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Evaluation of Unconventional Resource Plays

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Abstract

Making sound business decisions in one of the hottest domestic exploration plays, unconventional gas, offers a set of challenges not usually encountered with more traditional opportunities. Unlike with standard prospect and conventional play risk analysis, geologic chance is not a major issue, and estimates of initial production, decline rates, mechanical efficiency, and success planning dominate the analysis rather than traditional volumetric determinations. The valuation and assessment of unconventional or "continuous resource" opportunities is not feasible using traditional probabilistic, volumetric-based methods. A fully stochastic business, value-chain model is the best way to assess the potential of an unconventional play. Such an evaluation method allows for multi-disciplinary and cost input that affords decision makers with the appropriate data to make good decisions.

The boundaries of unconventional reservoirs extend well beyond the limits of most individual acreage holdings. As such, the recommendations of Schmoker and others to base the full resource availability on a cell or single well drainage area should be embraced as a starting point.

Resource uncertainty is handled by a continuum of well size distributions arranged to form an EUR Envelope. Volumes are only part of the equation, however. Uncertainty in the production profile must be taken into account, with variations in initial production, decline rate, and hyperbolic exponent figuring prominently in the final assessment of profitability.

There are four main stages in the exploitation of unconventional opportunities: Exploration, Evaluation, Delineation, and Development. Proper assessment, including identification and management of downside risk, requires a decision-focused, integrated, multi-discipline evaluation process through the four stages.

Unconventional plays use an initial number of wells to test the viability of a play and stimulation technology/methods. These pilot programs can be optimized, for number of wells, and company risk tolerance. Pilot Effectiveness is the (measurable) probability of the pilot program providing truthful results given the small number of test wells modeled.

Output from the proposed stochastic evaluation method include both single economic and product-based metrics in cumulative probability curves, as well as time series output in both aggregate and pathway forms. A thorough understanding of results analysis, Value of Information, and decision options is encouraged in order to take full benefit of the stochastic assessment method.

Introduction

In recent years, resources recoverable from reservoirs of difficult nature have come to be called "Unconventional Resources". In addition to fractured reservoirs, unconventional plays include tight gas, gas/oil shale, oil sands, and coal-bed methane (CBM).

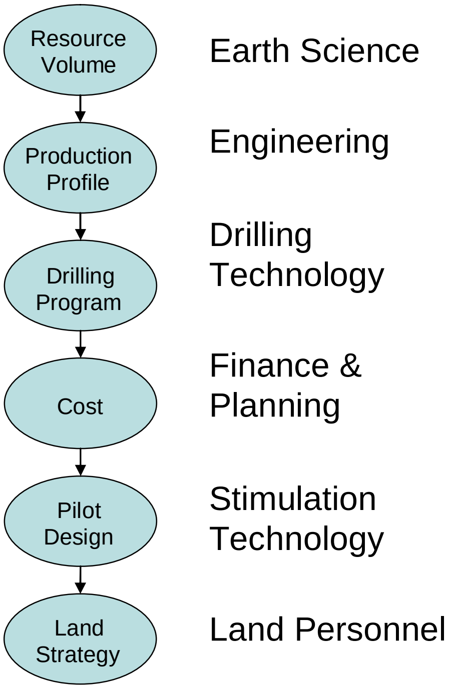


Figure 1: Valid unconventional play assessment relies on multi-disciplinary understanding, cooperation, and input.

Since commercial exploration and production of oil and gas reservoirs began there have been circumstances where the reservoir character or depositional model has caused difficulty in assessment. Volumetric and production assessment of unconventional reservoirs have been notoriously problematic using standard probabilistic methodology, and evaluations have often relied on rules of thumb or deterministic shortcuts.

The evaluation of unconventional resource requires a different approach that must take into consideration uncertainties in rate and rate through time. Ideally, the evaluation method will take a value chain approach that includes all significant uncertainties from exploration through the end of production. This comprehensive approach will provide companies with the insight to make correct appraisal and development decisions and allocate the level of capital and resource appropriate for the play and risk tolerance of the company.

Unconventional Resource

The defining characteristics of an unconventional resource are at best nebulous. Etherington (2005) states "An unconventional reservoir is one that cannot be produced at economic flow rates without assistance from massive stimulation treatments or special recovery processes." Others (Stabell, 2005; Schmoker, 1999) use a definition based upon two common aspects: that they are comprised of large volumes of rock pervasively charged with hydrocarbon, and that the accumulation types are not dependent on buoyancy.

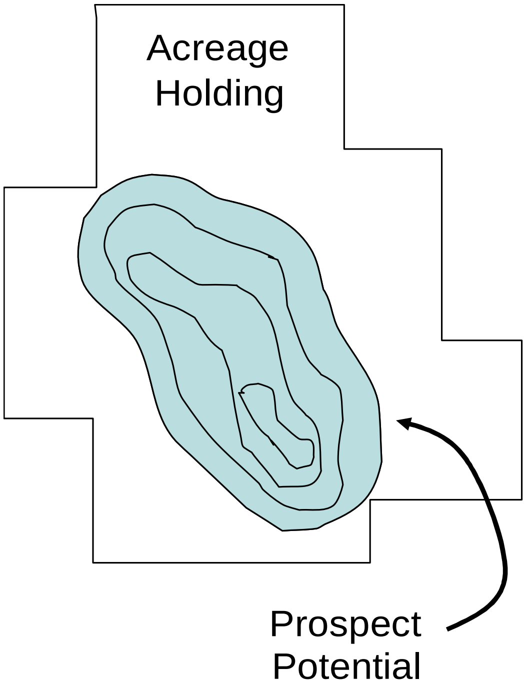


Figure 2: Conventional prospect assessment has definable boundaries to the potential reservoir or is enclosed within a specific geographic area.

More importantly Schmoker continues with "…and, therefore, cannot be analyzed in terms of the sizes and numbers of discrete entities delineated by downdip water contacts, as are conventional fields or pools."

Others such as Shanley et al (2004) have challenged the assignment of low permeability reservoirs to a widespread, continuous resource model, favoring a more traditional, structurally controlled model for such resources. The method that the authors of this paper present is applicable to either situation.

Ultimately, a business-type model is indifferent to the nature or genesis of the overall accumulation. Whether an accumulation is continuously pervasive over a larger area or the result of low-permeability, poor-quality reservoir rock in conventional traps, the requirement is the same. Proper risk and uncertainty assessment requires a method that may be applied to a portion of a much larger reservoir.

