High Performance Computing and Competitiveness

Grand Challenge Case Study

Keeping the Lifeblood Flowing: Boosting Oil and Gas Recovery From the Earth

Council on Competitiveness

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Applications of high performance computing to oil and gas exploration during the past several decades have dramatically increased the effectiveness of reservoir management and production. During this timeframe, recovery rates have risen from historical averages of 30 percent to the current average of 50 percent. But improvements in recovery rates, as impressive as they have been, still leave 50 percent of oil reserves in the ground. Significantly enhanced computational models and more powerful high performance computers to run them could provide a much more accurate understanding of the distribution of complex natural materials within an oil and gas field, ranging from fine particles to boulders the size of a house. With this new understanding, predictive capabilities could be enhanced to drive recovery rates significantly beyond current limits, with tremendous benefits in energy security and economic growth.

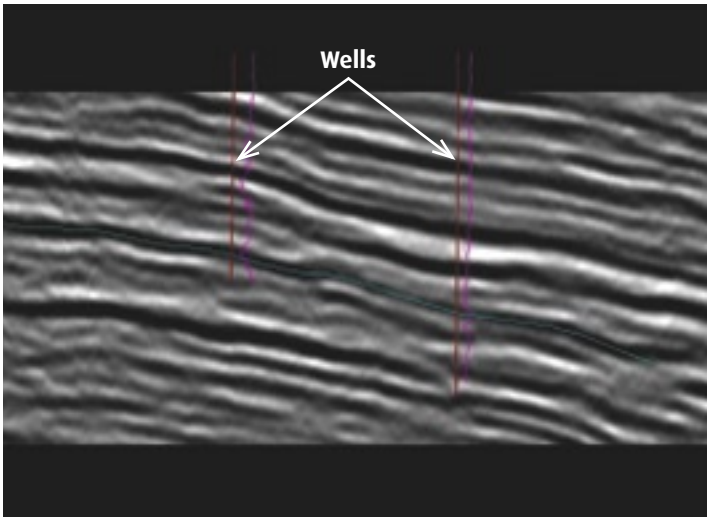

Figure 1 State of the art, two-dimensional image of a cross section of Earth, generated from .25 gigabytes of seismic data processed on a high performance computer in 1994. Vertical lines represent wells. Geophysicists used images such as this to try and identify layers of sand, which hold the hydrocarbons that indicate the presence of oil or natural gas. The better the understanding of the geological structure, the higher the probability that wells will be drilled in the optimum locations. The seismic data from which this image was derived generated several hundred images. Processing time to generate the images was several months.
Image Courtesy ChevronTexaco

Economic Growth Depends on Predictable Energy Supplies

Ensuring a ready and predictable supply of reasonably priced oil and gas is central to economic stability and growth, as well as national security. For the foreseeable future, oil will continue to be the lifeblood of the economy—not only powering our transportation, industrial processes, and buildings, but also embedded in products as diverse as carpets, cosmetics, medicines, detergents, synthetic fibers, and all things plastic. Demand for oil in the United States averages three gallons each day for every person in the country, for a total national demand approaching 20 million barrels of oil per day.[1] At the same time, growing world demand for oil and gas exerts pressure on supplies, which ultimately are finite.

Oil and gas supplies depend not only on the volume of known reserves, but more directly on the known ability of suppliers to recover and deliver reserves in ways that are economically and competitively sustainable and winnable. Surmounting the current limits of scientific understanding, computational capability, and recovery technology presents an opportunity to dramatically expand inventory for national use.

Pushing Recovery Limits with New Technologies

Current technology, oil prices, and extraction costs determine the point after which it becomes uneconomic to extract any more oil from a field. At the more inflexible point of "irreducible saturation," it becomes physically impossible to extract more oil from a given field, regardless of the economics, due to the dispersion of oil and natural conditions. Technological advances could shift both limits.[2] In fact, technology already has increased recovery considerably from an average of 30 percent several decades ago to an average of 50 percent today. These gains are due substantially to more precise computer modeling of underlying geological structures.

With the advent of cluster computing and the migration of high performance computing applications from centralized research centers into the oil fields, supercomputing has became a workbench tool for reservoir engineers and earth scientists. "It's a period of (high performance computing) for everyone," an oil company executive said. Increased computing capability has enabled the industry to develop computer models and software that help predict where oil is located and how to get better performance from oil drilling.[2]

These computer models incorporate 3-D seismic imaging data to create more accurate simulations of oil reservoirs. Seismic images show an approximation of geological features below the Earth's surface. Such visual images are invaluable because they show where oil and gas may lie and provide a representation of surrounding geological features that must be dealt with in order to extract the reserves.

