polinares
EU Policy on Natural Resources

*POLINARES is a project designed to help identify the main global challenges relating to competition for access to resources, and to propose new approaches to collaborative solutions*

**POLINARES working paper n. 23**
**March 2012**

# Unconventional Oil

**By Georg Babies and Jürgen Messner**

EUROPEAN COMMISSION
European Research Area
SEVENTH FRAMEWORK PROGRAMME
Funded under Socio-economic Sciences & Humanities

The project is funded under Socio-economic Sciences & Humanities grant agreement no. 224516 and is led by the Centre for Energy, Petroleum and Mineral Law and Policy (CEPMLP) at the University of Dundee and includes the following partners: University of Dundee, Clingendael International Energy Programme, Bundesanstalt fur Geowissenschaften und Rohstoffe, Centre National de la Recherche Scientifique, ENERDATA, Raw Materials Group, University of Westminster, Fondazione Eni Enrico Mattei, Gulf Research Centre Foundation, The Hague Centre for Strategic Studies, Fraunhofer Institute for Systems and Innovation Research, Osrodek Studiow Wschodnich.

# 11 Unconventional Oil

*Georg Babies, Jürgen Messner*

**Amongst the unconventional types of petroleum, oil shale is the energy resource with the highest energy demand for turning it into a liquid energy fuel. A cost and energy-efficient production method of exploiting oil shale oil is not in sight for the near future. Up to now, the easy availability and the cheap price of conventional petroleum prevented the expansion of the oil shale industry. With increasing world market prices for petroleum, however, for a few geologically and logistically well-placed oil shale occurrences an economic production might become reality in the not too distant future.**

## 11.1 Oil Sands – High-Viscosity Oil in Sandstone

A uniform definition of the term unconventional oil is currently not accepted. The pragmatic reason for the differentiation between conventional and unconventional oil is the greater technical effort and expenditure for extracting unconventional oil. Unconventional oil comprises bitumen or crude oil from oil sands, extra-heavy oil and crude oil from oil shale. Thus the denomination unconventional refers to geological aspects of the formation and properties of the deposits as well as technical necessities for an ecologically acceptable, economical exploitation.

Oil sands are naturally occurring mixes of bitumen, water, sand and clay. On average, oil sands contain approximately 12 wt. % bitumen, a high-viscosity petroleum. The individual grains of sand are coated by a thin film of water of some µm and this in turn is surrounded by the high-viscosity oil. Oil produced from oil sands is also called natural bitumen or synthetic crude oil (SCO). It is a sticky, high-viscosity form of petroleum, which behaves like cold syrup at room temperature. Up to 50 % or 60 % it consists of substances comparable to conventional oil, 25 % to 35 % are resins and 15 % up to 25 % are asphaltenes. The components of the oil itself vary with the region of occurrence just as do traces of heavy metals, such as iron, molybdenum, nickel or vanadium. On average, the percentage of carbon is little more than 80 % that of hydrogen is around 10 %, sulfur ranges from 3 % to 5 %, dissolved oxygen is 0.9 % and nitrogen ranges from 0.36 % to 0.7 %. Bitumen has a density of more than 1 g/cm$^3$ (≤10° API) and a viscosity of more than 10 000 mPa·s. In the reservoir, bitumen is not capable of flowing.

In general, heavy oils and all transitions up to bitumen are the results of secondarily altered, previously conventional petroleum occurrences. Reservoir rock is generally highly porous and permeable fluviatile sandstone of deltaic or very near-shore sedimentary environments. In the case of the gigantic Canadian oil sand occurrences, the oil migrated from the deeper source rocks of the western Canadian sedimentary basin over a lateral distance of up to 360 km into the more shallow sandstones of the Aptian and Albian (upper Lower Cretaceous). Here, organic mudstones of the Devonian or Carboniferous are considered petroleum source rocks. In the course of its migration the petroleum was biodegraded by microorganisms in the rock. The light hydrocarbon molecules were degraded in the course of the microbial activity, the heavy, complex molecule chains were left behind and today make up the bitumen rich in sulfur in the deposits.