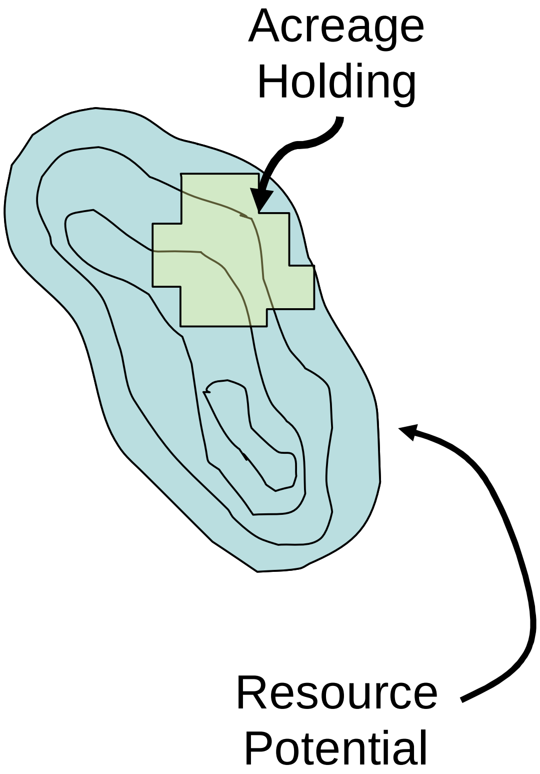


Figure 3: Unconventional resource potential extends well beyond the limits of the area being assessed. This aspect demands a change from traditional probabilistic volumetric methods.

Chance and Uncertainty

For this paper we will assume a continuous accumulation of basin centered or permeability challenged gas-bearing reservoir. By definition, such continuous accumulations have little if any probability of not producing hydrocarbons (Play Chance approaches 1.0), given a technical ability to reach the producing horizon.

Individual well risk remains, as reservoir heterogeneity demands that some wells may encounter reservoir so poor as to not be capable of production even after stimulation. Individual wells also have mechanical risk. Some objectives are difficult to drill to and there is always a chance of mechanical problems that will cause a hole to be junked. In general, however, the impact of chance variability is significantly less than that associated with conventional resource analysis.

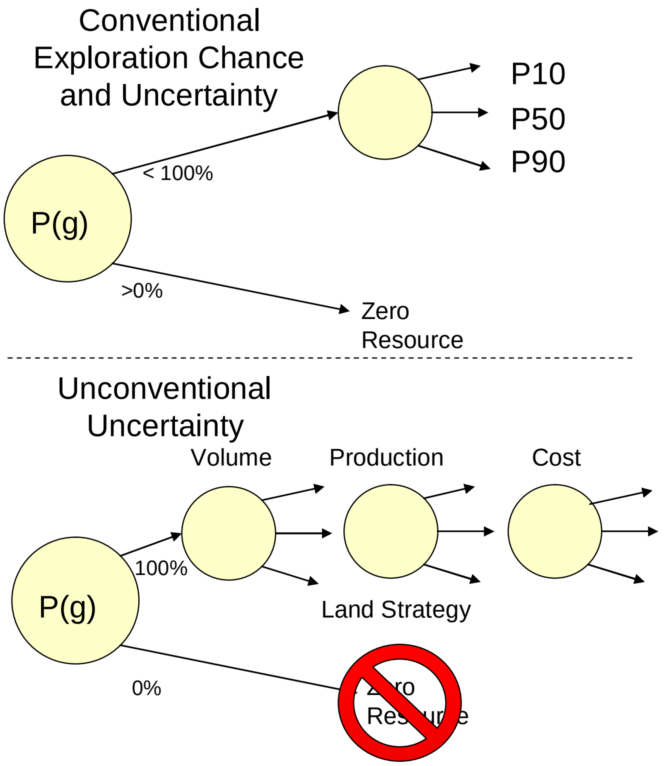


Figure 4: Comparison of conventional chance vs. unconventional. Continuous accumulations or areally extensive accumulations show little if any chance of P(g) failure.

The primary analysis therefore should focus upon the uncertainty associated with how much will be produced, and at what rate through time. The standard probabilistic volumetric approach as derived and presented by Baker and others in the 1980's, and evolved by many authors since, assumes the presence of conventionally trapped hydrocarbons in discrete entities variously defined as pools or fields. Primary uncertainties include hydrocarbon saturation, formation volume factor, recovery efficiency, and porosity in combination sometimes referred to as Hydrocarbon Recovery Factor, pay thickness, and area.

Area is problematic. Without field or pool boundaries in a regionally extensive production regime, area uncertainty is virtually meaningless as an input to volumetric uncertainty. Yet, from the personal experience of the authors, many major companies still force their staff to include area uncertainty within the confines of their acreage holdings as they mistakenly attempt to force unconventional plays into a conventional volumetric cookbook assessment. The impact of using an inappropriate approach is particularly influential at the low side end, where the assessor often places values associated with a single-well accumulation, which makes no geologic sense as a plausible success-case outcome in an unconventional accumulation.

Schmoker *et al* (1999 and 2002) advocated the breakup of continuous reservoirs into a set of discrete cells that have the potential for production, with each cell having a fixed drainage area, the sum of all cells being equal to the volume of the hypothesized total field. The suggested drainage area is equal to that attributed to a single well.

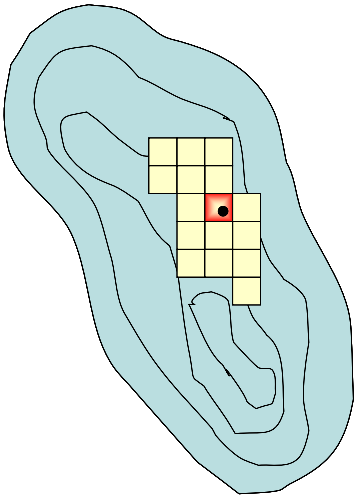


Figure 5: Building the evaluation from a cell basis including cell volumetrics, production, and cost uncertainty provides a valid way to assess partial ownership of an extensive resource.

The single cell will be the basis of the described evaluation method. Evaluation of unconventional resource plays starts with volumetrics at the cell level and moves on to production profile uncertainty assessment. The evaluation should be built up from the cell level and include cost and drilling program uncertainty. As we will show, volumetric success, while contributing to economic viability, is not the primary uncertainty. Production profile, including initial production rate, and decline rate combine with cost, program timing, and land strategy to drive profitability. A valid assessment of an unconventional opportunity must take all these major uncertainties into consideration.

