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Technical Progress Report

Stimulation Technologies for Deep Well Completions
DE-FC26-02NT41663

for

National Energy Technology Laboratory
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Report Date: June 2003

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ABSTRACT

The Department of Energy (DOE) is sponsoring a Deep Trek Program targeted at improving the economics of drilling and completing deep gas wells. Under the DOE program, Pinnacle Technologies is conducting a project to evaluate the stimulation of deep wells. The objective of the project is to assess U.S. deep well drilling & stimulation activity, review rock mechanics & fracture growth in deep, high pressure/temperature wells and evaluate stimulation technology in several key deep plays. Phase 1 was recently completed and consisted of assessing deep gas well drilling activity (1995-2007) and an industry survey on deep gas well stimulation practices by region. Of the 29,000 oil, gas and dry holes drilled in 2002, about 300 were drilled in the deep well; 25% were dry, 50% were high temperature/high pressure completions and 25% were simply deep completions. South Texas has about 30% of these wells, Oklahoma 20%, Gulf of Mexico Shelf 15% and the Gulf Coast about 15%. The Rockies represent only 2% of deep drilling. Of the 60 operators who drill deep and HTHP wells, the top 20 drill almost 80% of the wells. Six operators drill half the U.S. deep wells. Deep drilling peaked at 425 wells in 1998 and fell to 250 in 1999. Drilling is expected to rise through 2004 after which drilling should cycle down as overall drilling declines.
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OBJECTIVES

Pinnacle Technologies (Pinnacle) is performing a study on stimulation for deep well completions as part of the Department of Energy’s (DOE) Deep Trek Program. The Department of Energy’s (DOE) Deep Trek Program is targeted to improving the economics of drilling and completing deep wells. This work is focused on the second objective of the Deep Trek program, “Improved Economics In Deep Well Completions.” The objective of the work is to review current and past stimulation activity and research results for deep well completions and develop information for industry that will help reduce uncertainty and increase success in frontier and emerging deep formation plays.

The work is focused on three major objectives:

1. Evaluate the current state-of-the-art in stimulation technology for deep formations through industry interviews and a comprehensive literature review and assessment.

2. Evaluate rock mechanics issues and fracture growth behavior in deep formation completions through literature review, interviews and rock mechanics analysis.

3. Evaluate the success of stimulation techniques in three to five deep formations. Drilling, completion, stimulation, production, and geological data will be obtained from operators and a comprehensive assessment of current and past stimulation practices will be conducted for selected plays.

This report covers the first six months of the study during which efforts focused on the first objective.

PROGRESS REPORT

Task 1 State-of-the-Art in Deep Formation Stimulation Technology

Task 1 consists of a comprehensive review of current literature on stimulation technology for deep formations and interviews with operators, service companies and consultants. The result will be documentation of stimulation and completion practices in major deep formations and the identification of operator and service company technical requirements.

Task 1.1 Literature Search

Pinnacle worked with Ann Priestman (Information Specialist, GTI Information Center, Denver, CO) to perform searches of multiple databases for information on deep wells and
deep well stimulation. Over 750 publications were identified that could pertain to this subject. Abstracts of these publications were reviewed and full-length copies of over sixty articles were ordered. These were reviewed and about forty will be included in the bibliography with key words noted for each citation.

**Task 1.2 Deep Formation Completion Survey**

Pinnacle worked with Spears and Associates (SAI) to conduct a study to determine deep well activity levels by region, key organizations, current basic well/completion/stimulation practices, successes, failures and technology issues. SAI ordered and evaluated deep drilling records from HIS Group (HIS); identified activity level by region, formation and operator from 1995-2002 and forecast activity to 2007 and conducted in-depth interviews with 50 engineers/ managers to survey completion practices and problems. This subtask was completed and a report on it is included in APPENDIX - STIMULATION FOR DEEP WELL COMPLETIONS, SUBTASK 1.2 REPORT.

**Task 1.3 Key Play Interviews**

The goal of this task was to focus on three to five significant deep gas plays for detailed study based on current and anticipated activity levels and deep gas potential. Based on the response from participants in the Task 1.2 survey it is apparent that additional detail will not be available from operators for Task 1.3. Only operators participating in Task 3 are willing to supply additional information on completions practices in key deep gas plays. Resources targeted for this subtask will be directed to Task 3.

**Task 2 Review/Summary of Rock Mechanics and Fracture Growth in Deep Reservoirs**

Task 2 will consist of an evaluation of the rock mechanics issues and fracture growth behavior in deep formations. Work on this task will be performed during the next phase of the project.

**Task 3 Fracture Modeling, Production Data Analysis, Reservoir Modeling, and Case Histories**

Task 3 will consist of a comprehensive evaluation of stimulation technology in three to five deep gas plays identified in Task 1. The focus of the evaluations will be the integration of fracture modeling and production data analyses to better understand fracture performance. The fracture modeling and production data analyses will be supplemented by selected reservoir modeling studies to provide an improved understanding deep formation reservoir characteristics and the affect of various stimulation alternatives on well performance.
Based on the activity levels forecast in Subtask 1.2 and resource potential in each region NETL has selected the following regions for consideration for further study:

- South Texas
- Gulf Coast (Shelf)
- Rockies
- Mid-continent
- South Louisiana (Onshore)
- Permian

Some early contacts have been made with operators in South Texas and the Rockies. This task will be a major focus for the next phase of the project.

**Task 4 Technology Transfer**

The objective of Task 4 is to ensure that the results of the project are effectively and efficiently transferred to industry. This will include two workshops, three technical papers/articles and a comprehensive final report. The bulk of activity for this task is scheduled for the next phase of the project. Informal, periodic progress reports have been sent to the DOE Project Manager. Pinnacle and SAI took part in a detailed briefing with DOE at Morgantown, WV on February 13, 2003. A project management plan was prepared and submitted to DOE on February 20, 2003.
APPENDIX - STIMULATION FOR DEEP WELL COMPLETIONS, SUBTASK 1.2 REPORT
Activity Level and Deep Well Activity Survey

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Executive Summary

- DOE’s DeepTrek program is geared to improve the economics of drilling and completing extremely deep (>15,000’), hot and high-pressure (HTHP) wells in the US. This research component dealt with the completions.

- Of the 29,000 oil, gas and dry holes drilled in 2002, about 300 were drilled in the DeepTrek category. 25% were dry, 50% were HTHP completions and 25% were simply deep completions.

- South Texas has about 30% of these wells, Oklahoma 20%, Gulf of Mexico Shelf 15% and the Gulf Coast about 15%. The Rockies represent only 2% of deep drilling.

- Between December 2002 and March 2003, Spears & Associates, acting as subcontractor to Pinnacle Technologies, interviewed operators who drilled 55% of the deep, HTHP wells. Operators of 25% of the wells refused to cooperate and operators of the other 20% were not contacted.

- Of the 60 operators who drill deep and HTHP wells, the top 20 drill almost 80% of the wells. Six operators drill half the U.S. deep wells.

- 100% of the operators report using injection tests during completions. Also commonly performed are pre and post frac flow tests, real time frac modeling and fluid quality control. Fracture mapping and special logging runs are less common.

- DeepTrek-type holes peaked at 425 in 1998 and fell to 250 in 1999. Drilling will rise through 2004 after which drilling should cycle down as overall drilling declines.

- South Texas has the greatest number of HTHP wells in the world – about 100 this year, 80% of which will be completed.

- El Paso leads the pack, drilling 20% of all wells.

- Operators in South Texas and Oklahoma would like to participate in further DeepTrek studies. Operators in other regions are generally not interested in participating.
Objectives

SPEARS & ASSOCIATES’ (SAI) RESPONSIBILITIES SPANNED THE FOLLOWING:

Conduct interviews with operators, service companies, consultants, and drilling contractors regarding current state of the science/art in stimulation and completions in deep and HTHP formations. The result shall be a detailed documentation of stimulation and completion practices in deep and HTHP formations. The operator and service company technical requirements and the geographic location of the wells drilled in the last 5-7 years at the targeted deeper depths and HTHP environments shall be identified by the recipient and be included in the detailed documentation. Deep and HTHP wells in the U.S. shall be delineated and broke out separately.

MODIFICATIONS

Since so little drilling is done below 16,000’ \(^1\) and since fields tend to be developed over a 3-4 year period, forecasting with accuracy county and depth-segmented drilling activity is simply not possible. Additionally, SAI’s standard drilling forecasting model – in fact, the industry’s natural depth segmentation – breaks US drilling into 5000’ depth segments.

