Project no. 723678

ñThe next Generation of Carbon for the Process Industryò

Coordination and Support Action

Theme [SPIRE 5] ï Potential use of CO_2 and non-conventional fossil natural resources in Europe as feedstock for the process industry

Deliverable *1.3*: Map and potential of other non-conventional natural carbon sources like tar sands, coal bed methane and gas to liquid; as well as alternative technologies as coal to liquid technologies

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1. Executive Summary

This report aims to map all of the potential ‘unconventional’ sources of carbon available for use by the processing industry, with the exception of CO_2/CO and shale gas which were covered by the previous report (work package 1.1 and 1.2 respectively). Additionally, the findings regarding the potential of these unconventional carbon resources within Europe are presented.

According to the IEA, unconventional hydrocarbons are “any source of hydrocarbons that requires production technologies significantly different from those used in currently exploited reservoirs”, while recognising the imprecision and time dependence of this definition. This report maps and explores the potential of heavy oil (including oil sands or tar sands); oil shale (or kerogen oil), light tight oil (including shale oil), tight gas, coal-bed methane, and methane hydrates. The potential is reviewed by looking at the technologies used, the challenges, outlook and impacts.

The conclusion is that unconventional hydrocarbon resources in Europe are limited. For example, there are only 13 proven crude oil reserves in Europe compared to 226 in the US. Similarly, heavy oil reserves in Europe are a small fraction of the total reserves in the World. We have identified several production challenges including significant capital investment, environmental issues such as those related to fracking, risk of gas explosions, large water demands and water contamination for coal-bed methane as well as a need for stable conditions in terms of pressure and temperature which requires a large amount of resources.

It is concluded that the environmental concerns surrounding the utilisation of these unconventional carbon sources are high and that their potential is very low. We therefore do not foresee that these sources will have a significant impact upon Europe’s processing industries and it is proposed that they be disregarded from further research.

2. Introduction

2.1 The objective of this deliverable

The present report (deliverable 1.3) gives an overview of the potential of non-conventional natural carbon resources such as tar sands, coal bed methane and gas to liquid as well as alternative technologies as coal to liquid technologies in Europe. Deliverable 1.2 provides an overview about the potential for shale gas in Europe. The reports aim to map all non-conventional carbon resources in Europe to estimate the potential impact of these resources on process industry in Europe.

2.2 What are unconventional carbon resources?

Hydrocarbon resources, also known as fossil fuels, continue to serve most of the world's primary energy supply which continues to rise. At the same time, fossil resources are used as feedstock for the process industry with the chemical industry being dependent on carbon from fossil sources. Previously uneconomical energy sources are becoming more viable due to diminishing conventional energy sources, (expected) rising energy prices, and improved technologies.

While there is no universally agreed definition of conventional and unconventional resources, the IEA defines unconventional hydrocarbons as "**any source of hydrocarbons that requires production technologies significantly different from those used in currently exploited reservoirs**".[1] It is important to note that this is not a very clear distinction and lots of grey areas exist. Non-conventional technologies like fracking and increased compression have been used for decades in what we call generally 'conventional' extraction, though they are considered unconventional when applied to certain resources in Europe.

Hydrocarbon resources can be roughly split into oil and gas resources. Both unconventional oil and unconventional gas are umbrella terms for several types of resources that could serve as alternative or additional sources of energy or feedstock to supply the economy. The table below presents an overview of the different resources described in this report and their definitions.

Table 1. Overview of unconventional hydrocarbons and their definitions

Type	Name	Definition
Oil	**Heavy oil (including oil sands, also known as tar sands)**	Heavy oil and extra heavy oil are highly viscous with American Petroleum Institute (API) gravity up to 22° and 10° respectively. Oil-sands (or tar sands) are unconsolidated sands that contain bitumen, a dense and very viscous form of petroleum (heavy oil).
	Oil shale (also known as kerogen shale, from which oil is produced by retorting)	Oil shale refers to the low-permeability sedimentary rock that contains kerogen, from which oil is produced by heating the kerogen up to 500 degrees Celsius for an extended period of time (retorting process).

[1] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future".

Type	Name	Definition
	Light tight oil (including shale oil)	Light tight oil (LTO) refers to the light crude oil trapped in low permeability, low porosity shale, limestone and sandstone formations. Geologically, light tight oil is ñan analogue of shale gasò
Gas	**Tight gas**	Natural gas trapped in extremely low-permeable and low-porous rock, sandstone or limestone formations.
	Shale gas	Shale gas is trapped in a fine-grained sedimentary - shale - rock. The gas has very little connectivity, which makes it more difficult to extract than gas from conventional reservoirs, requiring fracking. The types of reservoir are similar to that of tight gas, which is why shale gas is sometimes considered as a sub-category of tight gas. (See deliverable 1.2 for more information)
	Coal-bed methane	It refers to methane adsorbed on to the surface of coal and trapped within coal seams.
	Methane hydrates	Methane hydrates are made up of methane molecules trapped in a solid lattice of water molecules under specific conditions of temperature and pressure

2.2.1 Unconventional oil

Unconventional oils are usually difficult to extract (often requiring different methods and more energy than the conventional oil well approach) and/or have a high viscosity.[2] Because of this, unconventional oil usually needs to be diluted or upgraded before the refining process.[3] They tend to be ñheavy, complex, carbon laden, and locked up deep in the earth, tightly trapped between or bound to sand, tar, and rock.ö[4] In order to develop these resources, horizontal wells and hydraulic fracturing (or fracking) are required.[5] According to WEC (2016), the main differences between conventional and unconventional oils are ñin the reservoirs where the hydrocarbons are found and the techniques required to extract themò

The IEA[6] categorises unconventional oil in the following:

- Oil shale
- Oil sands
- Light tight oil (LTO, including shale oil)
- Oil from gas-to-liquids (GTL) and coal-to-liquids (CTL) processes

Other sources (such as the DoE) categorise unconventional oil based on density or API gravity as heavy and extra-heavy oil.[7] However, others (such as WEC, 2016) consider certain heavy oils as conventional, given that they use conventional methods for their recovery, and certain oil that can be recovered with traditional technology as unconventional (Arctic). See figure below.

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[2] IEA (2013), ñResources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Futureò, ISC & WPC (2013), ñWorld Petroleum Council Guide - Unconventional Oilò and Gordon, D. (2012), ñUnderstanding unconventional oilò
[3] ISC & WPC (2013), ñWorld Petroleum Council Guide - Unconventional Oilò
[4] Gordon, D. (2012), ñUnderstanding unconventional oilò
[5] WEC (2016), ñWorld Energy Resources 2016ò
[6] IEA (2013), ñResources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Futureò
[7] API gravity (American Petroleum Institute) is a measure of the density of oil. Lower API gravities indicate heavier and more viscous oil. IEA (2013), ñResources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Futureò

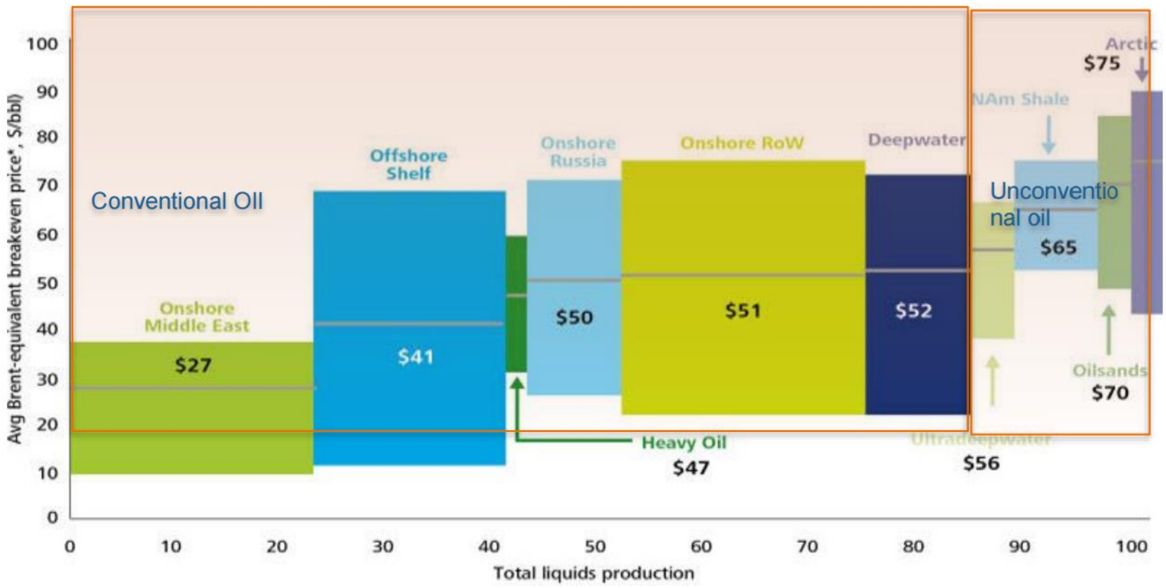

Figure 1. Differentiation between conventional and unconventional oil. Source: WEC (2016)

In general, unconventional oil uses techniques other than the conventional ones for production, transport and/or refining. These include highly energy intensive production techniques as well as innovative methods to access the oil placement or its unusual composition.[8] Therefore, there are substantial differences in the overall carbon footprint from all different fossil sources.

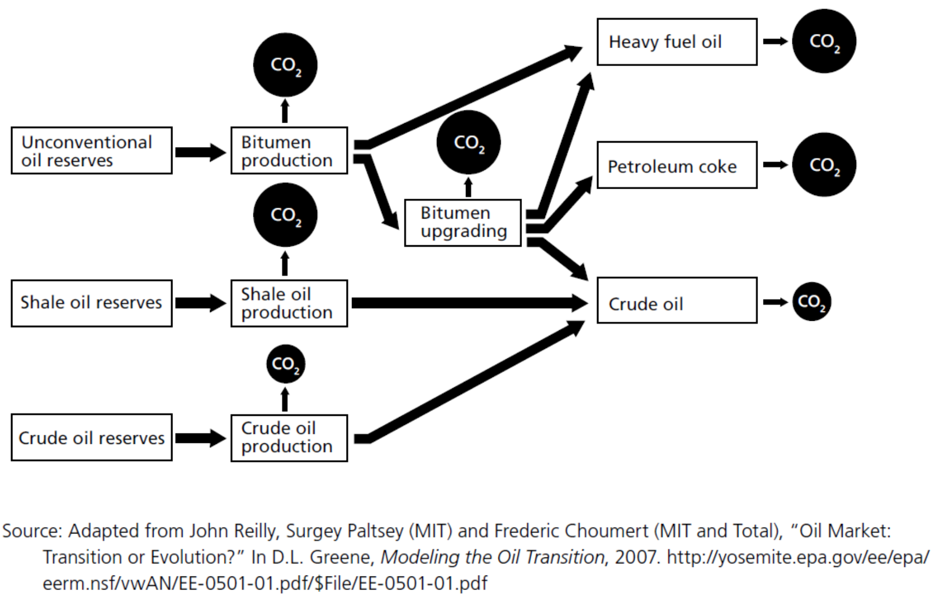

Figure 2. Carbon footprint of oils. Source: Gordon, D. (2012)

The images below provide an overview of the conventional and unconventional oil reserves and resources.

