gas production from coal beds (CBM – coal bed methane). However, a regional analysis of CBM reservoirs and coal beds reveals that peak has already been reached in the largest and most promising regions like Wyoming. The supposed game changer shale gas is attributed to future developments. Indeed, the share of US production from gas shales increased from below 1 per cent around the year 2000 to about 30 per cent in 2012.

Figure 13 shows the US gas production between 2000 and 2012. Without shale gas production, the gas output would have declined already by 30 per cent. Recent data until November 2012 show that the production increase from shale gas is already flattening. This is

a common pattern due to the steep decline rates of individual shale gas wells. The combined decline of producing wells requires ever faster development of new wells. As soon as this treadmill comes to an end – as the prolific claims become rare, or environmental restrictions slow the development, or rising costs restrict the drilling activity – the aggregate shale gas production immediately starts to decline. This is quite similar to the production profiles already discussed for light tight oil in Figure 4 with the major difference that decline rates in shales are even steeper with a 70 – 85 per cent decline in the first year.

**Figure 13: Natural gas production in the USA – shale gas and conventional gas**



Commonly, the fast production increase of shale gas is extrapolated to other shale plays in the USA and also to other countries around the world and is extended far into the future not taking into account the rising problems mentioned above.

Figure 14 provides a more detailed look at the gas production in Texas, which contributes the largest share to US production. Regional production data from the Texas Railroad Commission show that Texas shale gas production, which predominantly is coming from the Barnett shale, has already peaked in 2011 and is now already in decline. This decline adds to the decline of the conventional production. In the last year, Texas experienced a total production decline of 20 per cent. Also shown in the figure are the corresponding production data from US-EIA statistics. Obviously, these two statistics differ starkly by almost 25 to 30 per cent with a rising trend. EIA statistics relating to recent months should be seen very cautiously.

**Figure 14: Details of gas production in Texas, discrepancies between regional and federal state statistics are obvious**

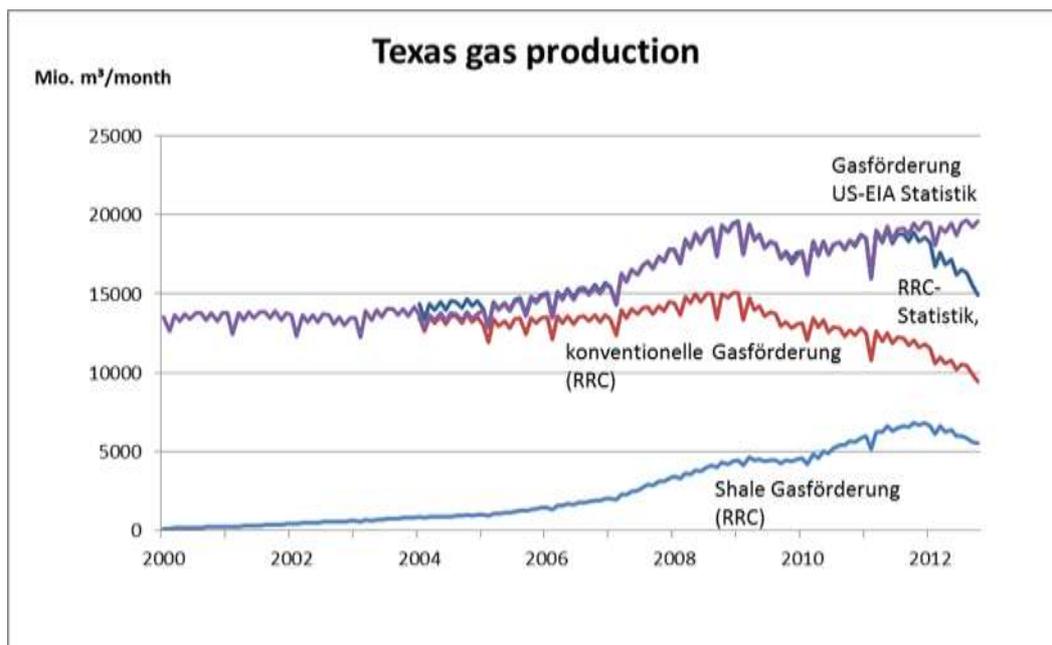
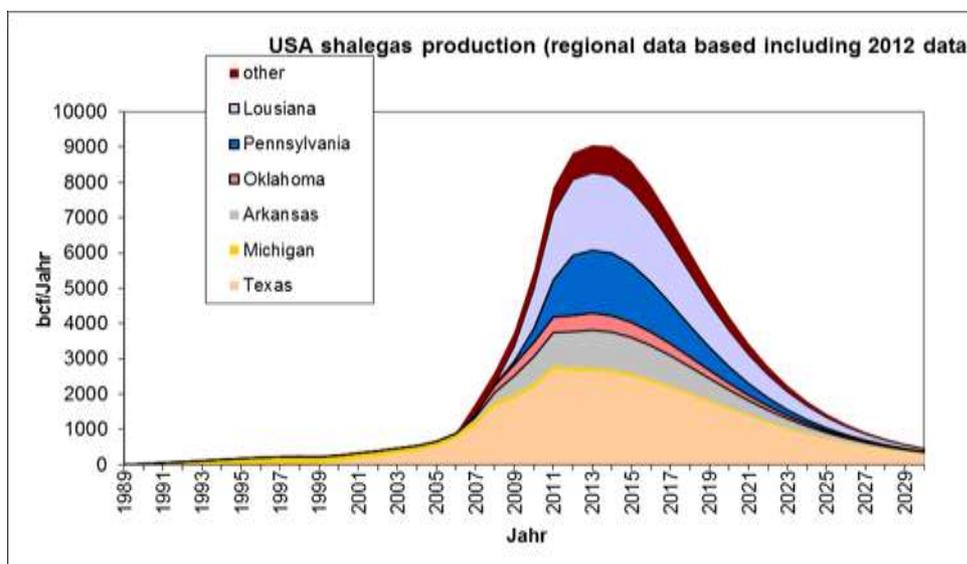


