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Autor: Chew, Ken

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Unconventional Hydrocarbons: opportunities, risks and impact on global resources

Ken Chew[1]

1. Introduction

Neither of the earliest significant commercial production operations for natural gas (shale gas, New York State, 1821) or oil (retorted oil shale, Scotland, 1851) came from what we today consider to be conventional hydrocarbon accumulations. Despite these unusual beginnings, oil and gas from conventional hydrocarbon accumulations has dominated production for the past 150 years.

While production of hydrocarbon liquids and natural gas still continues to increase, the rate of discovery of new conventional accumulations peaked in the early 1960s for oil and early 1970s for natural gas, giving rise to concerns that production itself may also peak in the not-too-distant future. Although since the time of the first production there has always been some form of non-conventional hydrocarbon production, it was the decline in the discovery rate of conventional accumulations that prompted renewed interest in less conventional forms of oil and gas production.

1.1 What are unconventional hydrocarbons?

A number of analysts, especially those who favour the view that «conventional» oil production has peaked or is about to do so, have a very restricted view of what represents conventional oil and include in unconventional oil, Arctic oil, deepwater oil and heavy oil.

Early definitions of unconventional hydrocarbons reflected their occurrence in rock formations that were difficult to produce. Initially, therefore, the distinction frequently reflected production economics.

Geologically, however, unconventional hydrocarbons are considered to be naturally-occurring hydrocarbon accumulations that are not significantly affected by hydrodynamic influences and that lack well-defined downdip water contacts. Generally referred to as «resource plays», these accumulations are often pervasive throughout a large area. The limits of such occurrences tend to be those of the containing lithology, and exploitation focuses on the identification and development of «sweet spots».

This geological definition therefore excludes non-fossil, renewable and conversion sourced hydrocarbons such as landfill gas, bioethanol/biodiesel and coal-, shale- and gas-to-liquids conversion.

1.2 Resource play characteristics

Resource play projects tend to be complex both in terms of the geological knowledge required before development can proceed and in terms of the development technology required.

Each project is different. For example, each coal basin has its own distinctive thermal history and each coal within that basin will have its own unique physico-chemical properties. Nevertheless, there are certain generalisations that one can make about the pluses and minuses of unconventional hydrocarbon development and these are summarised in Fig. 1.

[1] IHS Inc., Morenish Mews, Killin, Perthshire FK 218TX, Scotland UK

2. Unconventional Liquids

Unconventional liquids currently provide 2.1% of world annual liquids production. Annual average production growth, however, is unlikely to exceed 0.4 million b/d (barrels/day). This compares with ~ 4 million b/d annual decline in the world's currently-producing conventional fields.

Unfortunately, liquid unconventionals also come with a lot of issues: energy intensity (and therefore greenhouse gas emissions); water supply/disposal; high capital costs and labour requirements; footprint. We can expect that technology will solve many (but not all) of these issues.

There are three principal types of unconventional hydrocarbon liquids:

2.1 Natural bitumen

Bitumen is generally defined as being of less than 10° API gravity and having a viscosity greater than 10,000 centipoise. Some 90% of the world's in-place bitumen resource is found the «oil sands» of northern Alberta, Canada. With a potential in-place resource of 2.5 trillion barrels of «oil» this is the world's largest hydrocarbon accumulation.

The oil was originally trapped at the shallow updip edge of the Rocky Mountain foreland margin (Western Canada Sedimentary Basin) and subsequently modified by microbial biodegredation following Eocene uplift and influx of oxygenated meteoric water from the eastern margin of the basin. Although commonly referred to as «oil sands», some 25% of all resources occur in vuggy carbonate formations which have not yet been developed commercially.

Production is by mining, thermal methods (steam-assisted gravity drainage [SAGD]; cyclic steam stimulation [CSS]) and cold production with sand (CHOPS). A significant volume of undeveloped resource lies between the maximum depth for mining and the minimum depth for wells. Future development challenges include developing this intermediate-depth resource and the carbonate reservoirs.

