

Comprehensive Evaluation and Development of Unconventional Hydrocarbon Reserves as Energy Resource

Ghareb M. Hamada*

Petroleum Engineering Department, Faculty of Geosciences and Petroleum Engineering, Universiti Teknologi Petronas

***Corresponding author:** Ghareb M Hamada, Petroleum Engineering Department, Faculty of Geosciences and Petroleum Engineering, Universiti Teknologi Petronas, Malaysia, E-mail: ghareb.mostafa@utp.edu.my

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Abstract

Today, the global energy industry is facing a growing number of uncertainties, including price volatility, rising demand and increasing costs which are leading to greater pressures for energy producers and consumers alike. Furthermore, almost a quarter of the world population has no access to modern energy and little hope of joining the world's energy consumers any time soon and unconventional energy resources can answer this question.

Conventional and unconventional oil and gas come from the same original geologic formations multiple layers in sedimentary basins all over the world and the recovery rate may also vary significantly from one reservoir to another. Unlike conventional reservoirs, unconventional gas reservoirs typically have very fine grain rock texture and complex geological and petrophysical system. Unconventional oil is petroleum extracted using techniques other than the conventional oil well method. Oil industries across the globe are investing in unconventional oil sources due to the increasing scarcity of conventional oil reserves. Unconventional oil and gas reserves include: 1) Tight oil and gas reservoirs, 2) Oil shale is an organic-rich fine-grained sedimentary rock containing significant amounts of kerogen from which technology can extract liquid hydrocarbons (shale oil) and combustible shale gas and 3) Unconventional gas reserves refer to sources of natural gas production that are, in a given era and location, considered to be new and different such as coalbed methane and synthetic natural gas.

This study presents comprehensive understanding of the latest advances in the exploitation and development of unconventional resources. It addresses all aspects of the exploitation and development process, from data mining and accounting to drilling, completion, stimulation, production, and environmental issues. It offers in-depth coverage of sub-surface measurements. This study concentrates on how to develop the conventional hydrocarbon reserve to keep its global production as effective as possible and how to activate the unconventional oil and gas reserve and proposing technology to optimize the recovery of the unconventional reserves as energy resources in 21st century either complement or new energy resources to the conventional hydrocarbon reserve.

Keywords: Conventional reserves; Tight gas; Oil shale; Shale gas; Coalbed methane; Forecasting & Development and Energy resources.

Introduction

Conventional petroleum resources are oil and gas found in reservoir rock that can be extracted using traditional methods, and with few wells for each basin. The oil and gas resources are usually from another formation but move into the sandstone and are trapped by an impermeable 'cap' rock. Conventional petroleum

resources are extracted using traditional methods of drilling down through the 'cap' rock and allowing petroleum to flow up the well. The resources that can be extracted from conventional petroleum reserves include crude oil, condensate and natural gas. The products that can be refined include liquefied petroleum gas, fuel oils, petrol, diesel, kerosene, asphalt base and others [1].

Decades of oil and natural gas production in North America and around the world have resulted in a decline of these conventional resources. Basically, most of the oil and natural gas that can be produced using traditional methods is already being accessed. As new technologies are introduced, oil and natural gas producers

are able to produce “unconventional” oil and natural gas resources that were previously impossible to obtain. Unlike the conventional pools of oil and natural gas, unconventional oil and natural gas do not flow naturally through the rock, making them much more difficult to produce. Think of the difference between a sponge and a piece of clay: it’s easy to squeeze water out of a saturated sponge that’s conventional oil and natural gas; squeezing water out of saturated clay is harder that represents unconventional oil and natural gas, and the challenge forces producers to find new ways to release the oil and gas. Unconventional often refers to low permeability rock where the pores are poorly connected, making it difficult for oil and natural gas to move through the rock to the well. Today, the global energy industry is facing a growing number of uncertainties, including price volatility, rising demand and increasing costs which are leading to greater pressures for energy producers and consumers alike. Furthermore, almost a quarter of the world population has no access to modern energy and little hope of joining the world’s energy consumers any time soon. It is clear that the current energy system is unsustainable. Can the unconventional oil and gas resources induce badly needed changes?

Unconventional petroleum resources are oil and gas found in a variety of rocks that need to be extracted using additional technology, energy or investment to release the resource from the source rock. Unconventional resource development usually requires extensive well fields and more surface infrastructure. Unconventional oil and natural gas shale gas in particular has been called the future of gas supply in North America and other places in the world, it has tremendous economic potential and we know that the interest in these considerable resources will increase. Key features of unconventional petroleum formations are low permeability and low porosity. Regardless of how they are produced or the rock they come from, unconventional oil and natural gas are essentially the same as their conventional counterparts. The term “unconventional” simply refers to the methods that are used, as well as the types of rock from which the oil and natural gas are produced. The Alberta Energy Regulator (AER) refers to unconventional natural gas as 1) tight gas: natural gas found in low-permeability rock, including sandstone, siltstones, and carbonates, 2) shale gas: natural gas locked in fine-grained, organic-rich rock and 3) coalbed methane (CBM): natural gas contained in coal [1,2].

Unconventional resources are natural resources which require greater than industry-standard levels of technology or investment to exploit. In the case of unconventional hydrocarbon resources, additional technology, energy and capital has to be applied to extract the gas or oil, replacing the natural action of the geological processes of the petroleum system. Examples of unconventional oil resources include oil shales, oil sands, extra-heavy oil, gas-to-liquids and coal-to-liquids. Oil shale is an example where a thermally immature source rock has not generated and expelled hydrocarbons. Oil or tar sands occur where conventional crude oil

has failed to be trapped at depth and has migrated near to the surface and has become degraded by evaporation, biodegradation and water washing to produce a viscous heavy oil residue. In contrast to conventional gas reservoirs, natural gas can also be found in more difficult to extract unconventional deposits, such as coal beds (coal seam gas), or in shales (shale gas), low quality reservoirs (tight gas), or as gas hydrates. Unconventional gas accumulations reflect the failure or under-performance of the petroleum system. This study addresses the different aspects of unconventional oil and gas resources which are geological, extraction and production and finally the environmental impact certain unconventional resources such as oil and shale gas industry. Gas has been produced from shale since the first shale-gas well in the organic rich Devonian Dunkirk shale in New York in 1821. Gas- shale productivity depends upon reservoir quality and successful execution of an effective hydraulic stimulation techniques.

