Unconventional Oil & Gas Production

HIGHLIGHTS

- **PROCESSES AND TECHNOLOGY STATUS –** The unconventional oil and gas resources include: ■ **Extra heavy oil** (oil with high viscosity and API gravity of less than 10°.); ■ **Oil sand** (sand containing bitumen); ■ **Oil shale** (sedimentary rock containing kerogen); ■ **Tight gas** (natural gas with low permeability); ■ **Coal bed methane** (CBM, natural gas associated with coal); ■ **Shale gas** (nat. gas associated with shale oil); and ■ **Natural gas hydrates** (structures of water ice trapping natural gas). The Orinoco belt in Venezuela has a production capacity at 570 kb/d of extra heavy oil. Canada is the only country with commercial extraction of oil sand. The oil sand production was 1.3 mb/d in 2008. Oil shale is currently exploited in Brazil, China, Germany and Israel. In 2005, the worldwide oil shale production was 5 mb. North America is the continent with largest production of unconventional gas. The US production in 2006 was 161 bcm of tight gas, 51 bcm of CBM and 31 bcm of shale gas. Currently, there is no commercial production of gas hydrates. Development and production of unconventional oil and natural gas resources requires processes and technologies that differ considerably from those used for conventional resources in terms of energy input, cost and environmental impact. Because of the high viscosity, extra heavy oil does not flow easily at reservoir conditions. There are several techniques to decrease viscosity and facilitate extraction using steam injections, horizontal wells and multilateral technologies. Oil is extracted by surface mining or by in-depth in-situ mining (without physical extraction). In in-depth mining, the extra heavy oil is extracted from drilled wells where, for example, steam is injected to allow the bitumen to flow to the well head. Oil shale can be combusted directly or converted to oil by heating rocks in the absence of oxygen (retorting). Oil shale mining also includes basically two options, the surface mining (most common) and in-situ retorting using, for example, underground heating systems. Tight gas, CBM and shale gas extraction technologies include hydraulic fracturing and horizontal wells to allow the fluids to flow more easily through a well. As natural gas hydrates exist a high pressure and low temperature, gas production methods are based on thermal and inhibitor injection, and depressurisation.

- **PERFORMANCE AND COSTS –** Production of unconventional oil is an energy intensive process that requires significant amounts of heat. The energy used as a percentage of the energy produced is about 20 -25 % for extra heavy oil, 30 % for oil sand and 30 % for oil shale, as compared to 6 % for conventional oil and gas. The ratio between energy used to energy produced is relatively small for tight gas, CBM and shale gas. The associated emissions depend on the energy used in the production process. Natural gas is the most common fuel used for heating purposes during production. Associated CO_2 emissions range from 9.3 to 15.8 g/MJ for oil sand and extra heavy oil, and from 13 to 50 g/MJ for oil shale. Production of tight gas, CBM and shale gas involves lower emissions compared to unconventional oil due to lower energy requirement. The production cost of extra heavy oil and oil from sand ranges from $6.6 to $13.1/GJ. Oil from oil shale is more costly and ranges from $8.2 to $19.7/GJ. As a comparison, the cost of conventional oil ranges typically between $1.6 to $6.6/GJ, with some exceptions. Production costs of unconventional natural gas range from $2.6 to $7.6/GJ for tight gas, from $3.8 to $7.6/GJ for CBM and from $3,8 to $8.6/GJ for shale gas. The estimated production cost of natural gas from hydrates is between $4.4 and $8.6/GJ, but little or no practical experience exists. For comparison, the production costs of new conventional natural gas resources range from $0.5/GJ to $5.7/GJ, with some exceptions. In general, production costs of unconventional resources are projected to decline in relative terms as well as the extraction technologies improve

- **POTENTIAL AND BARRIERS –** At the end of 2005, estimated unconventional resources were: 2484 BBL of extra heavy oil; 3272 BBL of oil sand; 2826 BBL of oil shale; 210 tcm of tight gas, 256 tcm of CBM, 456 tcm of shale gas and between 1000 and 5000 tcm of natural gas from hydrates. The Orinoco belt in Venezuela have the largest extra heavy oil deposits with about 2 200 BBL and a production capacity at 570 kb/d. The largest oil sand deposits are located in the Western Canada. The United States have the largest oil shale resources. Asia pacific is the region with largest estimates of tight gas and shale gas, while the Former Soviet Union has the largest CBM resources. Estimates of unconventional resources availability and prospects for production vary significantly in the literature. The role of unconventional resources in the future depends on developments in production technologies, on future market demand, and on the development of other energy sources. According to Mohr and Evans (2010), the peak production for unconventional oil would range between 49 mb/d in 2076 and 88 mb/d in 2084. Oil shale is estimated to offer the largest potential followed by oil sands and extra heavy oil. At present, unconventional gas resources are mainly produced in North America and in this region the production is expected to increase towards 2030.