Oil sand occurrences are known in more than 20 countries (figure 1 and table 1), in nearly 600 individual occurrences (WEC, 2007). The total potential of petroleum in oil sands all over the world is extraordinary large and has been assessed at about 462 Gt in-place. Of these, Canada and the CIS together possess 98 %. The best-known and most important oil sand occurrences are located in Canada. The Energy Resources Conservation Board (ERCB) of Canada estimates that approximately 26.9 Gt of crude oil in oil sands in the state Alberta have to be regarded as reserves. This corresponds to about 17 % of the reserves of conventional petroleum. The reserves and resources of the countries with the greatest oil sand occurrences should largely be regarded as estimates, as the data basis for many countries is still rather inadequate.

Even if the oil sand occurrences are distributed over many countries, the greatest part of the resources is concentrated in Canada, Russia and Kazakhstan. Of these, the Canadian occurrences have been investigated most thoroughly. Thus, the data on the amount of resources are still unreliable, last but not least because the distinction between heavy oil, extra-heavy oil and oil sands is not clear. Thus, of the estimated 200 Gt of unconventional oil in the CIS about half are oil sands. A major portion of these occurrences is bound to carbonate reservoir rocks, whose treatment is technically even more difficult than for oil sands. The largest occurrences in Russia are supposed to be in the Tunguska Basin on the East Siberian Shelf, in the Timan-Pechora Basin and in the Volga-Ural Basin. In principle, it can be assumed that the resource data for oil sands in Russia are underestimated.

Even though for Kazakhstan large bitumen occurrences in the North Caspian Basin are known, their possible exploitation will not be started in the foreseeable future because of the still abundant conventional hydrocarbons. The oil sand occurrences in the US are distributed over several states, with the largest in Utah and Alaska, further smaller occurrences in California, Alabama, Kentucky and Texas. Large-scale mining is not intended here either, as either the geological setting is too complicated, the oil sands are located too deeply or are too thin. The bitumen occurrences in the Dahomey-Basin in southwestern Nigeria will only be considered, when the reserve situation of the conventional oil of the country decreases. In Indonesia, bitumen occurrences on the island Buton are known, but up to now they have only been mined for manufacturing road asphalt. For nearly 200 years, asphalt from an asphalt lake on Trinidad has been mined, which is also used as tarmac. The annual production here is 10 000 to 15 000 t.

Considerably smaller oil sand occurrences are known in Angola, Gabon, the Republic of Congo and the DR Congo. They are bonded to Cretaceous sandstones. In Europe, marginal occurrences in Germany, France, the Netherlands, Poland, Romania, Spain, Switzerland and Hungary are known. The most interesting occurrences from an economic point of view of combined heavy oil/extra-heavy oil/asphalt in Europe occur in Sicily/Italy. Here, heavy and extra-heavy oil have been produced since the 1950s.

The greatest and best-known oil sand occurrences are the **oil sands of Canada** in the northern part of the Province Alberta. They cover a surface of more than 140 000 km$^2$, which is mainly located in the three regions Athabasca, Peace River and Cold Lake. Currently, Canada is the only producer of importance of bitumen from oil sands. Already in 1967, then still with public subsidies, the bitumen production from oil sands was started. Only approximately 16 Gt, corresponding to 6 % of the *in-place* oil sand volume will presumably be available for surface mining. The remaining amounts are located too deeply and can only be produced using drill holes and in-situ processes. Canada quantifies its *in-place* volume of bitumen currently at about 270 Gt, of which 26.9 Gt are listed as reserves (ERCB, 2011). Taking into account the proportion accessible for surface mining and the in-situ areas as well as the different degrees of oil recovery, oil sand resources of 81.9 Gt remain. Between 2000 and 2007, the crude oil production from oil sands in Canada has doubled from 35 to 69 Mt per year. 2010 production increased to about 85 Mt crude oil. For 2010, this corresponds to more than 2 % of the global production of petroleum.

Oil sands are produced by surface mining (ex-situ) as well as using the so-called in-situ process, for which the bitumen viscosity is reduced by the injection of steam. The oil can finally be pumped out like conventional crude oil. Both processes are aimed at extracting the petroleum or bitumen, respectively, and they are technically and energetically complex.