Conventional Petroleum Resources

Oil reserves are the amount of technically and economically recoverable oil. Reserves may be for a well, for a reservoir, for a field, for a nation, or for the world. Different classifications of reserves are related to their degree of certainty.

The total estimated amount of oil in an oil reservoir, including both producible and non-producible oil, is called oil in place. However, because of reservoir characteristics and limitations in petroleum extraction technologies, only a fraction of this oil can be brought to the surface, and it is only this producible fraction that is considered to be reserves. The ratio of reserves to the total amount of oil in a particular reservoir is called the recovery factor. Determining a recovery factor for a given field depends on several features of the operation, including method of oil recovery used and technological developments.

Conventional petroleum resources are oil and gas found in sandstone that can be extracted using traditional methods, and with few wells for each basin. The oil and gas resources are usually from another formation but move into the sandstone and are trapped by an impermeable ‘cap’ rock. Conventional petroleum resources are extracted using traditional methods of drilling down through the ‘cap’ rock and allowing petroleum to flow up the well. The resources that can be extracted from conventional petroleum reserves include crude oil, condensate and natural gas. The products that can be refined include liquefied petroleum gas, fuel oils, petrol, diesel, kerosene, asphalt base and others. Both conventional and unconventional petroleum activities are regulated under the Environmental Protection Act 1994 and an environmental authority is required before any petroleum activity can begin. The environmental authority imposes conditions to reduce or avoid potential environmental impacts associated with the petroleum industry. In general, most early estimates of the reserves of an oil

field are conservative and tend to grow with time. This phenomenon is called reserves growth. Many oil-producing nations do not reveal their reservoir engineering field data and instead provide unaudited claims for their oil reserves. Global reserves of oil and gas will last only a few decades, according to a report given by BP analysts at the 21st World Petroleum Conference in Moscow on June 16. However, the experts identified Russia as one of four nations with excellent prospects for developing production of shale oil. Oil remains the main type of fuel in use around the world, but it has been losing ground to other forms of energy for 14 years now. Last year, petroleum accounted for less than 33 percent of energy usage. Foreign analysts calculate that global supplies of the “black gold” will suffice for 53 years, assuming the present rate of production continues, while just under 55 years of natural gas remain. The numbers disclosed by some national governments are suspected of being manipulated for political reasons, **Fig. 1** illustrates the top ten countries of estimated proven oil reserves and oil production in the world [2,3].

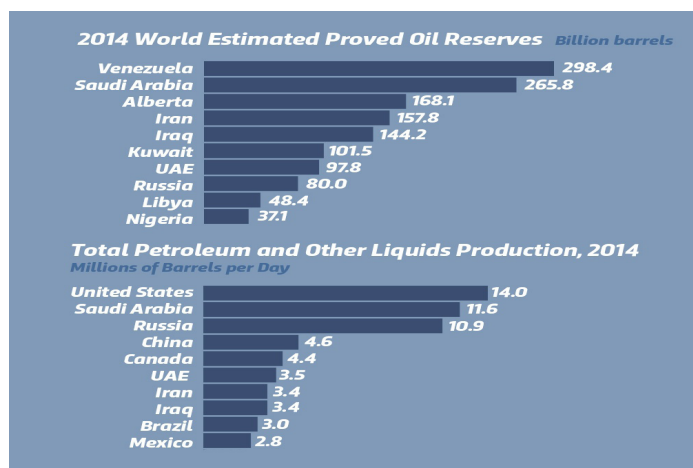


Fig 1: Top ten countries for proven oil reserve and oil production, year 2014 [2].

Unconventional Petroleum Resources

Conventional oil is a category that includes crude oil - and natural gas and its condensates. Unconventional oil is petroleum produced or extracted using techniques other than the conventional (oil well) method. Oil industries and governments across the globe are investing in unconventional oil sources due to the increasing scarcity of conventional oil reserves. Unconventional oil included “oil shales, oil sands-based synthetic crudes and derivative products coal-based liquid supplies, biomass-based liquid supplies, gas to liquid (GTL). This study covers selected examples of unconventional petroleum resources; oil shale, coalbed methane and tight oil & gas reservoirs **Fig 2** shows the interrelationship between reservoir permeability and its potential either conventional or unconventional [3,4].

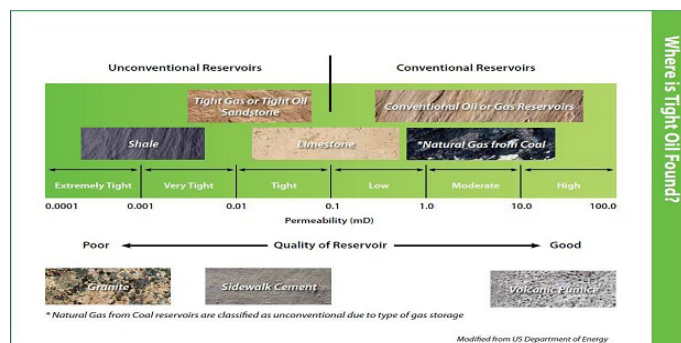


Fig 2: Unconventional and conventional reservoirs versus permeability [4].