The assessment must run from exploration through the pilot phase, appraisal, development, and production. A full business assessment is required to provide a valid outcome that can be readily incorporated into a company portfolio. An additional benefit of a full value chain assessment is that the decisions that may need to be made through the course of the exploiting the opportunity are more likely to be anticipated and appropriate resources can be allocated to maximize learning, efficiency and value.

Field Size Distributions vs. Well Size Distributions

Field size distributions, though important for conventional assessment, are altered to reflect well size distributions in the unconventional assessment.

Field size potential is the basic volumetric component of the conventional assessment method (Figure 6). Traditional conventional evaluation includes the creation of a potential field size distribution for the discovery, given success. Economics may be run at the P10, P50 and P90 outcomes. Prospective field discoveries may be compared to the historical field size distribution as a cross-check for validity. All inputs to the field size distribution recognize variance in area as well as variance in *field* *average* *reservoir character*.

Field size potential and more particularly, field average estimates are not applicable to unconventional assessment due to the implausibility of total field capture as well as the inability to validly portray production uncertainty, pilot effectiveness, drilling program management, and early program exit options. We must look to replace the field size distribution with distributions reflective of the cell-based framework (Figure 7).

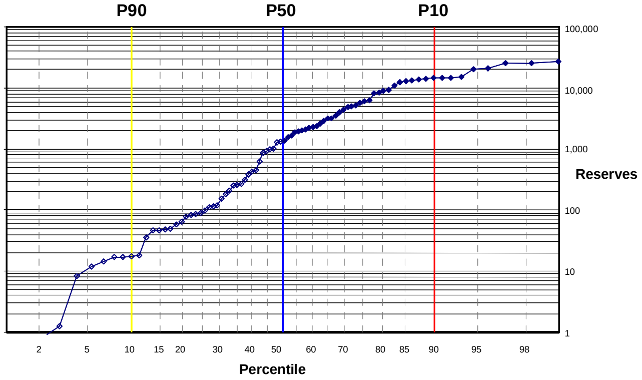


Figure 6: An example of a field size distribution showing fair conformity to lognormality between P10 and P90.

Field size distributions describe the range of volume anticipated in a success case of an exploration opportunity. The difference between the two ends of the field size distribution reflects the combination of area uncertainty and reservoir character uncertainty. In unconventional assessment, at the single cell level, there is no area uncertainty. If we remove the area uncertainty from the field size distribution, or look at a distribution of roughly equally sized fields, the remaining variation is purely related to reservoir character (producibility issues). It is the variation in reservoir character that defines the well size distribution in the unconventional play.

Every point on a field size distribution is made up of a distribution of individual wells. A field size point is the summation of the area of the contributory wells but the average of the reservoir characteristics. With area uncertainty removed, one would expect that the well size distribution for the P10 field size expectation would be different from the well size distribution for the P90 field size distribution.

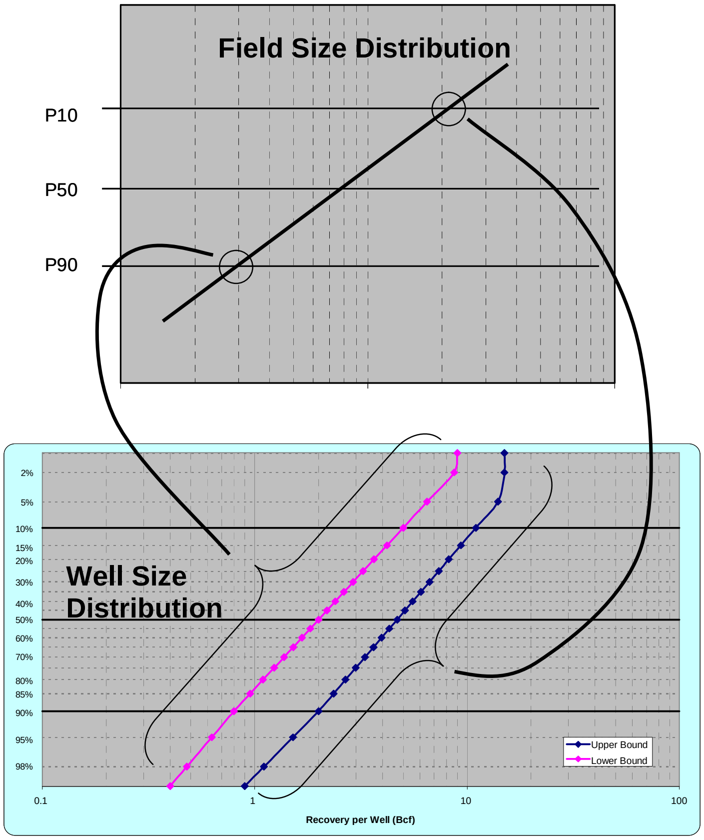


Figure 7: Each point on a field size distribution is the result of an aggregation of individual wells.

The EUR Envelope

The two distributions form the basis for what is called the Estimated Ultimate Recovery (EUR) Envelope (Figure 8). The EUR Envelope approach should be used for any assessment that has the productive horizon extending beyond the limits of the acreage being evaluated, whether for a conventional or an unconventional reservoir.

An EUR Envelope is essentially the range (defined by maximum and minimum distributions) within which the distribution of cell outcomes exists (Figure 8). It is representative of a distribution of distributions. The well size distributions that are assumed in the conventional field size distributions are now visible and critical to the unconventional assessment.

There are two primary advantages to the EUR Envelope approach. Firstly, using a single distribution removes the full field variability. Since we are operating at the cell level, and the cells will aggregate to the field (or pseudo-field in our limited acreage position). The use of one EUR distribution reduces the variance of the rollup to zero. In essence, the evaluator is assuming that the future size characteristics can be perfectly predicted. The EUR Envelope approach maintains appropriate cell and project uncertainty.

Secondly, unconventional plays typically require a pilot phase. The question then arises, “what is being learned in the pilot phase?” Since we don’t know the ultimate productivity and recoverability of the reservoir we must include that uncertainty in our original assessment. Reducing the well size distribution to a single distribution is equivalent to saying that we know the results of the pilot. If the mean of the well size distribution is greater than the average economic requirements of the wells, then the project has no risk of failure. We would know the outcome of the pilot prior to running it. There would be no need for the pilot. Since this is not the case, and the pilot does tell us about the stimulation potential and ultimate recovery of the play, this uncertainty must be included in the original assessment. This is a cell level uncertainty that should not be reduced to a “representative” mean. Follow-on variability of production profile elements (effective or nominal decline, hyperbolic exponent, and initial production rate) is related to cell variability in EUR.