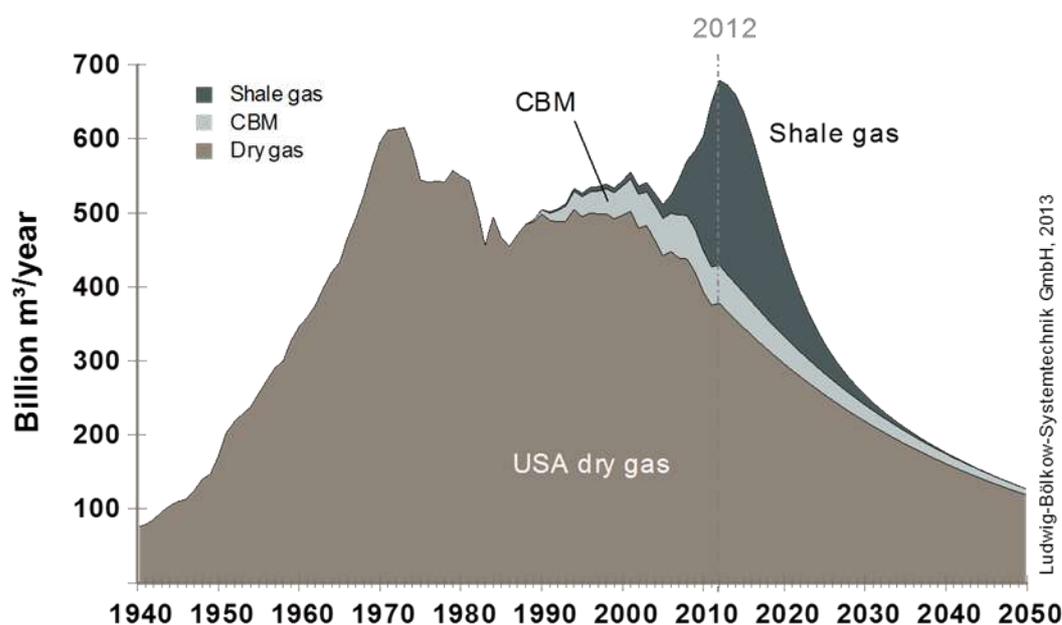
Figure 15 shows shale gas production for individual states and a forecast based on our analysis. It should be mentioned that these production profiles still exceed the proven reserves by far though they are much lower compared to scenarios by US-EIA or IEA. Actually, we believe that shale gas production is very close to its peak. This is due to rising development costs, much too low gas prices well below production costs, rising environmental side effects and conflicts with the population, and – most important – shrinking gas production volumes of new wells and shrinking access to new well sites. We regard it as highly probable that gas production from shales will start to decline by around 2015.

**Figure 15: Historical and future shale gas production according to this report**



As a future decline of shale gas production will further increase the ongoing decline rate of conventional gas production, this will create a supply cliff in the USA as shown in Figure 16. Obviously, the decline of conventional gas production creates such a huge gap that even a doubling of cumulative shale gas production could not close that gap. The falling off the supply cliff seems to be unavoidable within the next few years. Coal bed methane has by no means the potential to contribute substantially to US gas production.

**Figure 16: History of US Gas production and Scenario calculation until 2050; different shale gas, coal bed methane and conventional gas are shown explicitly**



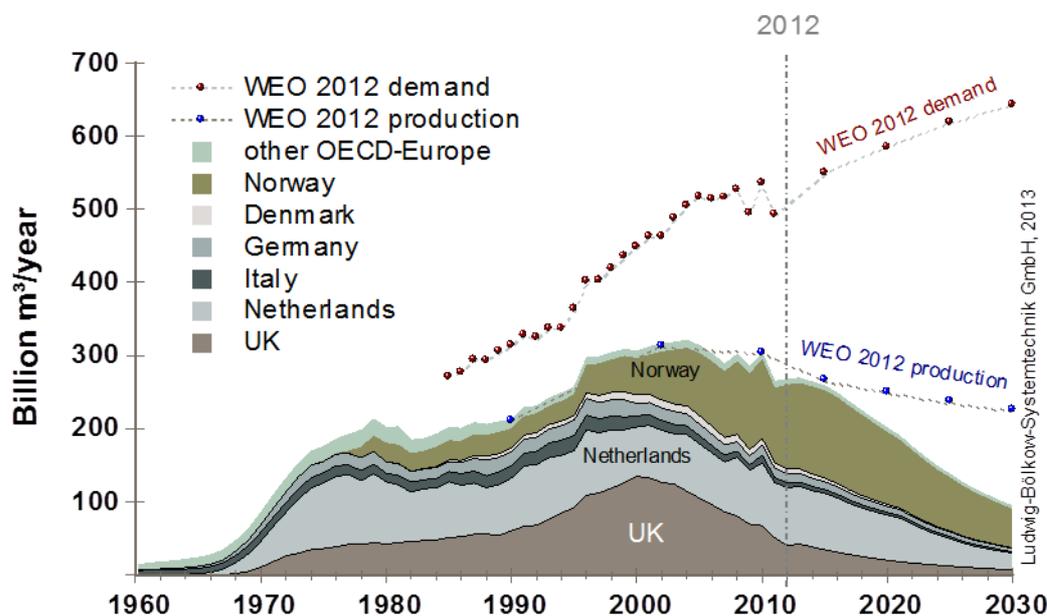
In face of these developments, the excitement about the speculative and more expensive unconventional gas resources must be interpreted as a strong indication of imminent natural gas supply problems.

### *Natural Gas in Europe*

All large gas producers in Europe except Norway have already passed peak production. Even Norway seems to be very close to peak which is expected to be reached around 2015. Total domestic gas production in Europe will decline considerably until 2030. This is consensus among all observers including IEA and Eurogas (the European gas producers association). There is only some disagreement about the size of this decline. Figure 17 shows the results of the scenario calculations in this study. Domestic production might decline by about 75 to 80 per cent until 2030. In the figure it is assumed that gas imports by pipeline from Eurasia and North Africa and via LNG from other parts of the world remain constant. The red line shows the projected demand by the International Energy Agency. Such a rise of demand would require a doubling of imports within less than 20 years. This seems almost impossible from an

infrastructure perspective alone, apart from the question where these volumes should come from.