Tight Oil and Gas Reservoirs

Most of us are familiar with oil and natural gas “pools” that are found underground. Pools are located in rock with tiny connected pore spaces that contain oil or natural gas. One common example is sandstone.

Decades of oil and natural gas production in North America and around the world have resulted in a decline of these conventional resources. Basically, most of the oil and natural gas that can be produced using traditional methods is already being accessed. As new technologies are introduced, oil and natural gas producers are able to produce “unconventional” oil and natural gas resources that were previously impossible to obtain. Unlike the conventional pools of oil and natural gas, unconventional oil and natural gas do not flow naturally through the rock, making them much more difficult to produce. Unconventional often refers to low permeability rock where the pores are poorly connected, making it difficult for oil and natural gas to move through the rock to the well [5,6].

Tight gas is natural gas produced from reservoir rocks with such low permeability that massive hydraulic fracturing is necessary to produce the well at economic rates. Tight gas reservoirs are generally defined as having less than 0.1 milliDarcy (mD) matrix permeability and less than ten percent matrix porosity. Although shales have low permeability and low effective porosity, shale gas is usually considered separate from tight gas, which is contained most commonly in sandstone, but sometimes in limestone. Tight gas is considered an unconventional source of natural gas. Rock with permeability as little as one nanodarcy, reservoir simulation may be economically productive with optimized spacing and completion of staged fractures to maximize yield with respect to cost.

Tight Oil and Gas Production

In the past, the oil and natural gas industry considered resources locked in tight, impermeable formations such as shale uneconomical to produce. Advances in directional well drilling and reservoir stimulation have dramatically changed this perspective. Economic production from tight oil formations requires the same hydraulic fracturing and often uses the same horizontal well tech-

nology used in the production of shale gas [6,7].

Tight oil does not flow naturally in the source rocks, which means that high density drilling is required to bring up as much oil as possible. Even so, only 1%-5% of the oil in place is expected to be recovered versus 60%-70% from conventional oil fields. Tight oil is more capital intensive per barrel of oil produced than deep water oil and the mega oil-sands projects that the major oil companies favor. Well costs for tight oil are typically in the \$8-10mn range per well, bringing them within the ambit of smaller oil companies. Moreover, since production can be ramped up within months of the start of drilling, cost recovery is swift, which suits the smaller operators, who are usually pressed for cash.

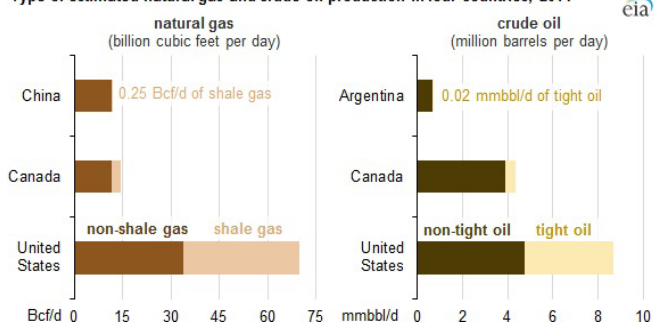
A tight oil project is likely to be successful if:

- There is good source rock
- Water for hydraulic fracturing is abundant
- The sub-surface mineral rights belong to individuals
- Drilling rigs and crews with the right skills are freely available
- The right infrastructure exists to collect and transport the oil to refineries [7].

Production Cost of Tight Oil and Gas

The present oil price collapse is because of over-production of expensive tight oil. The collapse occurred because of the inability of the world market to support the cost of the new expensive oil supply from shale, oil sands and deep water. Demand was progressively destroyed during the longest period of sustained high oil prices in history from 2010 through 2014. The United States, Canada, China and Argentina are currently the only four countries in the world that are producing commercial volumes of either natural gas from shale formations (shale gas) or crude oil from tight formations (tight oil). The United States is by far the dominant producer of both shale gas and tight oil. Canada is the only other country to produce both shale gas and tight oil. China produces some small volumes of shale gas, while Argentina produces some small volumes of tight oil. While hydraulic fracturing techniques have been used to produce natural gas and tight oil in Australia and Russia, the volumes produced did not come from low-permeability shale formations [7,8].

Type of estimated natural gas and crude oil production in four countries, 2014



Oil Shale

Oil Shale Reserve

Oil shale is a rock that contains significant amounts of organic material in the form of kerogen. Up to 1/3 of the rock can be solid organic material. Liquid and gaseous hydrocarbons can be extracted from the oil shale but the rock must be heated and/or treated with solvents. This is usually much less efficient than drilling rocks that will yield oil or gas directly into a well. The processes used for hydrocarbon extraction also produce emissions and waste products that cause significant environmental concerns [9].

Oil shale usually meets the definition of “shale” in that it is “a laminated rock consisting of at least 67% clay minerals,” however, it sometimes contains enough organic material and carbonate minerals that clay minerals account for less than 67% of the rock [10].

Estimating shale oil reserves is complicated by several factors. Firstly, the amount of kerogen contained in oil shale deposits varies considerably. Secondly, some nations report as reserves the total amount of kerogen in place, including all kerogen regardless of technical or economic constraints; these estimates do not consider the amount of kerogen that may be extracted from identified and assayed oil shale rock using available technology and under given economic conditions. By most definitions, “reserves” refers only to the amount of resource which is technically exploitable and economically feasible under current economic conditions. The term “resources”, on the other hand, may refer to all deposits containing kerogen. Thirdly, shale oil extraction technologies are still developing, so the amount of recoverable kerogen can only be estimated [10,11,12].

Deposits of oil shale are in many parts of the world. These deposits, which range from Cambrian to Tertiary age, may occur as minor accumulations of little or no economic value or giant deposits that occupy thousands of square kilometers and reach thicknesses of 700 m or more. Oil shales were deposited in a variety of depositional environments, including fresh-water to highly saline lakes, epicontinental marine basins and subtidal shelves, and in limnic and coastal swamps, commonly in association with deposits of coal.