[8] Gordon, D. (2012), "Understanding unconventional oil"

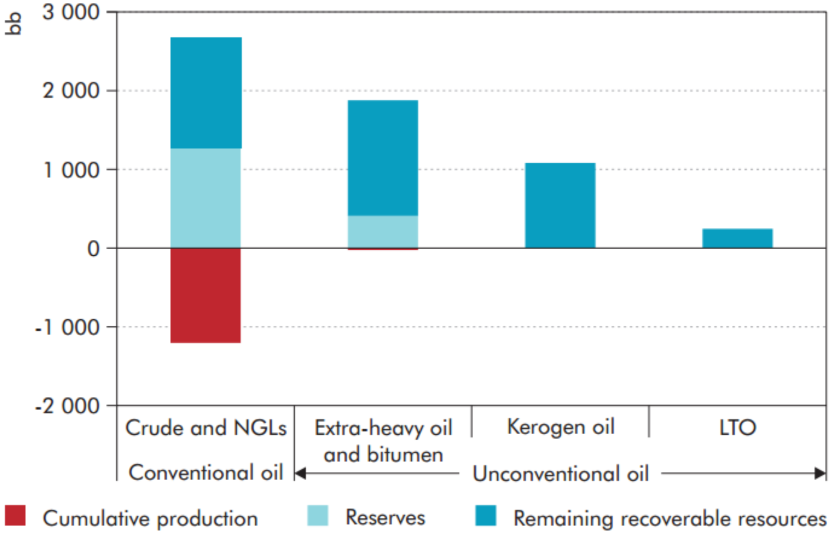

Figure 3. Conventional and unconventional oil reserves and resources in 2011. Source: IEA (2013)

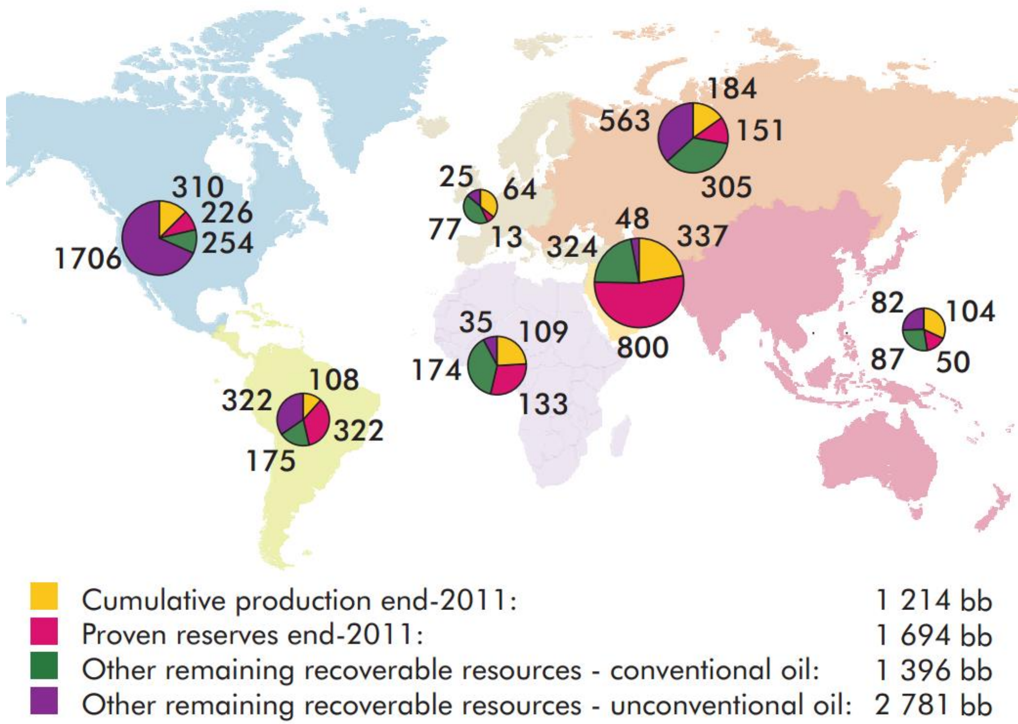

Figure 4. Regional distribution of crude oil resources, reserves and production in 2012. Source: IEA (2013)

2.2.2 Unconventional gas

Unconventional gas is generally defined as any natural gas that “cannot be produced economically by using conventional technology.”[9] Conventional gas is usually extracted from discrete, well-defined reservoirs. These reservoirs are developed by using vertical wells and have recovery rates of over 80% of the original gas in place. In contrast, unconventional natural gas is generally located in less permeable rock formations, and is distributed over larger areas. They require more technologies to become productive, and recovery rates are usually below 30%.[10]

The IEA focuses on the following categories[11]:

- Tight gas;
- Shale gas (see deliverable 1.2);
- Coal-bed methane (CBM);
- Methane hydrates.

“Lean gas” and “sour gas” are also sometimes categorised as unconventional. These types of gas refer to gas contained in conventional reservoirs, but with a high concentration of impurities (nitrogen and CO_2 for lean gas, hydrogen sulphide [H_2S] for sour gas). These impurities have a negative impact in the economics of production.

Technological advances in horizontal (or directional) drilling and hydraulic fracturing made unconventional gas economically viable, leading to the successful development of shale gas in the last decade. Economies of scale in tight gas, shale gas and CBM have enabled their production at similar costs to those for production of conventional gas.[12] Literature suggests that shale gas currently has the most significant growth prospects, due to these technological developments.[13]

Unconventional gas production made up almost 13% of global gas supply in 2009. According to the IEA, this could rise to over 20% by 2035.[14] Shale gas has become an important part of the energy supply in the United States[15], accounting for 34% of total domestic gas production in 2011. Tight gas, shale gas and CBM resources are growing in importance for domestic gas production in Canada and China.[16] In Europe, the subject caused a lot of debate as the environmental risks where considered high by some. Only in the UK today there is both support as well as actual successful activities. In Poland, earlier estimates had to be lowered when exploratory testing started. In other countries such as France and Germany, shale production has been banned by political decision. The best estimate for technically recoverable resources (TRR) of shale gas is 12 Tcm in Western Europe and 4 Tcm in Eastern Europe.[17]

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[9] IEA (2012), “Golden Rules for a Golden Age of Gas – World Energy Outlook – Report on Unconventional Gas”
[10] JRC (2012), “Unconventional Gas: Potential Energy Market Impacts in the European Union”
[11] IEA (2013), “Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future”
[12] IEA (2013), “Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future”
[13] JRC (2012), “Unconventional Gas: Potential Energy Market Impacts in the European Union”
[14] IEA (2013), “Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future”
[15] EPRS (2014), “Unconventional gas and oil in North America”
[16] IEA (2013), “Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future”
[17] JRC (2012), “Unconventional Gas: Potential Energy Market Impacts in the European Union”

The following table and figures provide an overview of the existing conventional and unconventional gas resources. It is difficult to assess reserves due to the heterogeneity of the rock formations, their very low permeability and the uncertainty in the reservoir volume that can be connected to a production well.[18]

Table 2. Estimates of global and European gas reserves (TRR and proved). Source: JRC (2012) and IEA (2013)

	TRR / remaining recoverable sources (tcm)		Proven reserves (tcm)		Ultimately recoverable resources (in 2011, tcm)	
	JRC 2012 World (TRR)	IEA 2013 World (remaining recoverable)	JRC 2012* World	IEA 2013 World	IEA 2013 World	IEA 2013 OECD Europe
Shale gas	200				210	17
Tight gas	45	330		Difficult to assess	78	4
CBM	25				48	2
Conventional gas	425	460	190	220	519	35

* JRC definition: resources that can be easily recovered with the highest degree of confidence

[18] IEA (2013), “Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future”

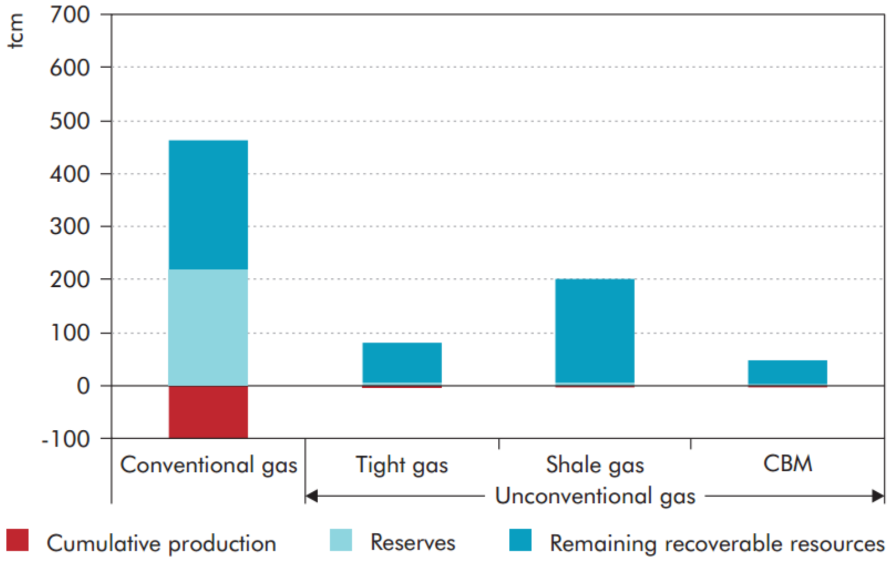

Figure 2. Conventional and unconventional gas reserves and resources in 2011. Source: IEA (2013)

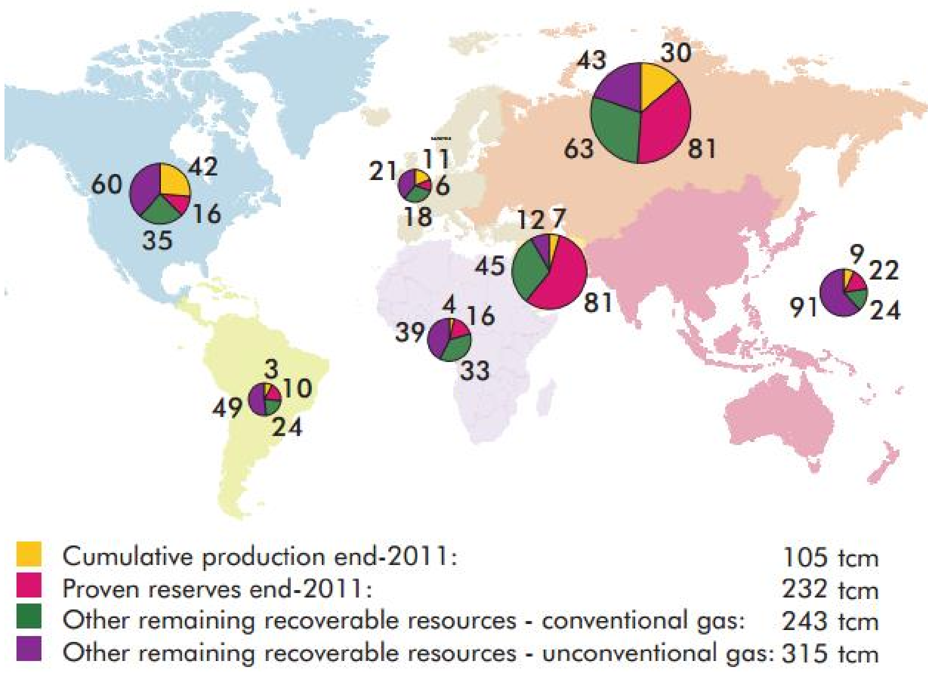

Figure 3. Regional distribution of natural gas in 2012. Source: IEA (2013)