Please send comments to Pernille.Seljom@ife.no, Author, and to
Giorgio.Simbolotti@enea.it and Giancarlo Tosato (gct@etsap.org), Project Coordinators

PROCESSES AND TECHNOLOGY STATUS - The unconventional resources[1] covered in this brief are[2]: **Extra heavy oil** (oil with high viscosity); **Oil sand** (sand containing bitumen); **Oil shale** (rocks containing kerogen, a solid bituminous materials); **Tight gas** (natural gas with low permeability) **Coal Bed Methane, CBM** (natural gas associated with coal that is not profitable for extraction); **Shale gas** (natural gas associated to oil shale); and **Natural gas hydrates** (natural gas trapped in the structure of water ice).

Table 1 shows resources, reserves and cumulative production of extra heavy oil, oil sand and oil shale as estimated at the end of 2005. out of the 2484 billion barrels (BBL) of extra heavy oil resources, only 60 BBL were considered economically profitable and approved for production. The cumulative production amounted to 27% of the reserves (16 BBL). Some 166 extra heavy oil deposits have been discovered in the world [1]. The largest one is the Orinoco Oil Belt in Venezuela, with estimated resources of 2200 BBL and a production capacity of 570 thousand barrels per day (kb/d) [1]. As for bitumen from oil sand, at the end of 2005 the estimated global resources were 3272 BBL, of which only 256 BBL economically profitable for production. The cumulative production was 2% of the reserves (5 BBL). Some 586 recorded oil sand deposits exist in 22 countries. The largest deposits are located in the Western Canada sedimentary basin where the three oil sand areas, Athabasca, Peace River and Cold Lake contain about two thirds of the world resources. Canada is the only country where oil sand are commercially extracted to produce synthetic crude oil. The oil sand production was 1.3 million barrels per day (mb/d) in 2008 [24]. With 3272 BBL at the end of 2005, oil sand is the largest unconventional oil resource. For comparison, the 2005 estimate of worldwide conventional oil reserves was 1215 BBL. Also, at the end of 2005, oil shale resources were estimated at 2826 BBL, mostly located in the United States. They are currently exploited in Brazil, China, Estonia, Germany and Israel [10], but the 2005 production was only 5 mb.

Tab. 1 – Unconventional oil resources, reserves and production [1]

Extra Heavy Oil	Resources BBL	Reserves BBL	Cumulative Production BBL
L. America	2 448	59	14.
(Venezuela)	*2 446*	*59*	*14.*
Asia	18	0.8	0.9
Others	19	0.3	1.4
World	**2 484**	**60**	**16.5**
Nat. Bitumen			
N. America	2 451	174	5
(Canada)	*2 397*	*174*	*5*
Asia	427	42	0.0
Europe	349	29	0.0
Others	6	1.5	0.0
World	**3 272**	**246**	**5**
Oil Shale			**Product. 2005 MBL**
N. America	2 100	NA	0.0
United States	*2085*	NA	0.0
Africa	159	NA	0.0
Europe	368	NA	2.5
Others	198	NA	2.5
World	**2 826**	NA	**5**

Tab. 2 - Unconventional natural gas resources [3, 4]

Region	Tight gas tcm	CBM tcm	Shale gas tcm
M. East & N. Africa	23	0	72
Sub-Saharan Africa	22	1	8
F. Soviet Union	25	112	18
Asia Pacific	51	49	174
N. America	39	85	109
L. America	37	1	60
Europe	12	8	16
World	**210**	**256**	**456**
Easy Accessible	**100**	**180**	**380**
US product. (bcm)			
1996	102	31	8
2006	161	51	31

Table 2 shows the regional distribution of the unconventional gas resources. Shale gas is the largest resource with 456 trillion cubic meter (tcm), followed by CBM with 180 tcm and tight gas with 210 bcm. North America is the continent with the largest unconventional gas production. In the United States between 1996 and 2006, the total production of unconventional gas has increased by 72%, mostly based on tight gas. Natural gas hydrates are by far the largest unconventional gas resource, with estimated resources between 1000 and 5000 tcm [3]. Their exploitation requires however improved technologies and at present there is no commercial production of natural gas hydrates.