Terrestrial oil shales include those composed of lipid-rich organic matter such as resin spores, waxy cuticles, and corky tissue of roots, and stems of vascular terrestrial plants commonly found in coal-forming swamps and bogs. Lacustrine oil shales include lipid-rich organic matter derived from algae that lived in fresh-water, brackish, or saline lakes. Marine oil shales are composed of lipid-rich organic matter derived from marine algae and marine dinoflagellates.

Relatively little is known about many of the world’s deposits of oil shale and much exploratory drilling and analytical work

need to be done, **Fig 3**. Early attempts to determine the total size of world oil-shale resources were based on few facts, and estimating the grade and quantity of many of these resources were speculative, at best. The situation today has not greatly improved, although much information has been published in the past decade or so, notably for deposits in Australia, Canada, Estonia, Israel, Jordan, Morocco and the United States.

More than half of the identified shale oil resources outside the United States are concentrated in four countries Russia, China, Argentina and Libya while more than half of the non-U.S. shale gas resources are concentrated in five countries China, Argentina, Algeria, Canada and Mexico. The United States is ranked second after Russia for shale oil resources and fourth after Algeria for shale gas resources when compared with the 41 countries assessed, Table 1.

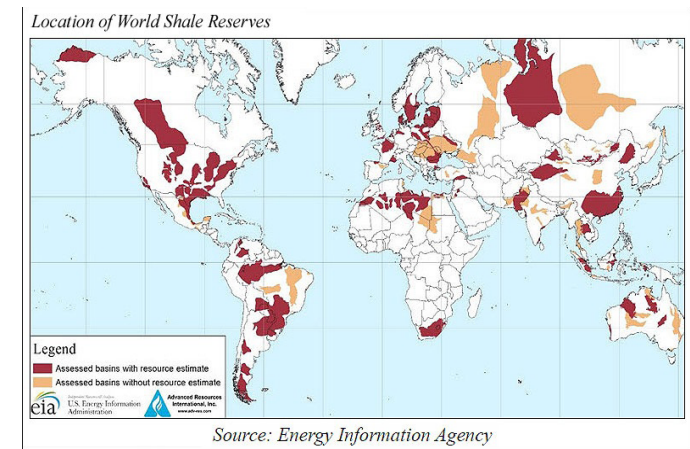


Fig 3: Global distribution of Oil shale reserves [10].

Table 1 Top ten countries with technically recoverable oil shale and gas shale Resources [10].

Top Ten Countries By Shale Oil Reserves			Top Ten Countries By Shale Gas Reserves		
Rank	Country	Shale oil (billion barrels)	Rank	Country	Shale gas (trillion cubic feet)
1	Russia	75	1	China	1,115
2	U.S. ¹	58 (48)	2	Argentina	802
3	China	32	3	Algeria	707
4	Argentina	27	4	U.S. ¹	665 (1,161)
5	Libya	26	5	Canada	573
6	Australia	18	6	Mexico	545
7	Venezuela	13	7	Australia	437
8	Mexico	13	8	South Africa	390
9	Pakistan	9	9	Russia	285
10	Canada	9	10	Brazil	245
World Total		345 (335)	World Total		7,299 (7,795)

¹ EIA estimates used for ranking order. ARI estimates in parentheses. ¹ EIA estimates used for ranking order. ARI estimates in parentheses.

Source: Energy Information Agency

Oil Shale in South Asia

Estimating shale oil reserves is complicated by several factors. Firstly, the amount of kerogen contained in oil shale deposits varies considerably. Secondly, some nations report as reserves the

total amount of kerogen in place, including all kerogen regardless of technical or economic constraints; these estimates do not consider the amount of kerogen that may be extracted from identified and assayed oil shale rock using available technology and under given economic conditions. By most definitions, “reserves” refers only to the amount of resource which is technically exploitable and economically feasible under current economic conditions. The term “resources”, on the other hand, may refer to all deposits containing kerogen. Thirdly, shale oil extraction technologies are still developing, so the amount of recoverable kerogen can only be estimated [11].

Major oil shale deposits are located in China, which has an estimated total of 32 billion metric tons, of which 4.4 billion metric tons are technically exploitable and economically feasible. The principal Chinese oil shale deposits and production lie in Fushun and Liaoning; others are located in Maoming in Guangdong. In addition to China, major deposits are located in Thailand (18.7 billion metric tons), Pakistan (227 billion metric tons) of which 9.1 billion metric tons are technically exploitable and economically feasible; Kazakhstan (several deposits; major deposit at Kenderlyk Field with 4 billion metric tons. Thailand’s oil shale deposits are near Mae Sot, Tak Province, and at Li, Lamphun Province. Deposits in Turkey are found mainly in middle and western Anatolia. According to some reports, also Uzbekistan has major oil shale deposits of 47 billion metric tons, mainly located at Sangruntau but also at Baysun, Jam, Urtabulak, Aktau, Uchkyr and Kulbeshkak [16]. Smaller oil shale reserves have also been found in India, Turkmenistan, Myanmar, Armenia and Mongolia [12].