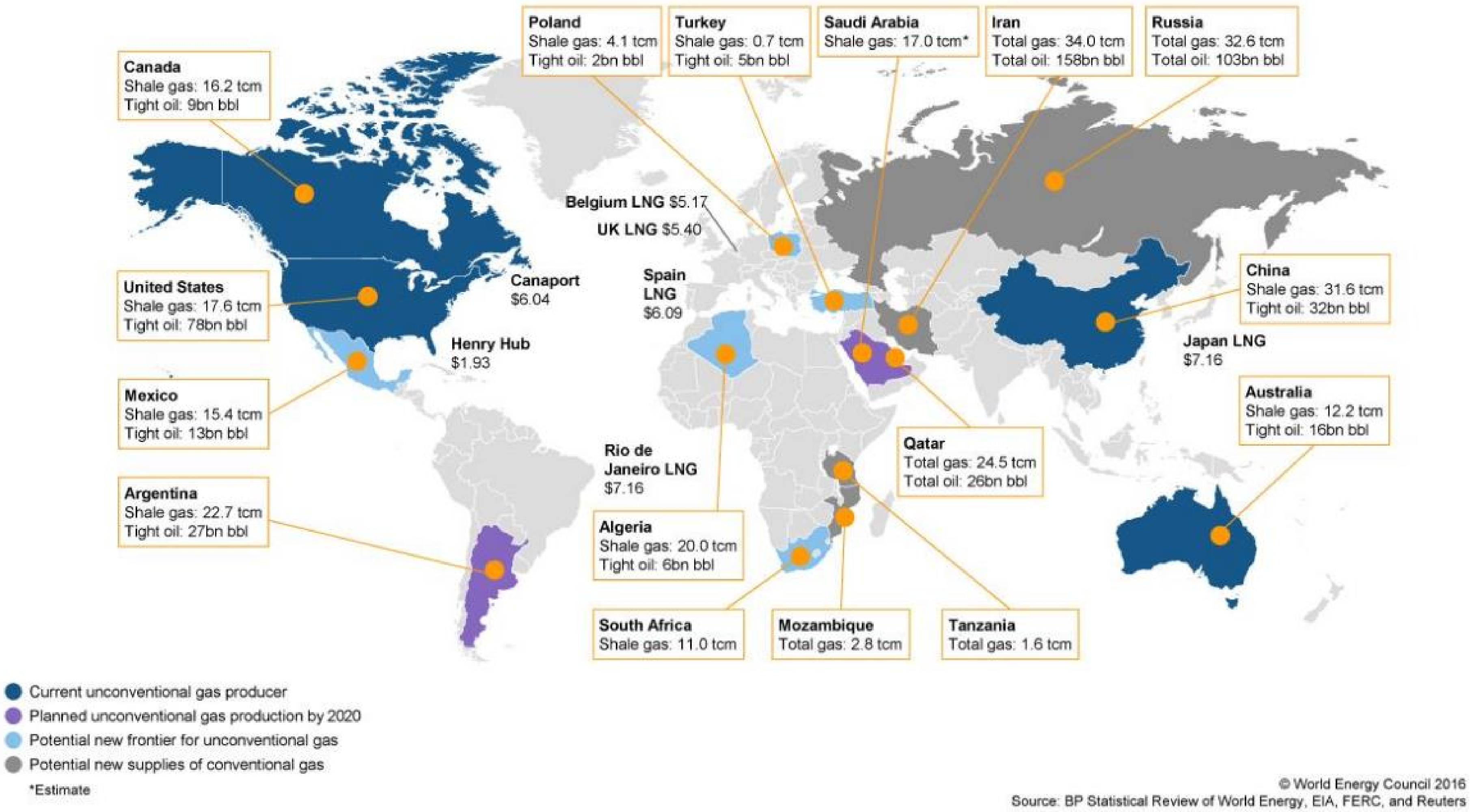

Figure 4. World shale gas & tight oil resources. Source: WEC (2016)

2.2.3 Coal to Liquid and Gas to Liquid

Both in the Terms of Reference and in the Description of Work (annex A) of our project we have included Gas to Liquid technology and Coal to Liquid technology as “non-conventional fossil natural resource as alternative feedstock for the process industry”.

But when analysing the subject more in depth we came to the conclusion that both gas to liquid (GtL) and coal to liquid (CtL) do not fit well with the definition of non-conventional natural resource as they are fully based on the transformation of conventional sources of fossil carbon (gas and coal). It is just a transformation of fossil fuels from a physical state (solid or gas) to another that has more demand in the market (notably liquid transport fuel).

The origin of classifying GtL and CtL technologies as non-conventional sources lies at the IEA Clean Coal Centre, which was analysing the potential of these technologies (combined with CCS) in the early 21st century, in order to decrease the dependency on oil imports.[19] The use of these technologies is not part of the greenhouse gasses reduction debate as both increase CO_2 output instead of decreasing it. These technologies are clearly differentiated from the so-called Power to X (PtX) technologies (where some routes use H_2 produced with renewable energy and combined with waste CO_2 emissions could reduce the carbon food-print of (transport) fuel and to serve as chemical energy storage system). In both cases additional energy has to be added. The key distinction is that PtX processes that belong to the CCU portfolio use waste CO_2 as carbon source while the GtL and CtL technologies start from fossil carbon. Therefore, the resulting products need to undergo a precise carbon footprint analysis in order to show the different carbon footprint of the concepts. However, PtX could fit in a climate friendly scenario for Europe, whereas CtL and GtL, even with full CCS are difficult to combine with greenhouse gas reduction targets.

Coal to Liquid

CTL enables coal to be used as an alternative to oil by using a direct or indirect coal liquefaction process. The liquids obtained (such as petroleum or diesel) can be used as fuels or feedstocks e.g. in the petrochemical sector. [20]

[19] IEA (2009), “Review of worldwide coal to liquids R&D activities and the need for further initiatives within Europe”
[20] IEA (2013), “Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future” and ISC & WPC (2013), “World Petroleum Council Guide - Unconventional Oil”.

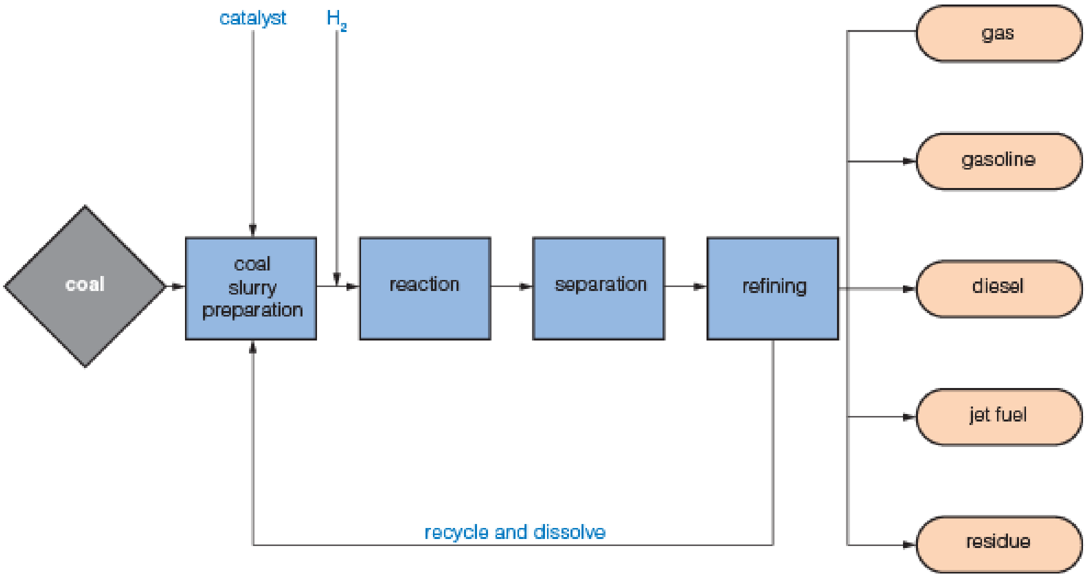

Figure 5. Coal to Liquid process

Coal to Liquid can be distinguished in:

- **Direct Coal Liquification (DCL)** where, generally, the H/C ratio is increased by adding gaseous H_2 to the slurry of coal and coal-derived liquids;[21] and
- **Indirect Coal Liquification (ICL)** which is a high temperature, high pressure process which comprises a gasification stage with syngas clean-up, followed by either Fischer-Tropsch (FT) or methanol synthesis. Oxygen blown gasification of the coal produces a syngas consisting mainly of CO and H_2, which can be modified as necessary by using the water gas shift reaction in which water and carbon monoxide react to form carbon dioxide and hydrogen, thus increasing the H_2: CO ratio.[22]

Most of the technology is well known and established early 20th century. Both the ICL and DCL are under research in countries like China and Mongolia to see if they can use their large coal reserves to avoid oil imports. However, large scale production has only taken place in WWII in Germany (to compensate for the lack of oil imports) and in South Africa as a result of the oil embargo. Today, only the South African Sasol production facility is producing Coal to Liquid commercially, with a total capacity of 160,000 barrels per day.[23] "Currently around 30% of the country's gasoline and diesel needs are produced from indigenous coal."[24] However, the process is highly energy intensive and the carbon footprint makes the Sasol plant the single biggest CO_2 emitter in the world.

Gas to Liquids

GtL converts fossil gas into a range of products like diesel and aviation fuel, oils for advanced lubricants, naphtha to make plastics, and paraffin for detergents.

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21 IEA (2009), "Review of worldwide coal to liquids R&D activities and the need for further initiatives within Europe"
22 IEA (2009), "Review of worldwide coal to liquids R&D activities and the need for further initiatives within Europe"
23 WEC (2016), "World Energy Resources 2016"
24 WEC (2016), "World Energy Resources 2016"

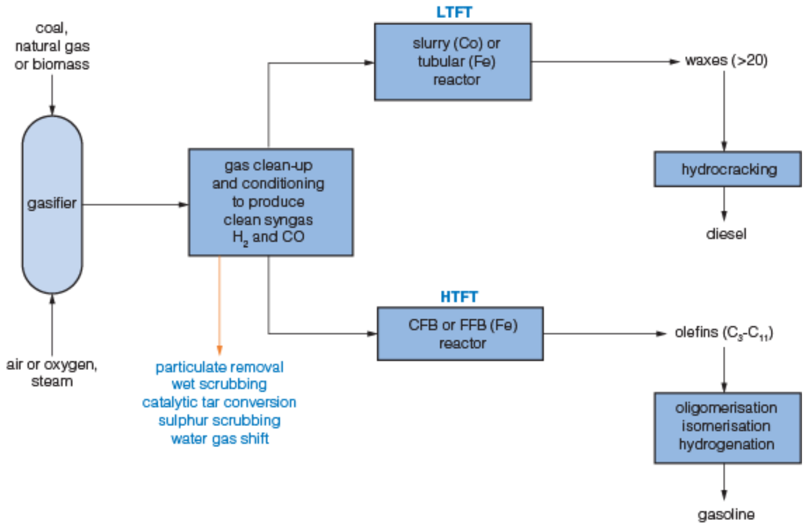


Figure 9. Gas to Liquids process

Gas to Liquids is being used in several commercial locations, where the Shell Pearl GtL project in Qatar is by far the biggest GtL plant in the world (and the biggest project ever by Shell).

The technology's main advantage is to make products that are easier to transport than gas, creating liquid and final products that are cleaner than their normal fossil variants. The production cost is considerable and the energy and CO_2 penalty are high. Currently, it is possible to make a commercial GtL conversion plant where methane is otherwise a waste product or where it is very cheap.

Conclusion on GtL and CtL

There is an abundance of coal in the world in general and in Europe as well. Most European coal production has come to a halt as imports are much cheaper and mining is considered a relatively unattractive working environment. This does not mean that in times of need coal-production cannot be increased rapidly again. In case of very high oil prices or oil import limitations, the production of oil or chemicals from coal is a technically feasible option.

