Energy in the XXIst century - Unconventional oil and gas

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The views expressed in this paper are those of the author and do not necessarily represent those of the U.S. Department of Energy. The paper is based on the Society of Petroleum Engineers (SPE) Distinguished Lecturer Program by the author for 1999/2000.

Abstract

This paper considers the world's ***unconventional*** hydrocarbon fuel options in light of the inevitable onset of production decline from conventional oil and gas resources. Unconventional hydrocarbons greatly exceed traditional sources of oil and natural gas. Unconventional oil and gas include heavy oil, tar sands, oil shale, gas and oil from coal, gas in ultra-tight formations, very deep gas, low quality and/or stranded gas, coalbed methane, and methane hydrates, Figure 1. These resources were used only in small amounts during the XXth century, but are expected to become very important additional sources of future energy supply. The ever increasing demand for oil and gas is assured by population growth that demands higher quality of life, and by the inevitable advances in technology for their exploration, production and processing.

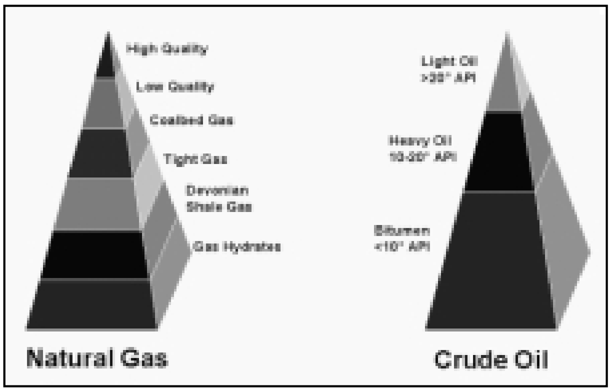

Figure 1: Resource base.

Extraordinary progress has already cut the cost of finding and producing conventional oil by 60 percent in real terms over the last ten years. Additional technology advances will permit production from abundant unconventional oil and gas resources, some of which are already on the verge of commercialization. The importance of traditional Enhanced Oil Recovery (EOR) methods will continue, particularly in countries with already declining oil production, such as the United States.

Unconventional Oil

Naturally, industry started to produce oil that was the easiest to find and least expensive to produce. But there are even larger, nontraditional resources, generically known as ***unconventional oil***, that can be exploited with improved technology and moderately higher prices. These are known as ***heavy oil, extra heavy oil*** and ***bitumen*** (or ***tar sands***), Figure 2. Limited amounts of oil and gas could also be produced from oil shale and coal gasification/liquefaction.

	Heavy Crude	Extra Heavy Crude *	Bitumen (Tar)
Gravity (°API)	10-20	<10	<10
Viscosity (cp)	100-10,000	100-10,000	>10,000
Sulfur (%wt)	<0.5	0.5-3.0	>3.0

* Example: Cerro Negro crude, 8 °API and 2,000 - 8,000 cp at res. cond.

Figure 2: Nomenclature, unconventional oil.

There are no reliable figures of the magnitude of these resources. Geoscientists postulate that, whereas the earth's conventional oil endowment is about three to four trillion barrels (of which nearly one trillion has already been produced), heavy oil amounts to about two trillion barrels, and bitumen amounts to about six trillion barrels [1]. Total world oil endowment is estimated at the 9-13 trillion barrels, Figure 3. These are probably conservative estimates.

Heavy oil is generally accepted to have API gravity ranging from 10-20 degrees. It is already produced commercially in many areas; more than one-half of the U.S. EOR production is heavy oil. The predominant production technique is steam flooding, because heavy oil's high viscosity is very effectively reduced by heating. It is noteworthy that the world crude slate is getting progressively heavier, while sulfur content of that crude gets higher. There is every reason to believe that the trend will continue unabated.

