Why Choose Halliburton as a Deepwater Partner

• A dynamic Health, Safety, Environment, and Service Quality philosophy permeates all of Halliburton’s work from the top management down. Our ethics, enforced throughout the company, state that every person is responsible not only for his or her own personal safety but also that of the people who work around them. All employees are empowered with Stop Work Authority, compelling any unsafe work to cease until a resolution is created.

• Comprehensive training and competency of all employees is enforced throughout the organization. Working safely and protecting the environment are conditions of employment, and are absolute requirements at all our work locations, as well as the communities in which we work. Compliance with applicable laws and regulations is mandatory.

• Fifteen (15) innovative state-of-the-art research and development centers are located around the world. Three recent center openings are the Houston Technology Center in 2012 and the Singapore Manufacturing and Technology and Brazil Technology Centers in 2013. These centers enable closer collaboration with the customer to deliver deepwater-specific answers to any challenges that may arise. In the last three years, over thirty deepwater technologies have been developed.

• Flexibility and integration enable procurement and delivery of material and equipment to remote locations, enabling new frontiers or existing deepwater regions to be developed where the oil and gas were previously unreachable.

• Groundbreaking deepwater-specific solutions can make new reserves recoverable that were not previously accessible. These solutions maximize recovery in deeper, more complex, and more remote environments while minimizing nonproductive time without sacrificing safety, quality, or ecological responsibility.

  – A comprehensive exploration solution portfolio ensures quality reservoir characterization data is delivered, including coring, subsea testing, MWD/LWD, wireline, and a host of other evaluation methods that carry on to the production phase of the life cycle. This data returns high value to the entire life of the asset.

  – The award-winning Enhanced Single-Trip Multizone (ESTMZ”) FracPac™ completion system is designed specifically for deep water and ultra-deep water to reliably deliver a high volume of proppant at a high flow rate in just one trip, thus stimulating more of the reservoir in less time. This increased efficiency can save 18 days on average, and reduce costs by approximately $22 million for an average Gulf of Mexico Tertiary completion, enabling the economic viability of the development.

  – The Low Equivalent Circulating Density (ECD) portfolio addresses the challenge in multiple facets of well construction. The VersaFlex® ECD expandable liner-hanger system is ideal for deep water and mature assets. This system has trip-in speeds and circulation rates up to 90% better than standard liner-hanger systems, and a high torque rating to enable aggressive reaming and drill-in without the risk of the well packing off at the hanger area.

Halliburton is committed to delivering safe, reliable, and efficient solutions that bring “bottom-line value” to the oil and gas stakeholder.
The last 15 years have seen incredible progress in our industry’s move into difficult and demanding environments in deep and ultra-deep water. From the Golden Triangle of the Gulf of Mexico, offshore Brazil, and offshore West Africa, deepwater exploration and development has rapidly expanded to East Africa, the Mediterranean, India, and Australasia. Dreams of drilling and producing in more than 10,000 feet of water are rapidly becoming realities. Twenty-eight percent of all global licensing activity that has ever taken place in deep water was done in the last year. Nowhere is that more evident than in the Gulf of Mexico. Current projections foresee an increasing “boom” in the area, with activity growth rising to 20% in 2014, followed by continued, strong growth in the years that follow.

The immense reservoirs are expected to yield higher than average recovery factors (EURs) and high individual well production. To fuel this growth, technology that only recently seemed the province of space exploration now regularly is loaded onto workboats headed to an increasing number of deepwater developments around the world. But, as exciting and glamorous as these new operating environments are, the move into deep and ultra-deepwater regions is based on solid industry tenets that have stood the test of time in our industry for decades. At its foundation are three distinct principles – we encounter a challenge, Halliburton collaborates with our customers to develop a solution, and we create value for our customers, ourselves, and the global community.