The various recovery methods pose many challenges: technological; economic; infrastructural; environmental and social. Although many projects have been announced, production growth has tended to lag behind forecasts (Fig. 2). This has occurred for a number of reasons: labour shortages; spiraling costs; the dependence of major projects on a small number of specialised synthetic crude oil (SCO) upgraders which have experienced significant unscheduled downtime.

Much of the ongoing investment in advanced technology is taking place with a view to mitigating the downside aspects of oil sands production. One such innovation is toe-to-heel air injection (THAI™) which is being tested as an alternative to steam-assisted gravity drainage (SAGD). In SAGD, two horizontal wells are drilled, one 5 metres above the other. Steam is injected into the upper well and heated bitumen produced from the lower.

Upside	Downside
• Low exploration risk	• Expensive drilling and completion
• Long-life reserves	• Oil upgrading is capital intensive
• Stable, predictable production	• Low energy return on investment
• Assembly-line development	• Large greenhouse gas emissions
• Long project life provides: - opportunity to improve recovery - opportunity to improve efficiency - security of supply	• High oil recovery requires large amounts of water • High gas recovery requires high well density
• Gas decline rates decrease with time	• Potential for groundwater contamination

Fig. 1: Summarised pluses and minuses of unconventional hydrocarbon development.

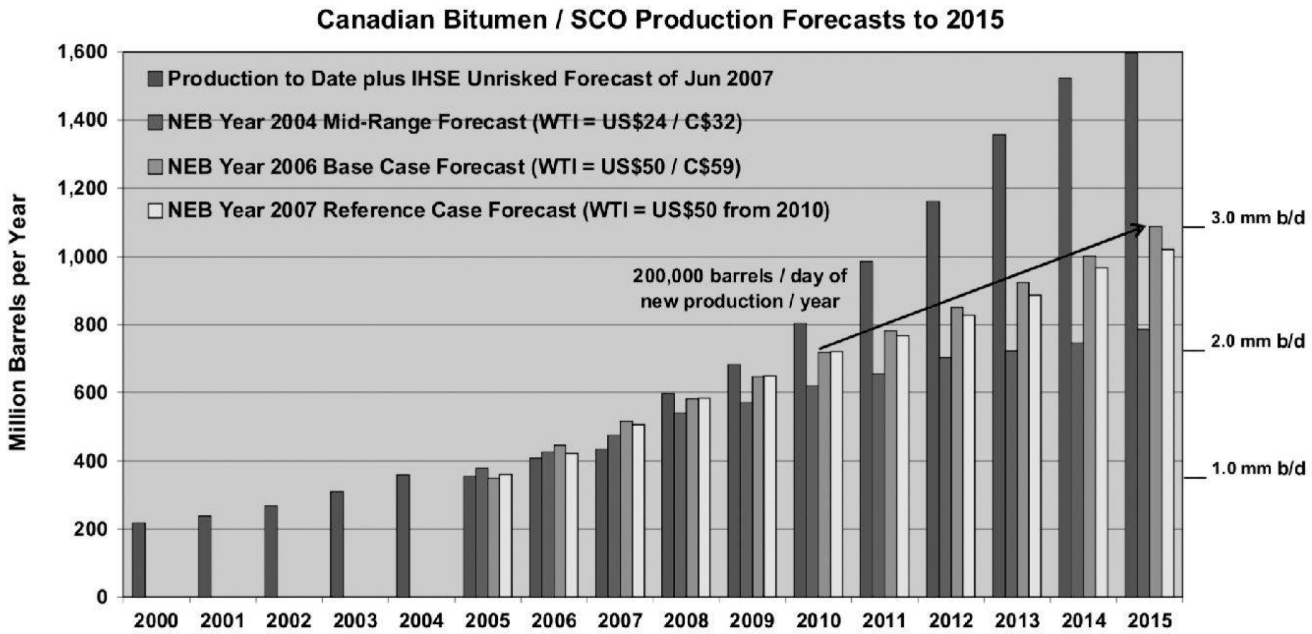

Fig. 2: Canadian bitumen production forecasts 2000 - 2015.

THAI (Fig. 3) reduces capital costs – only one horizontal well; minimal steam and water processing facilities; faster project execution – and operating costs – negligible natural gas use; minimal steam generation and minimal water processing; partial upgrading within the reservoir. Environmental benefits include the reduced use of water, fuel at surface and containment of greenhouse gases within the reservoir.