**Figure 17: Natural gas production in OECD Europe, imports and prognosticated demand until 2030**

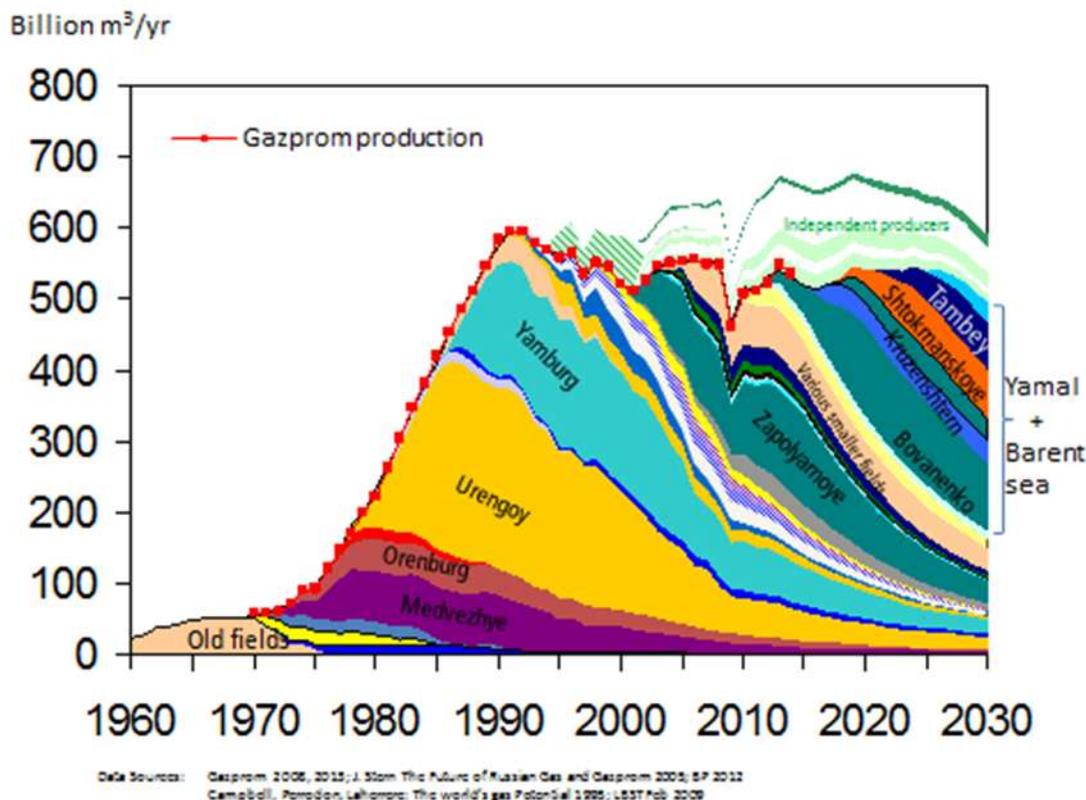


### *Natural Gas in Russia*

Total natural gas production in Russia peaked in 1989, when the production from the three largest fields Urengoy, Medvezhe, and Yamburg having a combined share of more than 90 per cent of Russian gas production reached its maximum. Since then, the decline has been stopped and reversed for some time by the expensive development of already known fields. This occurred when new market conditions in the wake of the disintegration of the Soviet empire attracted new investments. However, the remaining new fields are more remote from the markets and in geographically more challenging regions, requiring higher specific investments and longer lead times for development due to the short arctic summers. In addition, the decline of the base production from Urengoy and other large fields is still continuing and just to compensate this decline requires increasing investments. Presently, Russia faces a competition between the steady decline of its base production, the development of expensive new fields, a rising domestic demand, and rising demand for exports from abroad, from Asia as well as from Europe.

Figure 18 sketches this problem where historical gas production is shown with a detailed field by field analysis. The decline pattern of these fields is extrapolated into the future and possible new field developments which are claimed by Gazprom are added. A rising share of Russian gas production comes from independent producers.

**Figure 18: Gas production in Russia and field by field analysis with production scenario until 2030**



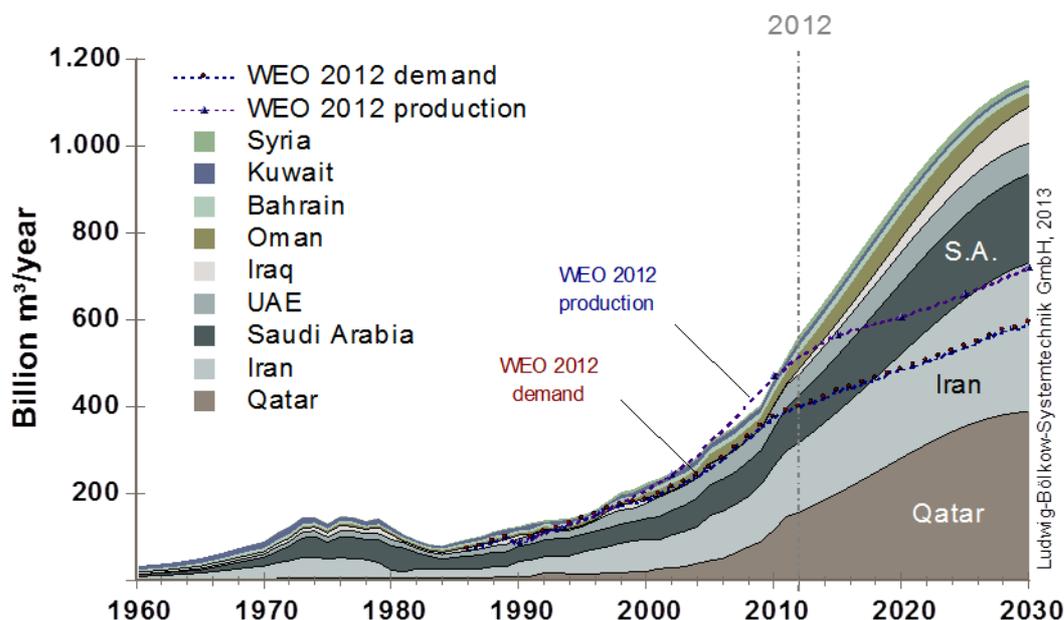
These scenario calculations were already performed in 2009. They are adapted to actual data. Recent developments point to a delay of the development of Shtokmanskoye at least until 2017 or 2018. This will immediately result in a steeper decline within the next years. Plans by Gazprom expect a fast rising contribution from the Yamal Peninsula. According to Gazprom, production from Yamal could be in the range of 310 – 360 billion m<sup>3</sup> in 2030. This is close to the 280 billion m<sup>3</sup> shown in the above figure (marked with the bracket). However, it will not be enough to compensate for the declining base production unless many more fields are developed within time.