Oil Shale Extraction

Shale oil extraction process decomposes oil shale and converts its kerogen into shale oil a petroleum-like synthetic crude oil, **Fig 4** shows an overview of shale extraction. The process is conducted by pyrolysis, hydrogenation, or thermal dissolution. The efficiencies of extraction processes are often evaluated by comparing their yields to the results of a Fischer Assay performed on a sample of the shale. The oldest and the most common extraction method involves pyrolysis (also known as retorting or destructive distillation). In this process, oil shale is heated in the absence of oxygen until its kerogen decomposes into condensable shale oil vapors and non-condensable combustible oil shale gas. Oil vapors and oil shale gas are then collected and cooled, causing the shale oil to condense. In addition, oil shale processing produces spent oil shale, which is a solid residue. Spent shale consists of inorganic compounds (minerals) and char a carbonaceous residue formed from kerogen. Burning the char off the spent shale produces oil shale ash. Spent shale and shale ash can be used as ingredients in cement or brick manufacture. Heating the oil shale to pyrolysis temperature and completing the endothermic kerogen decomposition reactions require a source of energy. Some technologies burn

other fossil fuels such as natural gas, oil, or coal to generate this heat and experimental methods have used electricity, radio waves, microwaves, or reactive fluids for this purpose. Two strategies are used to reduce, and even eliminate, external heat energy requirements: the oil shale gas and char by-products generated by pyrolysis may be burned as a source of energy, and the heat contained in hot spent oil shale and oil shale ash may be used to pre-heat the raw oil shale. For ex situ processing, oil shale is crushed into smaller pieces, increasing surface area for better extraction. The temperature at which decomposition of oil shale occurs depends on the time-scale of the process. In ex situ retorting processes, it begins at 300 °C (570 °F) and proceeds more rapidly and completely at higher temperatures. The amount of oil produced is the highest when the temperature ranges between 480 and 520 °C (900 and 970 °F). The ratio of oil shale gas to shale oil generally increases along with retorting temperatures. For a modern in situ process, which might take several months of heating, decomposition may be conducted at temperatures as low as 250 °C (480 °F). Temperatures below 600 °C (1,110 °F) are preferable, as this prevents the decomposition of lime stone and dolomite in the rock and thereby limits carbon dioxide emissions and energy consumption [12].

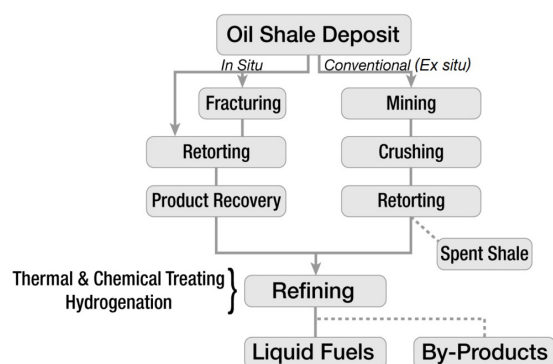


Fig 4: Overview of oil shale extraction [12].

Classification of Extraction Technologies

Industry analysts have created several classifications of the technologies used to extract from oil shale.

By process principles: Based on the treatment of raw oil shale by heat and solvents the methods are classified as pyrolysis, hydrogenation, or thermal dissolution [13].

By location: A frequently used distinction considers whether processing is done above or below ground, and classifies the technologies broadly as ex situ (displaced) or in situ (in place). In ex situ processing, also known as above-ground retorting, the oil shale is mined either underground or at the surface and then transported to a processing facility. In contrast, in situ processing converts the kerogen while it is still in the form of an oil shale deposit, following which it is then extracted via oil wells, where it rises in the same way as conventional crude oil.

By heating method: The method of transferring heat from combustion products to the oil shale may be classified as direct or indirect. While methods that allow combustion products to contact the oil shale within the retort are classified as direct, methods that burn materials external to the retort to heat another material that contacts the oil shale are described as indirect.

By heat carrier: Based on the material used to deliver heat energy to the oil shale, processing technologies have been classified into gas heat carrier, solid heat carrier, wall conduction, reactive fluid, and volumetric heating methods.

By raw oil shale particle size: The various ex situ processing technologies may be differentiated by the size of the oil shale particles that are fed into the retorts. As a rule, gas heat carrier technologies process oil shale lumps varying in diameter from 10 to 100 millimeters (0.4 to 3.9 in), while solid heat carrier and wall conduction technologies process fines which are particles less than 10 millimeters (0.4 in) in diameter.

By complexity of technology: In situ technologies are usually classified either as true in situ processes or modified in situ processes. True in situ processes do not involve mining or crushing the oil shale. Modified in situ processes involve drilling and fracturing the target oil shale deposit to create voids in the deposit. The voids enable a better flow of gases and fluids through the deposit, thereby increasing the volume and quality of the shale oil produced [12,13].

Oil Shale Production Feasibility

Oil shale economics deals with the economic feasibility of oil shale extraction and processing. Although usually oil shale economics is understood as shale oil extraction economics, the wider approach evaluates usage of oil shale as whole, including for the oil-shale-fired power generation and production of by-products during retorting or shale oil upgrading processes.

The economic feasibility of oil shale is highly dependent on the price of conventional oil, and the assumption that the price will remain at a certain level for some time to come. As a developing fuel source the production and processing costs for oil shale are high due to the small nature of the projects and the specialist technology involved. A full-scale project to develop oil shale would require heavy investment and could potentially leave businesses vulnerable should the oil price drop and the cost of producing the oil would exceed the price they could obtain for the oil [13].

Due to the volatile prices and high capital costs few deposits can be exploited economically without subsidies. However, some countries, such as Estonia, Brazil, and China, operate oil-shale industries, while some others, including Australia, United States, Canada, Jordan, Israel, and Egypt, are contemplating establishing or re-establishing this industry. The production cost of a barrel of shale oil ranges from as high as US\$95 per barrel to as low US\$25

per barrel, although there is no recent confirmation of the latter figure. The industry is proceeding cautiously, due to the losses incurred during the last major investment into oil shale in the early 1980s, when a subsequent collapse in the oil price left the projects uneconomical [14].