2.2 Extra-Heavy Oil

Extra-heavy oil is generally defined as being of less than 10° API gravity but having a viscosity less than 10,000 centipoise. Some 90% of the world's in-place bitumen resource is found in the Orinoco Oil Belt of eastern Venezuela where the potential in-place resource could be as much as 1.9 trillion barrels.

The trap comprises a north-dipping homocline with southerly onlap of sands onto basement and partial self-sealing with extra-

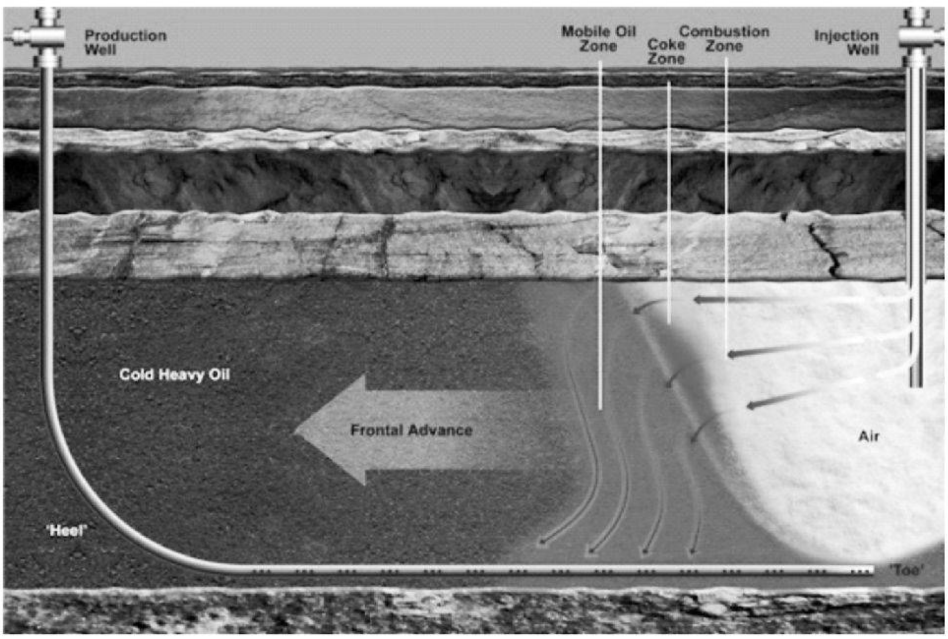

Fig. 3: The THAI™ combustion process. Source: Petrobank Energy and Resources Ltd.

heavy oil. As in the case of the Alberta oil sands, the accumulated hydrocarbons were subject to microbial biodegredation following influx of oxygenated meteoric water.
Unlike Alberta, however, where reservoir temperatures average 15°C, reservoir temperatures are in the range of 48-55°C, significantly lowering viscosity.
Production to date has come from four projects that have applied only primary methods. From the wellhead, the oil is mixed with higher-gravity diluent and pumped to dedicated upgraders at Jose on Venezuela's Caribbean coast. Each of the four upgraders uses Delayed Coking technology. Delayed Coking is a carbon rejection technology, i.e. by reducing the carbon content of the bitumen it upgrades it to higher gravity oil.
There are significant differences in the cost of each of the four projects and this is because of the substantial difference in API gravity of the synthetic crude oil (SCO) produced by each upgrader, which ranges from 16.5° to 32°. There is a direct correlation between SCO gravity and project cost.
The Magna Reserva project that is currently underway sets out to quantify the resource of the undeveloped portion of the Orinoco Oil Belt and bring it into production. The Venezuelan authorities wish to see enhanced recovery techniques applied that will increase recovery factors from the current 8-10% to 20-22%.

