Conditions for an Economical and Acceptable Development of Unconventional Resources Out of North America*

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Abstract

Between 2006 and 2012, a period that barely covers the exploration and delineation phases of a conventional field, the US production of unconventional hydrocarbons has risen from 2 Bcf/day to 26.5 Bcf/day for gas and from 0.3 Mbopd to almost 2 Mbopd for oil, making the United States the leading source of growth in the world (Figure 1). Although a number of plays significantly contribute to US shale gas production, the Barnett (North Texas), Haynesville (Louisiana and Texas), Marcellus (New York State) and to a lesser extent Fayetteville (Arkansas) were the main contributors to the shale gas ramp up, whereas Bakken (North Dakota) and Eagle Ford (Texas) are the main contributors for tight oil.

Introduction

On the technical side, the US Oil & Gas shale boom is nothing revolutionary and is not the result of any major technological breakthrough. It is the consequence of the association of two "mature" technologies, namely horizontal drilling and hydraulic fracturing implemented in a "trial and error" factory business process which consists of drilling and fracturing a huge number of cheap wells (Figure 2) without examining geological attributes in detail and accepting that statistically, a significant number of wells will under-perform and not produce cost-effectively. Such a model was made possible in the US thanks to four main pillars:

- A good knowledge of the subsurface thanks to nearly a million wells drilled since the beginning of the twentieth century,
- A strong political support for federal and local authorities,
- Very favorable mining rights,
- The historical presence of many service companies in an open and competitive market.

A "cut and paste" of this model outside the U.S. does not however seem feasible in most cases. Exporting the shale oil & gas revolution outside US relies on two major challenges.

Challenge 1: Identify Sweet Spots, an Appraisal 4G Process

Play and SRV Quality

Contrary to conventional hydrocarbons that migrated to a reservoir where they became trapped, shale oil and gas come from the exploitation of the source rock itself. Remember that hydrocarbons are the product of the maturing process of organic matter (i.e. kerogen) buried in very fine sediments, which were heated enough to trigger a chemical reaction similar to cracking. As depth increases, first oil is found, and then wet gas associated with condensate and finally dry gas. Unlike reservoir rocks that result from the diagenesis of quite large grains of sand or limestone with a fairly low clay mineral content (1% a 2%), source rocks generally deposited in a calm marine environment are heterogeneous comprising a mixture of very fine grains of limestone, silica and shale (20-40% on average) in highly variable proportions. A source rock also contains between 1% and 10% of organic matter by weight, which alone can represent up to 50% of the total porosity. The fine granulometry and the significant presence of organic matter give a source rock a very large specific surface area, a micro-porosity and a nanometric permeability, i.e. a thousand to a million times lower than that encountered in the poorest conventional reservoirs. Source rocks are also often naturally fractured and do not need traps, the low permeability plays this role. For this reason, source rocks spread out horizontally over incredible distances when compared to the extension of traditional reservoirs, covering areas of thousands of square kilometers. The Barnett (North Texas) covers an area of 30,000 km^2, the Marcellus in the North East United States, an area of 246,000 km^2 and the Bazhenov in west Siberia nearly one million square kilometers.

In conventional reservoirs, the permeability is usually sufficient to allow the well to produce hydrocarbons economically. In the case of source rocks, the very low permeability means that they cannot be produced economically without using an artificial means of increasing the permeability, i.e. "***hydraulic fracturing***". This technique consists in creating a connected fracture network within the formation by injecting a fluid (usually water) under pressure and loaded with calibrated sand, the role of which is to maintain the created (or reactivated when the fracture is natural) fractures open. This fractured volume of rock, called **SRV** (**S**timulated **R**ock **V**olume - Figure 3) occupies a volume around the well in which the permeability increases to deliver economic production. To maximize its size, long horizontal wells are drilled parallel to the minor horizontal stress and, using the hydraulic fracturing technique, a set of transverse fractures is created. This set of parallel fractures (recent shale gas developments in the US use up to 30 fractures or "fracture stages" per well) enhances the formation of a secondary fracture network (Soliman et al., 2010) composed of both induced fractures as well as reactivated natural fractures (Mirzaei and Cipolla, 2012). The size and the equivalent permeability of the SRV are data essential to estimating the well spacing required to economically produce the play and avoid abandoning undrained areas.

Play (rock before fracturing) and ***SRV*** (rock after fracturing) qualities are the keys to transforming a play (i.e. hydrocarbons in place) into a reservoir (i.e. reserves) and to producing it economically. They depend on a number of "**attributes**" that are summarized in Figure 4.

"*Play Quality*" will be governed mainly by geochemical (TOC, maturity window), petrophysical (natural matrix permeability, porosity, mineralogy) and pore pressure attributes. Apart from many factors related to the fracturing operation itself (type of fluid, pumping rate, proppant concentration), "SRV quality" will depend on the state of stress that impacts the well azimuth, the presence or absence of natural fractures and the ability of the rock to fracture. The latter is called "*brittleness*" and depends on the elastic properties of the rock (Young's modulus, Poisson's ratio) which in turn are strongly related to the mineralogical composition. Low clay content favors high brittleness (Romanson et al., 2011).

Production Sweet Spot

A production "***sweet spot***" is an area of both good play and SRV qualities where economic production can be expected. Figure 5 presents a Play & SRV quality exercise resulting from the analysis of 8,000 wells. Using a number of attributes, play and SRV quality maps have been drawn and then superposed (the colors refer to Play Quality and the elevation to SRV quality). The map highlights three different zones (1) low play and SRV qualities (2) good play quality but low SRV quality (3) both good play and SRV qualities. By comparing play & SRV quality map and production results, it becomes obvious that the production "***sweet spot***" (optimal production zone) correlates well with zones having both good play and SRV qualities. The left-hand sector, where more than 30% of the wells were drilled, remains virtually unproductive. Anticipating production sweet spots as far upstream as possible thanks to a proper mapping of play and SRV quality using the right attributes should therefore help minimize the number of wells drilled in unproductive areas, an action inherent to the "trial and error" model.