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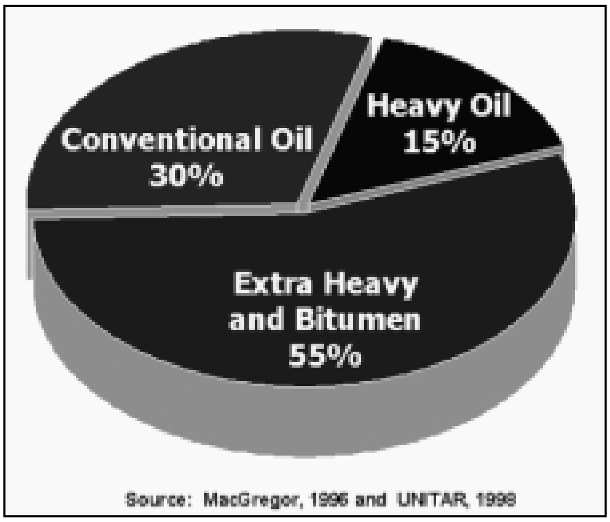

Figure 3: World oil endowment (OOIP), total: 9-13 trillion barrels.

Extra Heavy Oil and Bitumen, also known as tar sands, are generally accepted to have API gravity less than 10°API (density is higher than that of water). This resource is also produced commercially to some extent, particularly in Canada and Venezuela. In Canada, the predominant technique is surface mining and bitumen extraction at the surface, with application of heat and chemicals. About one-quarter of the Canadian oil is produced that way. In Venezuela, some extra heavy oil can actually be produced cold, but steam injection is more effective.

Oil shale is a fine-grained rock containing hydrocarbon material called kerogen. When heated to about 950° F, large kerogen molecules break down to form synthetic oil and combustible gas. The amounts of oil and gas produced depend on retorting conditions and the richness of the shale. The identified resource of shale oil in the United States is 1.1 trillion barrels (with at least 10 gallons/ton), or 400-600 billion tons in richer shales that contain 25-30 gallons/ton. Other known large oil shale resources are found in Estonia, Australia and Russia. Several major field test projects have established the technical feasibility of oil production from oil shale, but it could not compete with low conventional oil prices.

Coal liquefaction is also a potential source of liquid and/or gaseous hydrocarbons. The process was used for the production of transportation fuel as far back as World War II. It was improved and field-scale tested in the 1980's, however, similar to shale oil, it could not compete with the inexpensive conventional oil.

There is no reasonable doubt that heavy oil and tar sands will become major contributors to the mix of energy options needed in this century. In fact, it is already a minor contributor, waiting for further technology improvement, and better oil and gas prices. The sheer magnitude of these resources ensure increasing supply of liquid hydrocarbons well into the end of the XXIst century, and even further into the future.

One major obstacle on the road to wide-scale development of unconventional resources is environmental issues. Production and processing of unconventional oil resources presents unique environmental problems, including air and water pollution and despoiling of surface areas. Research, technology improvements and regulations will help to overcome the problems, but not sufficiently to make peace between the environmental groups and petroleum industry. It is possible that environmental issues might loom larger than technology development in harnessing the unconventional hydrocarbon resources of the future.

The so-called "renewable," solar and wind energies evoke all sorts of emotional responses, but their capacity to provide a sizable portion of future energy is limited. For the very long-term future, nuclear fission and fusion for stationary energy (electrical power) and hydrogen for movable energy (transportation) are two important options. Hydrogen, propelled into the world economy as a hydrocarbon-derived fuel, will eventually have to originate from nonhydrocarbon sources, such as water. Such a transition will require the most demanding technology development drive in the history of humankind [2]. In the meantime, first conventional, then unconventional oil and gas can cushion this transition, both by providing robust interim solutions and by paving the way to a hydrogen-based economy.

Unconventional Gas

It is generally accepted that the term "unconventional gas" includes: coalbed methane, low quality and/or stranded gas, ultra-tight gas formations, Devonian shale gas, very deep gas, and methane hydrates. The potential for commercial gas production from unconventional gas resources in the XXIst century is no less promising than that for commercial development of heavy oil and tar sand resources. The magnitude of unconventional gas resources is less known than that of heavy oil and tar sands, but in terms of equivalent units of energy, it is believed to be even larger, Figure 4.