At Halliburton, we welcome the challenges. More importantly, we are committed to collaborative solutions. We have assembled a team of dedicated professionals whose goals are safe and reliable operations, higher ultimate recovery, lower development cost, and minimal environmental impact, all bound together in our commitment to innovation and delivery. At the heart of these goals is an overarching commitment to world-class well integrity, the key to deliver on our commitments. Our adherence to these goals is illustrated daily in our global operations. We continually deliver reliable solutions in the most difficult environments, keeping our pledge to be there when and where you need us and working with your team and the local culture to ensure value-added performance in a safe, sustainable manner. Our capacity and manpower can meet all your needs. In the Golden Triangle, our manpower has increased by 35%. Our training and manpower development infrastructure is working overtime to replicate that exercise in other deepwater areas. These commitments manifest themselves in our solutions to challenges like minimizing nonproductive time and eliminating reservoir uncertainties to maximize production over the full life cycle of a well. From the pre-spud meeting until the final barrel is produced, Halliburton is there for you, optimizing drilling activities, ensuring well completion reliability, and constantly monitoring the reservoir and participating in the crucial day-to-day planning and execution that drives enhanced performance in the field and profitability for the development. At the end of the day, these commitments drive high value, which enables us to constantly pursue the solutions that can provide a safe and secure energy future for all.
# Table of Contents

- **Why Choose Halliburton as a Deepwater Partner**: 2
- **Halliburton Commitment**: 3
- **Health, Safety, Environment, and Service Quality Excellence**: 5
- **Deepwater Goes Global**: 6
- **Innovation Delivery**: 9
- **Value-Added Procurement and Logistics**: 13
- **Exploration Infrastructure**: 14
- **Plan, Develop, and Produce Deepwater Developments with Speed and Accuracy**: 16
- **Addressing Reservoir Uncertainties**: 24
- **Managing Risks to Optimize Safety, Efficiency, Reliability**: 34
- **Reducing Drilling NPT**: 35
- **Managing the Low-ECD Challenge**: 50
- **Ensuring Long-Term Well Integrity**: 53
- **Reducing Completion NPT**: 56
- **Reliable Completions**: 61
- **Sustainable Production**: 67
- **Flow Assurance**: 69
Health, Safety, Environment, and Service Quality Excellence

Effective health, safety, environmental, and service quality processes permeate Halliburton’s global business and provide the foundation that makes its broad range of services efficient, effective, and safe. Halliburton believes firmly that zero HSE incidents is an attainable goal company-wide and reaching that objective requires a methodical approach to continuous improvement of all HSE and SQ systems. Many of our geographic and product lines have demonstrated that zero HSE incidents are achievable over the past few years and our continuous improvement in injury rates and service quality is noticeable.

The following principles guide Halliburton’s global operations:

- HSE incidents are preventable.
- Leadership and management commitment are fundamental.
- HSE performance is each individual’s responsibility.
- Compliance with applicable laws and regulations is mandatory.
- Working safely and protecting the environment are conditions of employment.

- Stop any task or operation if a concern or question regarding an HSE risk exists.

Halliburton’s deep-rooted HSE tenets place particular emphasis on continual training to instill a high level of competency in all its employees, as well as providing all personnel full stop-work authorization should they recognize any unsafe activity. Specifically, Halliburton’s guiding HSE principals are:

- Ensure training and competency of the workforce. Halliburton HSE training gives employees the skills and knowledge to perform their jobs safely and competently. The training prepares the employees to recognize hazards, prioritize risk, assign controls to reduce risk to an acceptable level, and to understand internal and external reporting requirements. It also provides a basic knowledge of the applicable regulatory requirements and emergency response procedures. Also, workers are tested in various offshore jobs to meet certain competencies required for the specific job.

- Encourage employees to communicate and address risk. Employees are expected to observe each other’s HSE performance and to Stop Work when necessary. All employees or contractor personnel who observe an unsafe action or condition have an obligation to intervene by taking one or more of the following actions:

  - Communicate concerns directly to the persons involved.
  - Correct the condition or situation.
  - Relay the concern to the appropriate supervisor or customer representative.
  - Stop Work (within the scope of responsibility) if clear and present danger exists.