The IEA is investigating coal gasification/liquification for chemicals, gaseous and liquid fuels production as it can fulfil an important need, particularly in various developing countries where coal is the primary fuel source and oil and gas energy security is an issue. But they recognize that the economic and environmental constraints (water and CO_2) are major limitations.[25]

However, in the light of reducing greenhouse gases, it is probably the least favourable option for the process industry as the additional CO_2 emission would outweigh any of the advantages by far. Adding CCS could (partly) avoid that problem but it would increase the price for the oil considerably. This would only be a likely scenario in times of extreme high oil prices (rough estimate >$200/barrel) or

[25] Coal to chemicals challenges in developing countries, IEA Clean Coal Centre Presentation

war; but even then, the future damage for the climate should be considered. There are no current projects or serious plans in Europe to date. Therefore, this option will not be further investigated in this project.

On the other hand, gas is only abundant in Norway. Other major gas producing countries (UK and NL) are decreasing their production and will become import dependent soon. Gas imports from Russia and North Africa and maybe CNG (from USA or ME) are so far the most likely (biggest volume) options to replace the decreasing European production. Thus, shifting from oil-imports to gas-imports and then converting the gas into oil or chemicals in Europe would not bring many advantages, but rather some disadvantages like increased price and increased CO_2 emissions. There are no current projects or serious plans in Europe to date. Therefore, this option will not be further assessed in this project.

2.3 Oil and gas reserves and resources in Europe

In 2016, the JRC published its report "Unconventional oil and gas resources in future energy markets: A modelling analysis of the economic impacts on global energy markets and implications for Europe". This report gathered the oil and gas potentials from the most recent and relevant sources, and summary tables are presented below.[26]

[26] It used the assessment of oil and gas resources and reserves, both conventional and unconventional, performed by the German Federal Institute for Geosciences and Natural Resources (BGR). This source was selected for the following key reasons:
Recently available, i.e. published in 2014.
Based on its self-consistent geological analysis (no referral to other sources).
Coverage of all the JRC ETM regions.
Detailed, i.e. provides split between different types of gas and oil.
Estimates of unconventional resources per MS are based on the following sources:
Shale Gas and Oil: as defined in the JRC-EU-TIMES model nr. 20/2015
Coal-Bed Methane: as assessed by JRC (2016) - Environmental and Sustainability Assessment of Current and Prospective Status of Coal Bed Methane Production and Use in the European Union,
Tight Gas, Extra-Heavy Oil and Oil sand: as in BGR (2014) - Energy Study 2014. Reserves, resources and availability of energy resources.

Table 3. Estimates of gas reserves and resources for 2013 in PJ. Source: JRC (2016)

	AFR	AUS	CAN	CHI	CSA	EEU	FSU	IND	JPN	MEA	MEX	ODA	SKO	USA	WEU
Gas Reserves															
Conventional	541607	100471	73399	119203	287412	10650	2356312	46382	719	2990980	12959	278499	34	197182	137450
Shale gas	0	0	0	0	0	0	0	0	0	0	0	0	0	136482	0
CBM	0	36457	1936	2644	0	0	1639	4077	63	0	0	24480	3	14337	0
Total	**541607**	**136929**	**75335**	**121847**	**287412**	**10650**	**2357951**	**50459**	**782**	**2990980**	**12959**	**302978**	**37**	**348001**	**137450**
Share of unconventional gas	**0.0%**	**26.6%**	**2.6%**	**2.2%**	**0.0%**	**0.0%**	**0.1%**	**8.1%**	**8.1%**	**0.0%**	**0.0%**	**8.1%**	**8.1%**	**43.3%**	**0.0%**
Gas Resources															
Conventional	1294622	201092	376489	744785	770666	35866	4894352	74478	62	1584928	85650	310542	619	875122	197532
Shale gas	1480930	461022	604393	933960	1520031	86027	488951	101291	63	246124	574974	316093	630	643345	473798
CBM	52507	247641	136035	405908	7895	10480	586592	67403	33	3381	1117	164482	328	166459	57719
Tight gas	204816	297914	279294	446871	372	727	744785	0	28	28164	0	142843	285	355153	4003
Total	**3032875**	**1207668**	**1396210**	**2531523**	**2298964**	**133093**	**6714680**	**243172**	**186**	**1862595**	**661741**	**933960**	**1862**	**2020079**	**733017**
Share of unconventional gas	**57.3%**	**83.3%**	**73.0%**	**70.6%**	**66.5%**	**73.1%**	**27.1%**	**69.4%**	**66.7%**	**14.9%**	**87.1%**	**66.7%**	**66.8%**	**57.7%**	**73.1%**

AFR: Africa, AUS: Australia, CAN: Canada, CHI: China, CSA: Central-South America, EEU: Eastern Europe, FSU: Former Soviet Union, IND: India, JPN: Japan, MEA: Middle East, MEX: Mexico, ODA: Other developing Asia, SKO: South Korea, USA: United States, WEU: Western Europe

Table 4. Estimates of oil reserves and resources for 2013 in PJ. Source: JRC (2016)

	AFR	AUS	CAN	CHI	CSA	EEU	FSU	IND	JPN	MEA	MEX	ODA	SKO	USA	WEU
Oil Reserves															
Conventional	745083	22525	27884	102995	410893	6280	755927	31736	167	4542929	62467	96548	0	251669	80261
Oil sand	0	0	1112223	0	0	0	0	0	0	0	0	0	0	0	0
Extra heavy oil	0	0	0	0	887602	126	0	0	0	0	0	0	0	126	0
Tight oil	0	0	2847	0	0	0	0	0	0	0	0	0	0	10886	0
Total	**745083**	**22525**	**1142955**	**102995**	**1298494**	**6406**	**755927**	**31736**	**167**	**4542929**	**62467**	**96548**	**0**	**262680**	**80261**
Share of unconventional oil	**0.0%**	**0.0%**	**97.6%**	**0.0%**	**68.4%**	**2.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**4.2%**	**0.0%**
Oil Resources															
Conventional	1073077	102950	146538	678262	947557	20262	1157022	42008	710	1282626	124767	291927	0	658458	256532
Oil sand	13858	390	2093400	1047	419	129	468963	159	3	0	0	1105	0	35588	1628
Extra heavy oil	335	488	42	4982	2534103	129	879	199	3	42	42	1384	0	3182	1628
Tight oil	218467	41873	141933	183382	339549	9458	437521	17086	289	586	74525	118737	0	330757	119744
Total	**1305737**	**145701**	**2381912**	**867672**	**3821627**	**29977**	**2064385**	**59453**	**1005**	**1283254**	**199334**	**413153**	**0**	**1027985**	**379533**
Share of unconventional oil	**17.8%**	**29.3%**	**93.8%**	**21.8%**	**75.2%**	**32.4%**	**44.0%**	**29.3%**	**29.4%**	**0.0%**	**37.4%**	**29.3%**	**0.0%**	**35.9%**	**32.4%**

AFR: Africa, AUS: Australia, CAN: Canada, CHI: China, CSA: Central-South America, EEU: Eastern Europe, FSU: Former Soviet Union, IND: India, JPN: Japan, MEA: Middle East, MEX: Mexico, ODA: Other developing Asia, SKO: South Korea, USA: United States, WEU: Western Europe

2.3.1 Potential impact of unconventional resources in Europe

The 2016 JRC report uses JRC Energy Trade Model (JRC ETM) to explore the medium and long-term implications of the development of unconventional gas and oil (as well as their by-products) on global and European markets. The box below presents the reports main findings regarding the potential impact of unconventional resources in Europe.

Main findings regarding gas

- Natural gas in Europe will play the role of a transition fuel towards a low carbon economy. It will replace more carbon intensive fossil fuels and thus contribute to the decarbonisation of the energy system.
- Natural gas can supply 30% of the worldôs total primary energy by 2040 under scenarios with favourable unconventional gas development.
- Many regions will likely witness (at least) some level of unconventional gas production in the future, given that the resource is relatively evenly dispersed.
- USA, China and óOther Developing Asiaô are well placed to become top producers of unconventional gas under favourable scenarios.
- In the EU, exploitation of unconventional gas is driven by emission targets. More stringent decarbonisation policies lead to lower extraction. Activity takes place in the UK, and to a lesser extent in Germany.
- Significant unconventional gas production has the potential to lower natural gas prices.
- Global trade in natural gas will increase (in any scenario).
- Unconventional gas development has the potential to moderate the growth of pipeline trade, while increasing interregional LNG flows.

Main findings regarding oil

- The global oil market will expand in the medium term in all scenarios.
- From 2040, stricter decarbonisation policies may drive to a decline. Under these scenarios, oil represents 16-17% of the worldôs total primary energy supply.
- Unconventional oil production will grow, but has limited potential on lowering oil prices.
- Decarbonisation policies will have a small impact on unconventional oil production, i.e. the relative share grows to 60-62% of total oil production by 2040.
- Canada and Latin America are well placed to become the top producers of unconventional oil.
- EU exploitation of unconventional oil will be very limited.

Source: JRC (2016)

3. Heavy oil (including oil sands or tar sands)

3.1 Definition and context

Heavy oil and extra heavy oil are highly viscous with API gravity up to 22° and 10° respectively. [27]

Oil-sands are unconsolidated sands that contain bitumen, a dense and very viscous form of petroleum.[28]

3.2 Mapping resources

According to IEA (2013), resources are concentrated in Canada (provinces of Alberta and Saskatchewan) and Venezuela (Orinoco Belt). These countries have proven reserves of 175 and 220 billion barrels respectively. Resources have also been identified in Colombia (up to 110 bb), Ecuador, Peru and other countries along the Andes, China, Russia, Kazakhstan and countries in the middle East.

In 2012, there were more than 110 oil-sands projects in operation worldwide with a total raw bitumen capacity of 2.1 mb/d (of which Canada 1.5 mb/d and Venezuela 0.6 mb/d).[29]

Table 5. Resources, reserves and production at end-2008 in billion barrels of oil. Source: WEC (2010)

	Deposits (number)	Discovered original oil in place	Prospective additional resources	Total original oil in place	Original reserves	Cumulative production	Reserves
Natural Bitumen							
World	**598**	**2511.3**	**817.3**	**3328.6**	**249.7**	**6.5**	**243.2**
Europe **(Italy, Russian Federation, Switzerland)**	56	297.5	51.4	348.9	28.6	0.0	28.6
- ***Italy***	*16*	*2.1*	*-*	*2.1*	*0.2*	*-*	*0.2*
North America **(US, Canada & Trinidad & Tobago)**	449	1769.1	719.6	2488.6	176.8	6.4	170.4
South America	2	-	-	-	-	-	-
Middle East	1	-	-	-	-	-	-
Oceania	1	-	-	-	-	-	-
Asia	80	426.8	-	426.8	42.5	0.0	42.4

[27] ISC & WPC (2013), "World Petroleum Council Guide - Unconventional Oil"
[28] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future"
[29] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future"

	Deposits (number)	Discovered original oil in place	Prospective additional resources	Total original oil in place	Original reserves	Cumulative production	Reserves
Africa	9	18.0	46.4	64.3	1.8	-	1.8
Extra-Heavy Oil							
World	**162**	**1960.3**	**189.6**	**2149.9**	**76.2**	**17.1**	**59.1**
Europe (DE, IT, PL, UK, Albania & Russian Federation)	44	15.1	-	15.1	1.4	1.2	0.2
- ***Germany***	*1*	-	-	-	-	-	-
- ***Italy***	*31*	*2.7*	-	*2.7*	*0.3*	*0.2*	*0.1*
- ***Poland***	*2*	*0.0*	-	*0.0*	-	-	-
- ***United Kingdom***	*2*	*11.8*	-	*11.8*	*1.1*	*1.0*	*0.1*
North America (US, Mexico & Trinidad & Tobago)	58	3.0	0.0	2.6	0.2	0.2	0.0
South America (most in Venezuela)[30]	41	1924.0	189.5	2113.6	72.8	14.8	58.0
Middle East	4	0.0	-	0.0	0.0	-	0.0
Asia	14	17.7	-	17.7	1.8	0.9	0.9
Africa	-	0.5	-	0.5	0.0	-	0.0

3.3 Main technologies used

Some heavy or extra heavy oil can be produced cold using horizontal drilling and pumping. **Cold production** is a method used in the Orinoco Belt when viscosity is low enough for the oil to flow to the surface. It uses long horizontal or multilateral wells to “maximise well-bore contact with the reservoir and reduce the drop in pressure in the well bore.”[31] It has a low recovery factor (usually under 15%), and therefore thermal treatment is needed to increase recovery rates.