Unconventional gas has become an increasingly important component of the United States' total domestic pro-

Category	Source	Mean Gas Resource (Tcf)
Gas Hydrates	USGS, 1995	320,000 est. gas-in-place
Gas Shale Basins	NPC, 1992; Jennings, 1997; Kuuskraa, '98	254 est. gas-in-place 10 technically recov.
Deep Gas (>15,000')	GRI, 1995	184 technically recov.
Continuous-Type Gas	USGS, 1995	308 technically recov.
Sub-Volcanic Gas (OR, WA)	USGS, 1995	12.5 technically recov.
Shale/Low Perm Form.	GRI,1997	389 recov. with 2015 tech.
Coalbed Methane	GRI, 1997	110 recov. with 2015 tech.
Alaska Coalbed Methane	USGS, Smith, '95	1000 est. gas-in-place
Deep GGRB Coalbed CH_4	TBEG, Tyler, '95	314 est. gas-in-place

Figure 4: US unconventionnal gas ressources - est.

duction during the past decade. Exploitation of this abundant but generally higher cost resource, received a boost in the early 1990's with the successful implementation of tax incentives designed to encourage development. Since then, technologies developed and advanced in the pursuit of these resources have contributed to a continued growth in production, even in the absence of the tax incentives. Over the next two decades the role of the unconventional gas in meeting the United States' energy needs is projected to expand even further [3]. Behind these projections are important assumptions about future technological advancements and their effect on the industry.

Coalbed methane is already commercial in many areas of the world. It already supplies six percent of U.S. natural gas production and it continues to grow at ten percent per year, much faster than conventional gas production. Indeed, the resource base is impressive. A study by the U.S. Bureau of Mines estimated that the amount of gas contained in coalbeds in the conterminous United States is at least 300 Tcf [4]. According to the source, this is a low estimate that will undoubtedly be extended as additional information becomes available. Gas production from coalbeds has intrinsic merit; even if there were no use for the drained gas, reduction of hazards inherent in gas emissions from coal mines often warrants the effort. Conservation of valuable natural gas is another secondary effect, about 80 Bcf of natural gas is wasted each year from coal mines [5]. Methane is a greenhouse gas that is normally vented to the atmosphere.

Low quality and/or stranded gas, previously neglected out of necessity, it may be developed in the near future. Ongoing research on efficient gas separation technologies shows that undesirable impurities can be removed from dirty gas streams, making natural gas usable for commercial purposes. Huge quantities of natural gas are found in remote, inaccessible locations that lack infrastructure, so that even if the quality is acceptable, the gas is stranded. Exciting and proprietary research known as Gas-To-Liquids (GTL) may solve the problem by converting natural gas directly to transportation liquids. Several competing processes already exist (Exxon/Mobil, Shell, Texaco, Sasol, Syntroleum) and more are on the drawing board. The stakes are large and whoever wins stands to benefit greatly.

Ultra-tight gas sands, known as formations with a permeability of 0.1 millidarcy down to as low as one microdarcy, are found throughout the world. Perhaps the best known resource of ultra- tight gas sands is found in the southwestern United States, where numerous stimulation experiments were conducted with mixed success. These experiments included massive hydraulic fracturing and nuclear explosive fracturing. Several thousand wells in the area already produce natural gas at low, but commercial, rates. With long-reach horizontal wells, massive hydraulic fracturing, and better gas prices, the ultra-tight gas sand and the so-called Devonian shale can significantly contribute to the overall mix of natural gas supply.

Very deep gas and overpressured formations are found at depths where temperature exceeds 300°F (150°C). Very little petroleum is found so deep; this is the domain of natural gas [5]. In the Gulf Coast, these occur at depths of 9,000 to 22,000 feet (about 3 to 7 km deep). Drilling to such depths is very difficult and expensive, particularly going through overpressured zones. Furthermore, very deep gas tends to be sour, dangerous to handle, and corrosive. Further improvements in drilling technology and gas processing, along with improved gas prices, are likely to significantly increase production from this resource.