Therefore, Spears requested that we investigate drilling deeper than 15,000’ and that the smallest regions to be considered for our drilling forecast be broadened to include states (Railroad Districts, for Texas), rather than counties and that the forecast in each region be for all drilling deeper than 15,000’. DOE granted permission for these changes, subject to review at the end of the project.

\(^1\) Only about 1% of all drilling in the US.
Research Method

Spears & Associates followed this course of action in conducting the research assignment:

November 2002
- Buy well drilling and completion data from IHS Group, Denver.
- Download current and historic drilling rig activity from www.smith.com, website of Smith International, the leading US drill bit company.
- Review Spears’ prior research.
- Analyze Smith and IHS data to quantify deep drilling activity and identify and rank active operators.
- Search Spears’ contact databases, SPE membership roles and trade journal mailing lists to identify potential interview candidates working for active deep drilling operators.
- Develop questionnaire jointly with Pinnacle Technologies.
- Begin contacting potential operator interview candidates.

December - January 2003
- Conduct operator interviews by telephone, person and email.
- Interview deep-well focused service company engineers, sales personnel and managers using portions of the operator-oriented questionnaire.

February - March 2003
- Re-evaluate well drilling database from IHS and arrange for corrections to the database.
- Meet with DOE, Schlumberger and Pinnacle Technologies to review initial findings, identify priority areas and refine research objectives.
- Conduct additional interviews.
- Analyze data and write report. Present findings.

NOTES REGARDING WELL DATA QUALITY

Since we were looking for exceptionally deep drilling, the Smith International website was able to provide very good current and historic information regarding the location and proposed depth of drilling activity by operator. Table 1 shows a small portion of the Smith database:

---

2 Rig counts in North America tend to be comprehensive for wells deeper than 5000’. But they tend to miss at least half the activity shallower than 5000’ simply because the rigs move so frequently and use very few new bits.
Table 1. Example Data from Smith International Database

<table>
<thead>
<tr>
<th>STATE</th>
<th>COUNTY</th>
<th>OPERATOR</th>
<th>PROP TD DEPTH (FEET)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AL</td>
<td>MOBBAY</td>
<td>MOBIL</td>
<td>23085</td>
</tr>
<tr>
<td>CA</td>
<td>KINGS</td>
<td>ANADARKO</td>
<td>22000</td>
</tr>
<tr>
<td>LA</td>
<td>ACADIA</td>
<td>CABOT</td>
<td>16500</td>
</tr>
<tr>
<td>LA</td>
<td>ASSUMP</td>
<td>BRIDAS</td>
<td>15500</td>
</tr>
<tr>
<td>LA</td>
<td>ATWATE</td>
<td>BHP PET</td>
<td>17000</td>
</tr>
</tbody>
</table>

The problem, however, came with the IHS data set. For decades it has been assumed that IHS and the American Petroleum Institute (API), which uses the IHS data set for its own sourced well activity reports, have been reporting drilling and producing activity based on well depth since reports are issued under headings like, “New well drilling by 5000’ depth increment.” Knowing that many wells in the US are directionally drilled and knowing that the DOE’s program focused on wells with true vertical depth of 15,000 feet and greater, Spears bought a special database from IHS Group asking for wells with TVD greater than 15,000’. We had bought similar databases from IHS Group over the years. A database of almost 6000 wells was delivered and we went to work contacting operators with deep drilling activity over the last few years.

Immediately we began running into operators who told us their wells were not even close to 15,000’ deep, particularly in the most active region on the API and IHS list: The Austin Chalk area of Texas. In most cases the wells had TVDs of 9000’ with lateral extensions of 6000’. IHS Group and the API are actually reporting well length, not well depth. The database we bought certainly included all 15,000’ TVD wells, but it was burdened with an even greater number of wells with 15,000’ measured depth wells. These wells had to be systematically culled out to leave only those wells that fit the DOE criteria.

The area of greatest difficulty has been offshore, where almost every Shelf well is drilled directionally and where measured depth commonly exceeds 15,000’. Additionally, unlike on land where counties and formations can be identified to help cull out bad data, offshore well data does not allow easy rejection of certain classes of wells. In the end we negotiated with IHS Group to provide a special Gulf of Mexico data run that significantly reduced the number of potential candidate wells, but even with the revised data we believe the IHS database overstates the truly deep drilling on the Gulf Shelf.

NOTES REGARDING INTERVIEW QUALITY & COVERAGE

Although correctly identifying operators to interview is a well-defined science, the process of interviewing these same operators is an art. What incentive does an operator have to assist the interviewer? Why should the production engineer take the time to
answer DOE’s questions about deep well completion? But Spears has been conducting oilfield market research for 40 years and we work every day with these challenges. With enough persistence, the interviewing team will be able to interview a percentage of the targeted group over a short period of time. Some will be cooperative, some will not. Also, it is not possible to predict ahead of time how any individual or company will respond.

Over the course of the study, SAI contacted by telephone approximately 300 people working for 60 different companies, mostly gas producers, but also a number of service companies. For one large independent, a significant deep driller in the US, SAI contacted as many as ten different people seeking interviews including two engineers currently working in Canada who had until recently been on U.S. projects. This involved approximately 40 phone calls and half a dozen emails. In the end, this operator did not provide any usable data, yet never flat out told the firm they would not participate in the survey. By contrast, a few companies provided a quality interview with our first telephone call.

SAI has worked to ensure that the data and opinions collected have been correctly stated and understood, that the people providing the information were qualified to provide it and that the objectives of the study have been clearly understood and followed through.

NOTES REGARDING ANALYSIS

Very little analysis has been required – Pinnacle Technologies in Task 2 and beyond will do the majority. Most analysis centered on forecasting deep drilling. For this work Spears relied heavily on our ongoing drilling forecasting consulting services. The firm’s forecast of drilling activity is very accurate when looking at land versus offshore, but uncertainty and error is introduced when trying to forecast drilling in very small regions. So much of the forecast depends on the actions of one or two operators when looking at, say, just Texas Railroad District 4. Therefore, we have great confidence in our total US drilling numbers, but less confidence in our subregion forecasts.

PROJECT MANAGEMENT

Spears & Associates, as a subcontractor to Pinnacle Technologies, gathered the data and prepared the conclusions found in this report. Richard Spears, vice president of the firm, managed the project and is responsible for all content.

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**Thermal Profile of the U.S.**

There exists no easily accessible database whereby depth-related temperature and pressure of wells around the US can be determined. Old geologic surveys have some data, disparate well files have other data and wireline logs are yet a third source, but no one we have found has developed a searchable, geographically sensitive, depth-related source for temperature and pressure estimation.

The Gas Research Institute (GRI) had Spears conduct market research several years ago in the area of high temperature electronics for downhole use. During that project we developed for our own use an EXCEL-based model for identifying high temperature and high pressure wells based on well location and targeted depth. This was developed by reviewing old maps and charts, but mainly by interviewing operators and service companies in known HTHP regions. SAI can now take a database of IHS well data, run it through the HTHP filter and identify the likely candidates for HTHP service.

Table 2 shows in rough terms the approximate temperature of formations and their depth ranges by sub region of the US. For example, the hottest wells are found in Texas Railroad Districts 3 and 4 (see Figure 14) in the Wilcox, Vicksburg and Frio formations. Wells in these South Texas regions are some of the hottest in the US. Mississippi and Alabama also have very hot bottomhole temperatures, but these are at deeper depths.

**Table 2. Well Temperatures by Region**

<table>
<thead>
<tr>
<th>DEPTH</th>
<th>TX 1</th>
<th>TX 2</th>
<th>TX 3</th>
<th>TX 4</th>
<th>TX 5</th>
<th>TX 6</th>
<th>TX 7c</th>
<th>TX 8</th>
<th>TX 10</th>
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<td>14-15,000'</td>
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<td>15-16,000'</td>
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<td>16-17,000'</td>
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<td>17-18,000'</td>
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<td>18-19,000'</td>
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<tr>
<td>19-20,000'</td>
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</tbody>
</table>

We have supplemented our earlier work with data discovered during this series of interviews. The chart above reflects a few changes due to our current investigations.
As hard as it is to develop a temperature matrix, a pressure matrix proves to be impossible since much depends on past and current development of a property. For example, Oklahoma’s Morrow zones were once truly HTHP, but with the development of these fields, pressure has dropped significantly and, with the pressure drop, temperature has fallen. Despite having a reputation as a state with challenging downhole well conditions, the harshness of Oklahoma’s wells is moderating.
Drilling Forecast

After a cyclic low in 2002, drilling in the US is rising in 2003 and should continue to rise in 2004 when the next inflection point is expected occur. As Figure 1 shows, 2004 overall drilling should just about match the peak of the last boom in 2001.