Even if it is precisely positioned in a sweet spot however, the initial production of an unconventional well will decline very rapidly. As shown in Figure 6, in most US plays, more than 50% of the ultimate reserves are produced during the three first years, and 80% to 90% after eight years. Consequently, the economic life will be much shorter than regular conventional wells. This rapid decline is inherent to the nature of the rock: once the fractured part of the SRV has been produced, the matrix cannot supply more fluid at an economic rate.

Challenge 2: A Flexible Factory Development Model

To maintain a production plateau that satisfies all the Geoscience pillars (low permeability, large extension and rapid decline in production), the development of an unconventional play will require a considerable number of horizontal wells to be drilled, multi-fractured then connected over a short time period. DRILLEX (drilling + fracturing expenditures) often reach 70 to 90% of the total Capital Expense. Although such massive operations need to be conducted in a coherent and efficient manner, based on an integrated, continuous schedule to sustain low costs and rapid cycle time, they also need to be flexible enough to allow "on the fly" corrections when any given technical, commercial or acceptability markers change. This is why we often refer to a "flexible factory development model" (Forbes and Wilczynski 2010).

A license (typically between 10,000 and 25,000 km^2 - Figure 7) will rarely be developed in a single phase. It can be broken down into several core areas (typically 2,500 km^2) each being developed individually from PADS of 10 to 20 wells. Assuming a drainage area of between one and two square kilometers, a core area will typically be developed using 1,000 to 2500 wells. Before any development begins, the play needs to be assessed by a pilot phase carried out within the first core area envisaged. Designed to decide on the market value of a play to be developed the pilot phase aims to:

1. Assess Play and SRV qualities to reduce static and dynamic uncertainties as early as possible, prepare an economic and acceptable development scheme of the whole license and a detailed pre-project for the first core area. To de-risk uncertainties, the pilot phase will include an extensive monitoring program,

2. Assess and debunk potential acceptability (in particular acceptability related to environment) issues,
3. Start improving operational leaning curves (drilling/fracturing/surface layout) as much as possible without however penalizing the primary goals, for instance by cutting voluntary monitoring/measurements to save costs.

The pilot phase starts by a series of seismic campaigns (Bell et al., 2013) and several vertical wells including extensive logging and coring to assess play quality over an initial core area. In order to assess SRV quality, well productivity (short-term tests) and demonstrate the commerciality of the play (long-term tests) an Early Production System (1 or 2 experimental set of 5 to 10 horizontal wells all multi-fractured) will be developed. This "pilot phase" will also early include detailed acceptability studies (social/environmental baselines and impact assessments). A pilot phase will typically last 2 to 3 years, include five verticals wells and twenty horizontal wells.

Following the results of the pilot phase, a concept for developing the whole license in an **economic** and **acceptable** way will be proposed. It will be reviewed after the full or partial development of each core area according to updated acceptability, technical (in particular subsurface), financial and commercial data. Each core area will be developed on a "rolling" basis using a standardized modular approach with the objective of bringing wells on stream as soon as possible to maintain the production plateau, which can decline rapidly if new wells are not quickly connected. The global schedule can also be affected by the local/regional gas market as well as by acceptability considerations, which have a strong influence on the location of PADs.

Constantly improving this performance implies not only drilling quickly and economically (optimal choice of drilling tools and fluids, procedures that contribute to reducing non-productive time as much as possible) but also streamlining architectures (minimum number of casing points) while assuring safety excellence. To secure a large number (often several dozen) drilling rigs and fracturing equipment for long periods of time (10-20 years), companies must rework their long-term policies and in particular analyze new strategic alliances with Service Companies. The logistics chain will naturally play an essential role in terms of both transportation and supply (equipment, water, sand, chemicals) and on the management of the spare parts inventory. This new type of model will also require many new, highly cross-functional competencies (i.e. geosciences and geo-mechanics vs. drilling and completion) that will have to be introduced into a workforce of personnel mainly recruited locally.

Exporting the Revolution

The North American subsurface is not unique because of the quality of its source rocks. All conventional oil and gas producing regions of the world have source rocks and consequently, shale oil and gas resources. From Australia, through China and Europe to Argentina, there are many plays, some of which are very promising and have qualities that are sometimes superior to those of the American plays.

In its last report published in June 2013 the EIA (US EIA, 2013) estimated that the world's technically recoverable resources are somewhere in the region of 1,200 Gboe for shale gas (7,200 Tcf) and 347 Gbbls for shale oils. In addition to North America, the main gas plays are located in China, Argentina and, to a lesser extent, in Australia and South Africa, whereas in terms of oil Russia is thought to have the largest resources, followed by China and Argentina (Figure 8). In theory, unconventional hydrocarbons could therefore overtake conventional gas reserves and boost the conventional oil reserves by 20%.

These notional evaluations must nonetheless be considered with the greatest caution given that, except for those calculated for North America, they are based on simplistic volumetric calculations that do not factor in the economic, political and cultural context. Clearly, even if thorough geological knowledge of a play is the first milestone, it cannot alone “successfully export” unconventional resources. Once the geological uncertainties have been overcome, the maturity of a region will depend on multiple factors that will favor or, on the contrary, penalize future developments. These include (IHS CERA, 2013):

- the legal context including in particular acreage law and tax regulations
- the business environment and available capital
- accessibility to the site and to water, which is sometimes difficult for geographic and/or demographic reasons
- the local presence of operators and oil services (seismic, drilling and fracturing)
- existing infrastructures (roads) and gathering networks
- strong political support from governmental, regional and local authorities
- a positive public opinion to swing the balance in favor of opportunities rather than dwelling on risks.

If we roughly divide the learning curve into three periods (an immature period of de-risking reserves, an appraisal period with the realization of commercial pilots and a mature development period - Figure 9) it is easy to see that except for the US, the production of unconventional resources is still in its teething stages (McKinsey et al., 2013).