Methane hydrates are the least understood unconventional gas resource but the largest. It is possible that the gas volume in the world's hydrate reservoirs exceeds the volume of known conventional reservoirs [6]. Gas hydrates are methane-water, ice-like crystalline materials that are stable and naturally occur at pressure-tempera-

	Energy Content, ft^3 gas (per ft^3 of reservoir)
Conventional Gas	10-20
Methane hydrate	50
Coalbed methane	8-16
Tight sands	5-10
Devonian shale	2-5

(Assuming a reservoir with ø=30%, h=5000 ft)

Figure 5: Energy content.

ture conditions of deep oceans and polar permafrost areas. One interesting characteristic of methane hydrate is that its energy density is very high; one unit volume of gas hydrate contains 160-180 volumes of gas, or several times as much per unit volume as typical gas reservoirs, Figure 5. Important research programs have been initiated in the United States, Canada, Japan and India, among others. Initial research is focusing on resource characterization and physical characteristics of hydrates to assess their potential as a future global fuel resource. Total methane sequestered in US hydrates is estimated from 113,00 to 676,000 Tcf with a mean value of 320,000 Tcf, at 0.95 and 0.05 probability levels (no reference to its recoverability). One volume of water can accommodate from 70 to over 160 volumes of gas. A concept of how such resource might possibly be exploited are shown in Figure 6.

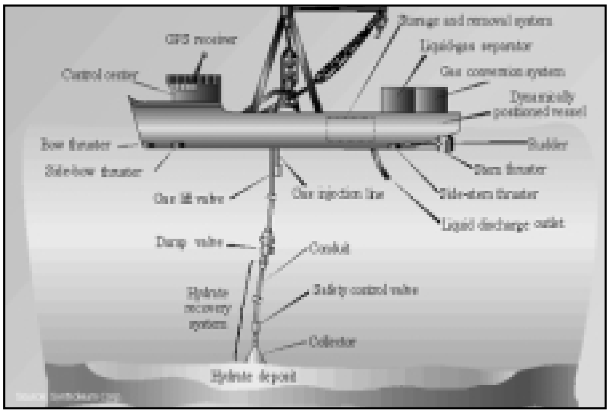

Figure 6: A concept of methane recovery from methane hydrate deposit.

The Role of Technology

In the 1990's, extraordinary technology improvements in exploration, drilling, and production contributed to the near record low energy prices (adjusted for inflation). There is every reason to believe that technology advances will continue unabated.

The following are but a few examples of technologies on the verge of a breakthrough (if not yet commercial), that will affect the development of the traditional as well as the unconventional oil and gas resources:

■ Cross-borehole seismic tomography, and the associated miniature (0.5 inch) geophone tools permit improved reservoir characterization on the interwell scale [7].

■ Through-casing resistivity logging that locates bypassed pays in old, steel-cased wells is already being used successfully.

■ Fuel cell technology is on the fast track to becoming the pre-eminent electric power generating option for the near future. Using an electrochemical process, rather than combustion to convert natural gas to electricity, fuel cells produce no emissions. Heat and pure water vapor are the only byproducts from the fuel cell's electrochemical reaction. The U.S. Department of Energy recently announced the development of a new hybrid fuel cell turbine that would generate electricity much more efficiently. The new power plant, the first in the world that would combine a state-of-the-art fuel cell with a gas turbine, is one of the cleanest and most efficient ways to produce electricity. The advanced power plant technology relies on a solid oxide fuel cell, which is made up of ceramic tubes that each operate like a battery; the fuel cell never runs down as long as natural gas and air are provided [8].

■ Recent advances in the design of downhole- or subsea-installed water separators may allow removal of produced water from oil close to the reservoir, with subsequent reinjection of that water in a different formation within the same well. The major advantages are avoidance of the long transport of brine to the surface and back for reinjection, reduced use of chemicals for treatments and reduced backpressure on the reservoir [9]. Subsea separation of produced water also frees more space at offshore platforms, allows smaller and fewer flowlines/risers, and reduces unstable flow due to slugging and surging. Several designs were tested in the United States, Canada and the North Sea with promising results.