Through careful analyses, five critical focus areas have been identified that present the biggest risk for HSE, process safety, and service quality incidents. When conducting operations in any of these areas, extra attention and absolute adherence to the processes are focused upon. Also, emphasis is put on weather conditions and the factor it plays on human performance while working.

- Barriers – Physical measures (such as packers, plugs, BOPs, surface valves, barrier fluids, i.e., drilling or cement fluids) that prevent unwanted gas or oil from flowing into the annulus or tubing from the formation and traveling to the surface

- Hydrocarbons to the Surface – Flow of gas or oil to the surface such as well testing or well cleanup operations

- Trapped Pressures – Equipment (i.e., discharge iron, lab machinery, BOPs, cement heads, swages, pipelines, hoses, tanks, or silos) in which a release of pressure could occur
• Well Collision – The potential for collision while drilling with a producing or existing wellbore

• Radiation and Explosives – Any surface activities concerning a radioactive source or explosive material

Halliburton also is at the forefront of regulatory compliance with products and execution practices that meet or exceed federal and state governmental regulations and help reduce HSE concerns. The worldwide regulatory environment is composed of numerous federal and state regulatory bodies, each issuing regulations for deepwater HSE and operations. U.S. Federal offshore HSE and operational regulations are complex and very extensive. While it is beyond the capacity of this publication to list and/or discuss all Federal regulatory mandates related to deepwater operation, basically they can be broken down into two types: Safety and Environmental Systems (SEMS) and mandatory regulations. The regulatory environment in the deepwater Gulf of Mexico is overseen by no less than five Federal government agencies. The SEMS II final rule, also known as the Workplace Safety Rule, provides requirements for employee training, empowering field-level personnel with safety management decisions and strengthening auditing procedures by requiring them to be completed by independent third parties.

In addition, a number of quasi-official bodies, such as the American Petroleum Institute, Det Norsk Veritas, and the American Bureau of Shipping, issue standards for recommended practices in deep water; many of these standards are subsequently adopted by federal and state regulatory bodies. Once the applicable federal, state, and local regulations have been identified, Halliburton complies accordingly.

Deep Water Goes Global

Opportunities for deepwater development, once focused primarily on the Gulf of Mexico, Brazil, and offshore Africa, now exist in a number of areas across the globe. From the Asia-Pacific to the Mediterranean, operators are gearing up to develop promising deepwater resources. This activity is reflected in the numbers for the last 10 years, in which: 1) deepwater wells have dominated reserves added per well; 2) they have led total volume of hydrocarbons discovered; and 3) they have topped the value per BOE developed. Wells have moved into deeper and deeper water, from an average water depth of a little more than 500 m in 1982 to more than 1,500 m in 2012. In this section, we take a brief review of the intense deepwater activity that is ongoing.

Meeting Brazil’s Deepwater Pre-Salt Challenges

Offshore Brazil oil and gas development has always been daunting due to ultra-deep water, deep wells, and long distances from shore. But in the face of these challenges, Halliburton has a lengthy record of success in optimizing deepwater drilling in Brazil’s Campos Basin and adjacent areas. With the discovery of highly productive formations under a layer of salt,
Deepwater drilling, evaluation, and completion in Brazil’s waters become even more complex.

Brazil’s offshore pre-salt reservoirs consist of a series of marine rocks up to 915 m (3,002 ft) thick, containing high-quality oil with low acidity and low sulfur content, and located below a salt formation as thick as 2,000 m (6,562 ft) that serves as a reservoir seal. However, some of the reservoirs contain oil with a CO₂ content ranging from 2 to 12% which can cause corrosion conditions. These highly prospective formations cover almost 150,000 sq. km and may contain recoverable reserves of as much as 50 billion BOE.

Heterogeneous, hard microbialite carbonate reservoirs under the thick salt layer contain waxy oil (24-30°API, 80-240 GOR, gradational composition). Reservoir temperatures are as high as 260°F (127°C), and pressures can reach 10,000 psi. Well depths can exceed 5,800 m (19,029 ft) TVD subsea. One of the biggest challenges now in Brazil is the pre-salt challenges that must be addressed. Halliburton specialists have defined some of the important pre-salt drilling fluids and cement issues, and solutions through high-performance invert emulsion drilling systems, specialized cements, and the holistic Low-ECD suite discussed later in this booklet.