Argentina

Up until 2004, Argentina was a gas exporter. In 2011, it was importing 0.7 Bcf/day, mainly from Bolivia and the Middle East (LNG). To limit gas imports the door is therefore wide open to develop the enormous potential of shale oil and gas that the EIA estimates respectively at 27 Bbbls of oil and 136 Gboe. The Neuquén basin represents more than half of this potential, stored in a source rock, which is recognized as being of the best quality in the world – la Vaca Muerta. The existence of local export infrastructures is a major economic advantage for the future development of this source rock, impregnated with both oil and gas.

China

With almost 200 Gboe (1,100 Tcf) of shale gas and 32 Gbbls of shale oil, China may have an unconventional potential comparable to that of North America. The resources are located mainly in the Tarim basin (216 Tcf) in the North West and the Sichuan basin (626 Tcf) in the southeast. Although the initial wells drilled have confirmed the potential, rapid commercialization will not be a simple matter. The average depth (between 3,000 mTVD and 4,500 mTVD), together with the complexity of the highly faulted geological structures and the high uncertainties concerning production, mean that these plays could only be competitive at a price of 12 - 14 $/MBTU (IHS CERA, 2013). Moreover, the Tarim basin is located in an arid region where the water supply (for hydraulic fracturing) will be one of the main obstacles.

Russia

Russia's unconventional potential is associated essentially with the Bazhenov, the source rock of the conventional reservoirs in Western Siberia, which, in 2012, were producing 7.5 Mbopd, i.e. 75% of Russian production. Extending over a gigantic surface area somewhere between 850,000 and a million km^2, it is the largest oil and gas basin in the world. It is located at a depth of 2,550 mTVD and 3,000 mTVD, and is 25 to 35 meters thick. Its southern section is impregnated with oil of excellent quality whereas its northern section is impregnated with gas and condensates. Despite the fact that it is located in a region with a hostile polar, the Bazhenov has the great advantage of benefiting from existing facilities and from the presence of a great many local operators and service companies and from the research centers which have been established in the area for some time.

Europe

According to the latest EIA evaluations, Europe is thought to have 93 Gboe of unconventional resources, of which 85% are gas resources (470 Tcf i.e. 80 Gboe of shale gas). The main resources are estimated to be in Poland and France (28 Gboe each) and to a lesser extent in Romania, Denmark, Holland and in the UK. However, these estimates, which are based on simplistic volumetric calculations, are somewhat inaccurate and must be considered with a great deal of caution. Only the data acquired during the drilling of exploration wells will provide a true picture of the actual stakes (Moore, 2012).

Conclusion: an Optimism to be Tempered

The US is the indisputable short-term economic winner of this energy revolution that they began and which they used as a springboard to get themselves out of the crisis. According to the IEA, the considerable potential of shale oil and gas should enable the US to increase their hydrocarbon production significantly over the next fifteen years: unconventional gas production could reach 7.3 Mboe/day by 2035 i.e. 50% of overall production, and a second peak oil between 2020 and 2025 at approximately 11 Mbopd, i.e. almost equivalent to that of 1970 is expected. However, contrary to what certain media would have us believe (Constantinou, 2012), even if the US can effectively become a gas exporter as from 2020, self-sufficiency in terms of oil is an unrealistic target.

Although the quantities of hydrocarbons in place dispersed in the source rocks are considerable, the recovery rates are only a few percent. An error of one percent on the recovery rates could therefore lead to massive mistakes regarding reserves. Furthermore, whereas production on conventional oil fields declines at a rate of somewhere between 3% and 6% and that on gas fields between 15% and 20% per year, unconventional plays "lose" between 30% and 40% per year (Berman, 2012). The cost of replacing lost production continues to rise. In Haynesville, for example, it has increased from $2.3 billion per Bcf/day between the beginning of 2008 and mid-2010 to $3.6 billion per Bcf/day between mid-2010 and mid-2011. In other words, more and more wells need to be brought on stream to maintain production targets: a "one-step-ahead" tactic that obviously has its limits.