Extra heavy crude has to be diluted (using gas condensates, lighter oil or naphtha), or upgraded into synthetic crude (or syncrude) for shipping to refineries.[32] **Upgrading viscous oil** entails lowering its viscosity by increasing the ratio of hydrogen to carbon, using methods such as coking or hydrocracking. Costs range from 9.5 USD to 11.5 USD per barrel (in Canada).[33]

In the case of oil-sands, the bitumen is extracted by open-cast mining (for shallow deposits), or in-situ treatment (for deeper deposits). It also needs to be diluted or upgraded for shipping.[34] **Mining,** which is used in large-scale only in Canada (where half the production comes from upgrading mined), uses

[30] Also resources in Cuba, Ecuador, Peru and Colombia
[31] IEA (2013), “Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future”
[32] ISC & WPC (2013), “World Petroleum Council Guide - Unconventional Oil”
[33] IEA (2013), “Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future”
[34] ISC & WPC (2013), “World Petroleum Council Guide - Unconventional Oil”

shovels and dump trucks. Approx. 90% of the bitumen is separated via the "hot froth flotation" method using heat and water, yielding 1.3 barrels of raw bitumen per cubic metre of ore.[35] Investments were estimated at 73,000 USD/barrel oil/day for a mining & upgrading project in Canada. [36] **In situ production** methods can be primary (only drilling wells and producing), thermal (using heat to lower the viscosity), and non-thermal (creating miscibility between oil and injectant). The most used in situ methods are thermal CSS (with a low recovery rate of 20-35%, though it can be used in combination with other methods) and SAGD (with a theoretical recovery rate of 50-70%).[37]

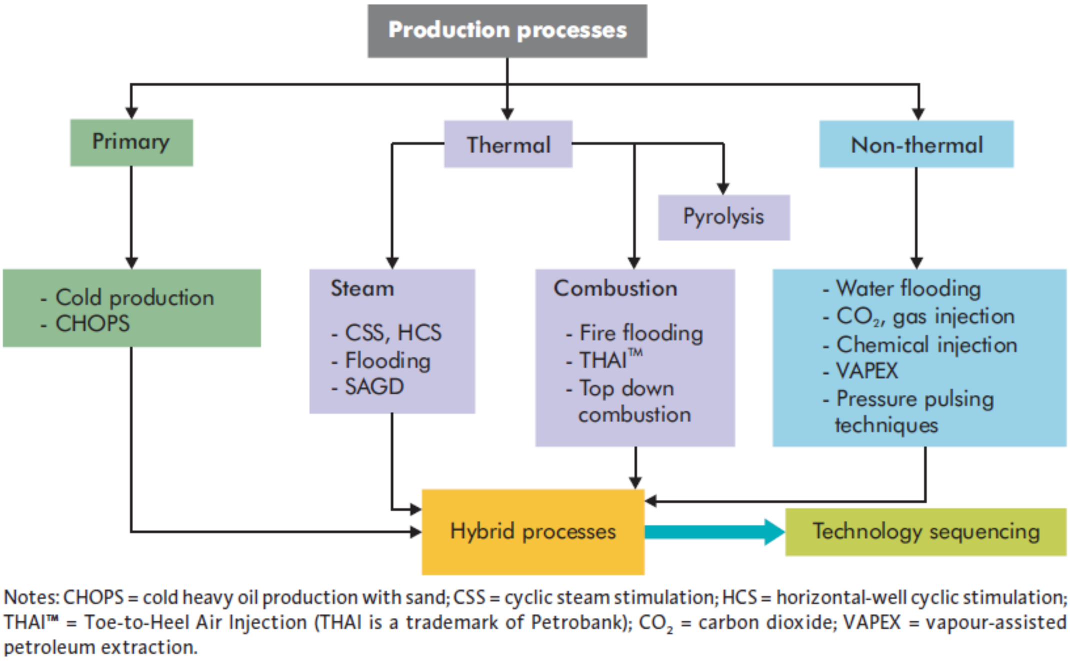


Figure 10 In situ methods of viscous oil production. Source: IEA (2013)

Methods such as cold production and CHOPS have lower costs than mining and thermal steam methods, but require sand management and have low recovery factors and low production rates. These methods are not suitable for high-viscosity reservoirs. "However, their lower costs make them attractive and they could still be deployed as the first technology in a sequence of primary, nonthermal and thermal methods designed to increase recovery factors."[38]

3.4 Key challenges and environmental issues

Key challenges identified by IEA (2013) include the need to extract viscous oil from the porous rock and the need to dilute or "upgrade" the oil such that it can be transported via pipelines. Furthermore, there is a need for significant capital investment.

[35] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future"
[36] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future"
[37] CSS (Cyclic steam stimulation) where a small amount of steam is injected into the producer well, after which it is closed in for some time before reopening it for the production of heated oil; SAGD (steam-assisted gravity drainage) where oil flows along the walls of a steam chamber down to a producing well.
[38] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future"

There are several environmental issues associated with heavy oil. IEA (2013) lists the following:

- High energy intensity & associated carbon footprint (GHG including CO_2, sulphurous gases & fine particulate matter)
- Energy sources for steam and hydrogen sources for hydrogenation
- Impact on the landscape (e.g. in situ viscous oil production & mining)
- Water usage (e.g. required to extract bitumen from oil sands)
- Waste water or fluid tailings (e.g. sludge & bitumen slurries generated by water-based extraction) and groundwater contamination (e.g. fluids used in well fracturing leaking into shallower potable aquifers)
- Sulphur (e.g. as a by-product of oil sands production)

3.5 Future outlook and potential impact

Production of heavy oil is expected to increase up to 6.7 mb/d in 2035.[39] Production of heavy oil from Venezuela is estimated to reach 2.1 mb/d by 2035, while Canadian oil-sands production is projected to be 2.3 mb/d in 2015 and 3.4 mb/d in 2030.

Canadian in situ production is expected to overtake mining production in the 2020's. SAGD production is also expected to increase.[40] The industry is looking into hybrid processes to improve recovery and production efficiency.

[39] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future"
[40] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future"

4. Oil shale (or Kerogen oil)

4.1 Definition and context

Oil shale refers to the low-permeability sedimentary rock - usually found at shallow depths - that contains kerogen. Oil shale is younger than the shale formations containing tight oil.[41] The rock can either be combusted directly or processed to produce oil.[42] Oil is produced via retorting which consists on heating the kerogen to up to 500ºC for an extended period of time.[43]

4.2 Mapping resources

Resources in place are estimated between 4.8 (2013)[44] and 6.05 trillion barrels of oil (2016).[45] The remaining recoverable resources estimated at 1.1 trillion barrels.[46] The largest resources in place are in US (~77%, main reserves in the Green River Formation), China and Russia.[47] However, Brazil, Israel, Jordan, Sumatra, Australia, Estonia, France, South Africa, Spain, Sweden, and Scotland also have considerable oil shale deposits.[48]

Table 6. Oil Shale resources. Source: WEC (2013) and WEC (2016)

Country	Proven resources (Billion bbl) Source: WEC (2013)	Resources (Billion bbl) Source: WEC (2016)
United States of America	4285	6 000
China	10	330
Russian Federation	248	270
Israel	NA	250
Congo	100	100
Jordan	34	100
Brazil	82	NA
Italy	73	NA
Morocco	53	NA
Australia	32	NA
Estonia	16	16
Total	**4933**	**-**

[41] ISC & WPC (2013), "World Petroleum Council Guide - Unconventional Oil".
[42] ISC & WPC (2013), "World Petroleum Council Guide - Unconventional Oil".
[43] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future".
[44] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future"
[45] WEC (2016), "World Energy Resources 2016"
[46] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future".
[47] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future".
[48] Gordon, D. (2012), "Understanding unconventional oil".

Oil shale mining for oil production, power generation, cement production and the chemical industry has taken place since the 1830ôs and peaked in 1981 at 46 Mt/year.[49] Production fell to 16 Mt/year in 2004.[50] 80% of the commercial kerogen shale is mined in **Estonia** and its main use is power generation. Oil shale is currently exploited in Brazil, China, Estonia, Germany, Israel and Jordan.[51]

The world production was estimated at around 20,000 barrels/day in 2013[52] and at 45,000 in 2015 (from China, Estonia & Brasil)[53] with Estonia alone producing about 25,000 barrels per day.[54] The figure below shows oil shale projects worldwide.

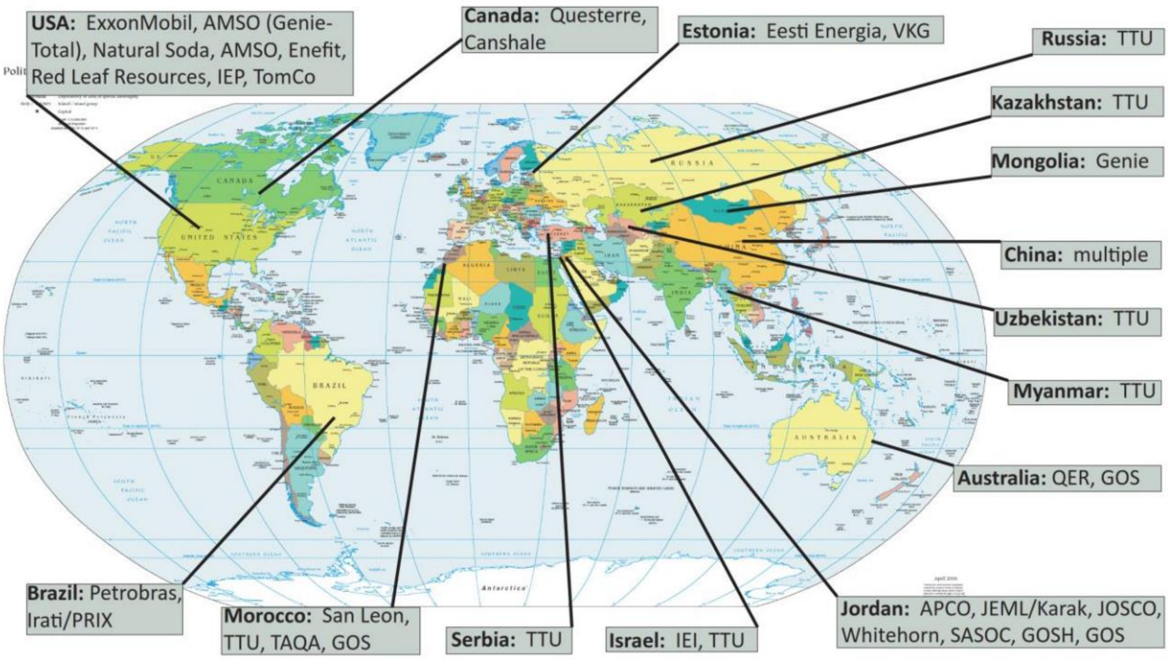


Figure 11. Global oil shale projects. Source: WEC (2016)

4.3 Main technologies used

Kerogen shale can be mined (when it outcrops the surface). The mined rock is then heated using a **retorting process** which ñpyrolyses (or thermochemically decomposes) the kerogen into oilò [55] Heating kerogen may produce other hydrocarbons, including methane. The retorting process can take place in a traditional refining capacity or using an in-situ process.[56] In order to enhance productivity from deeper deposits, technologies such as hydraulic fracturing and in-situ mobility enhancement technology are used.