■ **Extra Heavy Oil –** Because of the high viscosity, extra heavy oil does not flow easily and some deposits are too viscous to flow at reservoir conditions. There are several techniques to reduce viscosity. A traditional production technology is the Cycle Steam Simulator (CSS) that involves steam injection in the reservoir (through wells) to heat the viscous oil.

[1] Resources are deposits measured by field observation and expected additional deposits. Reserves are exploitable deposits that are profitable and approved for production.

[2] Bitumen "also called tar sands or oil sands, shares the attributes of heavy oil but is yet more dense and viscous. Natural bitumen is oil having a viscosity greater than 10,000 cP." Extra heavy oil "is that portion of heavy oil having an API gravity of less than 10°." Heavy oil "is an asphaltic, dense (low API gravity) and viscous oil that is chemically characterized by its content of asphaltenes (very large molecules incorporating most of the sulfur and perhaps 90 percent of the metals in the oil). Although variously defined, the upper limit for heavy oil has been set at 22° API gravity and a viscosity of 100 cP." "Kerogen is a mixture of organic chemical compounds that make up a portion of the organic matter in sedimentary rocks.[1] It is insoluble in normal organic solvents because of the huge molecular weight (upwards of 1,000 Daltons) of its component compounds. The soluble portion is known as bitumen".

Please send comments to Pernille.Seljom@ife.no, Author, and to
Giorgio.Simbolotti@enea.it and Giancarlo Tosato (gct@etsap.org), Project Coordinators

The mixture of steam, condensed water and heated oil are then pumped to the surface. A new, more recent technology is the Steam Assisted Gravity Drainage (SAGD), which implies two horizontal wells. Steam injected in the upper well heats the ground to reduce oil viscosity and allow oil to flow down and to be extracted through the lower horizontal well. In the Orinoco Belt, in Venezuela, the most used recovery technique is more simple as extra heavy oil can flow at reservoir conditions through horizontal wells using multilateral technology (several wells drilled in the same reservoir). However, at present, the Orinoco fields have a low recovery factor. The expected recovery factor in that area is between 8% and 12% [1] and the use of in-situ viscosity reduction techniques could significantly increase the recovery rate. At the surface conditions, the oil is too viscous to be transported by pipeline. Therefore, oil upgrading or the use of heated pipelines is needed.

■ **Oil Sand -** Oil sand, also called tar sand, contains about 83% sand, 10% bitumen, 3% clay and 4% water [5]. Bitumen is the heavy oil extracted from oil sand. Oil sand can be mined from either the surface or by in situ mining[3]. Oil sand located within a 75-m depth is considered suitable for surface mining. Of the remaining reserves, about 80% are considered recoverable by in-situ methods and 20 % is considered recoverable by traditional mining [6]. In surface mining, the oil sand is shovelled by large devices and driven to an extraction facility. About 90% of the bitumen is recovered in the process [7]. The separation of oil from sand is done by using hot water and chemicals. After the extraction, oil can be sold as raw bitumen or upgraded to a lighter hydrocarbon called synthetic crude oil. The upgrading is done by increasing the ratio of hydrogen to carbon by either removing carbon (coking) or adding hydrogen (hydro-cracking). The production of 1 barrel oil from surface mining requires removal of at least two tons of oil sand [5, 6]. In in-situ mining, steam is injected into wells to allow the bitumen to flow to the well head. In-situ mining techniques include the most used Cycle Steam Simulator (CSS) and the new, promising Steam Assisted Gravity Drainage (SAGD), also used for the extra heavy oil production. In 2008 Canada had two large CCS facilities in operation producing around 200 kb/d and 6 large SAGD facilities producing about 130 kb/d [8]. As in the case of extra heavy oil recovery, CCS is based on steam injection into vertical wells, with bitumen being pumped up to the surface using the same well. SAGD involves hot steam injection through horizontal wells, and the bitumen pumped out from a second horizontal located below the first one. The SAGD process requires thick and clean deposits, but needs less energy input and offers higher bitumen recovery, i.e. about 70% against 25%–30% from CCS [7]. Oil production from oil sand is a water consuming process. It takes about 2 to 3 barrels of water for one barrel of bitumen [5]. The water however is often recycled. If so, water requirement decreases to about 0.5 barrel water per barrel of oil [5].

