Appendixes

Appendix A
Methods of Estimating Discovered In-Place Resources and Reserves

An estimate is only as good as the quality and quantity of the data available at the time it is made. Estimating either in-place resources, recoverable resources, or reserves is inherently difficult because petroleum engineers cannot see the reservoir. Typically they must rely on indirect measurements (e. g., from well logs and cores, seismic work, regional geology, etc.) that supply them with only a partial picture about the shape and characteristics of the reservoir. As more data become available through exploratory drilling, development drilling, and production, early estimates can be refined, Reserve estimates often grow with time. For instance, accumulated initial domestic reserve estimates have averaged about 50 percent of final estimates. Also, there is a tendency to overestimate small discoveries and to underestimate large ones' (estimates of Prudhoe Bay's reserves have indeed grown over time, but estimates of original reserves (i.e., of ultimate recovery) appear to be converging on 12 billion barrels).

Several methods are available for estimating in-place resources. The volumetric method, for instance, is one of the simplest ways of calculating in-place resources and is useful when not much data are available. In the volumetric method, seismic and drilling information are used to determine the structure, areal extent, and thickness of potential reservoir rocks. A rough estimate of the bulk rock volume of the resewoir can then be made. In addition, estimates are made of the average porosity and water saturation of the reservoir and of oil and gas volume factors related to the reservoir's pressure and temperature. Knowledge of the porosity–a measure of the amount of void or pore space in a rock– enables the reservoir engineer to estimate the amount of fluids the reservoir is capable of holding. Knowledge of average water saturation within the pore spaces allows engineers to determine how much of the pore space is not occupied by water and could contain oil and/or gas. Once estimates of bulk volume, average porosity, water saturation, and oil/gas volume factors have been obtained, a calculation of the in-place resource can be made.

Estimates made using the volumetric method may vary widely depending on the amount of information available. If data are derived from only a few wells or from the results of pre-driiling surveys, the best one can do is assume uniform thickness, porosity, and water saturation for various segments of a reservoir. In reality, reservoirs are usually complex: for example, thickness, porosity, and water saturation may all vary considerably; faulting introduces barriers to flow, as do low permeability zones; and oil and gas within the gross reservoir may be in unconnected compartments. Hence, if the geological interpretation is not correct or not sufficiently precise, the result of gross volumetric calculations will be wrong.

A second technique sometimes used to obtain estimates of in-place resources (and reserves as well) is the material balance method. A material balance calculation relies on the assumption that a petroleum reservoir can function as a large closed tank containing oil, gas, and water. By measuring the change in pressure after various known increments of production, it is possible to calculate the original in-place amounts of oil, gas, and water.[2] A principal weakness of this method is that reservoirs are treated as a single unit under constant pressure. Typically, however, pressure will vary considerably throughout a reservoir. Treating the reservoir as an undifferentiated unit, therefore, may not adequately model the reservoir.

1. Riva, op. cit., p. 126.
2. Riva, op. cit., p. 125,

Several techniques are also used for estimating recoverable oil and gas. A rough estimate of recovery can be made using the analogy method. For this technique, one can simply apply a recovery factor to in-place resources. A recovery factor is the percentage of in-place resources that are expected to be recoverable in a reservoir, and the factor used to estimate recoverable volumes from a given reservoir is one associated with another reservoir having a recovery factor known from production history and characteristics similar to the one being investigated.

A second recoverable resource estimation technique is decline curve analysis. Peak production must already have taken place to properly use this technique. From a study of the production trend over time, a mathematical relationship can be established. Using this relationship, one can then project production into the future to the point where further production would no longer be economically feasible. The total production over time constitutes the ultimately recoverable oil and gas. A weakness in the decline curve method is that it is only indicative if wells are allowed to produce at their maximum (unrestricted) rate. If the flow rate is restricted, either by company policy or State or Federal regulations, the decline curve will show a downward trend in time that will not truly reflect recoverable oil and gas.[3]

The most sophisticated technique used to estimate recoverable oil and gas is reservoir simulation. In setting up a simulator, all available information on reservoir and fluid characteristics is used. Unlike the material balance method in which the reservoir is considered to function as a single tank, reservoir simulation more systematically considers the reservoir as an aggregate of many cells, each with its own parametric values, such as fluid saturations, permeabilities, pressures, etc. Using all the data, flow equations are developed for a reservoir which match the reservoir's history. These equations are then solved, using computer processing, to estimate recoverable resources. Typically, reservoir simulators are quite expensive to develop and are developed only for the largest fields. The Prudhoe Bay field, the country's largest, has been simulated using the best available methods.

All estimation techniques have their shortcomings. Specifically, one must always keep in mind that 1) although estimates may make use of the best available data, the availability and quality of data for oil and gas estimates are often limited, and 2) the estimate is usually based on a number of simplifying assumptions about the reservoir characteristics and/or future trends in price and technology development.

In addition to the inherent difficulty of making accurate resource and reserve estimates, data access problems hamper the accuracy, or at least the credibility, of published estimates. Published reserve estimates made by such agencies as the Alaska Oil and Gas Conservation Commission; the Alaska Department of Natural Resources, Division of Oil and Gas; and the U.S. Department of Energy's Energy Information Administration all ultimately rely on data supplied by the oil and gas industry. Although some oil company data must by law be released to these and other State and Federal agencies which make estimates and regulate the oil industry, much industry data is proprietary. Estimates that the oil companies themselves make are generally not publicly available. Moreover, oil companies usually are not willing to be too precise about estimates they do release. Typically, a company will confirm that recoverable resources, for example, are likely within a specified range, but they are reluctant to go further. Hence, public estimates, even if in the same range as the industry's estimates, are usually not based on all the information to which the oil companies have access.

The oil and gas business is competitive, and proprietary knowledge represents an advantage. Among the reasons for industry's desire to keep information proprietary are that: 1) a competitor with precise knowledge of a company's reserves estimate could gain an advantage in future lease sales in the area; 2) estimates, even by the companies themselves, are at best only approximate; hence, publication of a resewe estimate that later turned out to represent falsely company assets

3. Robert Hubbell, reservoir engineer, Golden Engineering, personal communication, Dec. 23, 1987.

could significantly affect investors or potential investors; and 3) a company's oil and gas resetves can be the object of hostile takeover attempts.

An additional caveat in comparing estimates made by different groups (particularly of reserves or recoverable resources) is that the assumptions on which each estimate is based may not be–in fact, usually are not– made explicit. Such assumptions usually include the projected price of oil, the amount of capital investment planned for the field, and the type of secondary or enhanced oil recovery techniques expected to be used. Also, it is sometimes difficult to determine which portion of a reported resewes estimate is proved and which is only inferred or potential (some North Slope estimates include both proved and potential reserves). This greatly complicates attempts to compare alternative estimates of reserves. Also, unless all reserve estimates are accounted to the same time for a specific field or group of fields, estimate comparisons will not be valid.