2.3 Shale Oil

Shale oil is produced from fractures within a mature source rock that lies within the oil window, i.e. the shale is source, reservoir and seal. Although there is some minor shale oil production from the Bazhenov Formation in West Siberia, the most prolific producer is the Bakken Shale in the Williston Basin of the USA/Canada. Further US production comes from the Barnett Shale (Texas) and the Niobrara Formation (Colorado).
US production rates have increased substantially in the past few years. Bakken Shale production averaged 2,500 b/d in 2001 but had increased to over 40,000 b/d by end-2005. The key appears to lie in understanding and applying the best horizontal fracturing stimulation (e.g. gelled water-sand frac). The prize is worth winning. Estimates of the in-place resource in the Bakken Shale range between 32 and 300 billion barrels. The US Geological Survey has recently estimated the technically recoverable resource at 3.65 billion b/d.

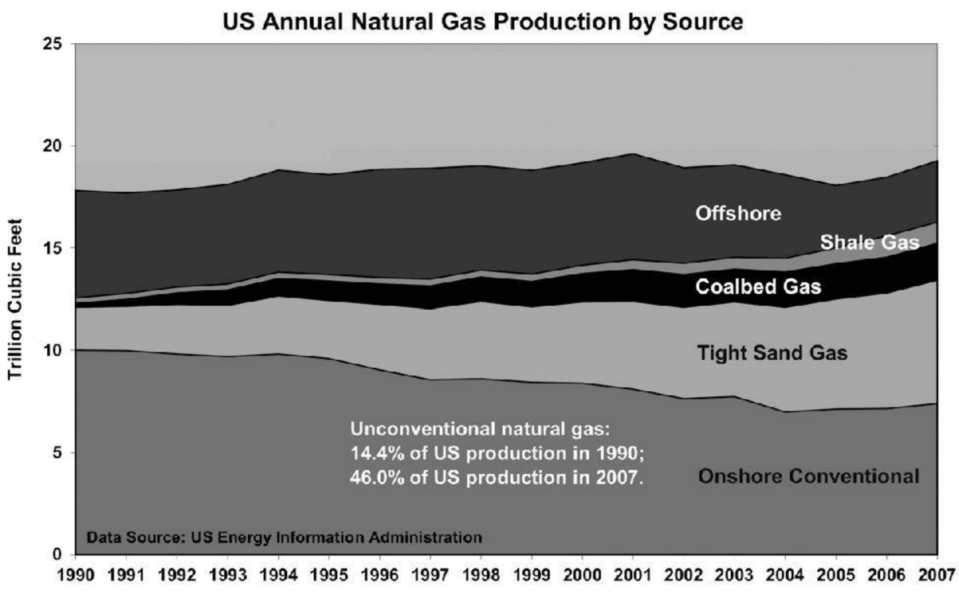

Fig. 4:
US annual natural gas production by source.
Data source: US Energy Information Administration.

3. Unconventional Gas

Unconventional gas is no longer unconventional in the United States. The three principal types of unconventional gas accounted for 46% of US gas production in 2007 (Fig. 4). In 2007, unconventional natural gas provided 9.4% of global gas production. Apart from the USA the other principal producers are Canada and Australia.

Unconventional natural gas resources offer significantly less resource potential than unconventional liquids but global distribution of these gas resources is much more evenly spread. Recoverable resources can require good technology in order to be converted into reserves (micro-seismic mapping; fracture and stimulation; smart wells). Most plays are «statistical» in nature: many wells are needed to understand the play and best drilling/completion techniques. Horizontal drilling with multilaterals has transformed unconventional gas production.

To convert resources into reserves may also require a very large number of wells (10-acre spacing vs. 640 for conventional).

As per-well reserves and productivity are low, unconventional resources are more attractive where an established pipeline infrastructure already exists (e.g. North America; Europe).

Unconventional gas has fewer serious issues than liquids. Most of these are environmental but it also provides the possibility of CO_2 sequestration in coal seams.

There are three main sources of unconventional gas production and a fourth that has significant future potential.

3.1 Coalbed Gas

Coalbed gas is methane-rich gas occurring in self-sourcing reservoirs in undeveloped coal beds and worked coal seams. Although the USA, Canada and Australia are the only significant coal bed gas producers, coal mine methane is produced in 13 coal-producing countries. Coal mine gas production has a dual purpose: to remove methane as a safety measure and to capture vented methane because of its severe impact as a greenhouse gas.