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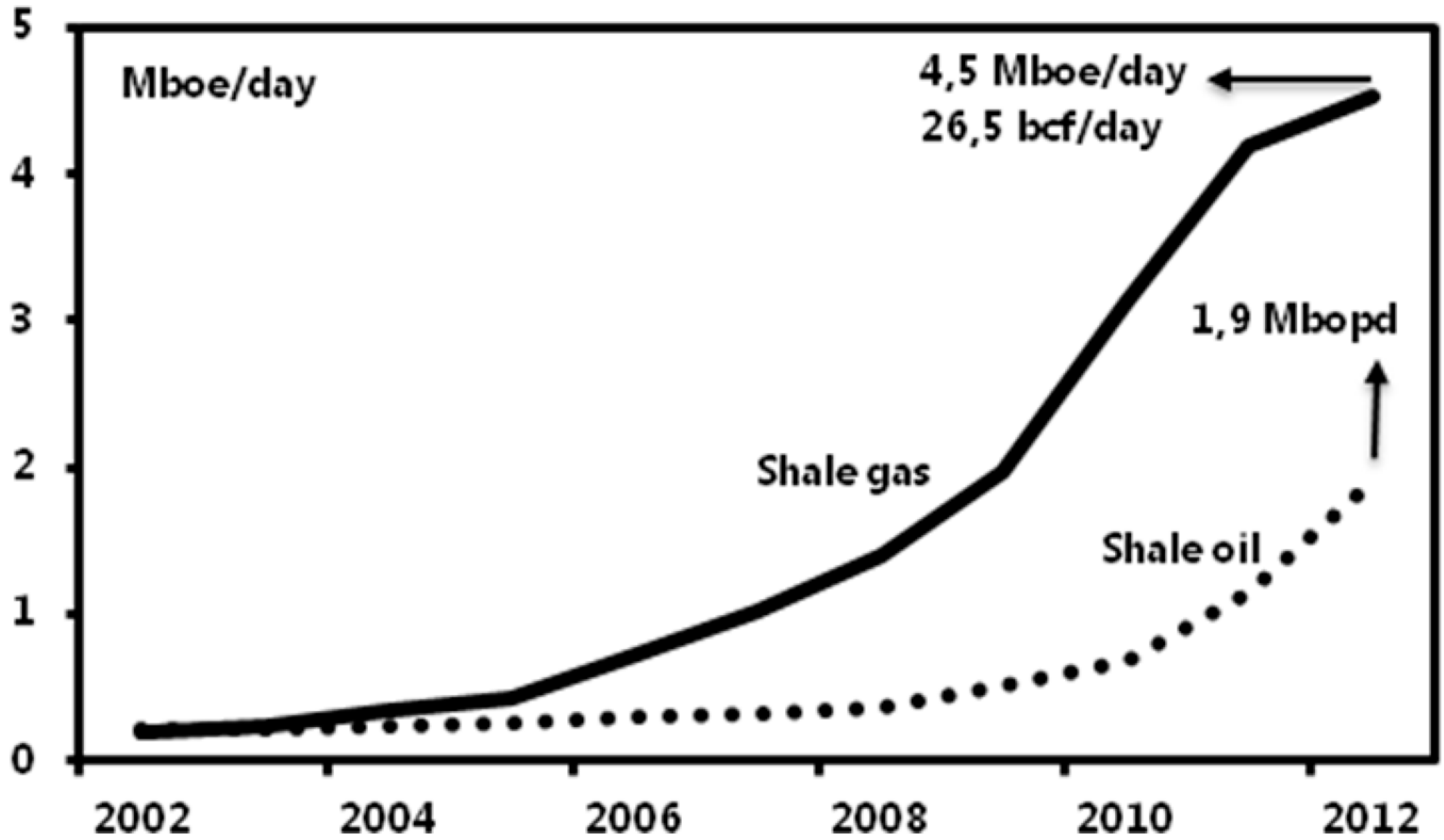
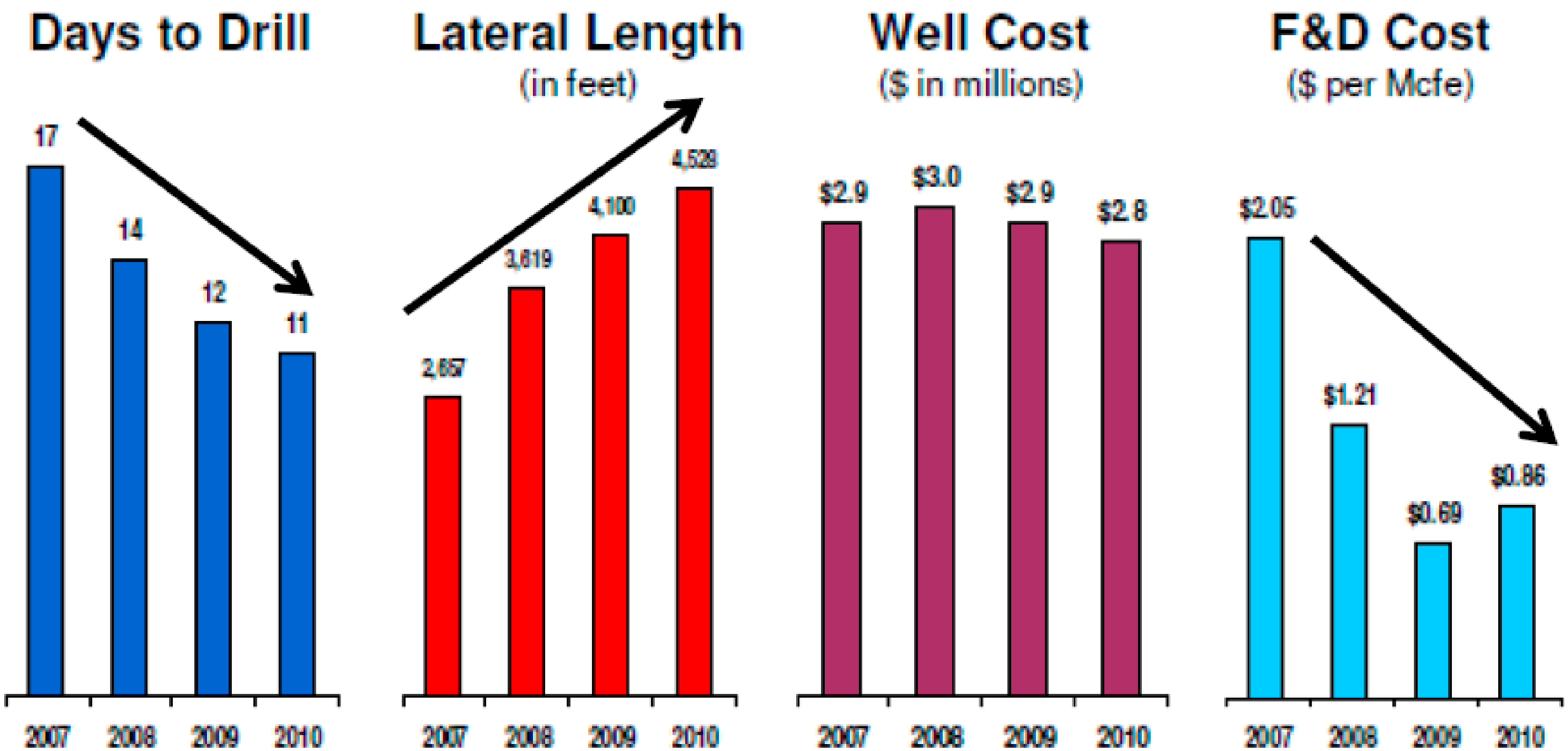


Figure 1. The spectacular shale gas and tight oil ramp up in the US (Source IHS CERA).



Drilling	Days	11
Lateral length	Feet	4529
Well cost	M$	2,8
Technical cost	$/MBTU	0,86

Figure 2. Positive evolution of main shale gas KPI (Schlumberger) (Bentley, 2012).