### *Natural Gas in Middle East*

By far the largest undeveloped gas reserves are believed to be in Iran and in Qatar (see Figure 11). Their development and liquefaction would result in an ample supply for decades. However, closer analyses strongly question that belief. The strongest indication is the rarely mentioned fact that the huge reserves of both countries almost completely depend on one offshore field in the Arab gulf crossing the border between the two countries: The southern part in Qatar is called the North Field; the northern part in Iran is called South Pars. The size of this field amounts to 6000 km<sup>2</sup> making it the world's largest gas field. Yet this assessment is based on only a few exploration wells in the 1970s after the discovery of the field. However, a few years ago gas exploration activities in an area which was thought to be well

inside the field boundaries did not find any gas, casting significant doubts on the reserve estimates which are still reported until today. Figure 19 shows the production until 2030 used in this scenario.

**Figure 19: Gas production in Middle East countries**



On a more general note, one has to keep in mind that in contrast to oil natural gas is volatile and requires a dedicated transport infrastructure. Regional markets developed where consumer and producer regions are connected by pipelines. Only a small fraction of world gas production is transported in liquefied form by ship to intercontinental destinations. Regions with a highly developed gas transport infrastructure are the USA with pipeline connections to Canada and Mexico, and Europe with connections to North Africa and Russia. China is also connected to Russia via pipeline. Korea and Japan are completely isolated. Their import needs are completely met by LNG. Based on these structures, regional bottlenecks and price differences between different markets are more likely for gas than for oil.

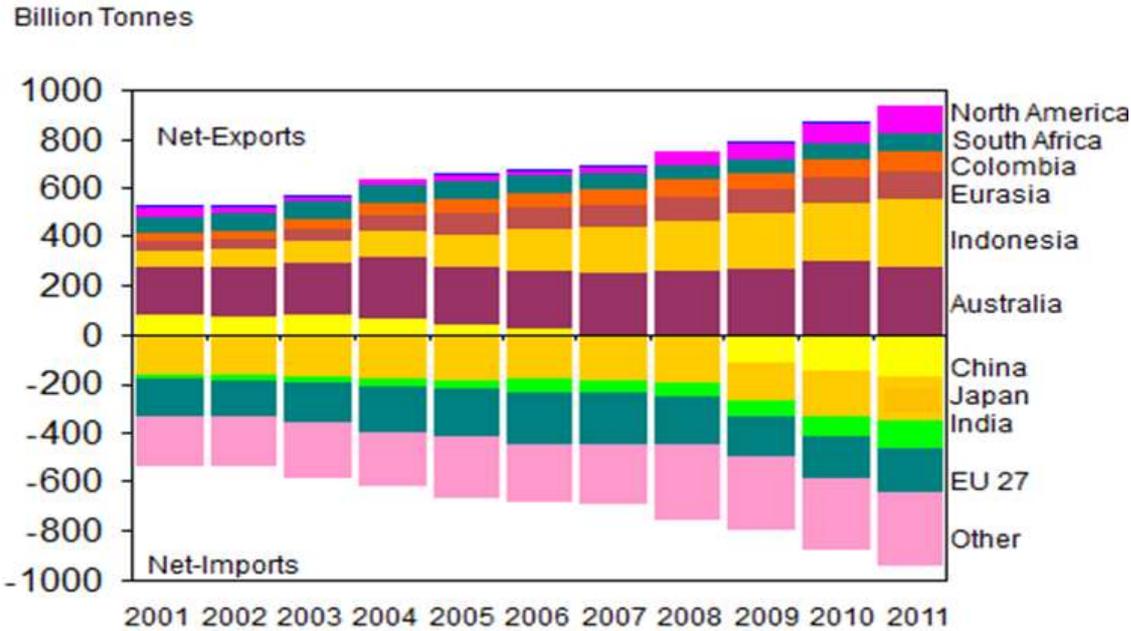
### Coal

- Coal appears to be a still abundant resource. However, in an international market it is only available from few sources (see Figure 20), signalling a supply risk that is actually larger than it seems at first glance:
- The USA have passed peak production of bituminous coal 25 years ago. Peak of total production was in 2008.

- China has the second largest reserves on paper, but within a few years it switched from being one of the largest coal exporters to being the largest coal importer, comparable in volume to the imports of Japan (see Figure 21).
- India is among the largest reserve holders, but also its coal imports are rising due to the low quality of domestic coal reserves which contain up to 70 per cent ash.
- Only about 10-15 per cent of world coal production is sea-traded. Trade volumes more than doubled over the last decade. This rising demand predominantly was supplied by two nations: Australia, the world’s largest exporter of coking coal for steel production, and Indonesia, the world’s largest exporter of steam coal for power production.
- Future world coal trade volumes will mainly depend on these two countries.