Environment Concerns of Oil Shale

Environmental impact of the oil shale industry includes the consideration of issues such as land use, waste management, and water and air pollution caused by the extraction and processing of oil shale. Surface mining of oil shale deposits causes the usual environmental impacts of open-pit mining. In addition, the combustion and thermal processing generate waste material, which must be disposed of, and harmful atmospheric emissions, including carbon dioxide, a major greenhouse gas. Experimental in-situ conversion processes and carbon capture and storage technologies may reduce some of these concerns in future, but may raise others, such as the pollution of groundwater. Main air pollution is caused by the oil shale-fired power plants, which provide the atmospheric emissions of gaseous products like nitrogen oxides, sulfur dioxide and hydrogen chloride, and the airborne particulate matter (fly ash), **Fig 5**.



Fig 5: Shows air pollution of Kiviõli Oil Shale Processing & Chemicals Plant in Ida-Virumaa, Estonia [14].

Shale Gas

Shale gas is natural gas that is found trapped within shale formations. Because shales ordinarily have insufficient permeability to allow significant fluid flow to a wellbore, most shales are not commercial sources of natural gas. Shale gas is one of a number of unconventional sources of natural gas; others include coalbed methane, tight sandstones, and methane hydrates. Shale gas areas are often known as resource plays (as opposed to exploration plays). The geological risk of not finding gas is low in resource plays, but the potential profits per successful well are usually also lower. Shale has low matrix permeability, so gas production in commercial quantities requires fractures to provide permeability. Shale gas has been produced for years from shales with natural fractures; the shale gas boom in recent years has been due to modern technology in hydraulic fracturing (fracking) to create exten-

sive artificial fractures around well bores. [15]

Shales that host economic quantities of gas have a number of common properties. They are rich in organic material (0.5% to 25%), and are usually mature petroleum source rocks in the thermogenic gas window, where high heat and pressure have converted petroleum to natural gas. They are sufficiently brittle and rigid enough to maintain open fractures [16].

Shale Gas in South Asia

The race to develop shale gas in Asia, which some have likened to a gold rush, has begun to feel more like a marathon than a sprint. China's Shale Gas Development Plan for 2011-2015, released in March 2012, set a production goal of 6.5 billion cubic meters of shale gas by 2015, amounting to roughly 6 percent of China's total natural gas output. But the region's biggest shale player recently scaled back these projections, as China has run into more obstacles than expected in developing its abundant reserves. India and Indonesia are likely to emerge just behind China as major shale gas players in the coming decades, but both face similar or greater obstacles to reach that point. As of 2009, Pakistan stands 19th in the world in terms of total technically recoverable shale gas reserves. Pakistan has about 51 trillion cubic feet of shale gas reserves.

Shale Gas Extraction

Shale gas formations are "unconventional" reservoirs – i.e., reservoirs of low "permeability." The bottom line is that in a conventional reservoir, the gas is in interconnected pore spaces, much like a kitchen sponge, that allow easier flow to a well; but in an unconventional reservoir, like shale, the reservoir must be mechanically "stimulated" to create additional permeability and free the gas for collection. Shale gas refers to natural gas in organic rich fine grained rocks (shale and/or mudrock). Gas stored in shale as: 1) adsorbed gas attached to organic matter, 2) free gas in matrix pores, micropores and natural fractures and 3) solution gas in liquids such as bitumen and oil. For shale gas, hydraulic fracturing of a reservoir is the preferred stimulation method (see graphic below). For shale gas, hydraulic fracturing of a reservoir is the preferred stimulation method. This typically involves injecting pressurized fluids to stimulate or fracture shale formations and release the natural gas. Sand pumped in with the fluids (often water) helps to keep the fractures open. The type, composition and volume of fluids used depend largely on the geologic structure, formation pressure and the specific geologic formation and target for a well. Another major technology often employed in producing natural gas from shale is horizontal drilling. The shallow section of shale wells are drilled vertically (much like a traditional conventional gas well). Just above the target depth – the place where the shale gas formation exists – the well deviates and becomes horizontal. At this location, horizontal wells can be oriented in a direction that maximizes the number of natural fractures intersected in the shale.

These fractures can provide additional pathways for the gas that is locked away in the shale, once the hydraulic fracturing operation takes place [18,19].

There is significant debate over the production costs of shale gas. Estimates of shale gas extraction costs in North America range from US\$4- 8/Mcf. The differences in estimates is significant and complex. On the one hand, low-price proponents argue that exploitation of shale gas can be as little as three months from the beginning of the drilling effort. Further, they say the ease of hydro-fracturing multiple times is reason that the price will remain low for the foreseeable future. High-price proponents argue that the actual drilling costs are more significant and will be pushed higher as environmental regulations are established. Costs related to water reclamation and chemical cleanup will add to production costs which could drive prices between US\$6-8/Mcf [18].

Typical completion for shale gas reservoirs are horizontal, multi-stage hydraulically fractured wells. As more knowledge is gained through microseismic monitoring of these fracture treatments, it appears that they are likely creating network of fractures. Thus two permeabilities in shale gas need to be considered: matrix and system. Successful shale gas hydraulic stimulation depends on three reservoir assessment categories: storage capacity (gas in place), flow capacity (gas deliverability and mechanical properties of gas shale [19, 20].

Environmental Impact of Shale Gas Industry

Shale gas has received a good deal of attention recently for the potential negative impacts that its development may have on the environments and communities in which it occurs. Instances of water contamination, air pollution, and earthquakes have been blamed on gas extraction activities. A thorough understanding of the techniques used to extract gas from shale formations and the safeguards that exist to prevent environmental damage is critical to assessing the sources and magnitudes of risk involved in shale gas development.

Subsurface Contamination of Ground Water

A frequently expressed concern about shale gas development is that subsurface hydraulic fracturing operations in deep shale formations might create fractures that extend well beyond the target formation to water aquifers, allowing methane, contaminants naturally occurring in formation water, and fracturing fluids to migrate from the target formation into drinking water supplies. With the notable exceptions of the shallow Antrim and New Albany Shales, many thousands of feet of rock separate most major gas-bearing shale formations in the United States from the base of aquifers that contain drinkable water [20].