How are the bounds defined? There are a number of different ways to approach the creation of an EUR Envelope.

Alternative 1: Generation of cell variability from base input.
Individual distributions can be created on the basis of good well sets and poor well sets by anchoring the area uncertainty to the cell size and varying the reservoir character as one would in a conventional sense. The range inputs for porosity, S_w, FVF, and recovery efficiency will be entered twice into a stochastic model; one time to represent the poor well outcome, and once for the upper part of the pseudo field size outcome. The outputs from the individual resource assessments can then be used for the EUR Envelope bounds.

Alternative 2: Analogue plays or areas.
The EUR Envelope may be defined by asking for well distributions found in play analogues. The lower EUR Envelope bound represents the “it can be as bad as area X”; while the upper bound is “it can be as good as area Y”. Analogues must be defensible based on sound geology and reservoir engineering.

Alternative 3: Stimulation and completion effect.
The EUR Envelope may represent that range of well distribution outcomes that portray the ability to complete and the effects of well stimulation. The lower bound is composed of results where the wells respond poorly to anticipated stimulation whereas the upper bound represents an extremely successful stimulation program.

A general rule is that the EUR Envelope bounds may meet (usually, on the lower end) but never cross. A bad cell in a good distribution is not likely to be significantly better than a bad cell in a poor distribution. The greatest difference in cell outcome is often seen at the upper end of the EUR Envelope.

A second generality is that the EUR Envelope bounds are well represented by a lognormal distribution between P10 and P90. Down spacing with potential interference will affect the upper end of the individual distributions. As with lognormal distributions in conventional assessments, the upper end of the individual distributions should be limited, not truncated.

An option for low permeability reservoirs is to have the two defining distributions of the EUR Envelope be the limits of the well distributions (P1 and P99). The error in the use of endpoints as opposed to the 80% certainty interval of P10-P90 is less of an issue in unconventional cell based distributions due to the elimination of area uncertainty.

The overall stochastic assessment will take the form of a build up of cellular input/sampling to form a pseudo-field size distribution for the acreage in question. The acreage itself may also be variable. The ability to model acreage uncertainty provides the opportunity to apply Value of Control techniques that assist in the development of a comprehensive land strategy.

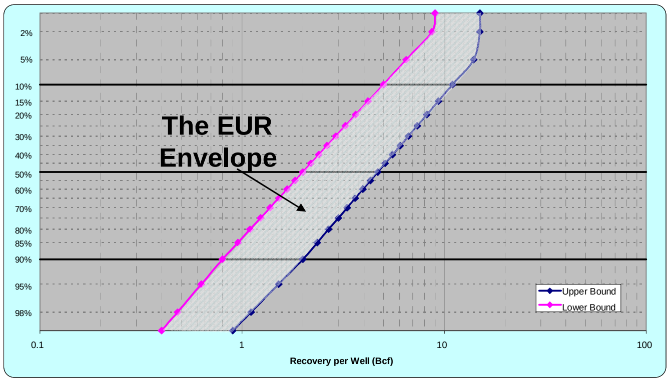


Figure 8: The volumetric assessment in unconventional play evaluation is a distribution of well distributions.

Production

The de-emphasis on risk and field size volume associated with conventional analysis is replaced with emphasis upon recovery per cell and uncertainty associated with production characteristics.

Evaluation is easiest when the cell represents a single well spacing. Ideally this should be the case for all of the evaluation, but some will argue that the ultimate well spacing is unknown. The unconventional assessment should start with the well spacing that is interpreted to efficiently drain the reservoir without significant interference. Potential down-spacing is an important economic decision to be made at a future point, based on the economic justification of accelerated production vs. cost.

There are three allowable uncertainty inputs for conventional production: initial production rate, plateau life, and EUR (Haskett 2005, Figure 9). In addition to these, unconventional plays may also require inputs for effective decline and the hyperbolic exponent.

Production profile uncertainty is the single biggest omission in most company’s unconventional volumetric assessment (and conventional value assessment as well). Volume by cell is

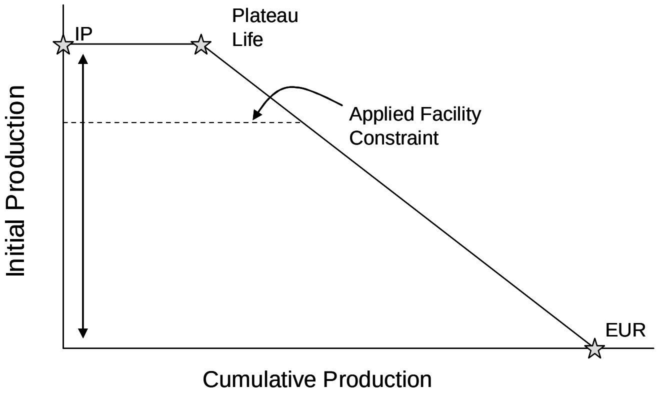


Figure 9: From Haskett (2005), a conceptual diagram showing the major components for exponential decline based production profile uncertainty.

only a starting point. Volume may form the basis for the evaluation, but it is the initial production rate (IP) and production profile that will make or break a play. Ranges for estimates should be provided for all production uncertainties as well as correlation coefficients between EUR and IP, EUR and decline rate, and EUR and the hyperbolic exponent.

As it may be difficult to input precise relationships between these variables we strongly recommend setting up a correlated sampling for a well or a handful of wells as a visual reality check. The production profile should be examined for the individual wells to check for valid profile shapes. Frequently, even experts provide invalid data and relationships. They should be allowed to see many random profile iterations in order to verify that their inputs are reasonable.

EUR is provided to the profile calculation from a sampling of the EUR Envelope in a two-step process. Step one involves the creation of a well size distribution from within the EUR Envelope. Step two samples a specific well size from that distribution for use in the cell. All producing wells within the iteration will fall on the same well size distribution. Each iteration is taken from a different random sampling of the well size distribution and assigns different EUR's to the individual wells.

Conventional fields, which are typically thought of as exhibiting exponential decline, usually have flow limited by pipe, choke, facility capacity, or well-bore interface. Most unconventional reservoirs exhibit a hyperbolic decline, as flow is inhibited by low permeability within the formation.

Decline can be troublesome as there are two distinctly different ways to specify it. The standard hyperbolic decline equation uses nominal decline, but it is far simpler for experts to describe effective decline. Effective decline is the percent decrease in the flow rate seen one year after the start of decline. Unconventional reservoirs typically have no plateau period except in instances of tubing, facility, or transport constraint.