[49] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future" and ISC & WPC (2013), ñWorld Petroleum Council Guide - Unconventional Oilò
[50] IEA (2013), ñResources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Futureò
[51] IEA (2013), ñResources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Futureò
[52] IEA (2013), ñResources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Futureò
[53] WEC (2016), ñWorld Energy Resources 2016ò
[54] WEC (2016), ñWorld Energy Resources 2016ò
[55] IEA (2013), ñResources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Futureò
[56] ISC & WPC (2013), ñWorld Petroleum Council Guide - Unconventional Oilò

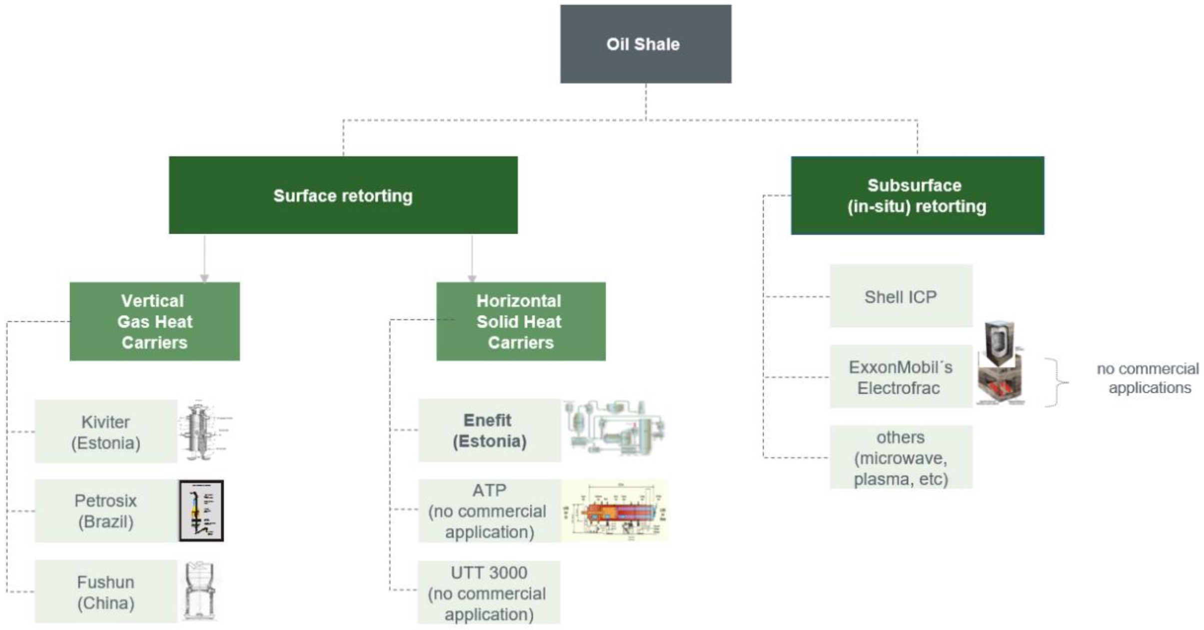


Figure 6. Oil shale processing. Source: WEC (2016)

For example, Shell assessed an in-situ conversion process using down-hole heaters yielding oil which was less viscous than oil produced by surface retort. In, 2013, this technology was not yet in large-scale demonstration phase. This process had lower environmental impact on surrounding land than mining (if wells could be drilled as little as 12m apart), but at the same time required both water and energy to heat and cool relevant areas (1.2GW required for 100 000 b/day unit, with a ratio of energy generated to energy used of between three and four to one). [57]

4.4 Key challenges

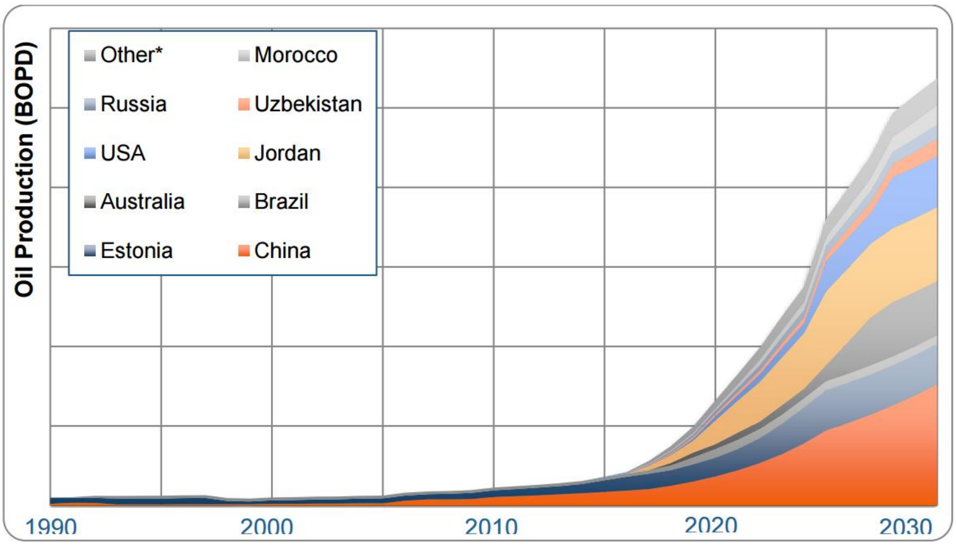
Key environmental issues include the fact that production is energy intensive. Retorting requires "almost 30% of the energy value of the oil produced"[58] CO_2 emissions are estimated at 180 – 250 kg CO_2-equivalent per barrel of oil produced.

4.5 Future outlook and potential impact

Oil shale resources are largely undeveloped due to high costs. Production costs are estimated to make commercial exploitation possible (in the US) at an oil price of around USD 60 per barrel in absence of carbon pricing. [59] However, experiments in the US were stopped due to high costs and poor performance.

[57] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future"
[58] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future"
[59] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future"

Resources seem to be on the conservative side and are being re-examined in many countries.[60] However, projections show that oil shale will not be a significant part of global production (>500,000 barrels of oil per day) before the [61] See oil shale production projections in the figure below.



Source: Boak (2014)

Figure 7. Projected production of oil shale. Source: WEC (2016)

[60] WEC (2016), ìWorld Energy Resources 2016ò
[61] WEC (2016), ìWorld Energy Resources 2016ò

5. Light tight oil (including shale oil)

5.1 Definition and context

Light tight oil (LTO) refers to the light crude oil trapped in low permeability, low porosity shale, limestone and sandstone formations.[62] Geologically, light tight oil is "an analogue of shale gas"[63] Hence, innovations in well technology for shale gas have unlocked LTO resources which were previously uneconomic.

5.2 Mapping resources

There is limited information regarding the size of existing LTO resources available and those that are technically and economically feasible to extract. Currently, North America has the most advanced appraisal and production of LTO, which explains why the region is estimated to have the largest resources. Major tight oil formations include the Bakken, Barnett and Eagle Ford shales.[64] The technically recoverable LTO from Bakken formation (US) was estimated at 3.5 bb in 2008. Industry estimates up to 18bb (unconfirmed) while the North Dakota Department of Mineral Resources estimates 10 bb in North Dakota alone. [65]

Resources in other world regions have not been quantified, but are likely to be found in many locations. There is potential for new LTO in China, Australia, the Middle East (especially Israel), Central Asia (Amu Darya Basin and the Afghan-Tajik Basin), Russia, Eastern Europe, France (Paris basin), Argentina (Neuquen basin), and Uruguay.[66]

Table 7. Shale Oil resources. Sources: EIA 2015 World Shale Resources, Attachment A. and ISC & WPV (2013)

Country	Risked Oil In-Place (Billion bbl)*	Unproved Technically Recoverable (Billion bbl)*	Technically Recoverable Resources (Billion bbl)**
Top 10			
US	-	78***	58
Russia	1243	75	75
China	644	32	32
Argentina	480	27	27
Libya	613	26	26
United Arab Emirates	376	23	NA

62 IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future"
63 IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future"
64 ISC & WPC (2013), "World Petroleum Council Guide - Unconventional Oil"
65 IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future"
66 Gordon, D. (2012), "Understanding unconventional oil"

Country	Risked Oil In-Place (Billion bbl)*	Unproved Technically Recoverable (Billion bbl)*	Technically Recoverable Resources (Billion bbl)**
Chad	393	16	NA
Australia	364	16	18
Colombia/Venezuela	297	15	13
Mexico	275	13	13
Europe			
France	118	5	NA
Netherlands	59	3	NA
Poland	36	2	NA
Lithuania/Kaliningrad	29	1	NA
UK	17	1	NA
Germany	14	1	NA
Romania/Bulgaria	8	0	NA
Spain	3	0	NA
Ukraine/Romania	2	0	NA
Denmark	0	0	NA
Sweden	0	0	NA
Global	**-**	**-**	**345**

**Source: EIA 2015 World Shale Resources, Attachment A*

***Source: ISC & WPV (2013) (approximate values)*

****Note: The value for the US was recovered from the EIA website[67], and was updated in April 2015.*

Currently, the US is the biggest LTO producer.[68] The production from the Bakken shale (US) started on a small scale in 1950, increasing significantly in 2000s and more steeply after 2005, reaching 669 000 barrels/day in 2012. US LTO production went from 1 000 barrels/day in 2005 to 840 000 barrels/day in 2011. Drilling is shifting from gas to oil in several locations in North America, including the Eagle Ford play in Texas, in the Niobrara play in Colorado, Utah and Wyoming, in various plays in California (including the Monterey play) and in the Cardium and Exshaw plays in Canada.

[67] http://www.eia.gov/analysis/studies/worldshalegas/

[68] ISC & WPC (2013), "World Petroleum Council Guide - Unconventional Oil"

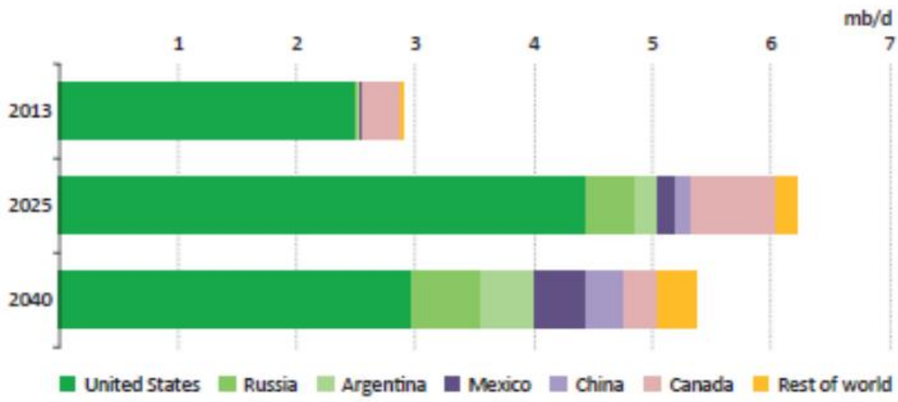


Figure 8. LTO production by country in the IEA WEO 2014 New Policy scenario (IEA WEO 2014 New Policy Scenario, cited by JRC, 2016)

The break-even oil price for an LTO development is around USD 60/b.[69]

5.3 Main technologies used

LTO extraction requires the same technologies as for unconventional tight gas and shale gas production. This includes drilling more wells, using horizontal drilling and hydraulic fracturing[70] to improve the oil flow from the reservoir towards the well bore. More information can be found in deliverable 1.2. The oil does not require further treatment before refining.[71]

5.4 Key challenges

LTO has higher viscosity and lower compressibility than gas, making its extraction from shale rock more challenging. The primary recovery rate is very low (5-10%)[72] and production declines rapidly. This leads to constant drilling activity, and ultimately more wells per unit of production volume when compared to conventional oil. Therefore, higher investments as well as further technology development are needed.