[3] In-situ mining is mining production without physical extraction of materials from the ground. Methods to recover deeply buried bitumen deposits include steam and solvent injection.

■ **Oil Shale -** Oil shale is a porous rock containing kerogen, an organic bituminous material. Would it have been buried deep enough and at high temperatures, kerogen would have been converted into oil and natural gas. As a consequence, oil shale resources are generally located at shallow depths. Oil shale can be combusted directly or converted into oil by retorting, i.e. kerogen heating up to 500°C in the absence of oxygen. The resulting product is a liquid with high concentration of nitrogen and other impurities that needs an upgrading process [9]. Oil shale mining processes include surface retorting (most common) and in-situ retorting, the second one being profitable when oil shale traditional mining is too costly because of the site characteristics. While surface mining involves low technical risks, in-situ retorting needs tight control of ground water to prevent environmental problems. Techniques involving underground oil-shale heating may access resources at greater depth. Shell is currently developing a new in-situ conversion process where oil shale is heated using electrical heaters placed in vertically drilled wells. After a heating period of 2 to 3 years, the shale is converted into oil and flows through the production wells. The in-situ process may include "freezing walls" created by pumping cooling fluids through a set of wells around the extraction area [10]. In 2010, Shell is expected to decide whether this technology will be commercialised [13].

■ **Tight and Shale Gas -** Natural gas with low permeability (below 0.1 mD) does not flow easily. Low-permeability natural gas is called tight gas when it is contained in oil rock and shale gas when it is in shale rock. This resource can not be developed profitably by vertical wells because of low flow rates. Production of tight and shale gas require hydraulic fracturing or horizontal wells. Hydraulic fracturing consists of pumping a fluid into wells to increase pressure and produce fractures in the formation rock. In order to keep the fracture open after the injection stops, sand with high permeability is added to the fracture. Horizontal wells techniques provide greater surface area in contact with the deposit compared to vertical wells, and enables more effective gas transfer and recovery of the gas in place. Today's technology is only suitable for onshore production and offers a maximum recovery rate of 20% of the volume in place [3]. These production technologies have significant potential for improvements as there is a lack of basic research on tight and shale gas production. So far, current production techniques have been developed based on empirical approaches.

■ **Coal Bed Methane –** In coal deposits, significant amounts of methane-rich gas are generated and stored within the coal structure. The gas is normally released during mining but more recent practices aimed to capture and extract the gas not only for safety and environmental reasons, but also for economic exploitation. CBM however is typically methane gas trapped within coal deposits that are not profitable for extraction because of high depth or poor coal quality.

Coal beds have low permeability that decreases with increasing depth. Therefore, hydraulic fracturing and/ or horizontal wells are needed to easy the fluid to flow through a well. Because of the pressure, water permeates into coal and traps the gas. It is then extracted again thus reducing the pressure and enabling methane to flow out of the coal through the well. Figure 1 shows a typical production curve of CBM, with volumes of methane and water production over time. In the first phase, a large amount of contaminated water is produced, which is usually re-injected in the formations. Today's research efforts aim to develop techniques based on CO_2 injections into coal bed formations to enhance methane production. The easy CO_2 adsorption by coal helps methane to be released and offers significant potential for CO_2 geological storage and reduction of CO_2. in the atmosphere.