![Active Drilling Rigs](image)

Figure 1. Drilling Activity, 1995-2006

Notice how the mix has changed between rigs drilling for gas and rigs drilling for oil since 1995. Despite almost record high oil prices today, gas is the target of 85% of the rigs drilling today versus 55% of the rigs drilling in 1995. Figure 2 shows the percent of rigs drilling for gas and shows that change over time – a ratio that we expect will not change significantly over the next few years.

![Percent of Rigs Drilling for Gas](image)

Figure 2. Percent of Rigs Drilling for Gas, 1995-2006

---

3 For a complete review of this forecast, please refer to Spears & Associates, Inc.’s Drilling and Production Outlook released March 7th, 2003. This 70 page forecast of global drilling has been used by the oilfield’s service companies and major oil companies since 1981.
We believe that 2001 will prove to be the peak year for all gas well drilling in the first half of this decade. As the next chart shows (Figure 3), annual gas well drilling should stall around 22,500 wells per year, dropping to around 20,000 per year in the slower years.

![Figure 3. U.S. New Gas Wells, 1995-2008](image)

**DEEP DRILLING ON LAND**

The US is now very much a natural gas province and average well depths are trending deeper and deeper. Of great interest, however, is the fact that the deepest gas drilling of all seems to have peaked several years ago (see Figure 4). Based on our research and our 22-year history of forecasting drilling activity, we believe that very deep drilling on land in the US peaked in 1998 and, despite testing that upper limit every few years, will again soon decline as a combination of factors effects the marketplace.

![Figure 4. Deep Drilling on Land, 1995-2007](image)
First, overall gas well drilling is expected to climb into 2004, after which activity will slump. This is a standard industry cycle based on the economics of drilling and producing gas wells, a cycle which has been shown on the previous page.

Second, we believe that operators have not seen the investment returns they had hoped for on these extreme wells. We are not in a position to evaluate the economics of these deep well projects, but from the anecdotes our researchers have been hearing, we believe operators are choosing to go after less technically challenging and less expensive prospects.

Third, some of the leaders of deep drilling are having very difficult financial problems. One of leaders is currently cutting their deep drilling programs to the bone and selling “non-strategic” assets in order to pay down debt and build up cash.

DEEP OFFSHORE DRILLING

After rising to almost 70 holes per year in the heady days of 2001, deep and HTHP drilling on the Shelf in the Gulf of Mexico has fallen to about 50 in 2002 (see Figure 5). Favorable economics is cycling activity back up now through 2004.

The collapse of almost 30% in 2002 soured many on the prospects of future deep drilling, but we believe that opportunistic producers will soon rediscover the Gulf and will cause drilling of all types to ratchet up.

Figure 5. Deep Well Drilling on the GOM-Shelf, 1995-2007
SUMMARY

With these very deep holes, about 50% can be considered high temperature and high pressure completions. Another 25% are deep, but are not HTHP completions. The last 25% are dry holes.

![Deep Gas Well Drilling, 1995-2007](image)

Figure 6. Deep Gas Well Drilling, 1995-2007

Seven years ago the ratios were different – HTHP wells were about one-quarter and dry holes were half the drilling. It appears that operators have chosen to develop known HTHP fields rather than explore for new prospects.
Suppliers to the Industry

OVERALL MARKET TRENDS
While deep drilling in the US appears to have hit a ceiling that restricts further growth, demand for pressure pumping services – cementing and stimulation – though cyclic, continues to grow as shown in Figure 7. As the chart below shows, the market is now cycling out of a low and heading for a near record $2 billion per quarter later in 2003.

![Global Pressure Pumping Services](image)

Figure 7. Global Pumping Services Market 1996-2003

Halliburton has always been the market leader in pressure pumping (Figure 8) and currently holds 35% of the market. Schlumberger, formerly known as Dowell, has 31% and BJ Services is 23%. Approximately 100 regional service companies around the world make up the remaining 11%.

![Global Market Share](image)

Figure 8. Global Market Share of Pumping Services
PREFERRED SUPPLIERS

One of DOE’s objectives of this study was to determine which of the service companies are preferred when operators are working on extremely deep, hot, high-pressure wells in the US. It is clear that the leaders are Halliburton and Schlumberger, particularly in South Texas and the Gulf of Mexico Shelf for well stimulation. BJ Services, which, in the US, is equal in size to Halliburton and Schlumberger, is not usually employed in the stimulation of HTHP wells. On the other hand, all three major service companies are employed for cementing deep, hot wells.

In 2002, Spears did a survey of North American pressure pumping service companies to determine the amount of frac horsepower serving the market. We found no independent frac companies operating in South Texas or along the Gulf Coast. Due to the extreme nature of these wells, operators want only the top service companies with their technology and their ability to handle the related financial risk⁴.

---

⁴ As a comparison, Spears found around 20 independent acidizing and fracturing companies working in the MidContinent region. These independents did about 25% of the work each year.
National Survey Results

SURVEY COVERAGE

Approximately 60 operators, according to IHS, drilled about 300 deep or HTHP wells in the US in 2002\(^5\). SAI managed to interview operators who drilled 55% of these wells as shown in Figure 9.

![Survey Coverage - By Well Population](chart)

**Figure 9. Survey Coverage by Deep Well Population**

Operators drilling 25% of the deep wells refused to cooperate and operators of the remaining 20% were not contacted because they only drilled one or two deep wells over a 2-year period. SAI concentrated on the most active operators. As Figure 10 indicates, the top one-third of the deep-drilling operators drilled three-quarters of the deep wells, while the bottom one-third drilled only 6% of the holes.

![Share of Deep Drilling by Activity Level](chart)

**Figure 10. Share of Deep Well Drilling by Activity Level**

\(^5\) Since no definitive source exists to exactly count recent drilling activity, we have limited the preciseness of our comments to round numbers.
Since it requires just as much effort to interview an operator with 50 deep holes as an operator with one, we focused on the larger players. However, we made sure to get a sampling of operators who drilled only one or two wells just to make sure that this part of the activity spectrum was represented. Despite our efforts, we were not able to conduct full-blown, engineering-related interviews with all the most active operators. No survey can accomplish 100% coverage, but we had conversations with all the top 30-40 producers. From Figure 11, of the top six operators – who drilled half the deep wells – four were willing to provide useful data to our interviewing team;

### Figure 11. Top Deep Drilling Operators

Figure 12 shows the regional share of deep and high temperature/pressure well activity. Almost 50% of the nation’s very deep drilling is done in Oklahoma and Texas Railroad Districts 2 and 4 (South Texas). South Texas has almost all the truly HTHP activity in the country. The Gulf of Mexico and the southern half of Louisiana contribute another 30% of the deep drilling. Every other part of the US has very little deep or HTHP activity.
This survey concentrated on the most active operators working in South Texas and Oklahoma, but also covered operators working in every region of the US except for Alaska (which has no extremely deep drilling).

**TECHNOLOGIES EMPLOYED IN FRAC DESIGN & DIAGNOSIS**

While the following section of this report breaks out regional responses to our survey, it is noteworthy to review how operators employ certain technologies on their deep wells. Operators were presented this question:

*I’m going to list for you 11 technologies or tests and I would like you to tell me which ones you use on HP/HT wells that you normally don’t use on your “typical” wells?*

Figure 13 shows the results of this question. Most operators performed injection tests\(^6\) and flow tests\(^7\) on their extreme wells, while very few ran extra logs\(^8\) and even fewer did fracture mapping:

---

\(^6\) The interviewer read off these tests and, in most cases, the engineer responded with yes or no, or a small descriptive comment. We did not go into great depth.

\(^7\) Diagnostic injection tests (step-down tests, mini-fracs, fluid efficiency).

\(^8\) Pre-frac and/or post-frac flow tests.