Off-ramps

The operator of an unconventional play should be ever mindful of downside risk. As such there are four principle decision points for the exit of the project (Figure 10). In chronological order they are:

Off Ramp 1: Play or Exploration Risk. An undrilled play has play risk. This is risk shared by all potential locations. If the initial well drilling into an unconventional play shows geologic or technical failure that all other locations share, there is no logical reason why further locations should be drilled and the play should be abandoned. Often, given the quality of information concerning the reason for failure, being what it is immediately after drilling one 'bad' well, a small number of failures may have to be drilled before the shared risk element is identified as the cause of the failure.

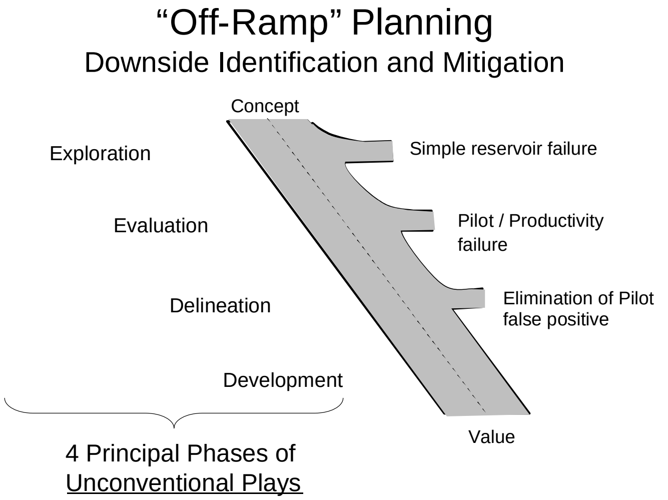


Figure 10: The four stages of Unconventional Projects with early exit points for downside risk mitigation.

Off Ramp 2: Pilot Failure. Since initial rate and profile are vitally important to predict future profitability, and given the ultimate result of stimulation programs remains uncertain, unconventional plays nearly always require pilot programs. Given an initial number of wells with experimental or standard stimulation completed, the pilot well collection shows insufficient rates or recovery profiles to warrant continued drilling.

This is notoriously imperfect information. The veracity or representative nature of the pilot well collection is dependent on a number of elements, the most obvious of which is the number of pilot wells drilled and tested. The more wells drilled, the closer the pilot result will converge upon the program result. Unfortunately, drilling a significant percentage of the program wells within the pilot defeats the main reason for doing the pilot, namely assessing the viability of the formation for continued and profitable production in order to mitigate downside risk.

Most knowledge from a pilot is gained with the drilling of the first few wells. The objective is to drill a sufficient number of wells so as to provide a reasonably correct assessment of overall program profitability. As the critical reserves and production rates approach the means of the respective distributions (critical reserves and rates being those levels above which the program will generally be profitable), a higher number of wells will be required to provide a relatively secure answer as to the expected outcome of the project. Another way of saying this: if the mean outcome is marginal, the amount of information, and therefore the number of pilot wells, necessary to make a good decision based upon pilot results increases.

The ability of the pilot program to provide a correct assessment of the profitability of the program is called Pilot Effectiveness (Figures 11, 14).

Every project has an optimal number of pilot wells, after which the information gained is minimal. As previously stated, the highest learning occurs with the first few wells. After the optimal number of wells has been drilled the incremental learning per well has decreased to a point at which the decision improvement capability in negligible. Typically, this optimal number of wells shows as an inflection point on the plot of Pilot Effectiveness vs. number of pilot wells.

Until now companies have been faced with having no set evaluation method that allowed them the ability to determine the appropriate number of pilot wells. With a stochastic model that samples the volume and rate profile uncertainties, this is now possible. Being able to do this may save millions of dollars in needless well expense on a single project.

Assessment of optimal pilot configurations is not possible without the preservation of individual cell uncertainty. The Industry tendency to roll up expected or "representative" forecasts, especially time series, as in the use of "type wells" prevents valid assessment and forecasting of Pilot Effectiveness, downside risk identification/mitigation, and ultimately economic viability. Reliance on only the median, mean or expected case for inputs or outputs is dangerous and frequently leads to poor decisions.

There are four outcomes possible from pilot programs: (Figure 11)

True results

- True Positive – Pilot indicates profitable area for exploitation, program is profitable
- True Negative – Pilot predicts unfavorable area, program creates a loss

False results

- False Positive – Pilot indicates profitable area for exploitation, program creates a loss
- False Negative – Pilot indicates unfavorable area, program is profitable

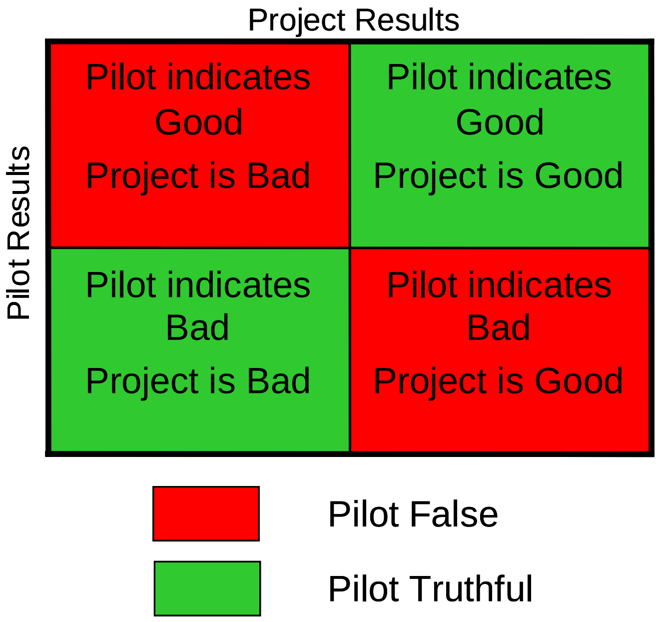


Figure 11: Pilot Effectiveness is the probability that the pilot will be truthful with a set number of wells in the pilot program.

Pilot Effectiveness is equal to the sum of the probability of True Positive plus the probability of True Negative.

A pilot program is successful if it delivers correct information, no matter what that information is. Naturally, we hope for profitable indications from the pilot, but a truthful result is of prime importance. A true negative will help a company avoid a bad investment and is just as, if not more important, than a true positive.

Companies should drill pilot wells until one of the following three limits is reached:

1) An acceptable effectiveness level (probability of correct result) has been reached (company risk tolerance context)
2) The statistically optimal number of wells is reached
3) The value of information provided by the incremental well is negative.