■ Gas-to-liquids (GTL) is a technology that converts natural gas into synthetic liquids fuels. Synthetic liquid fuels produced by the Fischer Tropsch process, such as gasoline, kerosene and diesel, have long been known as the cleanest fuels available that are free of sulfur, metals, particles, and aromatics. The process is also suitable for conversion of gas that is contaminated with nitrogen and/or carbon dioxide. The original driver for this technology was to monetize stranded and/or low quality gas, but it was rapidly refocused by the strong pressure to produce ultra clean fuels. Better catalysts and process improvements now have made this synthetic, ultra-clean fuel near-competitive with fuels produced by conventional processes. GTL conversion is particularly suitable for offshore applications as the technology improves, becomes less expensive, and is available in compact packages. Global natural gas reserves exceed 5,000 Tcf. More than one-half of that is stranded gas, unmarketable because of the prohibitive transportation costs, and about one-half of this stranded gas is located offshore [10].

■ The growth of horizontal wells has been exponential since early 1980's, when only one or two wells were drilled annually. Today, about 5,000 horizontal wells are drilled every year worldwide. Dramatic improvements in production are possible by providing greater contact between the horizontal section of the wellbore and the reservoir. In turn, decreasing pressure drops and fluid velocities around the wellbore reduces coning and cusping. Today, it is possible to create various flow patterns within the reservoir - a particularly desirable way of draining or displacing oil with enhanced oil recovery methods. Reservoirs that are thin, fractured, heterogeneous, under urban areas, deep offshore or within isolated and small sand bodies may not be reached and developed any other way.

■ The development of laser drilling provides an example of a really high-tech approach to change the old process of drilling as we know it today. As a result of the U.S. Congress mandate to transfer cold-war defense technologies to civilian applications, several laser systems are being tested for their application to rock drilling. The potential benefits of laser drilling are enormous and include increased rate of penetration, reduced or eliminated rig dayrates, enhanced well control and perforating and sidetracking capabilities. Bit ware, tripping in and out of the hole, and multiple casing strings might become things of the past. Initial laboratory experiments showed rate of penetration through a typical sand-shale sequence of 450 ft/hr - more than 100 times current rates. Furthermore, in preparation for NASA's plans to send a robotic spacecraft to Mars by the end of this decade, NASA is planning to drill on Mars to a depth of several hundred meters to search for ground ice, to measure temperature gradient and generally to characterize the subsurface in search of possible microbial life in the subsurface. Because size and weight will be at premium on Mars missions, new technologies will be needed. The attributes required to drill on Mars, such as robotic and totally automatic drilling systems, core sampling and analysis, and the general miniaturization of subsurface tools, may also benefit the oil and gas industry by spurring a much needed leap for oil and gas drilling and production [11].

■ A wave of business-to-business (B2B) electronic commerce is sweeping the world, and some believe that it has started another revolution in operational efficiency. Some vendors view e-commerce as the XXIst century version of partnerships and alliances that lowered prices of goods and services in the 1990's. Some even envision future oil and gas wells developed through "smart" wells, with downhole electronics that not only measure and react to geologic conditions, but also adjust to business situations through online connections to commodity markets. The internet may also prove valuable in overcoming the loss of skilled workers around the world (if not also cause further reduction in their number). The industry can stretch its skilled workforce through a global internet network that allows experts in various areas to share their knowledge. Operators can even go outside the industry by posting programs or problems on the internet and soliciting input. The personnel benefits could far surpass any advantages that the industry could achieve from online procurement activities. E-commerce should also increase competition by lowering entry barriers to small companies and entrepreneurs.

■ Baker Hughes, Inc. has revealed their dream of a future "***Downhole Factory***" - a production management system that combines fiber optics, robotics, artificial intelligence and other "previously unimagined" technology to refine oil or convert natural gas into electric power within the wellbore. The company already trademarked the "Downhole Factory" title for the new technology that it expects to assemble within ten years. If successful, the system could eliminate the need for offshore platforms, with production and processing automatically handled by robots inside the wells and their subsea production systems. The company has already formed alliances with other high-technology companies for a joint development of downhole fiber optic technology and robotics with artificial intelligence for downhole operations. To accommodate all the required tools, the system may initially require very large boreholes drilled with mining equipment [12].