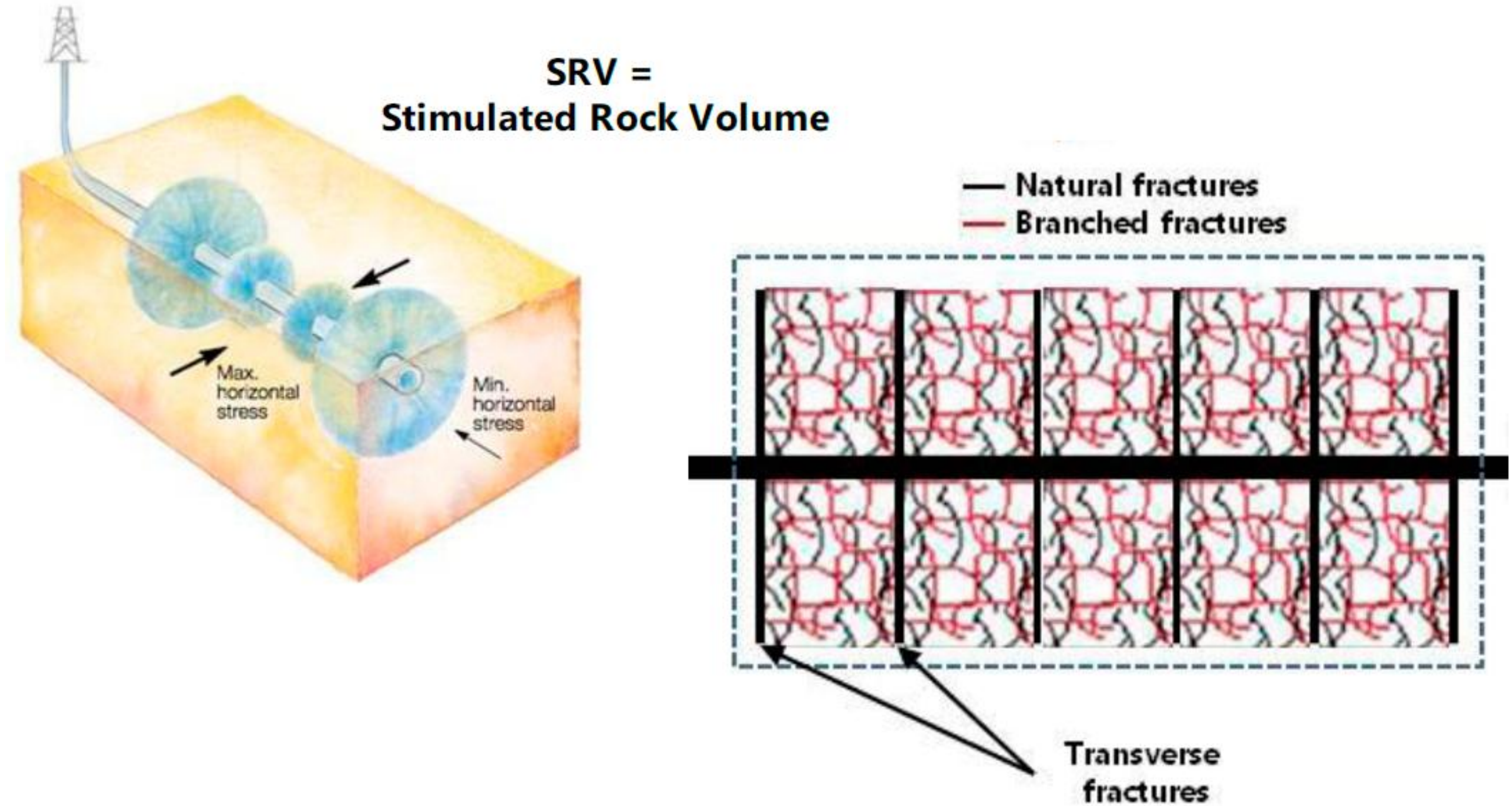


Figure 3. Multi-fracturing of a horizontal well. SRV concept.

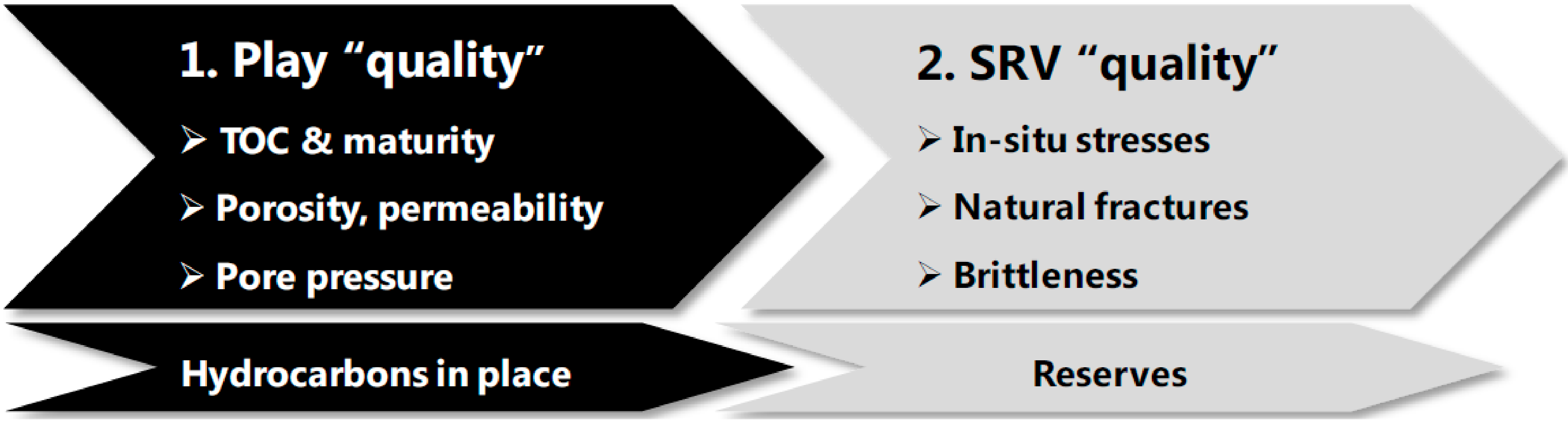


Figure 4. From "play" to "reservoir". Main play and SRV quality attributes.