\(^9\) Special wireline logs, such as sonic, FMI, and magnetic resonance.
Figure 13. Use of Fracture Diagnostics on Deep Wells
Regional Survey Results

SOUTH TEXAS

South Texas consists of Railroad Districts 2 and 4, which comprise an area south of Houston to the Mexican border and from the Gulf of Mexico inland about 250 miles. Figure 14 shows Oil and Gas District Boundaries for the state of Texas. Some companies refer to this as Gulf Coast land and extend the region up to the Louisiana border. We have not used this broader definition.

Figure 14. Oil and Gas District Boundaries for the state of Texas
Drilling Activity & Forecast

South Texas is the primary region in the US where HTHP wells are less than 15,000’ deep. Therefore, Figure 15 includes both >15,000’ drilling and the slightly shallower hot, high-pressure wells being drilled in the area.

![South Texas Deep & HTHP Holes](image)

It is possible that South Texas HTHP drilling could be somewhat greater than we have shown. If wells are drilled to about 12,000’ in certain areas, the Wilcox, a prolific HTHP zone, can be tapped. Given the budget constraints of this study, we have investigated as many shallower than 15,000’ wells as was practical, but it is possible that another 20% could be added to these numbers. Nevertheless, we believe we have identified and tried to contact all operators working in the HTHP areas of South Texas. Approximately 80% of these wells are completed.

Most Active Operators

<table>
<thead>
<tr>
<th>Annual Deep Wells</th>
<th>Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>El Paso</td>
</tr>
<tr>
<td>5</td>
<td>EOG</td>
</tr>
<tr>
<td>5</td>
<td>ExxonMobil</td>
</tr>
<tr>
<td>4</td>
<td>Shell</td>
</tr>
<tr>
<td>5</td>
<td>Dominion</td>
</tr>
<tr>
<td>2</td>
<td>TFE</td>
</tr>
<tr>
<td>2</td>
<td>Burlington Resources</td>
</tr>
<tr>
<td>1</td>
<td>ChevronTexaco</td>
</tr>
</tbody>
</table>
Since January 2003 the major deep driller in this area has been reducing their deep drilling program in the US due to corporate financial problems. In recent years this operator represented about half of all South Texas deep drilling and completion. We do not believe that their 2003 drilling will come close to their historic averages. This also suggests that our forecast of South Texas drilling may be too optimistic.

### Zones of Interest

<table>
<thead>
<tr>
<th>Depth</th>
<th>Zone</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>13,000’</td>
<td>Edwards</td>
<td>235 F</td>
</tr>
<tr>
<td>14,000’</td>
<td>Wilcox</td>
<td>300 F</td>
</tr>
<tr>
<td>15,000’</td>
<td>Vicksburg</td>
<td>350 F</td>
</tr>
<tr>
<td>16,000’</td>
<td>Frio</td>
<td>375 F</td>
</tr>
</tbody>
</table>

### Completion Techniques

Operators in South Texas tend to fall into two camps: One large operator believes that gas should be produced as rapidly as possible, blowing down all the zones found in the well, while others tend to complete one zone at a time. As a result, this operator performs frac jobs in South Texas that are many times larger than most other operators in the region. More and more producers are moving toward the rapid production model as other operators recognize the value of producing these wells as quickly as possible, particularly in a high gas price environment.

**RAPID PRODUCTION COMPLETION**

- 5-1/2” liner set into Vicksburg and Frio at 15,000’
- 5-1/2” production tubing set from top of liner to surface
- Perforate bottom zone
- Pump 500,000# bauxite in 200,000 gallons CMHPG fluid at 30 BPM @ 10k psi.
- Set composite bridge plug.
- Move up hole to next zone.
- Repeat 3-5 times.
- Drill out composite plugs with coiled tubing drilling unit under pressure
- Commingle zones.

**PACED DEVELOPMENT COMPLETION**

- 3-1/2” liner set into Vicksburg and Frio at 15,000’
- 3-1/2” production tubing to surface
- Perforate bottom zone
- Pump 200,000# bauxite in 225,000 gallons CMHPG fluid at 30 BPM @ 9k psi.
- Produce
Special Tests

Operators in South Texas run quite a few pre and post frac tests to gather information about reservoir response (see Figure 16). Nevertheless, cores, mapping and special logging runs are not widely used in the region.

Figure 16. Use of Fracture Diagnostics in South Texas

Real Time Monitoring

Based on operator comments, about 75% of all frac jobs use real time modeling. This is skewed by the most active operator, which performs real-time modeling on most wells. Counter to the industry, one major oil company uses real time modeling on less than 10% of its frac jobs.

Biggest Challenges

No single “biggest” challenge came out of these conversations, but the following were listed. Interestingly, evaluation of the frac job was not mentioned in this open discussion:
- Evaluating the structure of the formation(s)
- Getting good zonal isolation
- Getting good thermal isolation
- Meeting the limits of tubing
- Controlling the high costs of South Texas development
**Best New Completion Techniques**

The best new completion technologies tended to center on stimulation:
- New frac fluid systems over the last 2-3 years
- Stepwise fracs with composite plugs
- Proppants that bind together while in the zone

**Evaluating Completions**

One major operator summed up South Texas completion evaluations like this:

> “If it works, we understand. When it doesn't, we don't understand.”

Operators expressed cautious confidence that their process of evaluating treatments and understanding the behavior of reservoirs was satisfactory, but no one claimed to have a sure-fire way to handle the analysis. Other comments included:

*We like to think we understand what's going on, but that's not necessarily true. Yes, we could use some advice. We could always use that.*

*I think we use every source of information available to us. We're not experts, so any experience and advice somebody else has would be most welcome.*

*One of our biggest problems is post frac evaluation, accurate flow rate measurements, for example. We need greater accuracy. No, we're not satisfied yet.*
OKLAHOMA

Drilling Activity & Forecast

Oklahoma can be one of the most active regions for deep drilling in the US. Even with the industry’s downturn in 2002, >15,000’ drilling continued to climb. We are projecting deep drilling to peak around 85 holes per year in 2004 (see Figure 17). Approximately 87% of these wells are completed.

Figure 17. Oklahoma Deep & HTHP Holes

Most Active Operators

<table>
<thead>
<tr>
<th>Annual Drilling</th>
<th>Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Chesapeake</td>
</tr>
<tr>
<td>6</td>
<td>Apache</td>
</tr>
<tr>
<td>5</td>
<td>Marathon</td>
</tr>
<tr>
<td>5</td>
<td>St. Mary Operating</td>
</tr>
<tr>
<td>5</td>
<td>Sanguine</td>
</tr>
<tr>
<td>5</td>
<td>BP</td>
</tr>
<tr>
<td>5</td>
<td>Ward Petroleum</td>
</tr>
<tr>
<td>4</td>
<td>Cimarex</td>
</tr>
</tbody>
</table>
Zones of Interest

14,000’  Bromide  235 F
15,000’  Spiro  300 F
16,000’  Springer  300 F
17,000’  Morrow  325 F

Completion Techniques

Since operators in Oklahoma tend to work in a variety of zones, no single completion technique is found here. Some of the data gathered included:

MORROW COMPLETION

Pump 120,000# bauxite in 80,000 gallons HPG fluid at 20 BPM @ 13k psi.
Produce

SPRINGER COMPLETION

Pump 60,000# bauxite in 30,000 gallons HPG fluid at 30 BPM @ 8k psi.
Produce

Special Tests

The main difference between South Texas and Oklahoma is that producers in Oklahoma use radioactive tracers less frequently (see Figure 18). Additionally, fewer cores are taken.
Real Time Monitoring

Although 100% of the operators use real time modeling, this technology is not used on every job. About 80-90% of the deep zone frac jobs have real time frac modeling on location.

Biggest Challenges

The greatest challenge operators say is determining characteristics of the reservoir – pay determination, lithology issues. Formations in Oklahoma appear to be quite tight, with very low permeability. This complicates matters:

When permeability is low low, correct reserve estimation and transient analysis takes months.

Another is chemistry of the fluids in the reservoir, dealing with compatibility problems.

Best New Completion Techniques

Using composite plugs and fracturing multiple zones holds quite an appeal to operators. Critical to this is completing the well under pressure by using coiled tubing.