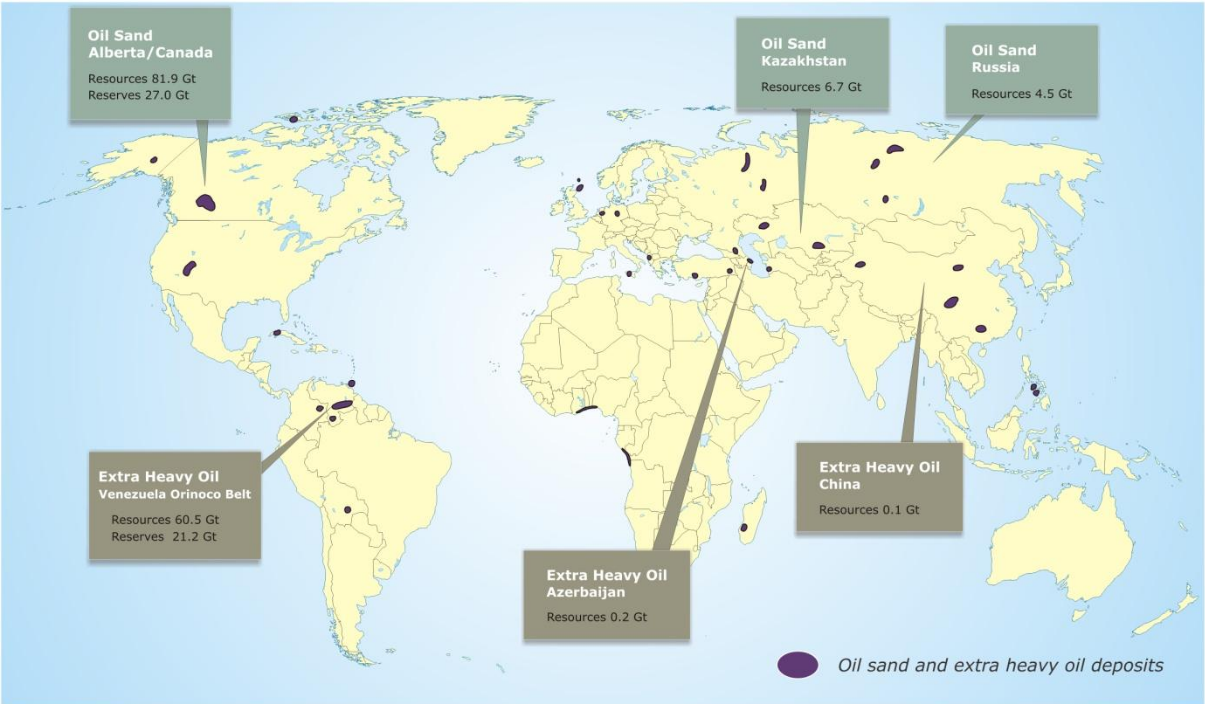


**Figure 1: Distribution of the known worldwide occurrences of oil sand and extra heavy oils with information on reserves, resources and production.**

**Table 1: The World's Most Important Oil Sand Deposits**

| Country | Resources (Mt) | Reserves (Mt) | cum. Production (Mt) |
|---|---|---|---|
| Canada | 81,853 | 26,900 | 1,194.3 |
| Russia | 4,500 | - | NA |
| Kazakhstan | 6,700 | - | NA |
| Nigeria | 90 | - | NA |
| Angola | 200 | - | NA |
| Madagascar | 35 | - | NA |
| Indonesia | 70 | - | NA |
| Italy | 30 | - | NA |
| Congo, DR | 5 | - | NA |
| Congo, Rep | 1 | - | NA |
| China | 25 | - | NA |
| USA | 850 | - | NA |
| Trinidad & Tobago | 10 | - | NA |
| **total** | **94,369** | **26,900** | **1,194.3** |

## *11.2 Extra-Heavy Oil*

Extra-heavy oil with a density of ≥1.0 g/cm³ is similar to the bitumen of the oil sands, but its viscosity is less than 10 000 mPa·s. Thus, extra heavy oil in the reservoir is more capable of flowing than the bitumen of the oil sands. The sulfur content is on average around 5 %, nickel and vanadium contents are 130 ppm or up to more than 700 ppm. Deposits of extra-heavy oil are regionally widespread and are known in at least 18 countries in the world in more than 160 fields.