This off ramp is the most evaluation and decision/risk tolerance based. A mistake at this off-ramp will be the most costly. Companies must be fully aware of what the overall play needs to have in order to be successful, what specific learnings are required from the pilot to support the necessary go-no go decision, and the degree of reliability that such information will have.

The nature of unconventional plays demands a high degree of efficiency from a company. Recognizing profit potential from reservoir performance after effective stimulation, combined with rapid tie-in and production is the foundation of success. Companies must hire and maintain technically proficient, integrated work teams, which are fully conversant with strategic and operational business considerations.

Off Ramp 3: Mid-point program test. A certain portion of the way into a program it is important to stop and assess the projected economic benefit of the program. Empirically, this seems to be around 20% of the program intended to be carried out, given a positive pilot response. The assessment needs to be carried out in order to avoid the pitfalls of a false positive pilot result. 20% of the greater well program is usually statistically significant enough to provide a high degree of validity in the answer. Larger programs may demand slightly smaller percentages of completed wells for a mid-point test.

The ability to exit at this point eliminates the massive loss due to blindly proceeding with a program or strategy that is unprofitable at its core.

Off Ramp 4: Pseudo-field production decline. The most satisfying outcome to the shareholder is when a project is fully and efficiently monetized. This final exit point is based on netback profit or, in some cases, materiality of the depleted project to the company's portfolio. Ultimately, wells are turned off when their production can no longer support their operating cost.

Cost assessment

We strongly recommend using a fully probabilistic cost assessment for the overall business decision evaluation of unconventional plays. Of particular concern is the uncertainty associated with costs due to well drilling and completion, which ties directly into the demands of capital allocation through time as well as HR requirements. Drilling uncertainty must be split into time (days to drill, days to complete), trouble time (which is a separate distribution that will be aggregated with the previous trouble-free drilling time distribution), and the fixed and variable costs associated with drilling and completion activities.

Other costs and distributions to be collected will include:

- the distribution of acreage held plus that to be picked up prior to pilot drilling and testing, with associated costs
- the distribution of acreage to be purchased after pilot success has bee determined, with associated costs
- dedicated pilot facility costs
- well specific facility costs
- central project facility costs
- export project pipeline costs

Examination and simulation of the time based drilling input allows for the construction of a range based drilling and completion program. This will provide forecasts for resource allocation goals and the foundation for decisions and management of project execution, which is a critical element for overall success. Project management professionals value this data, which can greatly assist their value maximization and "factory efficiency".

A value chain context for the evaluation allows the assessment of decision options at every point in the program. It will provide the opportunity for the effective and efficient use of scarce resources to maximize value and minimize time to full and profitable production. As such a full exploration, pilot, delineation, and development program should be modeled.

Output Analysis

A multiple-stage assessment is needed to account for and optimize the decisions that will be made in the project. The first run of the assessment model should be unconstrained with no minimum pilot size or minimum mid-point criteria. The purpose of the initial run is to provide a cross plot of project NPV vs. expected average EUR per well. This allows the data to be analyzed in order to provide pilot minimum success criteria. Once the pilot success criteria are determined, they should be entered into the model and the simulation run with pilot failure enabled.

Pilot minimum success can be roughly determined by assessing the approximate balance point of the swarm of points above and below the zero NPV line. In Figure 12, full project NPV is plotted against the average individual EUR associated with that iteration of the model. The balance point in Figure 12 seems to be approximately 3.75 Bcf per well.

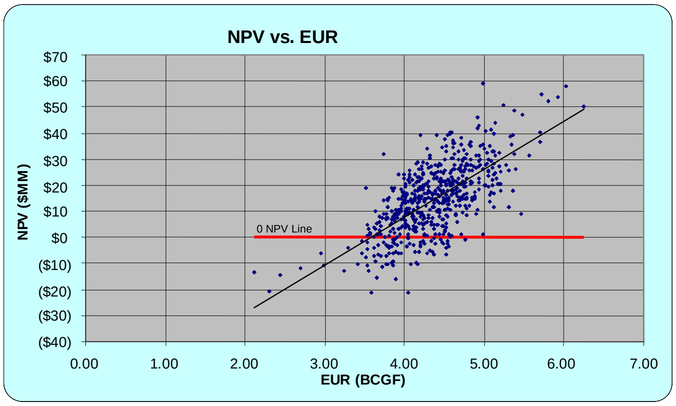


Figure 12: Cross plot of Net Present Value and Average EUR per Well.

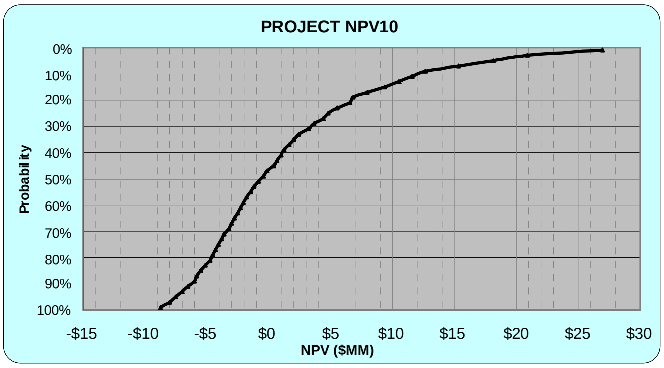


Figure 13: Cumulative probability curve for NPV

The standard output metrics are as available from unconventional plays as they are from conventional opportunities (e.g., aggregate volumes). However, their assessment may take on different forms, and with the varied exit points a tree diagram of the outcomes is more complicated than conventional projects.

See Haskett (2005) for a more detailed explanation of time series uncertainty assessment, aggregate vs. pathway methods and interpretation.

The collection of output displays and metrics that describe the unconventional play opportunity should include the following:

Cross-plots:
NPV vs. Average EUR per Well, also known as the NPV swarm plot (Figure 12)
NPV vs. Average IP per Well

Cumulative probability distributions:
NPV (Figure 13)
Payout date

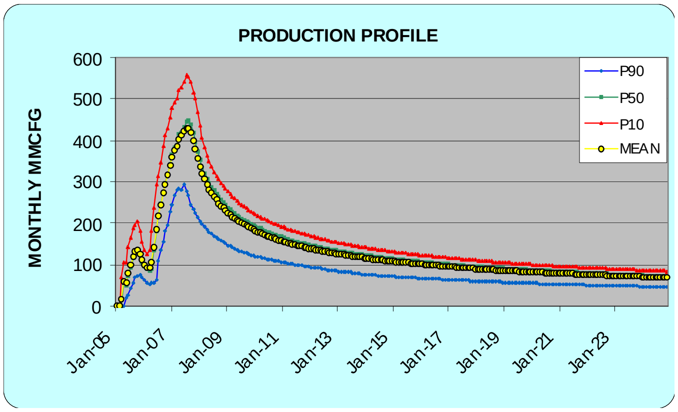


Figure 14: Production Profile Aggregate showing the distribution of production at any particular point in time.