■ **Natural Gas Hydrates -** Natural gas hydrates (also known as clathrates) are solid gas molecules surrounded by a lattice of water molecules. They are formed by water and natural gas (methane) at high pressures and low temperatures. In such conditions they are rather stable or dissociate very slowly. At present, in oil and gas industry, natural gas hydrates are seen as a problem rather than as a resource. Formation of "snow alike" hydrates can damage oil and gas pipelines and cause problems in well drilling. Three basic methods exist for gas hydrate exploitation as an energy resource, i.e. *depressurisation*, *thermal injection* and *inhibitor injection*. In some cases, hydrates are located above gas reservoirs and dissociate as the production of natural gas reduces the underground pressure. *Depressurisation* is therefore the easiest method to extract hydrates and implies a few technical challenges. However, well depressurisation does not necessarily reduce the pressure of entire hydrate layer. In general, more research is needed to improve understanding of hydrates behaviour. In *thermal Injection* techniques, steam and hot water are injected into the well to decompose hydrates and generate gas. A challenge in this process is that hydrates are often found at deep locations and injected fluids are cooled before it reaches the hydrate layer. *Inhibitors injection* techniques are used in offshore natural gas pipelines to prevent hydrate formation. Injection of inhibitors like methanol will dissolve methane from the hydrate and the gas is released. More research is needed to ensure that the inhibitor is evenly distributed through the hydrate layer. Ongoing research efforts are also exploring if compact hydrate structures can be used to transport natural gas over long distances.

PERFORMANCE AND COSTS – Extraction of unconventional oil and natural gas resources requires processes and technologies that differ considerably from those used for conventional resources in terms of energy input, cost and environmental impact. The energy input used in conventional oil and natural gas production is about 6% of the energy produced. To produce unconventional oil and gas resources the energy required in the process is much more. **Extra heavy oil** production requires about 20% to 25%

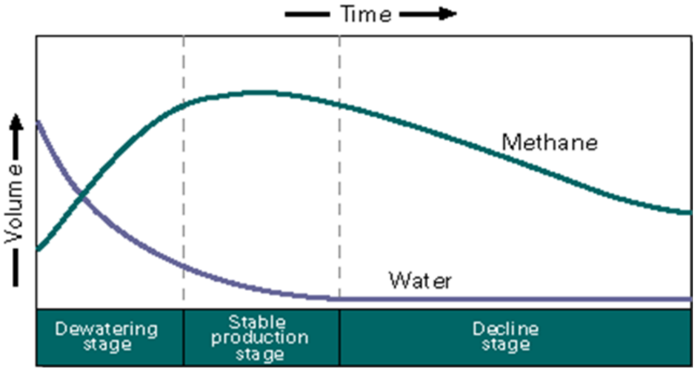

Fig 1 - Typical CBM production curves. (Source: [11])

energy input [17]. In the Canadian **oil sand** industry, the steam needed in the extraction processes is mostly produced from natural gas and the energy input amounts to about 30 billion cubic meter (bcm) for heat production and 15 bcm for bitumen upgrading [17]. The energy required for oil production from oil sand (in-situ and open pit mining) amounts to up to 30 % of the energy contained in the extracted oil [18]. For in-situ processes, steam requirement is a critical factor that is accounted for by the steam to oil ratio (SOR, i.e. the volume of steam required to produce a unit volume of oil). Many oil companies aim to a SOR of 2.5 but very few projects have achieved this target [22]. Natural Resources Canada assumes a SOR of 3.2 for SAGD and 3.4 for CCS [19]. In the Canadian SAGD projects using natural gas for steam production, one barrel of bitumen needs between 1 and 1.25 GJ natural gas [5]. **Oil shale** retorting also requires an energy input of about 30% of the energy produced [17]. The energy required to extract oil from shale by electrical heating is estimated between 250 and 300 kWh per oil barrel [20]. **Unconventional gas** (tight gas, CBM and shale gas) production is less energy intensive than unconventional oil production. The ratio of the energy used to the energy produced is rather small, but no study is available in the literature.

Of course, the **greenhouse gas emissions** associated to the unconventional oil and gas production depend on the amount of energy used in the process and on the type of energy source used. Figure 2 shows the greenhouse gas emissions from liquid fossil fuel production. The emission range is lower for oil sand and heavy oil if compared to oil shale. Emissions ranges from 28 to 46 gCO_2/MJ for tar sand and heavy oil and from 44 to 69 gCO_2/MJ for oil shale, including 20 gCO_2 per MJ of final energy from fuel combustion. While these data include emissions from production and combustion, in the rest of the discussion only emissions associated to production are referred to. Table 3 shows the CO_2 emissions from the production processes of oil sand, extra heavy oil and shale oil. If natural gas is used for steam production, the emissions for heavy oil production are 14 gCO_2/MJ, given a natural gas consumption of 45 m^3 per barrel [1]. Charpentier et. al. have reviewed some thirteen studies of greenhouse gas (GHG) emissions from oil sand production based on different reservoir characteristics, technologies and emission levels (Fig. 3). The emissions associated to