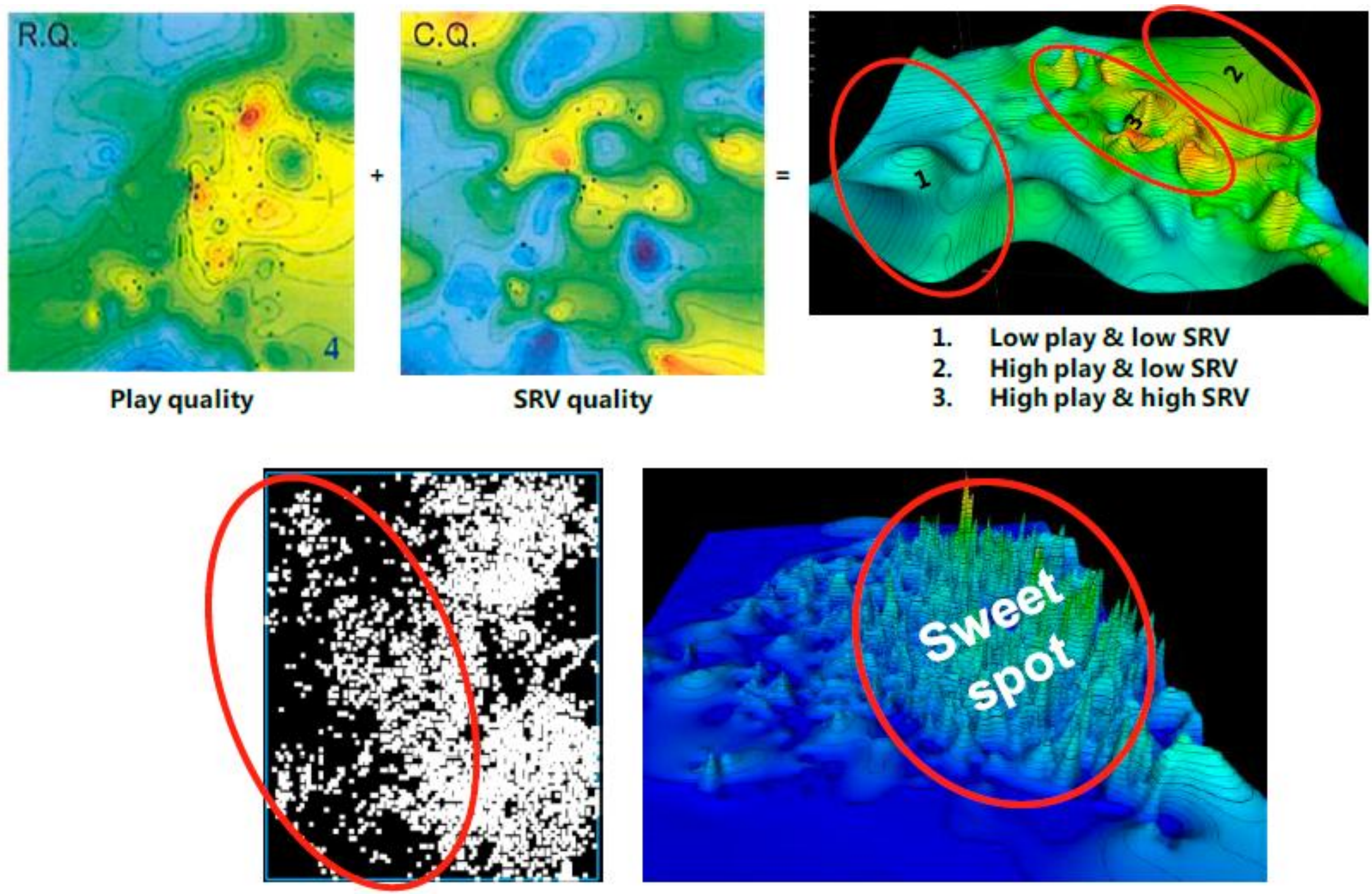


Figure 5. Play and SRV quality map. Production results (right) and well placement (left). After Terratek SLB.