Evaluating Completions

In the words of several operators:

*I think we don't quite understand it - the way wells produce, especially the lithology changes. There are many unknowns in terms of pressure, depletion, permeability, and things like that. So it would be good to get some advice to better understand how those wells produce, to improve the productivity of those wells.*

*We evaluate pre frac results and post frac results and compare with frac costs. We are not satisfied with the results.*

*We think we understand how these wells behave, but also know there's a lot of unanswered questions. What's coming from natural fractures vs. matrix perm?*
PERMIAN BASIN

Drilling Activity & Forecast

Permian Basin, which includes Railroad Districts 8, 8A, 7C and 7B (see Figure 14), has about a dozen wells drilled to 15,000’ each year (see Figure 19). Many are exploratory, looking for commercial gas in deeper horizons.

Figure 19. Permian Basin Deep & HTHP Holes

Many horizontal wells are drilled in the Permian, so quite a few wells have measured depths greater than 15,000’. If we have erred in the chart above, we have erred on the high side, having not culled out all the horizontal drilling in the region.

Approximately 60% of these wells are completed.

Most Active Operators

<table>
<thead>
<tr>
<th>Annual Drilling</th>
<th>Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Pure Resources</td>
</tr>
<tr>
<td>2</td>
<td>ExxonMobil</td>
</tr>
<tr>
<td>1</td>
<td>Anadarko</td>
</tr>
<tr>
<td>1</td>
<td>ChevronTexaco</td>
</tr>
</tbody>
</table>

Zones of Interest

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Zone</th>
<th>Temperature (F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16,000’</td>
<td>Morrow</td>
<td>200</td>
</tr>
<tr>
<td>17,000’</td>
<td>Fusselman</td>
<td>220</td>
</tr>
<tr>
<td>18,000’</td>
<td>Ellenberger</td>
<td>240</td>
</tr>
</tbody>
</table>

Completion Techniques

SAI interviewed a variety of producers in the Permian, including frac engineers for the service companies. We found no producers interested in participating with in the survey. Additionally, stimulation service companies noted that very few wells are completed below 15,000’ and that there are no HTHP wells drilled in the region.
EAST TEXAS / NORTH LOUISIANA

Drilling Activity & Forecast

East Texas, including Railroad Districts 5 and 6 (see Figure 14), along with the north half of Louisiana, has 10-20 wells drilled to 15,000’ each year, significantly less than the 100 drilled each year in the late ‘Nineties (see Figure 20). Currently a mini boom is going on in Freestone and Leon Counties in Texas as Anadarko and XTO drill in the 10-14,000’ range for the Bossier formation, but deep drilling appears to have fallen out of favor in the area.

![East Texas & North Louisiana](image)

Figure 20. East Texas & North Louisiana Deep & HTHP Holes

Approximately 75% of these wells are completed.

Most Active Operators

<table>
<thead>
<tr>
<th>Annual Drilling</th>
<th>Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Swift Energy</td>
</tr>
<tr>
<td>6</td>
<td>Anadarko</td>
</tr>
<tr>
<td>2</td>
<td>Clayton Williams</td>
</tr>
<tr>
<td>1</td>
<td>Pioneer</td>
</tr>
<tr>
<td>1</td>
<td>BP</td>
</tr>
</tbody>
</table>

Swift has been very busy in prior years, but is not drilling deep wells in North Louisiana in 2002 - they drilled a couple deep holes in South Texas recently.
Number two in the area, Anadarko, also has changed their focus away from deep drilling.

Zones of Interest

<table>
<thead>
<tr>
<th>Depth</th>
<th>Zone</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>15,000'</td>
<td>Austin Chalk</td>
<td>250°F</td>
</tr>
<tr>
<td>16,000'</td>
<td>Pine Island</td>
<td>260°F</td>
</tr>
<tr>
<td>17,000'</td>
<td>Bossier</td>
<td>275°F</td>
</tr>
</tbody>
</table>

Geology is complicated in this region. As one operator noted:

_The Cotton Valley Lime can be around 15,000' and can be hot. But it is the Bossier Sand that can make the big wells, if you can find it. You'll generally find it around 13.5 to 14.5k feet and temperatures can be 320 to 350 F. In Leon County I've seen pressures around 12 to 14,000 psi and you need mud weights of 17.5 ppg. Most the drilling we're seeing in the area now in Leon and Robertson and Limestone Counties is less than 15,000', but east of Fairfield, Texas ought to be deeper._

Completion Techniques

Our interviews with operators working in this region turned up very little useful data, other than the opinion that this region’s completions are fairly straightforward. East Texas is home to 10% of the nation’s fracturing horsepower (145,000 HHP), but only 7% of the dollars spent on stimulation ($170 million). Most frac work is done at shallower depths using lots of horsepower (5-10,000 HHP) and lots of slick water and sand (waterfracs and light sands fracs are common in this area). As a result, frac jobs are discounted heavily in this part of the U.S.
GULF COAST (TEXAS & LOUISIANA)

Drilling Activity & Forecast

The Gulf Coast, including Railroad District 3 (see Figure 14) and the south half of Louisiana, has 60-70 wells drilled to 15,000’ each year, down from the peak year of over 130 drilled in 1998 (see Figure 21). Drilling spiked up with $10 natural gas in 2001, but we are expecting drilling to be fairly flat through 2007. Approximately 55% of these wells are completed.

![Gulf Coast Deep & HTHP Holes](image)

Figure 21. Gulf Coast Deep & HTHP Holes

Most Active Operators

<table>
<thead>
<tr>
<th>Annual Drilling</th>
<th>Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>BP</td>
</tr>
<tr>
<td>3</td>
<td>ExxonMobil</td>
</tr>
<tr>
<td>3</td>
<td>Meridian</td>
</tr>
<tr>
<td>3</td>
<td>TransTexas</td>
</tr>
<tr>
<td>2</td>
<td>Murphy</td>
</tr>
</tbody>
</table>

The Gulf Coast region has several dozen operators who drill a well or two each year. The 5 listed above have been the most active in recent years.
Zones of Interest

<table>
<thead>
<tr>
<th>Depth</th>
<th>Zone</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>15,000’</td>
<td>Miocene (LA)</td>
<td>200 F</td>
</tr>
<tr>
<td>15,000’</td>
<td>Wilcox</td>
<td>300 F</td>
</tr>
<tr>
<td>16,000’</td>
<td>Vicksburg</td>
<td>325 F</td>
</tr>
<tr>
<td>17,000’</td>
<td>Frio</td>
<td>350 F</td>
</tr>
</tbody>
</table>

The majority of the South Louisiana wells appear to be in the Miocene, Oligocene and Tuscaloosa zones, while the Texas wells are in the Wilcox and Vicksburg.

Completion Techniques

From our discussions with operators and service companies, we believe that deep completions along the Gulf Coast are the simplest in the country:

*Our Tuscaloosa deep wells are not fraced and completions are very simple - they don't even run tubing. Perforated casing in light fluid.* - major operator

*There is no frac market in South Louisiana.* – service company

*We have so little frac work in South Louisiana that when we have a job we have to get the equipment out of Kilgore and Tyler. We only have cement in South Louisiana.* – service company

A major operator checked for us regarding neighboring operators’ completion methods in South Louisiana and confirmed that standard completion methods included setting 3-1/2” tubing into the producing zone and running it to the surface. These wells flow naturally.

It appears that there is very little uncertainty regarding the proper completion method of deep wells in this region.
ROCKY MOUNTAINS

Drilling Activity & Forecast

The Rockies is a large area from Northern New Mexico up to North Dakota. Most of the deep drilling, however, occurs in Wyoming in pursuit of deep gas.

Figure 22. Rocky Mountain Deep & HTHP Holes

Drilling spiked up with high gas prices in late 2000, but expensive hard rock drilling, combined with limited access to gas markets and apparently marginal finds has brought deep drilling expectations back down to the 5 well per year level, with most being exploration holes (see Figure 22). North Dakota reports dozens of >15,000’ wells, but these are all horizontal. 10

Approximately 50% of these wells are completed.

10 Spears interviewed Continental Resources in Enid and one of its suppliers, Oiltool Rentals, to confirm this.
Most Active Operators

<table>
<thead>
<tr>
<th>Annual Drilling</th>
<th>Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>ChevronTexaco</td>
</tr>
<tr>
<td>1</td>
<td>Anshutz</td>
</tr>
<tr>
<td>1</td>
<td>Burlington Resources</td>
</tr>
<tr>
<td>1</td>
<td>EOG</td>
</tr>
<tr>
<td>1</td>
<td>BP</td>
</tr>
</tbody>
</table>

In the last two years, only two companies have completed wells in the region, with the zone being right at 15,000’ or slightly shallower. Currently, there are two operators drilling to zones below 15,000’ and one drilling slightly shallower than 15,000’.