The acceleration in the quantification and certification of Australian coal bed gas resources in Queensland is such that up to six LNG (liquified natural gas) export schemes for the gas are now being evaluated. Global resource estimates show a wide range, from 3,250 to 9,000 trillion cubic feet (tcf) in place. Recoverable resources are probably of the order of 700 tcf but as completion technology for all types of unconventional gas accumulation is improving rapidly, this figure could be exceeded.

A major issue in the production of coal bed gas is the trade-off between greater pressure and gas content with increasing depth/coal rank and better permeability and produced water quality if shallow.

The shallow depth of many potentially productive coal seams gives rise to a number of environmental problems, however, among them being the need for a large number of wells and the potential impact of hydraulic fracturing on drinking water.

3.2 Anomalously-Pressured Basin-Centred Gas («Tight Sand Gas»)

This type of unconventional gas play comprises gas dissolved in abnormally-pressured low-permeability aquifers in the central (generally deeper) part of basins. They tend to be overpressured in subsiding basins and underpressured in uplifted and eroded basins.

Tight gas reservoirs are generally gas-saturated with little or no free water. As the name suggests the typical lithology is sandstone/siltstone and only very rarely carbonate. The updip seal may be a gas/water transition zone, causing a reduction in relative permeability. Matrix permeabilities are low in any case (0.001 - 0.1 millidarcies) as are matrix porosities (< 13%). As a consequence, tight reservoirs have significant irreducible minimum water saturation (> 30%) and require hydraulic fracturing.

In-place resources in North America alone are enormous (USA: 6,800 tcf; Canada: 560 tcf) but although tight gas reservoirs are known from around the world, estimated global recoverable resources are much smaller at some 1,500 tcf, mainly on account of the typically low recovery factors. Recovery is a function of the extent to which fractures extend from each well. In the US, this has resulted in drilling densities as high as one well per 10 acres (64 wells per square mile, 25 wells per square km).

3.3 Shale Gas

As in the case of shale oil, shale gas production comes from a tight self-sourcing shale reservoir. In this instance, however, the shale source/reservoir is over-mature for oil. In fact, the presence of liquid hydrocarbons impedes the relative permeability of gas and is detrimental to gas production.

Ideally gas shales should have low effective stress and it is preferable if the natural fracture system is contained, for example by being bound above and below by limestone, as in the case of the Barnett Shale. High quartz: clay ratios improve fracturing (natural and artificial).

Although shale gas was the oldest play in the US, it is now the fastest-growing play in North America. For over a century only the New Albany and Ohio shale gas plays in the US northeast were productive. Today over a dozen shale gas plays are being actively investigated throughout the country and the Newark East field (Barnett Shale) is second only to the San Juan coal bed gas area in US gas production, having risen from 11 billion cubic feet (bcf) in 1993 to produce 480 bcf in 2005. Exploration is booming in Canada too and the Muskwa Shale in the Horn River Basin northeast British Colombia may ultimately rival the Barnett Shale. The key to