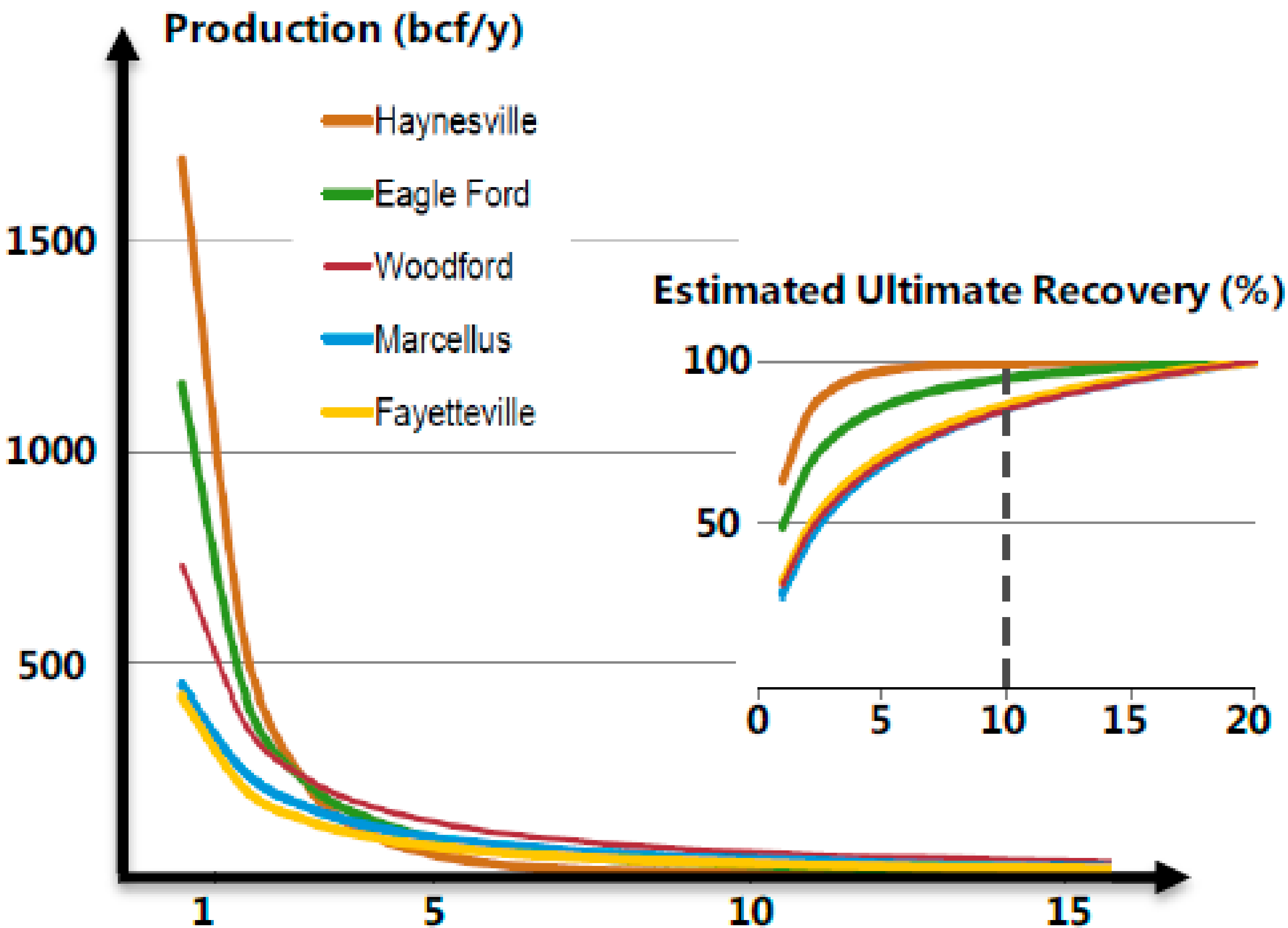


Figure 6. Typical decline curves of US shale gas wells (according to IHS CERA).

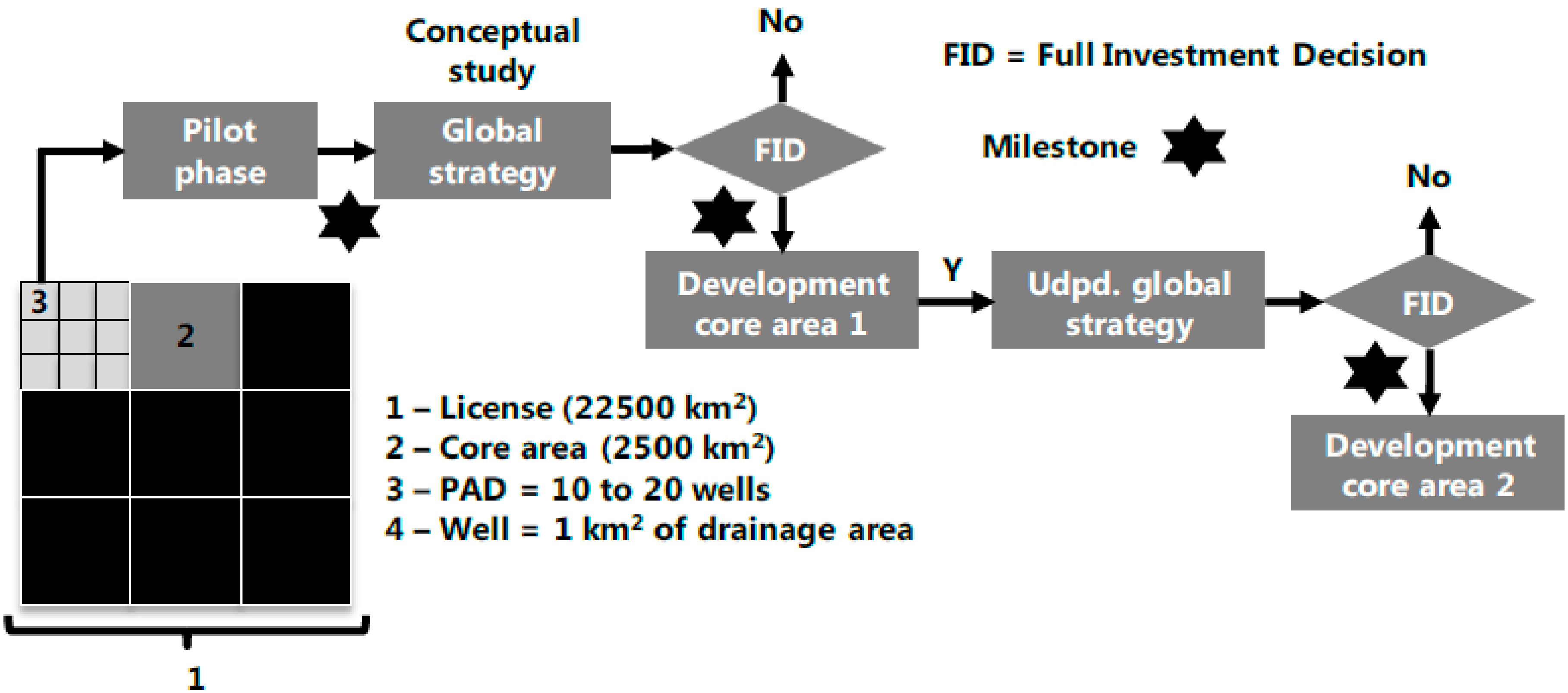
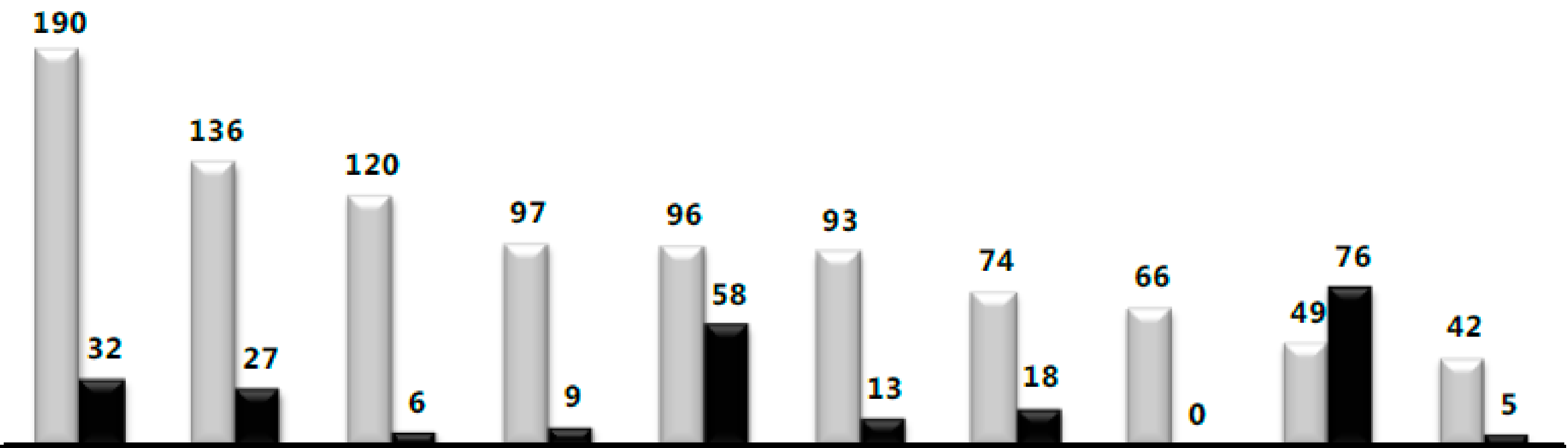