Zones of Interest

<table>
<thead>
<tr>
<th>14,000’</th>
<th>Mission Canyon</th>
<th>200 F</th>
</tr>
</thead>
<tbody>
<tr>
<td>15,000’</td>
<td>Nugget</td>
<td>210 F</td>
</tr>
</tbody>
</table>

These wells are reported to be normally pressured and are not considered high temperature.

Completion Techniques

The completion team leader for a major operator was interviewed about deep completions nationwide. When we addressed the Rocky Mountains, he dismissed the area as not appealing in their eyes for the DeepTrek project, that the wells were too plain:

*We do drill wells in Wyoming deeper than 15,000’, but the BHTs are less than 300 degrees and the BHPs are normal or below.*

Other operators we contacted in this area chose not to cooperate.
GULF OF MEXICO - SHELF

Drilling Activity & Forecast

As noted earlier, determining the exact number of deep wells drilled on the Shelf each year is challenging. Rowan Drilling, whose massive jackup rigs drill over half the deep Gulf Shelf wells, says that fewer than 50 holes were punched deeper than 15,000’ TVD in 2002. On the other hand, IHS Group lists almost 120 in the prior year, 2001. The problem is, 44 of the 118 they list have no vertical depth indicated, just measured depth with the additional notation that the well is directional. While it is certainly possible that some of the 44 are truly deeper than 15,000’, we are more inclined to believe the opinion of the drilling contractor whose business it is to drill these very deep holes. For example, BP’s subsidiary companies, Vastar and Amoco, are listed as drilling 13 holes deeper than 15,000’ TVD in 2001. But several conversations with BP indicated that none of their wells in recent years hit the 15,000’ TVD requirement. Therefore, we are using 50 for our 2002 estimated number and have tied deep activity to overall Shelf drilling for our history and forecast. Using this method, drilling in 2001 was almost 70 holes rather than the 74 actually reported by IHS Group (118 – 44 = 74)\(^\text{11}\). Figure 23 shows our estimate of deep well activity in the GOM-Shelf.

---

\(^{11}\) We believe it is possible to determine the actual number of Gulf wells deeper than 15,000’ TVD by doing a much more detailed analysis of the well record database, but the scope and budget of this study did not allow for this work to be done once it was determined that the standard IHS Group well database has inherent flaws. Perhaps the massive well record database residing in DOE’s Morgantown facility could provide enough detail to ferret out the actual numbers.
Although drilling in the Gulf remains lackluster, the incentives provided by the Department of Interior on 26 March 2003 for deep gas should bolster investment in drilling, on top of the normal incentives provided by high gas prices.

Approximately 60% of these wells are completed.

**Most Active Operators**

<table>
<thead>
<tr>
<th>Annual Drilling</th>
<th>Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>ChevronTexaco</td>
</tr>
<tr>
<td>8</td>
<td>El Paso</td>
</tr>
<tr>
<td>5</td>
<td>Anadarko/RME</td>
</tr>
<tr>
<td>5</td>
<td>Dominion</td>
</tr>
<tr>
<td>4</td>
<td>Bois D’Arc</td>
</tr>
<tr>
<td>2</td>
<td>Nexen Petroleum Offshore</td>
</tr>
</tbody>
</table>

The independents often use consulting companies to design and manage their drilling and completion projects. This introduces an interviewing challenge: The operator often refers the researcher to the consulting company, but the consulting company is reluctant to talk about its work with the client, considering the relationship confidential.

**Zones of Interest**

<table>
<thead>
<tr>
<th>Depth</th>
<th>Zone</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>15,000’</td>
<td>James</td>
<td>200 F</td>
</tr>
<tr>
<td>15,500’</td>
<td>Pleistocene</td>
<td>200 F</td>
</tr>
<tr>
<td>16,000’</td>
<td>Miocene</td>
<td>200 F</td>
</tr>
<tr>
<td>21,000’</td>
<td>Smackover (AL)</td>
<td>350 F</td>
</tr>
<tr>
<td>22,000’</td>
<td>Norphlet (AL)</td>
<td>400 F</td>
</tr>
</tbody>
</table>

Since the Gulf of Mexico Shelf is obviously a very large region, the depths shown above are rough averages of where the zones are commonly encountered.
EASTERN GULF COAST

Drilling Activity & Forecast

Mississippi and Alabama have some very hot, high pressure zones, but very little drilling is being done now (see Figure 24).

Figure 24. Eastern Gulf Coast Deep & HTHP Holes

But for a one-year spike in 2001, the trend in deep drilling has been falling since 1997. Approximately 50% of these wells are completed.

Most Active Operators

<table>
<thead>
<tr>
<th>Annual Drilling</th>
<th>Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Crosby’s Creek Oil &amp; Gas</td>
</tr>
<tr>
<td>2</td>
<td>Miller Exploration</td>
</tr>
<tr>
<td>1</td>
<td>Palmer Petroleum</td>
</tr>
<tr>
<td>1</td>
<td>Coho Resources</td>
</tr>
<tr>
<td>1</td>
<td>Cimarex Energy</td>
</tr>
<tr>
<td>1</td>
<td>Dominion</td>
</tr>
</tbody>
</table>

About 15 operators have drilled deep land wells over the last 2 years, but, as the table above points out, most only drill one well per year. And most of these are in Mississippi, not Alabama.
We notice that the bigger gas producers are not represented in this region. We do not know why.

**Zones of Interest**

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Zone</th>
<th>Temperature (F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14,000</td>
<td>Hosston</td>
<td>200</td>
</tr>
<tr>
<td>15,000</td>
<td>Cotton Valley</td>
<td>210</td>
</tr>
<tr>
<td>16,000</td>
<td>Smackover</td>
<td>325</td>
</tr>
<tr>
<td>18,000</td>
<td>Norphlet</td>
<td>350</td>
</tr>
</tbody>
</table>

**Completion Techniques**

One operator who has not drilled recently, but is producing from the Smackover Carbonate, summarized completion and production for us:

*The Smackover has high permeability and high porosity, so all we have to do when we complete these wells is pump a little acid. BHP is low – less than 500 psi – and since these are oil wells, we set a jet pump downhole and start producing. The main problem is this: You drill 4 wells and you might get one producer. That is our experience. Our field is near Stafford Springs, Mississippi at about 16,300’ with a BHT of 290 F. The one well that is a producer has produced 600,000 barrels of oil and produced about a million cubic feet of gas per day.*
OTHER US LAND

Drilling Activity & Forecast

About 10 deep holes are drilled in other parts of the US each year. In 1998, the Texas Panhandle (RRD 10) saw a spike in drilling when Crescendo, Sonat (El Paso) and Devon were pursuing an Upper Morrow play, but for the most part a little deep exploration goes on all the time.

![Bar chart: Other US Land Deep & HTHP Holes](image)

Figure 25. Other U.S. Land Deep & HTHP Holes

Regions of Interest

CALIFORNIA

Since 1995 only one well out of 12 has been completed deeper than 15,000’. Berkley Petroleum completed a Kern County well in 2000. Operators will try one or two holes each year in California.

PERMIAN BASIN – SOUTHERN NEW MEXICO

Several Ellenburger and Morrow gas wells were drilled 1995-1997, but very little since then. We notice that in this portion of the Permian Basin, Ten operators drilled 14 holes over 8 years. This suggests that prospects of deep production are not very promising.
UTAH

There has been no deep drilling in Utah since 1999.

TX RRD 1

Railroad District 1 (see Figure 14) is just west of the South Texas region and can be considered part of the basin. However, the region is not prolific in the deeper horizons: In the last 8 years, 6 different operators have each drilled one hole. Only one was completed.