More recently, 4-D time-lapse seismic imaging technology (similar in concept to time lapse photography) has introduced an additional dimension, showing how flow patterns of oil are changing in the underground formations over time. This 4-D capability has the potential to push recovery rates higher.[3] As an expert in supercomputing expressed it, "...the industry has advanced from assumption to knowledge."[4]

Despite Technological Advances, Increasing Recovery is Elusive

As oil and gas companies recover more and more oil from existing reservoirs, each additional increment becomes more difficult to extract. Remaining oil and gas increasingly is located in geologically complex structures that are more challenging to exploit. Geometrically more effort is often required to recover smaller and smaller amounts.[2]

While more sophisticated imaging technology is generating enormous volumes of data to characterize the underground or undersea geology, this information is still not comprehensive enough to permit scientists to map entire oil fields accurately from submicron particles to geological structures that are hundreds of meters. Mapping on this range of scale is necessary in order to sufficiently understand the geological details and

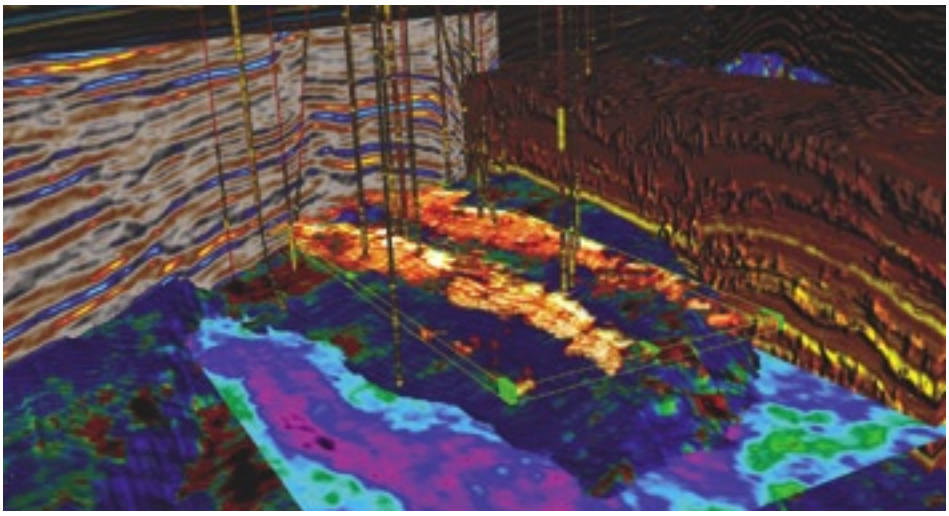

Figure 2 State of the art, three-dimensional image of Earth, generated from 6 gigabytes of seismic data processed on a high performance computer in 2004. Vertical lines represent wells. Because of advances in modeling and computing capability, geophysicists can now discern wavy sand "rivers" from other geological formations. This was not possible with the black and white image from 1994 in Figure 1.

While advances in modeling and computational capability have reduced drilling uncertainty by providing better images such as this, the imaging is still too imprecise to be able to discern the location of the hydrocarbons within the sand. Dramatically more computational capability is required to optimize the hydrocarbon potential.

The seismic data from which this image was derived generated several hundred images. Processing time to generate the images is several months, about the same amount of time needed as in 1994, even though there is 24 times the amount of seismic data.

Image Courtesy ChevronTexaco

make significant advances in future oil and gas recovery.

Scientists attempt to compensate for the missing data by using geological interpretations and approximations in the computational models they have developed to simulate oil reservoirs. By combining approximations with data and using the highest performance computers available to run the models, scientists hope to simulate the oil fields more accurately so that recovery can be increased.

Unfortunately, despite the advances in computational capability, the approximations available now do not provide the level of certainty that is needed to ensure increased recovery. As one industry executive explained, the approximations used in today's reservoir models are not robust enough to drive the production simulations that guide where and how to drill with a high degree of confidence. The uncertainty is still large. Inadequate approximations may lead to a faulty understanding of the underlying geological structure, potentially leading to errors in drilling that can be expensive in terms of investment costs as well as environmental impact.[2]

These uncertainties regarding the geological make-up of the reservoirs and the resultant trial-and-error in the extraction strategy, though not as pervasive as before, still hinder optimal recovery. (See Figures 1 and 2.) As a result, retrieval remains difficult and expensive.[3]

Grand Challenge: Drive Recovery Rates Higher by Substantially Reducing the Uncertainties in Current Computational Models

Oil and gas companies face a daunting challenge: Increase substantially their understanding of the uncertainties that are holding back higher recovery rates by developing significantly more precise computational models of the detailed subsurface characteristics of entire oil fields, including both fixed and dynamic attributes. As reservoir engineers and earth scientists are able to better understand these uncertainties, they can better determine how to reduce them and achieve higher yields.