■ Industry experts consider 3-D seismic, now a well established and commercial exploration tool, to be the

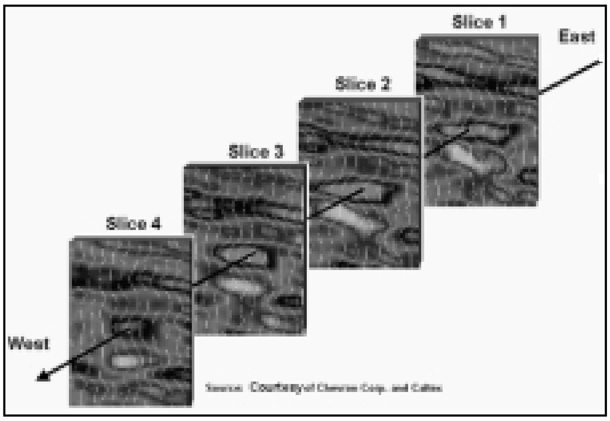

Figure 7: 4-D seismic enables monitoring of fluid movements.

greatest development in exploration since rotary drilling. Some even believe that it may have saved the industry by sharply increasing the success rate for drilling during a decade of low oil prices. The Gulf of Mexico was written off as a "dead sea" of inactivity in the early 1990's before 3-D seismic imaging uncovered previously unseen subsalt deposits that started a boom of new offshore exploration. Now 4-D seismic is increasingly used for tracking fluid movements within reservoirs - a real help in monitoring the performance of enhanced oil recovery projects, Figure 7.

Which Unconventional Oil and Gas Options? When? How Much? What Price?

Answering these questions, even in a qualitative sense, is no less difficult than predicting today's desktop computing power 20 years ago. The winning options will, of course, depend on such variables as the rate of technology development, the world's economic activity, climate change scenarios, population growth, politics, and many other, that are by themselves hard to predict.

Nonetheless, economists and geoscientists have tried to look into the future, as far as to the end of the XXIst century. Not surprisingly, what they see depends strongly on assumptions that are made. One such study of world oil supply is shown in Figure 8.

In general, there is agreement that the world's supply of conventional crude oil will peak between 2020 and 2030. Most researchers do not consider the contribution of unconventional oil and gas of the kind discussed in this paper, because it seems too speculative. In fact, some of these unconventional resources are already commercial and some are planned as commercial developments in the near future. Suncor and Syncrude have paved the way in Athabasca tar sands in Canada, Figure 9. Results were positive and new similar projects are planned. Royal Dutch/Shell, Chevron and Western Oil Sands approved the newest tar sand project in the Athabasca tar sands that will cost $2.4 billion and produce 155,000 barrels of oil by 2002.

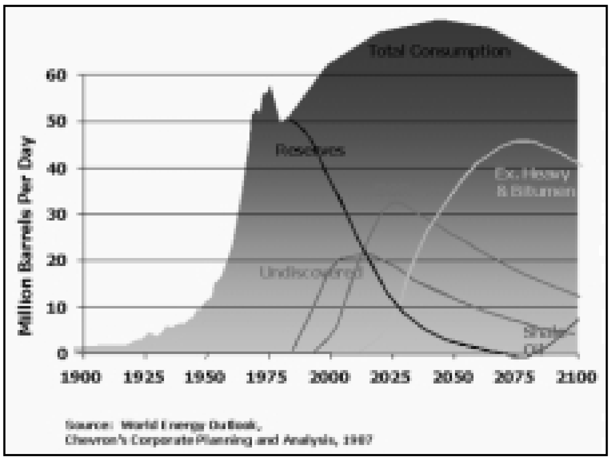

Figure 8: World crude oil supply.

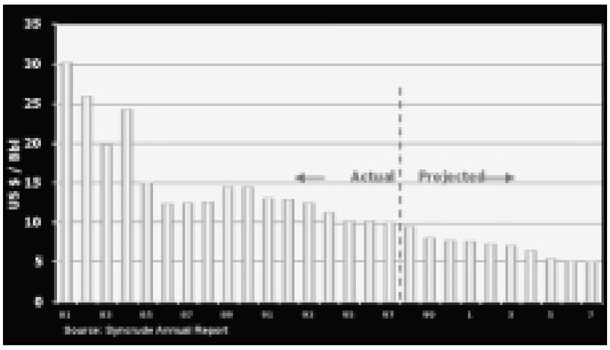

Figure 9: Operating cost of syncrude from Athabasca tar sands, Canada.