Figure 7. License development workflow.



	China	Argentina	Algeria	Canada	US	Mexico	Australia	South Africa	Russia	Brazil
Gas	190	136	120	97	96	93	74	66	49	42
Oil	32	27	6	9	58	13	18	0	76	5

Figure 8. World distribution of shale gas (gas in place). The export of unconventional gas outside the US: distribution of world reserves.

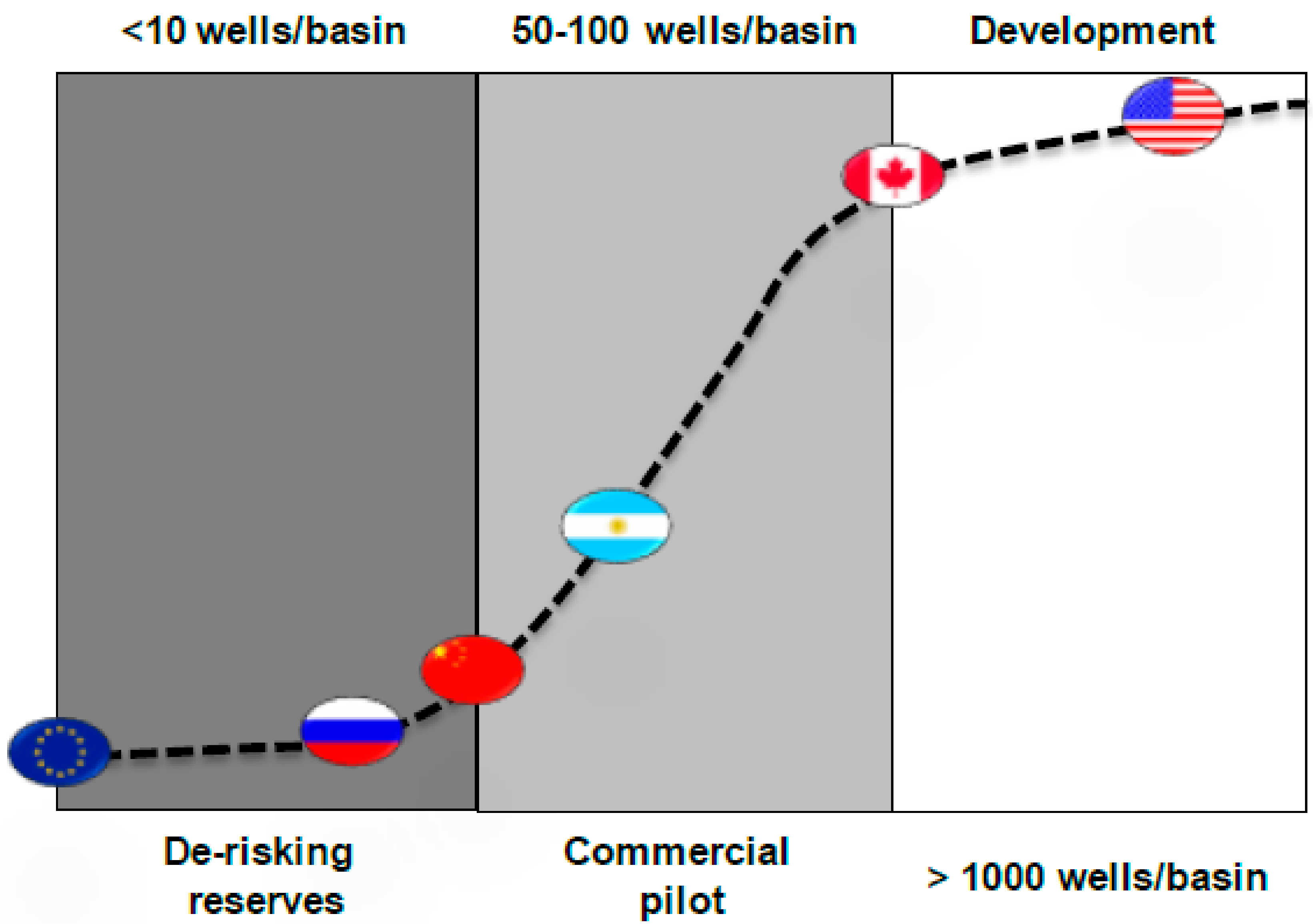


Figure 9. Learning curve and maturity for certain regions.