The total amount of the extra-heavy oil resources is, in accordance with WEC (2007) and Oil & Gas Journal (2010), about 60 Gt, of which approximately 21 Gt are listed as reserves. About 1 Gt of extra-heavy oil have been produced up to now. Venezuela contributes 35 % of the global production, followed by Great Britain at 28 % and Azerbaijan at 21 %.

The increase of the crude oil prices since 2000 has triggered increased investments in the area of extra-heavy oil and resulted in a considerable increase in production. Even though the high-viscosity oil is more difficult to produce, to transport and to process than conventional oil, the production level has risen from approximately 20 Mt in 2001 to 93 Mt in 2005. One problem with the assessment of extra-heavy oil is the difficulty of delineating it from other heavy oil. The information concerning extra-heavy oil can also contain proportions of heavy oil of unknown amounts.

The worldwide largest occurrences of extra-heavy oil are located in the so-called Orinoco Belt in Venezuela with more than 60 Gt of petroleum resources and 21.2 Gt reserves. In 2005, the annual production of conditioned extra-heavy oil was approximately 33 Mt and thus 20 % of the total oil production of Venezuela, the third largest crude oil exporter in the world. The Orinoco Belt constitutes the southern edge of the East Venezuela Basin or Maturin Basin and extends at a width of 50 km to 100 km and about 700 km in east-west direction. The deposits are largely related to Miocene sandstones in depths of 500 m to 1000 m, which rest on

Cretaceous, Paleozoic and Precambrian crystalline of the Guyana Shield. Towards the north, where the basin is deeper, the extra-heavy oil successively turn into light oil. The petroleum mainly dates back to the Cretaceous and Oligocene up to Miocene source rocks. The oil has migrated between 100 km and 150 km from the petroleum source until it reached today's reservoirs. During migration, the originally lighter petroleum was biodegraded to heavy and extra-heavy oil.

The production of extra-heavy oil is generally conducted using the same in-situ production processes as for the oil sand production. The injection of water vapor in vertical wells, but also the SAGD-process have become established because of the relatively good recovery rates. For the production of extra-heavy oil, new processes, which are even more efficient, are permanently looked for. For example, the so-called cold production is being tested, where horizontal wells are used to open a large section of the oil reservoir. It is attempted to extract sand and oil simultaneously from the deposit by adding solvents. Pilot tests using this method yielded production rates of 130 to 400 t/day with recovery factors of up to 20 %.

Currently, four major projects are active in the Orinoco Belt. The treatment of the extra-heavy oil to produce SCO is only conducted right before it is exported, as Venezuela has a limited availability of light oil for diluting the heavy oil. For this reason, the processing plants are located at the north-east coast of Venezuela. The conversion efficiency from extra-heavy oil to synthetic oil varies from 87 % to 95 %.

In the Orinoco Belt, approximately 42 Mt of extra-heavy oil were produced in 2005. In order to adhere to the specified production levels of the OPEC, the production of extra-heavy oil has been reduced by about 17 500 t/day (6.3 Mt/a) since the beginning of 2007.

**Table 2: Global Distribution of Extra Heavy Oil Fields**

| Country | Resources [Mt] | Reserves [Mt] | cum. Production [Mt] |
|---|---|---|---|
| Venezuela | 60,500 | 21,200 | 600 |
| China | 119 | NA | 22 |
| Azerbaijan | 20 | NA | 121 |
| Italy | 14 | NA | 28 |
| UK | 12 | NA | 160 |
| Egypt | 8 | NA | NA |
| Cuba | 8 | NA | NA |
| Ecuador | 7 | NA | 8 |
| Albania | NA | 3 | 3,0 |
| Columbia | 5 | NA | 1 |
| USA | 76 | 3 | 34 |
| Trinidad & Tobago | 5 | NA | NA |
| Peru | 1 | NA | 3 |
| Russia | 1 | NA | NA |
| Canada | 1 | NA | NA |
| Mexico | <1 | NA | 1 |
| Poland | <1 | NA | NA |
| Israel | <1 | NA | NA |
| **total** | **60,777** | **21,206** | **981** |

## 11.3 Oil Shale – Petroleum still to be generated

Oil shale is actually an immature petroleum source rock with a high proportion of organic material, which has not yet passed the geological conditions to turn into petroleum under natural conditions. The origin of oil shale can be a widely varied spectrum of depositional areas, consisting of ponds, lakes and swamps with fresh and salt water as well as the flat marine environment in the subtidal shelf area. Lithologically, oil shale originates frequently from calcareous mudstone and can have geological ages ranging from Cambrian to Tertiary. The organic material in oil shale, so-called kerogen, consists mainly of carbon, hydrogen and oxygen with small amounts of sulfur and nitrogen. Thermal treatment of the oil shale allows the extraction of oil. This oil derived from oil shale differs from natural petroleum by its higher percentage oxygen compounds.