Seismic Risks

Seismic Risks another subsurface risk that has received at-

tention recently is the possibility that drilling and hydraulically fracturing shale gas wells might cause low-magnitude earthquakes. In 2008 and 2009, the town of Cleburne, Texas, experienced several clusters of weak earthquakes all registering 3.3 or less on the Richter scale.³⁰ since the town had never registered an earthquake in its 142-year history, some residents wondered if the recent increase in local drilling activity associated with the Barnett Shale might be responsible. A study by seismologists with the University of Texas and Southern Methodist University found no conclusive link between hydraulic fracturing and these earthquakes but indicated that the injection of waste water from gas operations into numerous saltwater disposal wells that were being operated in the vicinity could have caused the seismic activity [19].

Coalbed Methane (CBM)

Coalbed gas, coal seam gas (CSG), or coal-mine methane (CMM) is a form of natural gas extracted from coal beds. In recent decades it has become an important source of energy in United States, Canada, Australia, and other countries. The term refers to methane adsorbed into the solid matrix of the coal. It is called 'sweet gas' because of its lack of hydrogen sulfide. The presence of this gas is well known from its occurrence in underground coal mining, where it presents a serious safety risk. Coalbed methane is distinct from a typical sandstone or other conventional gas reservoir, as the methane is stored within the coal by a process called adsorption. The methane is in a near-liquid state, lining the inside of pores within the coal (called the matrix). The open fractures in the coal (called the cleats) can also contain free gas or can be saturated with water. Unlike much natural gas from conventional reservoirs, coalbed methane contains very little heavier hydrocarbons such as propane or butane, and no natural-gas condensate [20].

Coal Bed Methane Reserve

The largest proven recoverable coal reserves, according to the latest published data, are in the USA (28.6%), followed by Russia (18.5%), China (13.5%), Australia (9.0%) and India (6.7%). Shallow coal deposits in many areas, such as in the UK and in some other European nations, have been extensively mined, yet deep coal seams beyond the reach of mining operations present opportunities for development. Even with little minable coal remaining, the UK still ranks sixth worldwide in estimated. Evaluating the potential for CBM production relies heavily on laboratory core analysis and reservoir characterization. Field-level evaluation has evolved considerably since the early days of CBM development when models were adaptations of mining-industry techniques. Today, factors required to economically produce natural gas from coal seams are better understood. As new basins are explored, this understanding continues to evolve. In addition, data from tools developed expressly for shallow wells and low-density reservoirs are improving reservoir modeling [21].

Coal Bed Methane Gas Production

During coalification, large quantities of methane-rich gas are generated and stored within the coal on internal surfaces. Because coal has such a large internal surface area, it can store surprisingly large volumes of methane-rich gas; six or seven times as much gas as a conventional natural gas reservoir of equal rock volume can hold. In addition, much of the coal, and thus much of the methane, lies at shallow depths, making wells easy to drill and inexpensive to be complete. With greater depth, increased pressure closes fractures (cleats) in the coal, which reduces permeability and the ability of the gas to move through and out of the coal. Exploration costs for coal-bed methane are low, and the wells are cost effective to drill. In a coal-bed methane well, water is produced in large volumes, especially in the early stages of production; as the amount of water in the coal decreases, gas production increases, **Fig 6**. The water must be disposed of safely, most frequently, water is re-injected into subsurface rock formations, **Fig 7**. In some cases, the water is allowed to flow into surficial drainages or is put into evaporation ponds [22,23,24].

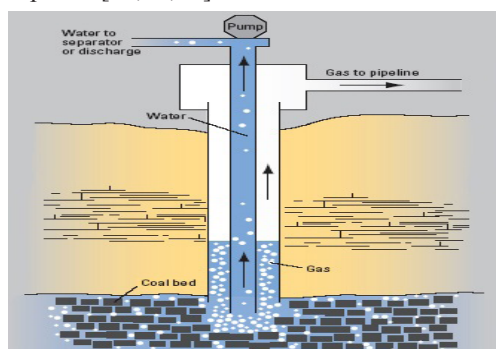


Fig 6: Diagram of Coalbed Methane recovery [20].

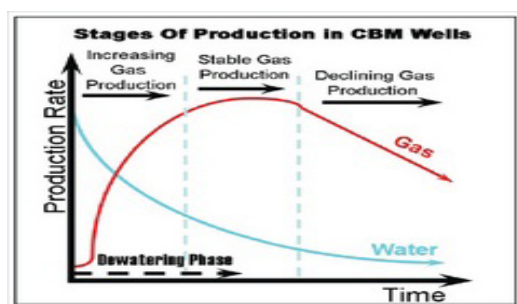


Fig 7: Typical production curves for CBM well showing relative volumes of water and methane through time [22].

Future of CBM

Approximately 70 countries have coal-bearing regions, and more than 40 of these have initiated CBM activity of some type. In about 20 countries, active drilling programs are either in progress or have been in the past. Several innovative applications to help

improve the economics of CBM development around the world have been covered in this article, but there are more in development [23,24,25].

FORECASTING of CONVENTIONAL and UNCONVENTIONAL PETROLEUM RESOURCES

Oil and gas are produced from underground reservoirs, at rates which greatly depend upon the porosity and permeability of the host rock. Over the years, as energy prices have gone up, oil and gas “reserves” have also gone up since higher prices justified the development and use of more expensive technologies to recover harder-to-get molecules. Recent technological advances, in particular 3D seismic, horizontal drilling and hydraulic fracturing (“fracking”), have spurred the exploitation of large tight oil and shale gas formations in the US [26].