As for shale gas, regulatory constraints and environmental concerns could hinder developments.[73]

Waters consumption and potential contamination of water sources are also issues. 0.2 b to 4 b of water are consumed during hydraulic fracturing for each barrel of oil recovered – which can amount to up to 20 000 m^3 of water per well for drilling and fracturing.[74] After fracking, 30% to 70% of the water injected flows out of the well and must be treated for disposal or reuse.[75] Potential contamination of water courses can occur due to disposal of flowback and produced water which often contains residual fracturing fluid (which is 99.5% water along with substances found in the reservoir and chemical additives such as "acid, friction reducer, surfactant, gelling agent and scale inhibitor").

[69] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future".
[70] Fracking generates cracks in the rock formation, allowing the oil to flow
[71] ISC & WPC (2013), "World Petroleum Council Guide - Unconventional Oil".
[72] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future".
[73] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future".
[74] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future".
[75] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future".

5.5 Future outlook and potential impact

Estimates indicate that production could exceed 3 million barrels/day by 2020 in the US.

Currently, secondary and tertiary recovery are being investigated as means to increase recovery rates. Technologies to reduce water consumption (or which require no water use) and an increase in water reuse will be necessary.

6. Tight gas

6.1 Definition and context

ñNatural gas trapped in extremely low-permeable and low-porous rock, sandstone or limestone formations. Such gas may contain condensates.ò[76]

6.2 Mapping resources

Resources are concentrated in Canada (15% of total natural gas production in 2011), United States, southern part of North Sea. Production costs range between $4 and $8/GJ.[77]

6.3 Main technologies used

Technologies enable (1) drilling of long horizontal wells from a single surface location, (2) opening (fracturing) of rock so that the gas can flow to the wells and (3) finding ñsweet spotsò in a large reservoir. Sweet spots are areas where permeability and porosity are significantly higher than the average values in the reservoir.

Hydraulic fracturing (ñfrackingò) refers to creating cracks in the rock through which the gas can flow to the wells. A fluid of water, sand and chemical additives (ôproppantõ) is injected at very high pressure so that the cracks stay open. Note that this technology is banned in certain European countries, such as France and Bulgaria.[78]

To tap a very thick stack of many thinner reservoirs, a dense pattern of deviated or horizontal drilling is combined with multiple fractures along the hole.[79]

ñDrilling wells and hydraulic fracturing are costly processes, but improvements in procedures have brought significant cost reductions.ò[80]

6.4 Key challenges and environmental issues

The gas has to travel through low-permeable rock. Wells should be in contact with a large reservoir, so that the distance the gas has to flow through extremely low-permeability rock is reduced.[81]

Regarding environmental issues, there are risks that hydraulic fracturing fluids that have been disposed of could open up routes connected with potable aquifers. Concerns have also been raised in densely populated areas due to the very dense patterns of surface wells drilled.

[76] IEA (2013), ñResources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Futureò.
[77] JRC (2012), ñUnconventional Gas: Potential Energy Market Impacts in the European Unionò.
[78] IEA (2013), ñResources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Futureò.
[79] IEA (2013), ñResources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Futureò.
[80] IEA (2013), ñResources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Futureò.
[81] IEA (2013), “Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future”.

6.5 Future outlook and potential impact

Technological developments are focused on improving the fracturing process, as well as disposing of the fracturing fluids.[82]

[82] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future".

7. Coal-bed methane

7.1 Definition and context

ñMethane adsorbed on to the surface of coal within coal seams.ò[83]

ñNatural gas trapped in coal seams, adsorbed in the solid matrix of the coalò[84]

Difference between CMM and CBM:

Strictly speaking, coal mine methane (CMM) is the portion of CBM that is released during mining. In practice, CBM and CMM usually refer to different sources of gas, with CMM referring to gas released from working coal mines and CBM referring to the gas in coal seams that are uneconomic to mine (due to its depth, thickness or poor quality of its coal).[85]

7.2 Mapping resources

Resources are concentrated in countries with coal mines. China has extensive coal deposits with a naturally gaseous nature. It has the worldõs third-largest reserves with a resource base of around 37 tcm at depths under 2 000 m.[86]

The technology has already been used for a few decades (e.g. in Australia since 1998); however, interest is increasing lately. The total CBM production in Australia, China, India and Indonesia is expected to increase from 14.9 mcm (2009) to 64.9 mcm in 2015.[87]

Countries producing CBM include: USA (7% of domestic gas production in 2010), Canada (8% of total gas production in 2010) and Australia (21% of total domestic gas production in 2011), upcoming in China, India, Russia, Indonesia.

7.3 Main technologies used

The main process involves releasing methane from the surface of coal when a coal seam is disturbed during mining or drilling. Although conventional technology is used in its recovery (i.e. using well-bores), the application of these technologies is quite different from conventional gas. A lot more water is needed (either naturally occurring or introduced during fracking) to capture the methane. To extract the gas, a steel-encased hole is drilled into the coal seam 100 to 1,500 metres below ground (less deep than conventional gas). Fracking fluid is forced into the coal seam causing the coal to fracture. The fluid and ground water is then pumped to the surface (ñdewateringò), and the pressure on the trapped methane gas is released (ñdesorptionò). Methane gas flows to the surface and is collected

[83] IEA (2013), ñResources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Futureò
[84] JRC (2012), ñUnconventional Gas: Potential Energy Market Impacts in the European Unionò
[85] IEA (2013), ñResources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Futureò
[86] IEA (2013), ñResources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Futureò
[87] IEA (2013), ñResources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Futureò

through tubing.[88] The produced water is either reinjected into isolated formations, released into streams, used for irrigation, or sent to evaporation ponds (not recommended, see environmental issues).

7.4 Key challenges and environmental issues

Compared to conventional gas winning, the use of water in CBM leads to additional operational requirements, increased investment and environmental concerns.[89] There is also the risk of gas explosions in mines.

Environmental concerns include the disposal of water. Even with treatment, it is unlikely that all of the water produced could be used. Some CBM reservoirs are also underground sources of drinking water and, as such, there are restrictions on hydraulic fracturing.[90] On the other hand, injecting CO_2 to displace CBM may offer advantages for the environment.[91]

7.5 Future outlook and potential impact

An upcoming technology is **enhanced coal-bed methane (ECBM)** would allow producing (additional) CBM from a source rock (similar to enhanced oil recovery applied to oil fields). CO_2 is injected into a bituminous coal bed, allowing for potential enhanced gas recovery. This technique may be used in conjunction with carbon capture and storage. It can also be used as a secondary production phase of CBM. Technology is not mature enough yet to control uncertainties and there has been limited follow-up on ñfirst generation testsò after 2005.[92]

[88] EY (2010), ñShale gas and coal bed methane. Potential sources of sustained energy in the futureò
[89] IEA (2013), ñResources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Futureò
[90] MPNG (2016), ñProduction of Coal-Bed Methane (CBM)ò
[91] IEA (2013), ñResources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Futureò
[92] https://www.iea.org/media/workshops/2012/ukraine/Van_Bergen.pdf

8. Methane Hydrates

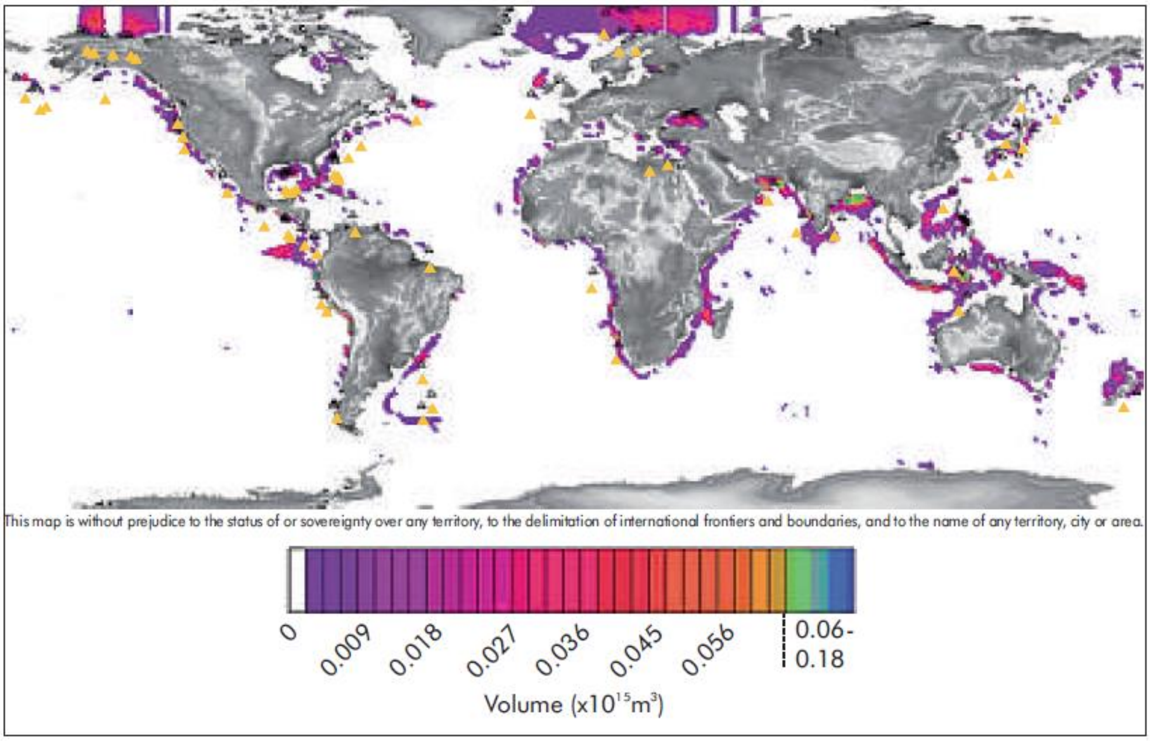
8.1 Definition and context

ñMethane hydrates are made up of methane molecules trapped in a solid lattice of water molecules under specific conditions of temperature and pressure.ò[93]

8.2 Mapping resources

Methane hydrates are thought to be the most abundant source of hydrocarbon gas on earth. The amount of natural gas in hydrate accumulations may be in the range of 1 000 tcm to 5 000 tcm (IEA, 2009), but there is great uncertainty and some estimates are much higher.[94] These potentially enormous resources are mainly found in coastal regions and the Artic region.[95] They can be found in permafrost Arctic regions at 200 m to 1 000 m depth or on the seabed between 500 m and 1 500 m water depth.

The greatest amounts of methane in hydrate form are predicted to be in the Arabian Sea, the western coast of Africa and near Peru, Chile and Bangladesh.[96] In Europe, it only seems interesting for Ireland and perhaps Spain, France, and Italy (see figure).



Note: triangles denote observed hydrates at seabed depths of less than 3 000 m.