Unfortunately the term shale oil is not to be confused with oil shale. Shale oil or tight oil is a light crude oil contained in formation of relatively low porosity and permeability like in shales. The same horizontal well and hydraulic fracking technology is being used as in production of shale gas. It is conventional oil, produced using unconventional means. The fact that the exploration for and the production of shale oil is a very recent development, reliable data for resources or reserves are insufficient or not available.

The **extraction of oil shale** can be done by surface mining for shallow overburden from 30 m to 40 m. For this purpose a minimum thickness of the oil shale layer of 3 m and an overburden-oil shale ratio of less than 5:1 is advisable. In areas with thicker overburden, such as the deposits in Estonia, the oil shale is produced using underground mining. The rock containing oil shale is blasted and crushed in a stone crusher (Vaher, 1998). The material can then be processed differently. Either it will be burned directly for power generation purposes, like in Estonia, or by coking or carbonization higher-order hydrocarbons can be extracted, for instance in carbonization reactors, so-called retorts, with downstream distillation plants (e. g. Lurgi-Ruhrgas Process). For the in-situ method, oil shale is pyrolysed in the deposit without extracting it. Oxygen is added through drill holes to the ignited oil shale and the resulting gases are processed further. In particular deep oil shale occurrences, such as the Devonian Black Shales in the East of the US can only be exploited using the in-situ process. In the US there are currently experiments being run concerning the in-situ pyrolysis based on heating the rock electrically.

In order to extract crude oil from oil shale, the process of oil generation, which takes several millions of years under natural conditions and requires an increase of the temperature conditions, has to be accelerated by an artificial process. To this end, the oil shale is heated to 300°C up to 500 °C for pyrolysis purposes and subsequently cooled down to below 50 °C. The kerogen is converted to a gas mixture, out of which the so-called shale oil condenses during cooling. For an efficient use of oil shale, a minimum content of about 4 % oil is required. This corresponds to a gross calorific value of approximately 3300 kJ/kg in relation to the waterless oil shale. The oil content of oil shale is defined on the laboratory scale in accordance with the standardized pyrolysis process by Fischer–Schrader (Fischer Assay), which supplies reliable data about the technological quality.