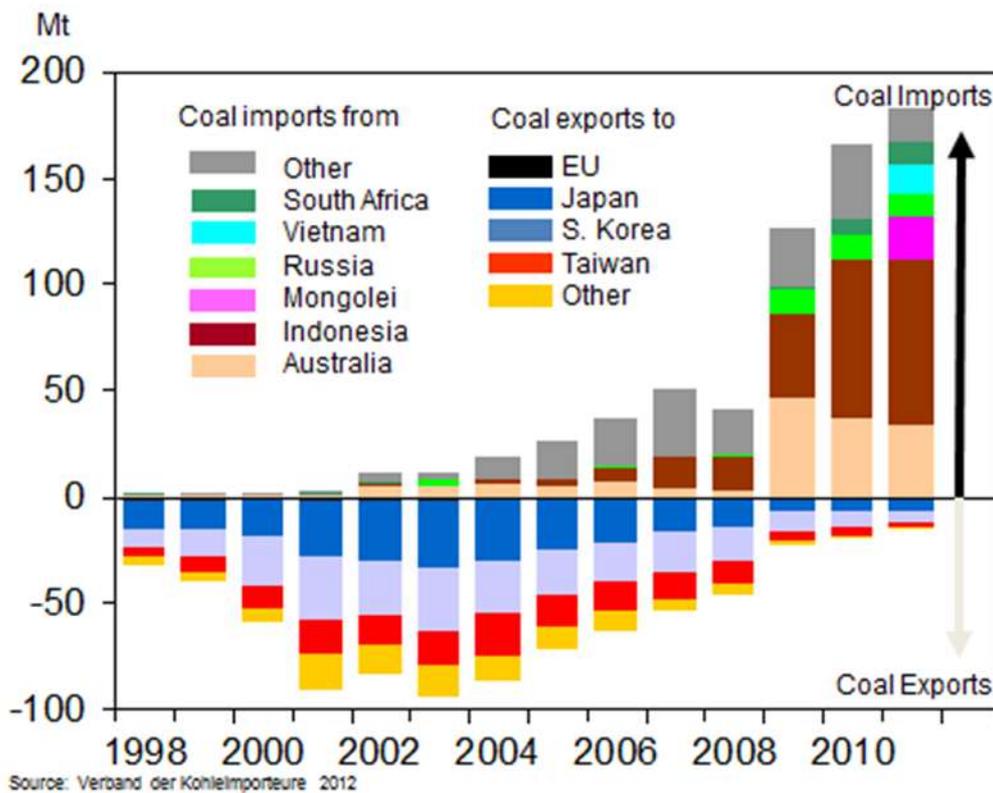
Quality of mined coal will gradually decrease. However, the most important finding is that coal production is expected to peak within the next few decades (see Figure 22).

**Figure 20: Largest coal exporting and importing countries**

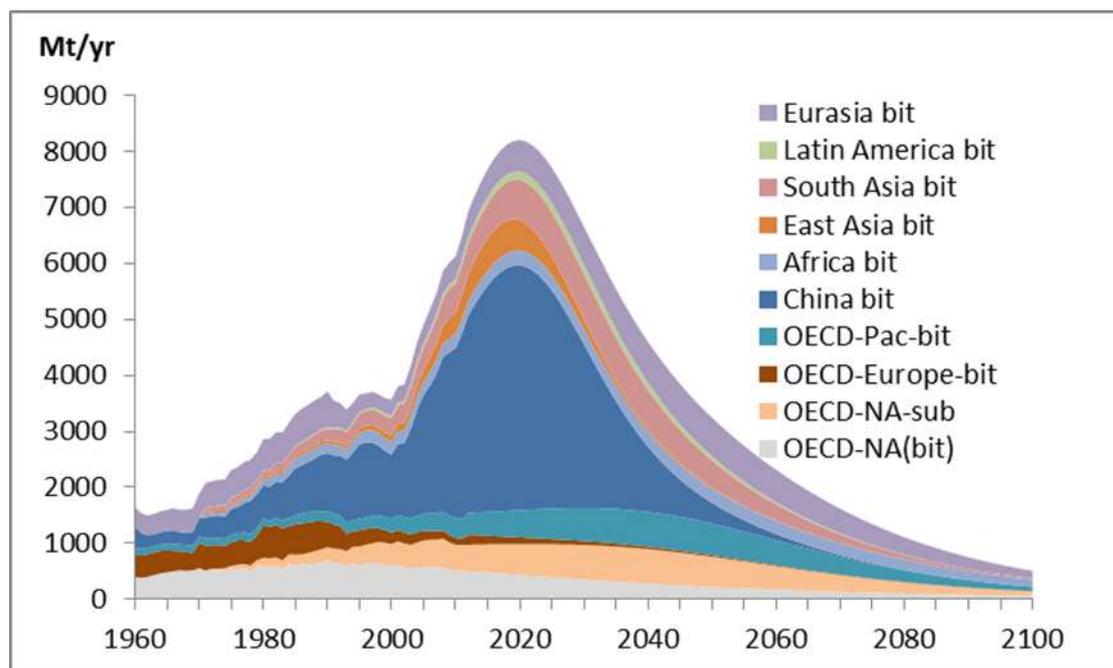


Source: Verband der Kohleimporteure 2012

**Figure 21: Regional disaggregation of coal imports to and exports from China**



**Figure 22: World hard coal supply according to LBST-scenario calculations based on proven reserves and critical assessment of data**