As one industry executive stated, "What we don't know could pay billions." The key is understanding what geological complexities were omitted in earlier models because the data sets were too large for current computing capabilities, or the physics interactions were not well enough understood to be incorporated into the models or were too computationally complex. "We need to move from less crude to more accurate approximations and iterate the solutions."[2]

New algorithms will have to be developed that more precisely represent these underlying approximations and their interactions. As more physics and more data are added, the resulting models will be larger and more intricate, and require enormously more compute power to run them. For example, if each iteration of a model takes a month to compute, the industry will not attempt to run the model. If that time could be reduced to a week or a day by using more powerful systems, the models will be run and run frequently.[2]

History shows that a minimum order of magnitude (factor of 10) increase in computing capability is needed to generate an approximate doubling in the resolution of the seismic mapping of an oil reservoir.[3] Such increased resolution will permit earth scientists and reservoir engineers to see things that weren't apparent before, further enhancing the understanding of the detailed subsurface characteristics of the oil fields. While enhancing this scientific knowledge base is important, the value-adding payoff is using that new knowledge to develop new tools, techniques, and methodologies that will improve the production and work processes used to extract oil from mature fields and optimize recovery in new fields.[2]

Economic and Competitiveness Benefits

Larger, more accurate computational models of oil field geology, and access to more powerful computers to run them, will significantly reduce the uncertainty that drillers now face. Meeting the challenge offers the possibility of increasing the recovery rate, while avoiding problems re-

sulting from unexpected field conditions—conditions that can lead to low recovery rates, high costs, and damage to the environment.[3] Increasing the recovery rate also provides a cushion of safety and stability for oil and gas companies and the economy. While the life of current inventory would be extended with marginal cost, companies simultaneously would have a strategic window within which they could explore alternatives for additional supply or completely new energy sources without disadvantaging current customers.

Demand and supply conditions in the United States highlight the importance of increasing recovery. Crude oil production in the United States is running about 3.2 billion barrels per year, while U.S. demand is about 7.3 billion barrels per year. Imports help bridge the gap. Meanwhile, the nation's oil reserves (not counting stockpiled strategic petroleum reserves) were estimated at 22.7 billion barrels as of the beginning of 2004.[5] Every 1 percent boost in the recovery rate would add approximately 32 million barrels per year in U.S. output. It also would mean the equivalent of 227 million barrels added to U.S. reserves.

Taking a worldview, every 1 percent boost in the recovery rate would mean adding almost 300 million barrels annually to world oil output. It would mean an extra 10 billion barrels—roughly equivalent to the size of Prudhoe Bay—from identified oil reserves.[2, 5] Thus, even small increases in the recovery rate would add the equivalent of whole oil fields to the global supply.

The economic value of increased recovery would be enormous. Using the bottom of the range of current prices ($30-$40/barrel) yields an estimated total value for each 1 percent boost in the recovery rate of nearly $1 billion in extra output from U.S. oil fields, and nearly $7 billion of increased value to U.S. oil reserves. From a worldwide perspective, each 1 percent boost in the recovery rate adds an estimated $9 billion in extra oil output and an estimated $300 billion of increased value to world oil reserves. Thus, even a 5 percent boost in the recovery rate would add an estimated $1.5 trillion of increased value to existing world oil reserves.

Beyond the enormous dollar value attached to recovering more oil, significantly more precise reservoir models would strengthen oilfield analysis and exploration decisions, and likely lead to fewer wells drilled, lower operational costs, fewer problems from unexpected and unstable field conditions, and less environmental impact. In addition, being able to extract more oil from domestic resources would convey strategic advantages and increased national security. Meeting the challenge would allow the nation and the world to make the most of a valuable and limited resource.

References

1 "Petroleum: An Energy Profile." U.S. Department of Energy, Energy Information Administration, National Energy Information Center.

2 Interview with oil and gas industry executives.

3 "Environmental Benefits of Advanced Oil and Gas Exploration and Production Technology." U.S. Department of Energy, Office of Fossil Energy. (undated.)

4 Bartling, Bill, SGI. "Trends Driving Advancements/High Performance Computing, Visualization." The American Oil and Gas Reporter. (January 2002.)

5 U.S. Department of Energy, Energy Information Administration, Tables on oil supply and consumption. Available at eia.doe.gov/emeu/ipsr.

The Council on Competitiveness is a nonpartisan, nonprofit organization whose members are corporate chief executives, university presidents and labor leaders dedicated to setting an action agenda to drive U.S. economic competitiveness and leadership in global markets. The Council helps shape the national debate on competitiveness by concentrating on a few critical issues including national and regional innovation, competitiveness and security globalization, workforce development and the benchmarking of U.S. economic performance against other countries.

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