TX RRD 10

Railroad District 10 (see Figure 14) is the top of the Texas Panhandle. Recently, Newton Corporation and EEX each drilled 1 gas well into the Upper Morrow at about 16,200’ TVD. As noted above, an earlier spike in drilling was also in the Upper Morrow. Still, very little deep work is being anticipated.
Sources

OPERATORS CONTACTED

AGIP USA Inc.
Amerada Hess
Anadarko Petroleum
Apache Corp.
BHP Petroleum
Bois D’Arc
BP Production
Burlington Resources
Chesapeake Operating
ChevronTexaco
Cimarex Energy
ConocoPhillips
Dallas Production
Devon Energy Production Corp.
Dominion
El Paso Energy Corp.
EOG
EOG Resources
ExxonMobil
Four Star
Gruy Petroleum Co.
Houston Exploration
Kerr McGee
Marathon Oil Co.
Murphy E&P Co.
Ocean Energy
ONEOK
OXY USA
Pioneer Natural Resources
Pure Resources
Samson
Shell Oil Co.
St. Mary Operating
Stroud Oil
Swift Energy
TotalFinaElf
UNOCAL
Walter Oil
Ward Petroleum
Whitmar Exploration
XTO Energy
SERVICE/CONSULTING COMPANIES

Baker Oil Tool
Benoit
BJ Services
Carbo Ceramics
Chandler Engineering
Cudd Pressure Control
ESSES, Inc.
Halliburton Energy Services
Hydril
Joshi Technologies International
Key Energy Services
King Well Service
M-I Drilling Fluids
Smith International
Steel Service Company
Weatherford International

OTHER EXTERNAL SOURCES

Helmerich & Payne, Inc.
IHS Group
Railroad Commission of Texas
Smith Tool STATS Database
World Oil Magazine

SPEARS’ IN-HOUSE SOURCES

2003 Drilling and Production Outlook
2002 Oilfield Market Report
2002 survey of fracturing horsepower in North America
2002 survey of global HTHP drilling
2001 survey of HTHP drilling and related drilling systems
Industry News Database
Questionnaire

NAME: __________________________________________
TITLE: __________________________________________
COMPANY: ______________________________________
ADDRESS: _______________________________________
________________________________________________
PHONE: _________________________________________
DATE: __________________________________________

________________________________________________

Our records show that your company has completed about ___ wells in _ (Region) over the last 12 months.

Does this sound about right and does your company consider these wells to be high temperature and high pressure?

(If not considered HP/HT)  Were they just high temperature or just high pressure?

Is (your company) planning to continue drilling HP/HT wells at about this pace in the near future?  If not, how will it change?

We would like to know some high level, general information on how you frac these wells, and how these stimulation techniques may have changed over the last couple of years.

<table>
<thead>
<tr>
<th>Component</th>
<th>Today</th>
<th>1999</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of proppant:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume of proppant (lbs):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluid System (CMHPG, HPG, etc.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total fluid pumped (gals):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average injection rate (bpm):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average surface treating pressure (psi):</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(If different) Why did you change the frac design?
I’m going to list for you 11 technologies or tests and I would like you to tell me which ones you use on HP/HT wells that you normally don’t use on your “typical” wells?

- Special wireline logs, such as sonic, FMI, magnetic resonance
- Cores (whole, rotary SWC, percussion SWC)
- Pre-frac and/or post-frac flow tests
- Pre-frac and/or post-frac PBU
- Radioactive tracers
- Intense fluid QA/QC
- Diagnostic injection tests (step-down tests, mini-fracs, fluid efficiency)
- Real-time data analysis and fracture growth modeling
- Fracture mapping (tiltmeters, microseismic)
- Immediate flowback to force/induce fracture closure
- Post-frac production tests
- Are there any others you employ that I haven’t mentioned?

How often (% of jobs) do you perform real-time frac modeling on these deep wells?

What are the biggest challenges you and (company) face in the completion of HP/HT wells?

What new completion technologies do you believe will have a significant impact on high pressure, high temperature wells?

How does your company evaluate treatments? Is your company satisfied with the results?

Does (your company) believe it understands how the producing zones in these deep, hot wells behave, or could you use some additional analysis and engineering advice in these fields?
Comments from Interviews

SOUTH TEXAS

“One-third of our production comes from South Texas – the Vicksburg Trend is the best, but you have to use the right kind of frac technology. For our average wells, which produce 45 MMCF/D, we pump 2.5 million pounds of bauxite in our frac jobs. For the big wells, which produce 60-80 MMCF/D, we pump 4 million pounds of bauxite. The North Monte Christo area has been a great area for us. We get a 100% rate of return on these wells. We have a large inventory of prospects in South Texas. I can pump a frac job in South Texas for half of what my competitors can do.

About 80 of our South Texas wells in 2002 so far are deeper than 13,000’. In fact, 40% are deeper than 15,000’. The average TD is 14,500’. The initial production on 40% of the wells is greater than 25 MMCF/D, on 35% the IP is 10-25 MMCF/D. In the Frio the prospects are 15,000-20,000’, Vicksburg is 15.5-19,000’, Wilcox is a little shallower.

We use the higher-grade carbon steels for casing and tubing unless we run into hole restrictions, then I go with 13-chrome because of its higher erosional abilities. I can flow 30% faster through chrome than I can through carbon steel. I don’t need chrome for corrosion, just erosion. But I don’t need anything else to be chrome, like the packers or the other downhole jewelry.”

- Independent Operator

“South Texas, Frio wells (+/- 25% of all wells drilled). About 20% of these are oil, 80% gas. About 15% of Frio wells are fracture-stimulated. About half of those stimulated use ceramics or resin coated ceramics, about a quarter use Ottawa sand, and a quarter use resin coated sand. In the three years I was in Corpus Christi, I only dealt with 3 Frio oil wells, and all 3 were shallow, done with sand.

South Texas, Vicksburg wells (+/- 15% of all wells drilled). About 10% of these are oil, 90% gas. About 75% of Vicksburg wells are fracture-stimulated. +/-80% of those stimulated use ceramics or resin coated ceramics, +/- 10% use Ottawa sand, and the balance (+/- 10%) use resin coated sand. I never fracture-stimulated a Vicksburg oil well, but there are a large number of Vicksburgs that flow retrograde condensate in ratios that approach oilwell classifications.

South Texas, Wilcox wells (+/- 50% of all wells drilled). Maybe 2-3% of these are oil, 97 - 98% gas. About 85% of Wilcox wells are fracture-stimulated. +/-50% of those stimulated use ceramics or resin coated ceramics, +/- 10% use Ottawa sand, and the balance (+/-40%) use resin coated sand. Most treatments
that utilize Ottawa sand also specify a small amount of resin-coated proppant. I never fracture-stimulated a Wilcox oil well.

Most of the ceramic jobs are wildly more expensive than sand, not just because of the price of the prop, but the size of the job, increased risk, and HPHT concerns.”

- Service Company

“15% of the world's frac jobs use ceramic proppants now. South Texas is still the largest ceramic market by far, but no additional market share growth is possible there. International markets are using ceramics partly because transportation costs are high, so Econoprop is used, but mainly because high flow rate oil wells need perfectly round proppants in the fractures.

Conoco along the Gulf Coast reported buys 3 million pounds of manufactured proppant each month.

El Paso will pump 200 million pounds of proppant this year, most of it manufactured. They’ll pump 1.5-2 million pounds per well, but in multiple stages. This is not typical for operators in South Texas, who tend to frac a single zone. Other producers go for a single zone, but El Paso fracs and commingles.”

-Service Company

“We drill our hottest, highest-pressure wells in an old major-operator field just north of McAllen in South Texas. These wells are 14,000 to 16,000 feet deep with bottom hole temperatures around 415 degrees F and pressures of 12,000 psi and higher. These wells are in the Vicksburg and Frio formations and actually have multiple producing zones.

We reenter these old wells and will drill down through the Vicksburg and Frio, which is maybe another 4-5000 feet. These are slim hole completions because we are drilling out of existing casing, so we usually set 3-1/2” liners and run the tubing all the way back to surface. These wells are then frac’d with bauxite proppant in multiple stages, so the frac jobs will cost us total anywhere from $400,000 to $1.5 million, depending on how many zones we are tapping.

The procedure goes something like this:

- Reenter well and drill through producing zones
- Set liner and run production tubing to surface
- Perforate bottom zone and swab to test well
- Frac with bauxite proppant
- Set composite bridge plug above zone
- Move up hole and perforate next zone
- Frac with bauxite proppant
- Set composite bridge plug above zone
- Repeat as many as three to six times total
When all zones have been frac’d, the composite bridge plugs are drilled out using coiled tubing and a downhole motor with the well under pressure. We never kill the well. The coiled tubing is retrieved from the well and the well is brought on stream with the zones commingled.