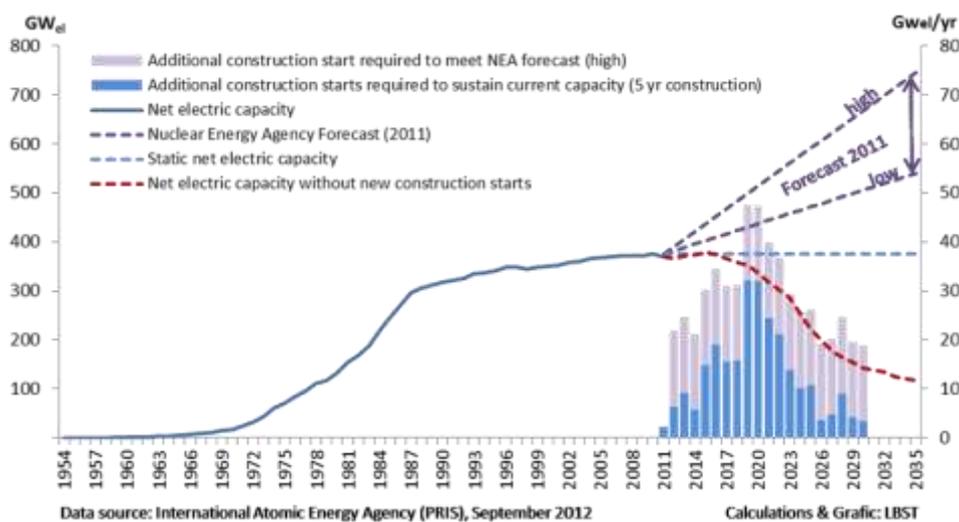


### **Uranium and nuclear power**

Uranium mining also obeys the rules of finite resource depletion. But the availability of nuclear fuels for power plants is not the only factor determining nuclear power generation. Equally important is the stock of operating nuclear power plants, the size of which is subject to special conditions. Useful lifetime of nuclear power plants, time to build them and investment costs are crucial factors. Especially the long lead times from the first planning stage of a plant to the start of operations of the finished reactor are limiting the possible growth rate of nuclear power generation capacity. The grid connection of new plants needs lead times of at least 4-5 years for construction and another 5 – 10 years for site selection, planning and approval procedures before that. Therefore reactions following changing market conditions are very slow. In the mid-1970s most reactor constructions were started at a rate of up to 40 units per year. This resulted in a peak of grid-connections ten years later, reflected in the steep rise of total nuclear power generation capacity in the early 1980s shown in Figure 23.

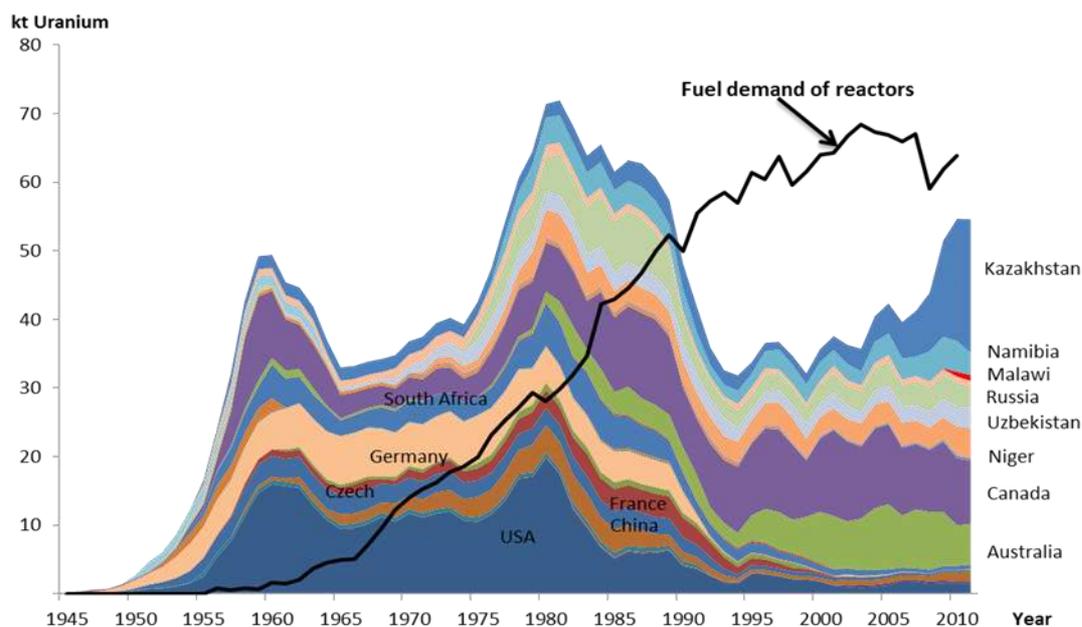
In the past, about 150 reactors have already been shut down. 437 reactors are still in operation which on average have operating for 26 years. The average operation time of reactors already shut down was 23 years, even though some reactors achieved operation times close to 50 years. For the scenario projections, it is assumed that reactors now in operation will on average be shut down after 40 years of service. If no new reactors were constructed, global nuclear capacity would decline by about 70 per cent until 2030 (red broken line in Figure 23). The figure also shows how many new reactors must be grid connected each year just to keep electric power capacity constant (blue bars). This would require a substantial increase in new construction starts with up to 30 GW/yr of total new capacity. Additionally, each year about 7 GW must be constructed in order to match the low scenario forecast by NEA 2011 (lower purple broken line). In order to match the high forecast by NEA 2011, more than 15 GW would need to be added annually in addition. This is shown in the figure by the pink bars which correspond to the upper purple broken line.

**Figure 23: Historical development of nuclear power capacity and scenario until**



Based on current plans for the construction of new reactors, it is highly probable that in 2030 electricity production from nuclear power plants will be below or around the present level. A huge extension of capacity to meet either the lower or the upper NEA 2011 forecast would require a much higher number of new construction starts than currently seen or anticipated in the market.