Figure 9 Global volume distribution of methane hydrates (IEA, 2013)

[93] IEA (2013), ñResources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Futureò
[94] IEA (2013), ñResources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Futureò
[95] IEA (2013), ñResources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Futureò
[96] IEA (2013), ñResources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Futureò

8.3 Main technologies used

At the moment, there is no production.

8.4 Key challenges

Methane hydrates require very specific conditions of pressure and temperature to form and be stable. If removed from those conditions, it will quickly dissociate into water and methane gas.[97] Production safety issues also include disturbances to the surrounding sedimentary layers due to drilling also sometimes called "geohazards". The extraction of methane hydrate requires a different skill-set and more expertise.[98]

8.5 Future outlook and potential impact

Significant production in the short or medium term is not anticipated. [99]

[97] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future"
[98] NAS (2009), "Realizing the energy potential of methane hydrate for the United States"
[99] IEA (2013), "Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future"

9. Conclusion

Work Package 1 aims to map all the potential ónewô sources of carbon for the processing industry (including those from CO or CO_2 containing gas streams from industrial processes, shale gas or other unconventional carbon resources in Europe). In this paper we present our findings regarding the potential of on unconventional carbon resources, excluding CO/CO_2 emissions and shale gas (presented in deliverable 1.1 and 1.2).

The IEA defines unconventional hydrocarbons as ñany source of hydrocarbons that requires production technologies significantly different from those used in currently exploited reservoirsò, while recognising the imprecision and time dependence of this definition. We have investigated heavy oil (including oil sands or tar sands); oil shale (or kerogen oil), light tight oil (including shale oil), tight gas, coal-bed methane, and methane hydrates. Unconventional hydrocarbon resources in Europe are limited. For example, there are only 13 proven crude oil reserves in Europe compared to 226 in the US. Similarly, heavy oil reserves in Europe (0.2 billion barrels of oil in Italy) are a small fraction of the total reserves in the World (59.1 billion barrels of oil). We have identified several production challenges including significant capital investment, environmental issues such as those related to fracking, risk of gas explosions, large water demands and water contamination for CBMõs as well as a need for stable conditions in terms of pressure and temperature which requires a large amount of resources.

We conclude that the potential in Europe is very low and the environmental concerns are very high. We therefore do not foresee that these sources will have an impact on Europeõs processing industry and we propose to disregard them from further research.

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11. Glossary

API gravity	The American Petroleum Institute (API) determined a measure of how heavy or light a petroleum liquid is compared to water. If the API gravity is greater than 10°, it is lighter and floats on water. If it is less than 10°, it is heavier and sinks. Although, mathematically, API gravity has no units, it is still referred to as being in "degrees". The API scale was devised so that most values would fall between 10 and 70 API gravity degrees.
Bitumen	Any of the different mixtures of hydrocarbons, which present as tar. These are often found together with their non-metallic, naturally occurring derivatives, or they can be obtained as residues after refining processes have taken place.
Carbon dioxide (CO_2)	A colorless, odorless, non-poisonous gas that is a normal part of Earth's atmosphere. Carbon dioxide is a product of fossil-fuel combustion as well as other processes. It is considered a greenhouse gas as it traps heat (infrared energy) radiated by the Earth into the atmosphere and thereby contributes to the potential for global warming. The global warming potential (GWP) of other greenhouse gases is measured in relation to that of carbon dioxide, which by international scientific convention is assigned a value of one.
Carbon monoxide (CO)	Is a colourless, odourless, tasteless, poisonous gas produced by incomplete burning of carbon-based fuels, including gas, oil, wood and coal.
Coal-to-liquids (CTL)	The result of converting coal to a liquid fuel, a process known as coal liquefaction. This can be done via direct or indirect liquefaction.
Conventional oil	Petroleum which is recovered through wellbores and typically requires minimal processing prior to sale.
Extra heavy oil	Extra-heavy oil differs from natural bitumen in the degree by which it has been degraded from the original conventional oils by bacteria. Extra-heavy oil has a gravity of less than 10° API and a reservoir viscosity of no more than 10,000 centipoises (density greater than 1000 kg/m^3).
Fracking / Hydraulic fracturing	The process of creating small fissures, or fractures, in underground formations to release oil or natural gas. It involves the use of high pressure truck-mounted pumps to push water, sand and chemical additives into a formation to create fractures. These fractures are propped open by the sand to allow the oil or natural gas to flow into the wellbore for collection at the surface.
Gas-to-liquids (GTL)	A refinery process used to convert natural gas or other gaseous hydrocarbons into longer-chain hydrocarbons, such as gasoline or diesel.
Heavy oil	Asphaltic, dense, viscous oil with a low API gravity. Oil with API gravity from 10° to 20° or 22° (density above 1000 kg/m^3). It is chemically characterised by its content of asphaltenes.
In-situ	A relatively new method used to extract bitumen from oil sand that is buried too deep beneath the surface to be mined with a truck and shovel. In-situ technology injects steam below the surface to separate the viscous bitumen from sand and then pumps it to the surface before upgrading. In-situ is Latin for "in place".
Kerogen	A solidified mixture of organic compounds. This mixture releases crude oil and natural gas when it is heated inside the Earth's crust. It is found in shale deposits where it can be exploited as shale oil or shale gas.
Kerogen oil / Shale oil	Unconventional oil extracted from shale rock by processes such as pyrolysis, underground mining and surface mining. These techniques convert the organic matter within the rock (also known as kerogen) into synthetic oil. This oil can be used as a fuel or upgraded to meet refinery stock specifications by adding hydrogen and removing impurities. The products can be used for the same

	purposes as those which come from crude oil
Light oil	Also known as ñconventional oilò, light oil has an API gravity of at least 22° and a viscosity less than 100 cP.
Oil sands / tar sands	Loose sand or partially consolidated sandstone containing naturally occurring mixtures of sand, clay, and, water saturated with a dense and extremely viscous form of petroleum (bitumen). Bitumen is a thick, sticky form of hydrocarbon, so heavy and viscous (thick) that it will not flow unless heated or diluted with lighter hydrocarbons. Bitumen has a viscosity greater than 10,000 centipoises under reservoir conditions and an API gravity of less than 10° API. The bitumen is extracted and processed using surface mining or in-situ processes.
Oil shale	Solid sedimentary rock that contains kerogen. Oil shale can be used to produce liquid hydrocarbons called shale oil (not tight oil) and oil shale gas (not shale gas). Best deposits of oil shale have more than 40% organic content and 66% conversion ratio into shale oil and gas.
Permeability	The property or condition of being permeable. Also refers to the rate of flow of a liquid or gas through porous material.
Reserves	Discovered quantities of hydrocarbons which are economically extractable at prevailing prices and current technologies.
Resources	All quantities of hydrocarbons which are estimated to be initially-in-place.
Tight gas	Natural gas that is found in low-permeability rock (including sandstone, siltstones, and carbonates), and is difficult to access because of the nature of the rock and sand surrounding the deposit. Tight gas is produced using hydraulic fracturing and horizontal drilling.
Tight oil	Light crude oil that is contained in shales with relatively low porosity and permeability. It is produced using horizontal drilling and hydraulic fracturing, the same technologies used in the production of shale gas. It differs from shale oil by the API gravity and viscosity. Also the method of extraction is different.
Unconventional resources	Hydrocarbons that are more difficult to produce. Resources such as shale gas, shale oil, tight gas, and tight oil, coal seam gas/coal bed methane and hydrates.
Upgrading	The process in which heavy oil and bitumen (extra heavy oil) are converted into lighter, more usable crude oil by increasing the ratio of hydrogen to carbon. This is normally done by either coking or hydroprocessing.
Viscosity	The property of a fluid that resists the force tending to cause the fluid to flow, or the measure of the extent to which a fluid possesses this property.

** Extracted from ISC & WPC (2013) and WEC (2016)*

12. Annex

12.1 How to measure resources

There are several ways in which the available amount of hydrocarbon resources is measured. However, it is important to highlight that “unconventional resource estimates are less reliable than those of conventional resources. They have generally been less thoroughly explored and studied, and there is less experience of exploiting them.”[100]

The **Petroleum Resources Management System (PRMS)**[101] “classifies resources and reserves according to the level of certainty about recoverable volumes and the likelihood that they can be exploited profitably. The classification applies to both conventional and unconventional resources.”[102] It covers the **production, reserves** (deposits that are viable commercially), **contingent resources** (deposits that are not yet viable[103]) and **unrecoverable resources**.[104]

The **JRC** uses the term **technically recoverable resources** (TRR), which – given the limited production experience of unconventional resources - takes no account of economic viability or any other constraints on resource recovery.[105]

The IEA[106] uses the term r**eserves** for resources that can be recovered economically with available technologies. Depending on the degree of certainty they are classified as proven, probable and possible reserves; while **other remaining recoverable resources** refer to resources that cannot be recovered economically or that “are based on geological research but are yet to be discovered”. The financial viability depends on oil price and technology availability.

IEA classification (Left) **PRMS (Right)**

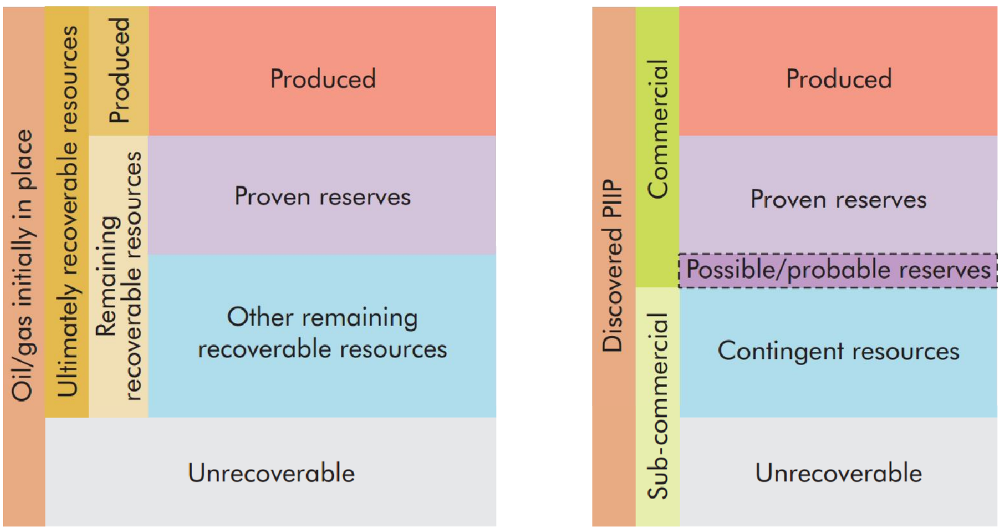

Figure 16. Classification systems for resources. Source: IEA (2013)

[100] IEA (2013), “Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future”
[101] Developed in an effort to harmonise approaches to classifying reserves. The PRMS was published in 2007 by the Society of Petroleum Engineers (SPE), the World Petroleum Council, the American Association of Petroleum Geologists (AAPG) and the Society of Petroleum Evaluation Engineers (SPEE). This system is compatible with the 2004 UN Framework Classification for Fossil Energy and Mineral Resources (UNFC), developed by the UN Economic Commission for Europe (UNECE).
[102] IEA (2013), “Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future”
[103] E.g. exploitation is not yet properly defined and approved, or essential technology developments are not yet completed.
[104] IEA (2013), “Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future”
[105] JRC (2012), “Unconventional Gas: Potential Energy Market Impacts in the European Union”
[106] IEA (2013), “Resources to Reserves - Oil, Gas and Coal Technologies for the Energy Markets of the Future”