The sentiment of this paper is best captured by a recent article in Oil and Gas Journal [13]: "Any suggestion that a decline in oil production from conventional sources will inevitably result in an increase in oil price is fallacious, as oil supply from conventional sources will be replaced by relatively low-cost (operating expenses from less than $5/bbl to $12/bbl) and long-life (>20 years) supplies of synthetic oil from non-conventional sources such as gas, coal, tar sand and oil shale. These factors mean that global peak oil production will probably be not achieved for at least 50 years (unless global demand for oil falls)."

The economics of synthetic fuels (from tar sands and gas-to liquid technology) places a long-term cap on future oil prices. Unconventional oil and gas resources provide a potential swing production that can be used to compensate for any major future production shortfalls. It is also conceivable that demand for oil (in particular) may be constrained, not so much by its supply, as by advancing developments in high efficiency automobiles, or by concern for the environment.

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Pétrole et gaz, encore un bel avenir de réserves mais pour combien de temps ?

Pierre-René Bauquis[1]

Les différences de visions concernant les réserves d'hydrocarbures et donc l'avenir des productions de pétrole et de gaz sont aujourd'hui toujours aussi éloignées les unes des autres qu'elles l'ont été depuis presque un siècle que cette problématique est apparue. Je ne rappellerai pas les articles des années 1930 ou 1940, parfois signés de noms prestigieux qui annonçaient un rapide déclin de l'industrie pétrolière par épuisement du potentiel de nouvelles découvertes et donc par épuisement corrélatif des réserves. Actuellement des géologues pétroliers de tout premier plan (Colin Campbell, Alain Perrodon, Jean Laherrère, etc.) représentent cette vision dite pessimiste. Bien naturellement ces géologues récusent cette appellation et considèrent leur vision comme réaliste, puisque fondée sur des études approfondies et une approche scientifique de la problématique des réserves. La vision opposée, dite optimiste, est illustrée dans ce numéro spécial de la revue de l'UFG par l'article de J.J. George Stosur du DOE (*US Department of Energy*). Cette vision est, elle aussi, illustrée depuis des décennies par des noms prestigieux, mais qui sont le plus souvent ceux d'économistes ou de généralistes pétroliers. Ces derniers abordent la question des réserves avec un regard différent, sous l'angle d'une l'analyse souvent nettement moins scientifique, mais l'histoire leur a jusqu'ici plutôt donné raison. La question qui se pose est donc de savoir quel point de vue paraît aujourd'hui le plus réaliste.

Cette question peut paraître incompréhensible : comment des personnes compétentes dans leurs domaines respectifs peuvent-elles avoir des visions aussi différentes, après plus d'un siècle d'auscultation et d'inventaire des bassins sédimentaires ? Il nous faut donc essayer de comprendre les raisons profondes de telles divergences, et essayer pour chacun de nous d'arriver à un point de vue sur cette question clef. Je me permettrai de livrer ici ma propre vision qui ne constitue qu'une pierre dans l'édifice intellectuel que représente la querelle dite des pessimistes et des optimistes.

Un bref article en guise d'épilogue n'est pas le lieu pour détailler des raisonnements et je me contenterai donc seulement de présenter mes propres conclusions quant à l'avenir des diverses énergies à moyen terme (2020) et à long terme (2050).