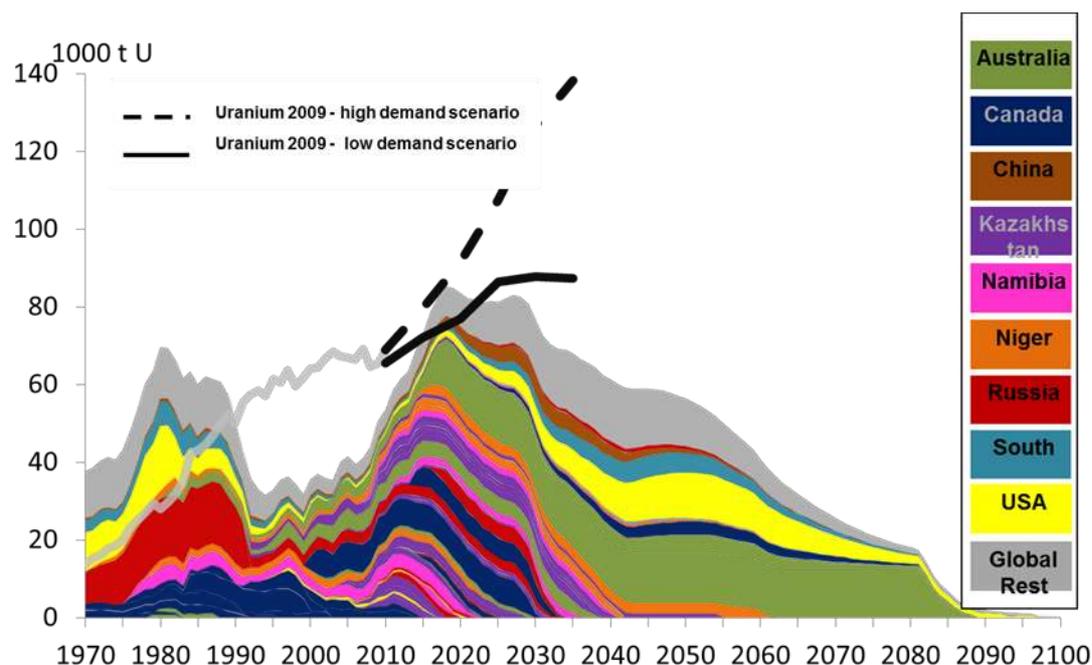
But even then, the problem of limited uranium resources remains. Figure 24 shows the historical supply of mined uranium. Forty years ago, the USA and Germany were by far the largest suppliers of uranium. Mining was mainly driven by the demand for nuclear war heads during the cold war. Eastern Germany at that time was the most important uranium supplier for Russia. Total production by far exceeded the demand from nuclear power plants. Uranium production in Germany was shut down due to depleted mines, but also due to the German reunification in 1990 which resulted in much stricter environmental regulations. Since then Canada and Australia expanded their uranium production. However, since 2000 the increase of global uranium production is completely attributable to fast expansion of uranium production in Kazakhstan.

**Figure 24: Historical development of uranium production**

However, the growing production in Kazakhstan will soon reach its peak and will decline thereafter. Besides the development in Kazakhstan mainly Australia and Canada will dominate the future supply of uranium. Figure 25 shows a scenario which is based on an in-depth analysis of every operating mine, considering known developments and expansion plans. Furthermore, the production scenario is designed to match the reasonably assured resources. This scenario accounts for the planned expansion of the Olympic Dam mine with a rising production from currently 3,800 t/yr to 14,000 t/yr in 2020, and maintaining that production level until 2080. This scenario projects a likely peak of uranium production at around or slightly before 2020, followed by a steady decline thereafter. The scenario also assumes a possible production extension in the USA in the next decades which at present is almost impossible to imagine due to the closure of many mines in areas where Native Americans live and where mining is now forbidden.

The black line in the figure shows the uranium demand required to match the NEA 2011 low scenario of nuclear power plant extensions (compare with Figure 23). The required fuel can probably be delivered from mines until about 2025. However, it is almost impossible to fuel the reactors required for the NEA 2009 high scenario (broken line) with mined uranium.

Based on these data, it seems almost impossible to fuel a fast expanding electricity production of nuclear power plants. But even in case this would be possible, the annual electricity production from nuclear power plants in 2030 would only amount to about 1500 TWh/yr, which even today would be a share of less than 10 per cent of global electricity production.

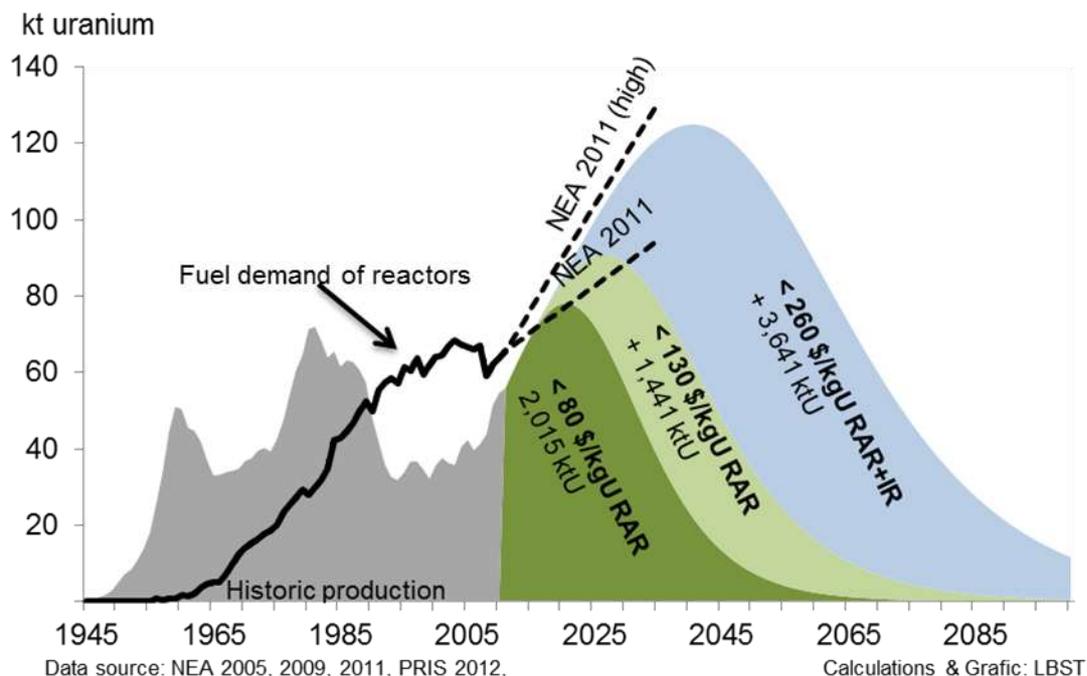
**Figure 25: Uranium production scenario based on mine by mine projections**

In addition to the detailed mine-by-mine analysis of future uranium production, Figure 26 shows by way of a simplified scenario projection for how long nuclear power plants could be fuelled if all reasonably assured resources (RAR) and even all inferred resources (IR) are converted into production volumes. The two scenarios based on RAR are comparable to Figure 25 with the difference that instead of production profiles based on individual mine-by-mine-analyses, a bell shaped general production profile for the whole resources is used. However, the conclusion is still valid that reasonably assured resources are not sufficient to fuel expansion plans for nuclear reactors for a longer period.