Time Series:
Cashflow aggregate
Production aggregate (Figure 14) and pathway
Payout probability through time
Number of producing wells

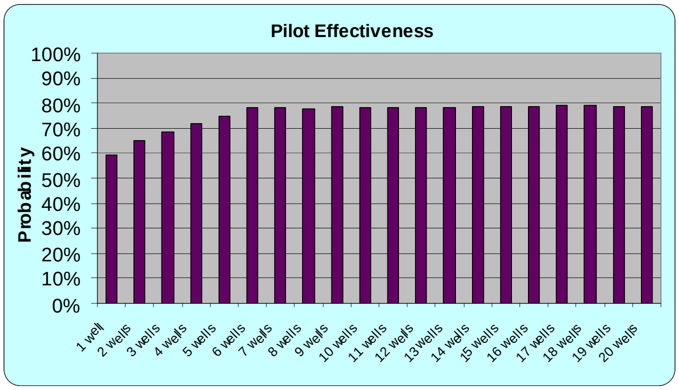
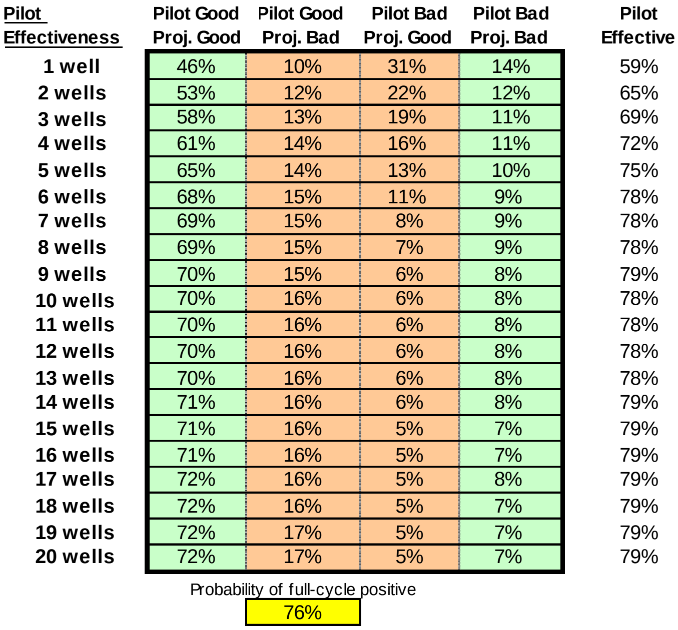


Figure 15: The Pilot Effectiveness bar chart shows an inflection point at six wells. For the case run, there was no statistically significant improvement in effectiveness after six wells.

Bar Graphs:
Pilot Effectiveness (Figure 15)

Tables:
Pilot Effectiveness (Figure 16)
Finding & Development Cost distribution
NPV Success Distribution (gross and net)
NPV Pilot Failure Distribution (gross and net)



Pilot Effectiveness	Pilot Good Proj. Good	Pilot Good Proj. Bad	Pilot Bad Proj. Good	Pilot Bad Proj. Bad	Pilot Effective
1 well	46%	10%	31%	14%	59%
2 wells	53%	12%	22%	12%	65%
3 wells	58%	13%	19%	11%	69%
4 wells	61%	14%	16%	11%	72%
5 wells	65%	14%	13%	10%	75%
6 wells	68%	15%	11%	9%	78%
7 wells	69%	15%	8%	9%	78%
8 wells	69%	15%	7%	9%	78%
9 wells	70%	15%	6%	8%	79%
10 wells	70%	16%	6%	8%	78%
11 wells	70%	16%	6%	8%	78%
12 wells	70%	16%	6%	8%	78%
13 wells	70%	16%	6%	8%	78%
14 wells	71%	16%	6%	8%	79%
15 wells	71%	16%	5%	7%	79%
16 wells	71%	16%	5%	7%	79%
17 wells	72%	16%	5%	8%	79%
18 wells	72%	16%	5%	7%	79%
19 wells	72%	17%	5%	7%	79%
20 wells	72%	17%	5%	7%	79%

Probability of full-cycle positive
76%

Figure 16: Pilot Effectiveness table. The probabilities of each of the four outcome possibilities for each pilot size are shown. Pilot Effectiveness is the total of the truthful outcomes as assessed through the full uncertainty range of the model. Decisions on pilot success can be made within context and with defendable data.

As a warning, the adaptation of conventional economic software products to an unconventional resource requires the adjustment of the evaluation period. It is easy to overestimate the value of a long-life unconventional play. Many economic packages built with conventional assessment in mind compress production and cash flow beyond 20 years to the last evaluation period. In conventional production, this compression changes the NPV and other single point outputs very little. However, due to the long-lived nature of unconventional production profiles, the compression can have a significant effect as many years of production are brought forward.

Be wary of payout dates and compressed production. Observe a discounted cumulative cash flow plot for the assessment. The cumulative cash flow line should asymptotically approach the discounted NPV in valid cases.

The Pilot effectiveness table can be used in analysis of the project in two ways. First, as previously mentioned, it can provide an indication as to the optimal number of pilot wells required to determine the post pilot exit. Its second use is to provide an assessment of the probability of program success given results of the pilot wells during the pilot well drilling and testing phase.

For example, if the first two wells in the pilot program show positive results, then the probability of the program being good is shown as a percentage of the first column (Pilot Good – Project Good) to the sum of the first two columns (total pilot good indications). Using the data in Figure 16, if the first two wells have indicated a Good Pilot, then the probability of the project being good, based on the pre-drill world view is 53/65 or about 82%. There is an 18% chance that the first two wells are giving a false positive. This can give an early warning as to the outcome-adjusted forecast of project viability. Similarly, if the two initial pilot wells were indicating a poor result, the ratio of (Pilot Bad – Project Good): (Pilot Bad – Project Good + Pilot Bad – Project Bad) would give an indication of the probability of a false negative. The false negative probability of the first two wells from Figure 16 is 22/34 or about 65%.