Forecast of global energy demand growth, coupled with declines in the production from conventional oil fields, have led observers to predict that tight oil and shale gas will play an increasing large role in the world’s energy markets and will affect large established players such as Saudi Arabia, **Fig 8**. Our review of specialized public domain industry information suggests instead that, for both technical and economic reasons, tight oil and shale gas production may increase substantially less that most observers assert [27].

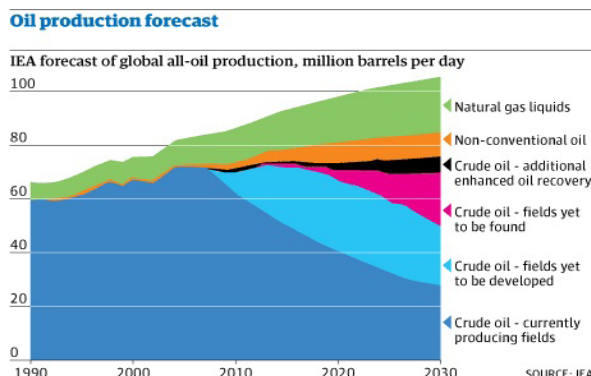


Fig 8: Forecast of global conventional oil production [27].

The view the growth of tight oil and shale gas mainly occurring in the US, not only because of technical reasons (attractive and well understood “tight” geological formations), but also because of uniquely favorable above ground factors such as efficient and low cost industrial services, infrastructure, legal and financial systems, and an accepting society. There is further doubt that, even in the US, production of tight oil and shale gas will increase as fast and as much in the medium and long term as most observers suggest. For tight oil, this is because, since the tight formations have by definition low permeability, each well has a restricted reach and

its production is limited and declines rapidly. Many wells are thus needed to sustain production, let alone expand it. Of the two major tight oil plays, which account for 85% of US tight oil production, we view only one as promising long term growth. We suspect that US overall tight oil production may decline after 2018. For shale gas, this is because, in addition to the rapid decline in production from each well and a constant need to drill more. Advances that have made these vast unconventional resources technically and economically viable have dramatically altered the outlook for the world's hydrocarbon supply. After declining for decades, US oil production is on the upswing, in large part due to increasing production of liquids from unconventional reservoirs. The swing has been so dramatic in just a few years that the US Energy Information Administration, in its latest Annual Energy Outlook, estimates that the nation's crude oil production will increase to 6.7 million b/d in 2020 and remain above 6.1 million b/d through 2035, **Fig.9** shows the potential of unconventional oil potential in US until year 2035. In all thus, we doubt that tight oil production will significantly impact the world's oil industry over the long term. In particular, we do not see it affecting Saudi Arabia's situation. With large volumes of cheap Natural Gas Liquids, we believe that US shale gas production will mainly impact the world's petrochemical industry and may induce Saudi producers to expand production there [27,28,29].

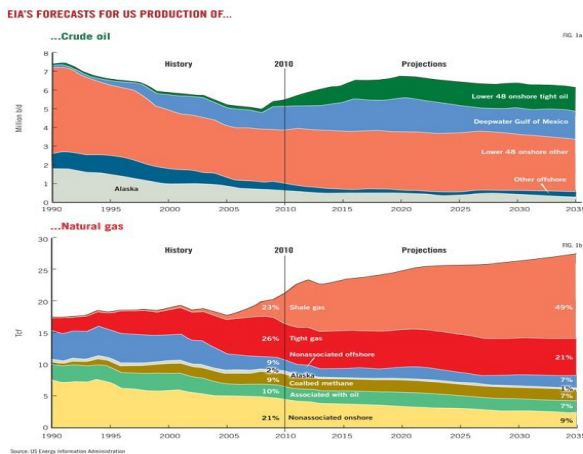


Fig 9: Oil and gas forecasting potential from unconventional reserve [28].

Conclusions

This study of unconventional oil and gas resources: exploitation and development provided a comprehensive understanding of the latest advances in the exploitation and development of unconventional resources and addresses different aspects of the exploitation and development process and explored future trends in reservoir and production technologies for unconventional resources development and reached the following points.

- Conventional and unconventional oil and gas come from the

same original geologic formations all over the world. Conventional petroleum resources are oil and gas found in reservoir rocks that can be extracted using traditional methods. Unconventional oil is petroleum produced or extracted using techniques other than the conventional method.

- Tight gas and oil reservoirs are that reservoir with such low permeability that massive hydraulic fracturing is necessary to produce the well at economic rates. Tight reservoirs are generally defined as having less than 0.1 mD matrix permeability and less than ten percent matrix porosity.
- Oil shale is a rock that contains significant amounts of organic material in the form of kerogen. Liquid and gaseous hydrocarbons can be extracted from the oil shale but the rock must be heated and/or treated with solvents. Oil shale economics deals with the economic feasibility of oil shale extraction and processing. Environmental impact of the oil shale industry includes the consideration of issues such as land use, waste management, and water and air pollution caused by the extraction and processing of oil shale.
- Shale gas refers to natural gas in organic rich fine grained rocks (shale and/or mudrock). Gas stored in shale as: 1) adsorbed gas attached to organic matter, 2) free gas in matrix pores, micropores and natural fractures and 3) solution gas in liquids such as bitumen and oil. For shale gas, hydraulic fracturing of a reservoir is the preferred stimulation method.
- Coalbed Methane (CBM) is a form of natural gas extracted from coal beds. During coalification, large quantities of methane-rich gas are generated and stored within the coal on internal surfaces. Because coal has such a large internal surface area, it can store surprisingly large volumes of methane-rich gas; six or seven times as much gas as a conventional natural gas reservoir of equal rock volume can hold.
- The economic feasibility of unconventional resources is highly dependent on the price of conventional resources, and the assumption that the price will remain at a certain level for some time to come. Available technology and development plans have great impact on the forecasting of unconventional resources either as complement or replacement of the conventional resources.

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