In the hypothetical case that, additionally, all inferred resources were converted into production volumes within the next decades it might be possible to fuel even the NEA 2011 high scenario for at 2 to 3 decades before production volumes reach a maximum of about 120 kt/yr. In that case, electricity generation by nuclear power plants in 2030 would amount to 5,000 TWh/yr, equalling less than 24 per cent of present world electricity production.

However, it must be emphasised that these scenario calculations are highly unrealistic since lead times for the construction of power plants as well as for mine developments are ignored here. In addition, any technical, economic or social problems in developing these mines are neglected. Even today, mine and reactor developments are usually delayed due to technical and political problems. The above sketched scenario (Figure 25) tries to account for these effects to a large extent by analysing each mine development individually. Even then, the production scenario in Figure 25 seems still optimistic concerning the development of large mines.

**Figure 26: Various scenarios for future uranium production based on various classes of resource data**



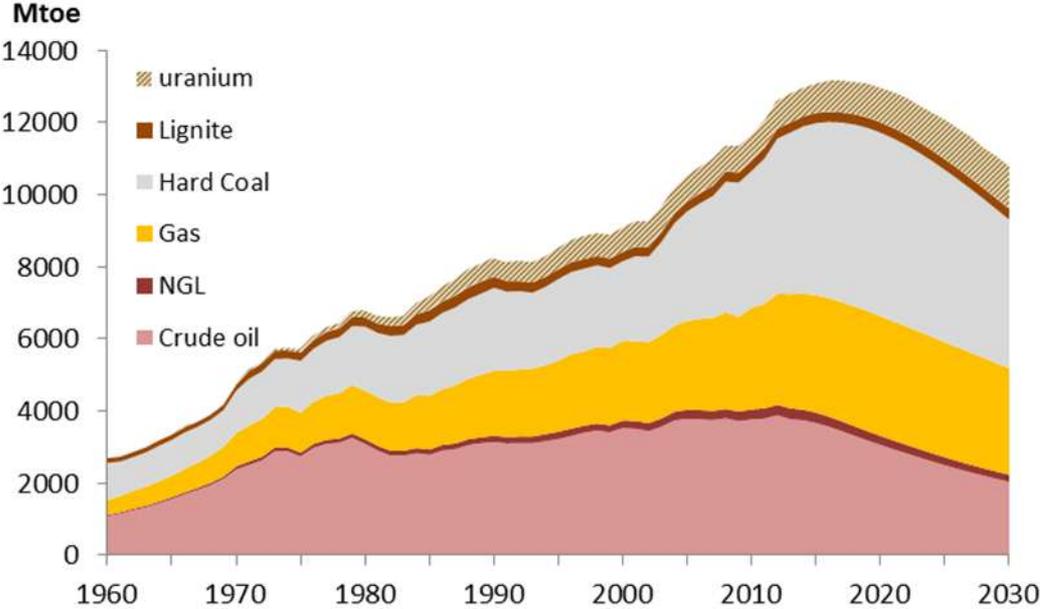
### Conclusion

Figure 27 shows the combined supply from oil, gas and coal in energy units. For the aggregation the following conversion factors are used:

- 1 Mtoe = 7.1 million barrels of crude oil and condensate
- 1 Mtoe = 10 million barrels of natural gas liquids
- 1 Mtoe = 1.16 billion m<sup>3</sup> of natural gas
- 1 Mtoe = 1.5 Mt hard coal (1.8 Mt subbituminous coal)
- 1 Mtoe = 3 Mt lignite
- 1 Mtoe = 58 t uranium

Though coal and gas production are not expected to peak around 2020 the combined supply from all fuels is likely to peak around 2015. Rising coal and gas production cannot compensate for the declining oil production. Electricity generation from uranium amounts to less than 40 per cent of the primary uranium supply.

**Figure 27: Summary of worldwide production of oil, NGL and naturalGas, hard coal, lignite and uranium in energy units**



A typical characteristic of the gold rush in the past was that stories of real successes were accompanied by many rumours and exaggerations. This created an atmosphere where rational thinking had no chance in the public perception. In most cases these rumours were not spread by the successful gold seekers (those kept their secrets for themselves) but by equipment traders which made large profits irrespective of gold seekers’ factual successes.

Neither the hype about huge reserves in the Caspian Sea in the year 2000 (“...reserves could rival Saudi Arabia”), nor the deep sea discoveries in the Gulf of Mexico or West of Angola, nor tar sands in Alberta (see the cover story of the ExxonMobil publication “Oildorado” in 2003), nor last year the rush on shale gas developments in the USA or recent news of shale gas in Australia can do away the fact that the era of cheap and abundant fossil fuels is coming to an end. Rather, these new frontiers create more problems than being solutions to problems they promise to solve.

But this is also a good message because climate change forces us to take action along the same lines, namely reducing the consumption of fossil fuels. Therefore, we must face these challenges and start in earnest to develop transition strategies towards a sustainable energy supply. The longer we try to delay that transition by pursuing dead end solutions which are aimed to prolong business as usual, the more we face the risk of falling off a cliff with severe disruptions in economy, politics and society.

### **ACKNOWLEDGEMENT**

The authors gratefully acknowledge many discussions and the critical reading of the manuscript by Jörg Schindler, ASPO Germany. Without his continuous support the work would not have been finished in the present form. We also greatly acknowledge the support by Colin Campbell, who made available to us his latest updates of his World oil and gas depletion model.