Please send comments to Pernille.Seljom@ife.no, Author, and to
Giorgio.Simbolotti@enea.it and Giancarlo Tosato (gct@etsap.org), Project Coordinators

the production of synthetic crude from oil sand are between 10.2 and 26.9 gCO_2/MJ (62 and 164 $kgCO_2$/bbl) for surface mining and upgrading, and between 16.2 and 28.9 gCO_2/MJ (99 and 176 $kgCO_2$/bbl) for in-situ techniques and upgrading. For comparison, the emissions from conventional oil production are between 4.4 and 4.7 gCO_2/MJ (27 and 58 $kgCO_2$/bbl). According to the study by APO Netherlands the CO_2 emissions from **oil shale** production are as high as 232% to 892% of the emissions resulting from conventional production [23].

Production costs for unconventional oil are referred to reserves. Table 4 provides production cost ranges for unconventional extra heavy oil, oil sand and oil shale. While production costs of conventional oil from new discoveries is typically between \$1.6/GJ and \$6.6/GJ, (with some significant exceptions) [13], the costs for unconventional oil range from \$6.6/GJ to \$19.7/GJ, with shale oil being in general more expensive than extra heavy oil and oil from tar sand. The capital cost component for oil sand production depends on global steel prices, construction costs of facilities. Major operational costs relate to the fuel source [14]. Figure 4 shows the historical oil sand production cost for Canadian oil sand by mining and by in-situ extraction (1 US$_{2000}$=1.6 US$_{2008}$). Technology developments in oil sand extraction by mining and upgrading have been leading to significant cost reductions from 1985 to 2003. Production costs for easy accessible unconventional natural gas resources are also presented in Tab. 4. Production cost of conventional natural gas from new-discovery range from \$0.5/GJ to \$5.7/GJ [3] (with some exceptions) while costs for unconventional gas range from \$2.6/GJ to \$8.6/GJ. Natural Resources Canada has estimated that the production cost of natural gas hydrates by depressurisation is between \$4.4/GJ and \$8.6/GJ [16].

FUTURE PROSPECTS – Significant uncertainties still exist on resource estimates for unconventional oil and natural gas. The future role of unconventional resources will depend on available resources, on developments in production technologies, on future demand for oil and gas, and on development of the other energy sources. In the Reference Scenario of the IEA Word Energy Outlook 2009 [3], the unconventional oil production is projected to increase from today's (2008) 1.8 mb/d to 7.4 mb/d by 2030. Mohr and Evans (2010) have modelled three future scenarios of unconventional oil production to 2200 (see Figure 5). The unconventional oil is divided into natural bitumen, extra heavy oil and shale oil. Three scenarios are presented: the production peak ranges between 49 mb/d in 2076 and 88 mb/d in 2084. The oil shale has the largest potential followed by natural bitumen and extra heavy oil. For unconventional gas resource, the majority of the production growth is expected in North America. Figure 6 shows the projected natural gas production in North America by the US Energy Information Administration including unconventional production. In the period 2010-2030, the shale gas is expected to double the production rate.

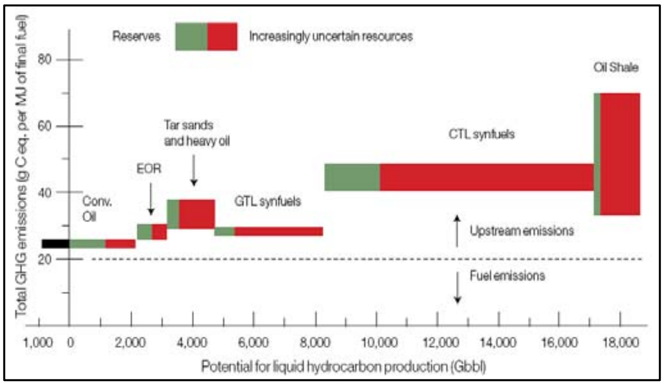

Fig. 2 – GHG emissions for liquid fuel production, [21]
(EOR Enhanced Oil Recovery; GTL Gas To Liquid; CTL Coal To Liquid)