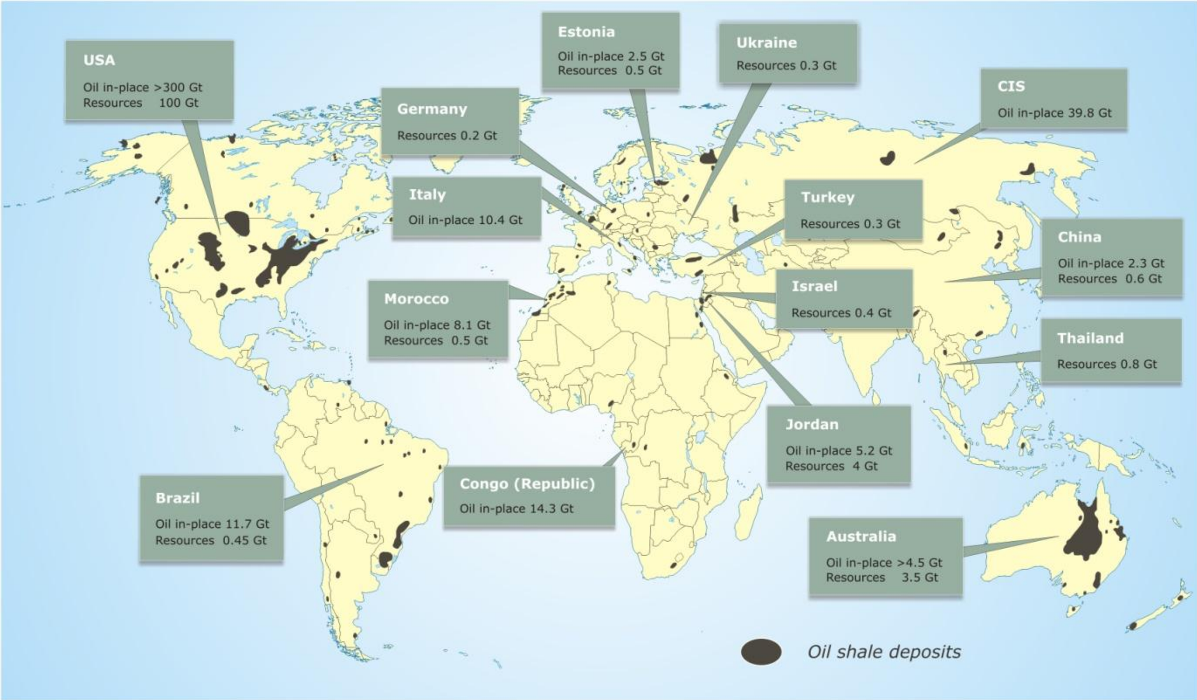


**Figure 2: Regional distribution of the oil shale occurrences worldwide with data concerning reserves, resources and production.**

The global total potential of oil shale oil resources is currently estimated to be more than 110 Gt of shale oil. Oil shale occurrences are known in nearly 40 countries of the world. The majority of the amounts of shale oil resources are possessed by the US (approximately 90 %), followed by Jordan, Australia and Thailand at together 7.5 %. Currently, many important parameters for the assessment of the contained crude oil potential are missing for many oil shale occurrences, thus global data concerning extractible amounts of shale oil are very uncertain. For example the CIS-countries have huge amounts of oil shale in-place in the order of 40 Gt but data concerning the producible amounts of oil are not known. Even though all of these data are very uncertain, the globally extractable resources of oil shale oil of about 110 Gt are regarded as conservative estimate, as for many countries there are no data available up to now.

Amongst the unconventional types of petroleum, oil shale is the energy resource with the highest energy demand for turning it into a liquid energy fuel. A cost and energy-efficient production method of exploiting oil shale oil is not in sight for the near future. Up to now, the easy availability and the cheap price of conventional petroleum prevented the expansion of the oil shale industry. With increasing world market prices for petroleum, however, for a few geologically and logistically well-placed oil shale occurrences an economic production might become reality in the not too distant future. But even countries with few occurrences of conventional petroleum and natural gas, which have considerable oil shale deposits, are interested in producing oil from oil shale, to decrease their energy imports in the long run. In all, this development in the past years resulted in re-assessments of oil shale resources, the development of improved conditioning technologies and new pilot projects. Only few deposits have been used to produce oil shale. These are located in Estonia, China, Brazil, Germany and Israel. Only in the three first-mentioned countries, oil has been extracted from oil shale in the past years. In all, in 2005 approximately 684 000 t of crude oil were manufactured worldwide, of which Estonia with 345 000 t has produced slightly more than half, followed by China with 180 000 t and Brazil with 159 000 t.

**Table 3: Global Distribution of Oil Shale Deposits**

| Country | Oil Resources [Mt] |
|---|---|
| USA | 100,000 |
| Jordan | 4,000 |
| Australia | 3,559 |
| Thailand | 810 |
| China | 637 |
| Estoina | 500 |
| Morocco | 500 |
| Brazil | 445 |
| Israel | 400 |
| Ukraine | 300 |
| Turkey | 269 |
| Germany | 150-180 |
| Spain | 9 |
| Hungary | 6 |
| total | 111,585 |

**References**

ERCB (Energy Resources Conversation Board) (2011): Alberta's Energy Reserves 2010 and Supply/Demand Outlook 2011-2019.

Oil & Gas Journal (2010): Total reserves, production climb on mixed results, 06.12.2010, Vol. 108, Issue 46.

Vaher, E. (1998): Sprengarbeiten beim Ölschieferabbau in Estland: In: Glückauf 6/1998, p. 284-289.

WEC (World Energy Council) (2007): 2007 Survey of Energy Resources, London. 586 p.