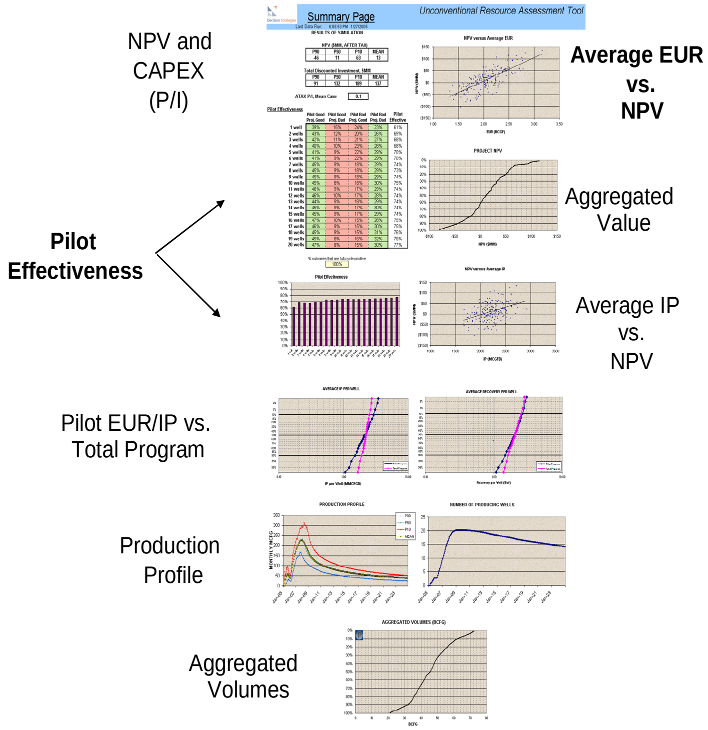


Figure 17: It is important to look at the entire suite of outputs in order to have a complete picture of the play value and to figure out available decision options.

Strategic assessment

As previously discussed, areal extent of the reservoir is not a factor in the 'typical' unconventional assessment. Rather, it is the land position that takes that variable's place. Land position, within certain limits, is a decision and not an uncertainty. Land position is a critical element in extent to which a company can pursue a play. Additionally, the strategic decisions regarding the timing of land acquisition may play a large role in the profitability of the program. Land costs are capital-intensive. Land also is subject to competition, limited availability, and price escalation, especially in areas near to activity. A solid land strategy is critical to the ultimate profitability of the play.

Some unconventional plays cover vast areas. It would be unlikely that a company could tie up a controlling land position prior to the implementation of drilling and pilot work. Subsequent to the start of drilling and testing, results become at least obvious to industry observers if not precisely known to them.

Companies implementing a "Fast Follower" strategy track the major players in the industry and grab land rights as close to the pilot activity as they can. Also, there are opportunistic companies with little in the way of operational intent that pick up available acreage around major investors hoping to make their profit directly from land buy-out.

While it is impossible for companies to secure all land prior to initial drilling, there is an opportunity to create a land strategy that optimizes capture without investing heavily and increasing the threat of loss on a play that may not be economic to pursue. A comprehensive multi-disciplinary and value chain approach such as the method being advocated is the only expedient and viable path to value maximization with risk protection.

There are a number of important questions to be answered and decisions to be made through the course of an unconventional project assessment (Figure 18). An integrated approach that combines technical assessment, business uncertainty, and behavior (targeted learning, risk tolerance, and exit point assessment) is required to validly assess the options and ramifications of decision paths and create maximum benefit for a company.

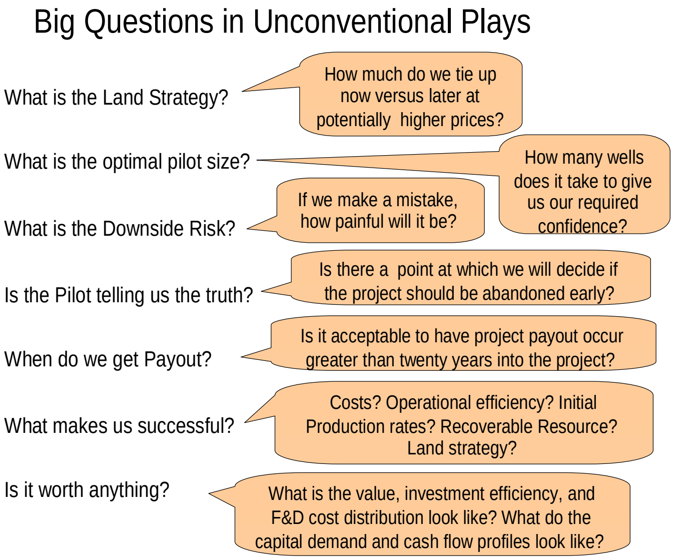


Figure 18: Significant questions to be answered in a comprehensive unconventional play assessment.

Summary

The assessment of unconventional resources uses the concepts of traditional risk and uncertainty analysis but applies them in a manner that is appropriate for the unique statistical, technical, and economic nature of such a class of opportunity. Standard volumetric approaches simply will not provide valid answers as they fail to take the full number of significant uncertainties into account, and are not capable of handling key uncertainties that vary through time.

Volumetric basis for the evaluation of unconventional resource plays begins at the cell level and includes the quantification of cell or well size distributions using the EUR Envelope approach.

Rate and production profile uncertainties play a key role in the assessment and the analysis of opportunities. Cost uncertainty and well timing allow for a drilling program to be developed as a by-product of the assessment.

Subsequent stochastic sampling to the distributions, correlated as necessary, provide the total distribution of Net Present Value, with appropriate output to help determine minimum pilot requirements.

Pilot Effectiveness is defined as the probability of truthful indications from the pilot. Pilot Effectiveness varies with size of the pilot program. Optimal pilot program size is a function of the incremental learning advantage of each incremental well within the context of its cost. Corporate risk tolerance plays a role in pilot effectiveness decisions.

Proper assessment provides the opportunity for decision-making and asset allocation that optimizes the probability of play success, and maximizes profitability within the context of downside risk management and mitigation. An integrated business decision context is applied in the assessment in order to provide the ability to analyze options for land acquisition, pilot design, pilot effectiveness, and downside mitigation through appropriate exit strategies.

The proposed integrated approach to unconventional resource assessment provides distinct advantages over traditional probabilistic or deterministic methods. It allows decision makers to more accurately assess the true potential of the play while assisting them to manage the downside risk exposure and it provides probabilistic output information that may be incorporated into portfolio management approaches.

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