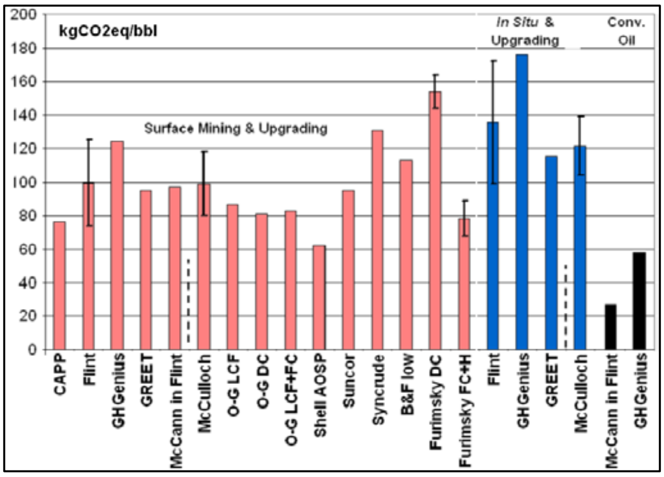

Fig. 3 – GHG emissions in synthetic oil production [22]

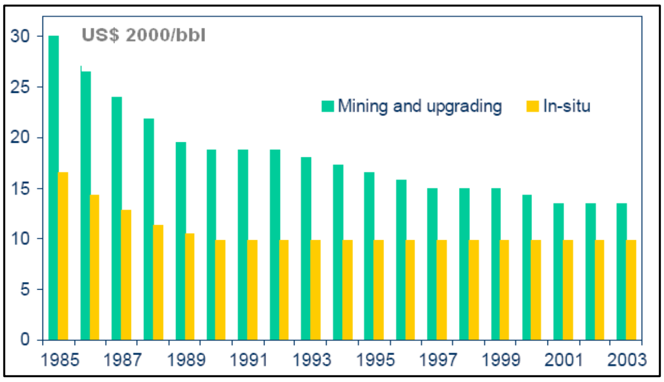

Fig. 4 – Production cost for Canadian oil sand [15]

Tab. 3 – Emissions in unconventional oil production (gCO_2/MJ), [23]	
Oil sand	9.3 – 15.8
Extra heavy oil	9.3 – 15.8
Oil shale	13.0 -50.0

Tab. 4 - Unconventional oil production cost [3, 13] (US$ 2008/GJ)		
Extra heavy oil	Oil Sand	Oil Shale
6.6 – 13.1	6.6 – 13.1	8.2 -19.7
Tight gas	CBM	Shale gas
2.6 – 7.6	3.8 – 7.6	3.8 – 8.6

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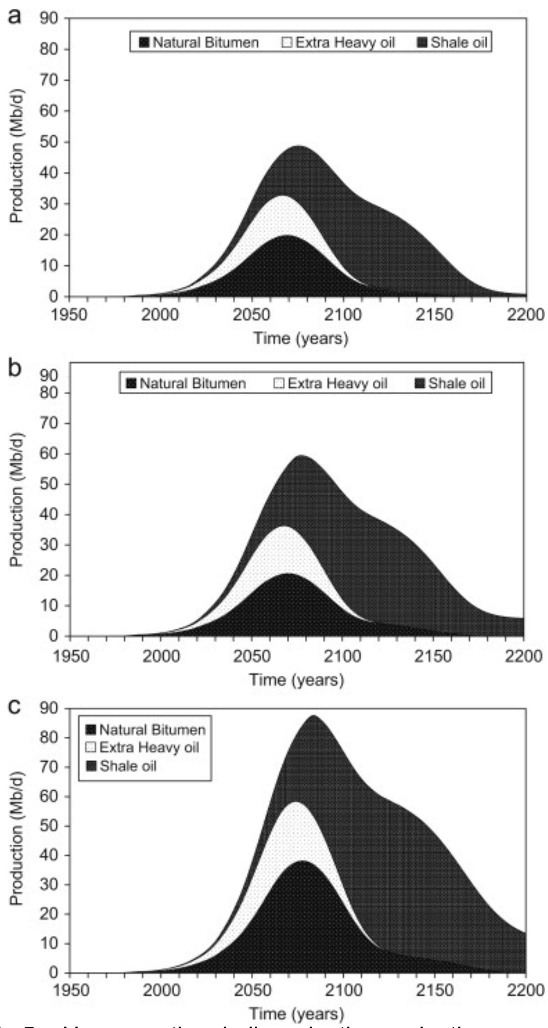