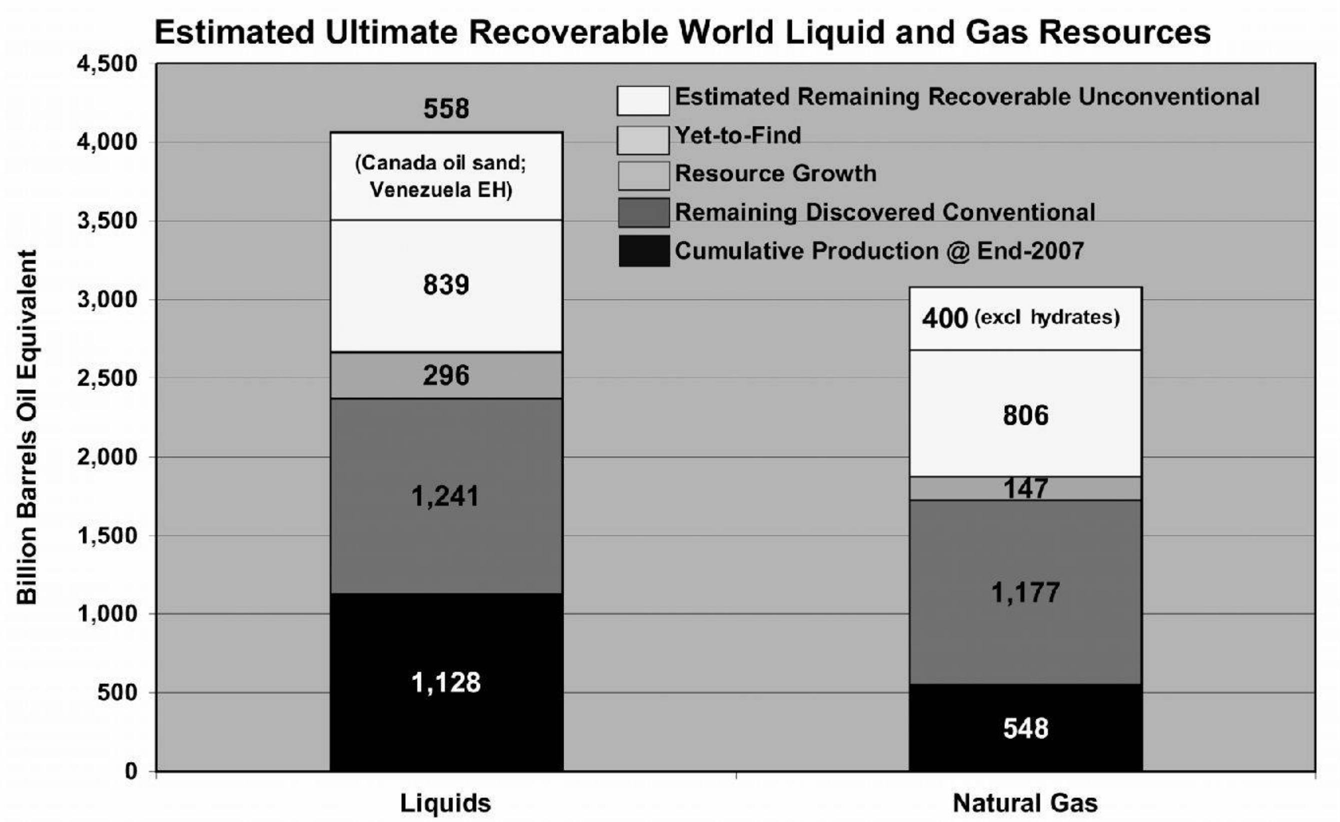

Fig. 5: Estimated ultimate world liquid and gas recoverable resources (Venezuela EH: Venezuela extra-heavy oil).

exploitation has been to find and implement the best fracturing technique.
Internationally, exploration is in its infancy but the dramatic growth in North America over the past five years will undoubtedly prompt countries with domestic experience to seek opportunities elsewhere.

3.4 Gas Hydrates

Gas hydrates or clathrates are methane trapped in a lattice of ice. They exist onshore in permafrost regions at depths from 130 - 2,000 m and on continental margins where water depths exceed 300 m and bottom water temperatures are around 0°C. Where present, hydrates themselves may act as a top seal for underlying free gas accumulations.
At present there is no viable development scheme but the potential resource is enormous so they have attracted considerable interest. An additional reason for interest in hydrates is that global warming could result in the release of enormous amounts of methane from oceanic hydrates. This in turn would result in further global warming so this is potentially a major positive feedback mechanism.

4. Unconventional Resources and the World Hydrocarbon Resource Endowment

Fig. 5 illustrates the possible future contribution that unconventional liquid and natural gas resources could make to the total global endowment of hydrocarbon resources. These values must, however, be treated with extreme caution.
With the exception of what has already been produced and the volume of conventional resources that have already been discovered, all other sources of resources for the future are subject to considerable uncertainty. We do not know how much extra resource can be obtained from existing fields by improved recovery (resource growth). We do not know the volume of resources that are as yet undiscovered (yet-to-find). And we can only estimate approximately how much will come from unconventional sources. In this case there are many unknowns but the principal among these are uncertainty over ultimate recovery factors and the possibility that much known resource (especially liquids) may never be developed because of the potential environmental consequences of doing so.