These wells do 2-3 MMCFD if they are completed by simply perforating, pumping some acid and swabbing, but they do 10-30 MMCFD when we frac everything and commingle. We learned this from Sonat, which was bought by Coastal and is now owned by El Paso. El Paso is doing the same thing down in South Texas and I think more and more operators are paying attention to their success. The Vicksburg and Frio zones are pretty tight. If you don’t frac them with a big bauxite frac, they produce 2-3 MMCFD, but have a very flat decline curve. They’ll produce forever, but you have to consider the time value of money, so we frac them hard and get the gas out quickly.

In South Texas, El Paso will have an 800-acre field – not big at all in terms of acreage – that will have 16 wells and a half TCF of reserves.

Halliburton and Schlumberger both have the horsepower and the frac technology to do these HTHP wells.”

-Independent

“Within the MidContinent business unit, the only wells that could be considered HTHP are in the McAllen Ranch field. Virgin pressures are in the 10,500 to 12,500 psi range. BHT is in the 325 F range. Maximum TD for these wells is around 14,300’. The latest wells that have been drilled in this field are development wells that target the much depleted Guerra Sand – 6-7 ppg EMW. There are no current plans to drill any wells deeper than 15,000’ with the MCBU which could be considered HTHP. “

-Major Operator

“The biggest challenge we have is probably cementing the pipe in these hot environments, getting good quality cement jobs. I think the redesign of the cement or the geometry or configuration of the well (would have a significant impact on these HTHP wells). What are really good are the new frac fluid systems that have been developed in the past 2 or 3 years. This is a big plus.

We have a pretty good pre and post system of tests and analyses, so that we have a pretty good handle about what’s going on with a well, what to expect on well performance early in the life of the well.”

-Large Independent
“We changed our frac design recently because we changed the size of the casing. We went from 4-1/2” and 5” casing to 3-1/2” casing. Pressures probably went up just because we’re using smaller diameter casing.

We’re reaching the tubular limit as far as the depth, that we’re getting to a point where we’re going so deep we can’t find casing that meets our needs for stimulation and production.”

-Major Operator

“We actually completed over 60 wells last year. But only these two wells were 16,000-17,000 feet deep.”

-Independent

EAST TEXAS / NORTH LOUISIANA

“We are taking what we’ve learned in South Texas through fracturing and moving to apply it in NW Louisiana and SE Oklahoma. In NW Louisiana we have an old field that would produce 2 MMCF/D after a 234,000 pounds of sand frac job in 1998. In 2001 we pumped 937,000 pounds of sand in a new well and got 4 MMCF/D. In 2002 we pumped 1,953,000 pounds of sand and got 5-6 MMCF/D. The funny thing was, the 1998 wells were costing $1 million completed and the 2002 wells were costing $1.2 million completed.”

-Large Independent

“We have a massive $1 billion drilling program going on and I can guarantee you that we won’t have one well on land deeper than 15,000’. We have horizontal drilling in Montana and East Texas that will take measured depth past 15k, but not TVD.”

-Large Independent

GULF OF MEXICO

“We do great big frac-packs on our deep Shelf wells. Any of the big three service companies can pump these fracs, but for the really critical ones we use Halliburton and Dowell. We use an intermediate grade proppant from Carbo Ceramics – we need it for crushing because closure pressures are around 17,000 psi. These will be 200-300,000 pound jobs, which are a lot bigger than everyone else is using. The deep Shelf is driving us toward the major suppliers and away from the moms and pops. I need their technology to help me get the gas produced. Our wells will deplete in 4-7 years because we do a lot of fracturing. We aggressively produce more than others.
On the Shelf we are seeing the independents beginning to complete wells our way, to get the production now rather than in 5-10 years. The NPV of gas in 20 years is zero.

With the deep Shelf we are trying to go tubingless like we do in South Texas, but the MMS requires an SSSV and I’m having a hard time getting an SSSV with the full open bore that will fit in my casing. In South Texas we set a liner and then set the same size tubing to surface – it is a full open bore with no restrictions. We complete the well then under pressure using coiled tubing. Out in the Gulf I want to run a 5-1/2” liner and then set 5-1/2” tubing right above it and run it to the surface for a full open bore, but I can’t get the SSSV. I’ve got Baker Oil Tools and Halliburton working on it, so I expect it will work. I may have to set a larger size casing in order to accommodate the OD of the SSSV.

I can’t wait for the Rowan Tarzan rig because I think it will cut 5 days off of my 40 day per well drilling program. They have bigger mud pumps with more horsepower; they have a mud system that can handle two types of mud at the same time. With our Shelf wells we drill with water at the top of the hole, oil based mud most of the way to the reservoir, then with completion fluids.”

-Large Independent

“Gulf of Mexico - typical sand control job costs.

<table>
<thead>
<tr>
<th>Frac pack:</th>
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<tbody>
<tr>
<td>Pumping and materials</td>
<td>$150,000</td>
</tr>
<tr>
<td>Tools &amp; Screens</td>
<td>$100,000</td>
</tr>
<tr>
<td>TCP Perforating</td>
<td>$60,000</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$310,000</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gravelpack:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumping and materials</td>
<td>$70,000</td>
</tr>
<tr>
<td>Tools &amp; Screens</td>
<td>$100,000</td>
</tr>
<tr>
<td>TCP Perforating</td>
<td>$120,000</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$290,000</strong></td>
</tr>
</tbody>
</table>

The perforating cost differential has a lot to do with gravelpacking needing the tubing conveyed perforating (TCP) to be underbalanced, while fracpack is overbalanced.
The only true HTHP wells are in Eugene Island Block 224. These wells are 12-14000’ deep and are frac-packed. You might also find some in West Cameron Block 580 and a couple around Matagorda Island. Also High Island.”

-Major Operator

“Premium jackup markets have very high utilization. Wells are becoming deeper, more complex requiring higher HHP, higher lifting capacity and zero discharge. Independents are 94% of our customer base.”

-Service Company

“These 4 wells are horizontal and average 14,000 feet depth. They are HTHP wells. We used frac-packs to frac them. We didn’t use any synthetic proppants, just gravel pack. I don’t think we’ll be interested in working with DOE on their project or will ever use synthetic proppants.”

-Independent

“We have only one well – 20,000 feet – with bottom hole temperature of 120 degrees F or so, that we are using gravel pack on. I can’t help you, we also used Carbo’s proppant to frac it.”

-Independent

“I don’t believe that we are currently planning any wells that would fall into these depth categories.”

-Major Operator

“This past year we drilled 3 or 4 offshore wells that are greater than 15,000’ TVD – average was about 17,000’ and all are HTHP.”

-Major Operator
OKLAHOMA

“We mainly use production decline analysis or Reverse Productivity Index (to evaluate our frac treatments). We are not satisfied, but I do believe we are understanding it better. Pay determination (is our biggest technical challenge). The permeability is so low, correct reserve estimation and transient analysis takes months.”

-Major Operator

“We just signed a nationwide deal with a major service company for frac work at some pretty good discounts. And we have a consulting company doing some frac analysis. We at least ought to talk with DOE. We definitely do not want to mess with the wellbore and our well performance must be confidential. It is very competitive out there.”

-Independent

“We’ve been partners in a number of wells. I think most of the fracs they did were on the super low perm wells that didn’t perform before or after, but they might have a different opinion or data. We have been using a consulting company on all of our fracs as I think our partner has also.

We tend to do a little more evaluation than most operators on zones prior to hauling in frac equipment. We like to perforate, flow test, pump a breakdown, flow test, run a BHPBU test, flow the well and evaluate for frac. I see a lot of operators not wanting to wait the couple weeks to a month prior to fracing and they just haul the horsepower in and get after it.”

-Independent

ROCKY MOUNTAINS

“We do drill wells in Wyoming deeper than 15,000’, but the BHT’s are less than 300 degrees and BHP’s are normal or below.”

-Major Operator
WEST TEXAS

“These Ward County wells are horizontal @ about 12,500 - 13,000 ft TVD, 205 deg F, 5,600 - 6,000 psi BHSP. These are the barnburner wells that everyone is talking about. The operator is nearly finished with the acreage. Another operator has only 6 or 7 horizontal wells in Ward, but they are in a different area and are not anywhere near as prolific as the other area.

The only HTHP work going on out here now of any significance is the some 17,000 ft work in Loving County (227 deg F, unknown BHP), and some Reeves County work in the Wolf Camp (abnormally pressured zones from 13,000 ft to about 15,000 ft); 215 deg F.”

-Service Company

“We only have one rig running deeper than 15,000’. It is an exploration hole. Deep really isn’t our focus.”

-Large Independent