Fig.5 – Unconventional oil production projections: (a) pessimism; (b) best guess; (c) optimism, [25]

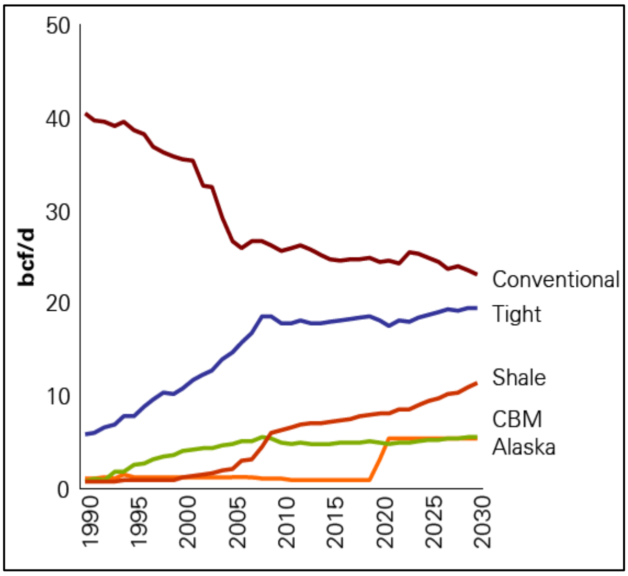

Fig.6 – Projections of unconventional natural gas production in North America, [26]

Table 5 – Summary Table : Key Data and Figures for Unconventional Oil and Gas Resources -

Definitions	
Extra heavy oil	Oil with high viscosity
Oil sand	Sand containing extra heavy oil (bitumen)
Oil shale	Rock containing a solid bituminous material (kerogen)
Tight gas	Natural gas with low permeability
Coal Bed Methane (CBM)	Natural gas associated with coal in non-profitable coal mines
Shale Gas	Natural gas with low permeability associated with oil shale
Natural gas hydrates	Natural gas trapped in the structure of water ice
Estimated Resources (2005)	
Extra heavy oil	2 484 BBL resources, 60 BBL reserves
Oil sand	3 272 BBL, 246 BBL reserves
Oil shale	2 826 BBL
Tight gas	210 tcm, 100 tcm easy accessible
Coal Bed Methane (CBM)	256 tcm, 180 tcm easy accessible
Shale Gas	456 tcm, 380 tcm easy accessible
Natural gas hydrates	1000 – 5000 tcm
Production method	
Extra heavy oil	Steam injection (CSS, SAGD), horizontal wells, multilateral well + upgrading
Oil sand	Surface mining, in situ mining with steam injection (CSS, SAGD) + upgrading
Oil shale	Heating in absence of oxygen (retorting), surface mining & in situ
Tight and Shale gas	Hydraulic fracturing, horizontal wells
Coal Bed Methane (CBM)	Hydraulic fracturing, horizontal wells
Natural gas hydrates	Depressurisation, thermal injection, inhibitor injection
Production Costs (US$2008)	
Extra heavy oil, $/GJ	6.6 – 13.1
Oil sand, $/GJ	6.6 – 13.1
Oil shale, $/GJ	8.2 – 19,7
Tight gas, $/GJ	2.6 – 7.6
Coal Bed Methane (CBM), $/GJ	3.8 – 7.6
Shale Gas, $/GJ	3.8 – 8.6
Natural gas hydrates, $/GJ	4.4 – 8.6
Energy usage	
Extra heavy oil	20 – 25 % of the energy value produced
Oil sand	30 % of the energy value produced
Oil shale	30 % of the energy value produced
Unconventional gas	NA
Emissions	
Extra heavy oil	9.3 – 15.8 gCO2eq/MJ, with natural gas as the energy input
Oil sand	9.3 – 15.8 gCO2eq/MJ, with natural gas as the energy input
Oil shale	13.0 – 15.0 gCO2eq/MJ, with natural gas as the energy input
Unconventional gas	Not Available

Please send comments to Pernille.Seljom@ife.no, Author, and to
Giorgio.Simbolotti@enea.it and Giancarlo Tosato (gct@etsap.org), Project Coordinators

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Please send comments to Pernille.Seljom@ife.no, Author, and to
Giorgio.Simbolotti@enea.it and Giancarlo Tosato (gct@etsap.org), Project Coordinators