Ces conclusions se résument dans le tableau ci-après :

1. TotalFinaElf - Président de l'AFTP

PRODUCTIONS D'ÉNERGIES COMMERCIALES en Gtep	2000 Gtep	%	2020 Gtep	%	2050 Gtep	%
Pétrole	3,7	40	5	40	3,5	20
Gaz	2,1	22	4,0	27	4,5	25
Charbon	2,2	24	3,0	20	4,5	25
Toutes énergies fossiles	**8**	**86**	**12**	**87**	**12,5**	**70**
Renouvelables	0,7	7,5	1	6,5	1,5	8
dont électricité	*0,5*		*0,7*		*0,9*	
Nucléaire	0,6	6,5	1	6,5	4	22
Toutes énergies	**9,3**	**100**	**14**	**100**	**18**	**100**

***Source** : P.R. Bauquis - Revue de l'Energie - Numéro spécial du cinquantième anniversaire de la revue - n° 509 Septembre 1999.*

Je crois qu'il ressort deux choses importantes de ce tableau. Il faut insister tout d'abord sur le rôle essentiel des hydrocarbures pour la période 2000-2020, avec une croissance forte des productions et un maintien ou même un renforcement de leur rôle dominant dans le bilan énergétique mondial dont le pétrole et le gaz continueraient à représenter environ les deux tiers. Ce schéma présuppose naturellement notre capacité à générer de nouvelles découvertes importantes de pétrole et de gaz sur cette période, à continuer d'améliorer les taux de récupération des bruts conventionnels, à développer à grande échelle les bruts non conventionnels et en particulier des sables bitumineux (Athabasca, Orénoque, etc.). Cette vision n'est pas complètement en ligne avec celle des experts les plus pessimistes qui voient plafonner dès 2005 ou 2010 les productions pétrolières, mais elle n'en est pas très éloignée. Elle suppose par ailleurs des contraintes relativement modérées sur les émissions de gaz carbonique, puisque le charbon verrait sa production doubler entre 2000 et 2050.

Au delà de 2020 nous verrions s'amorcer le déclin, lent mais inexorable, des productions pétrolières, dont le rôle resterait cependant important bien au delà de 2050. En effet, dans cette vision, nous serions revenus en 2050 aux niveaux actuels de production, mais bien naturellement avec un "*cocktail*" de sources très différent de ce qu'il est actuellement. Quant au gaz il plafonnerait à partir de 2030 environ, contrairement aux vues plus optimistes généralement exprimées. Il n'aurait pas encore entamé son déclin à l'horizon 2050, déclin qui devrait cependant s'amorcer peu après. Cette vision, tant pour le pétrole que pour le gaz est très différente de celle des "optimistes," telle celle de George Stosur, dont les fondements nous paraissent relever d'un acte de foi en s'écartant considérablement d'une approche scientifique.

Ce qui me semble néanmoins le plus important, au delà de toutes les polémiques, est le rôle que continueront de jouer les géosciences dans la recherche et l'exploitation des hydrocarbures, quel que soit le scenario que chacun de nous juge le plus crédible. Il va falloir dans tous les cas non seulement maintenir le rythme de l'exploration mais l'intensifier. Il va également falloir pour continuer d'améliorer les taux de récupération des pétroles conventionnels accentuer les efforts en matière de géophysique et de géologie de gisement. Enfin l'exploitation des ressources non conventionnelles va elle aussi engendrer une forte demande de recherches et d'études dans tous les domaines des géosciences : les ultra lourds de l'Orénoque ou de l'Athabasca (hormis les zones relevant d'une exploitation de type minier) vont exiger de combiner au mieux la palette des disciplines "3G." Ces gisements ne sont simples que dans une vision lointaine, alors que le succès d'une exploitation économique va au contraire reposer sur une compréhension fine de leur géologie, car c'est elle qui détermine les mouvements des fluides dans le processus de production.

Pour conclure, il faut souligner que notre vision d'un lent déclin global de la part des hydrocarbures à partir de 2020 (à cinq ou dix années près) posera naturellement la question du relais par d'autres énergies. Nous nous contenterons de rappeler à ce propos qu'à l'horizon 2050, le déficit énergétique non couvert par les énergies fossiles et la grande hydraulique serait de l'ordre du quart des consommations mondiales. Selon les quelques publications existant à ce sujet (*World Energy Council*, certains grands groupes pétroliers) ce déficit serait comblé pour l'essentiel par des énergies renouvelables. Notre vision est différente, ainsi que le montre le tableau : c'est au nucléaire et peut être à l'hydrogène dérivé du nucléaire qu'il incombera de combler l'essentiel de ce déficit. Mais cela est une autre histoire...