Gulf of Mexico – The Prize

Impressive discoveries in the deep water of the U.S. Gulf of Mexico have led to the development of next-generation technology to develop these prolific finds. To fully exploit this resource requires innovative solutions to drilling, completion, and production challenges posed by water depths to 3,050 m, thick salt layers, drilling depths to more than 9,100 m TVD subsea, reservoir pressures that can exceed 25,000 psi, and temperatures to 300°F (149°C).

An important target in the Gulf of Mexico is large, thick reservoirs of Lower Tertiary age stretching 300 miles across Federal waters offshore Texas, Louisiana, and Mississippi that could ultimately yield 3-15 billion bbl of recoverable oil.

As well depths increase and subsurface conditions become more hostile, the challenge has been to develop new completion systems that are more cost effective. The 2013 World Oil Deepwater Technology award-winning ESTMZ™ system was specifically developed for the Lower Tertiary and offers additional benefits over conventional stacked multizone completion technology by reducing rig time, providing zonal isolation and customized stimulation for up to five zones. Without this technology, many operators would not have started developments in the Tertiary due to the poor economics.
**Solutions for Africa’s Deep Water**

In some ways, offshore West Africa deepwater reservoirs are similar to those of Brazil and the U.S. Gulf of Mexico. But West Africa deepwater exploration also presents some unique challenges, including unconsolidated sands, multiple producing zones, and variable water and gas flows in the reservoir.

The primary deepwater exploration targets along the West African Transform Margin (Sierra Leone to Ghana) are turbidite fan sandstones in rotated fault block traps, stratigraphic traps, or combinations of the two.

In the Niger Delta and Lower Congo Basins, deepwater targets are thick, early Tertiary (Oligocene-Miocene) turbidite sands deposited in deepwater slope channel systems and basin floor fans.

There is also renewed interest in the potential for a deepwater extension of the pre-salt play offshore Angola and Gabon. Most West Africa deepwater discoveries have been in water depths of 305-2,000 m, but prospects exist in water depths to 3,000 m.

In deepwater wells offshore West Africa, Halliburton’s Intelligent Well Completion (IWC) (SmartWell®) system technology helps operators collect, transmit, and analyze downhole data and remotely control selected reservoir zones.

East Africa is an emerging deepwater play with increased focus from several operators for exploration, drilling, evaluation, and the installation of new facilities. While Mozambique began the East Africa activities, other countries up and down East Africa are in the investigation stage. Halliburton’s exploration solutions play a role in the East Africa deepwater arena to help acquire the right data for proper data analyses that influence final investment decisions.

**Asia Pacific Draws Attention**

A number of recent discoveries promise that significant deepwater petroleum resources exist in the Asia Pacific region. One of the many geological areas within the Asia Pacific petroleum theater with development potential is Malaysia. In Malaysia’s Sabah basin, the U.S. Geological Survey has estimated a mean of undiscovered reserves of 4.3 billion BBL of oil and 26.4 TCF of gas. The country’s Sarawak basin is also prospective. The shelf offshore northwest Borneo is dominated by thick middle Miocene–Holocene prograding shelf-slope sequences and complex slope topography of intra-slope basins and anticlinal structures.

Promising discoveries have been made in the deep water of the northwest Sabah Basin in these Miocene channel and fan turbidites. Primary plays in the area involve multiple stacked sandstone reservoirs in structural traps formed in hanging-wall folds above toe-thrusts; most prospects are defined by four-way closure of the anticlines. Seismic imaging is severely affected by the presence of shallow gas hydrates and complex crestal faulting. The presence of shallow hazards – methane hydrates and over-pressure – creates drilling risks. Real-time operations, reducing nonproductive time, and drilling optimization deliver significant returns in this area.
Innovation Delivery

Halliburton has significantly increased its technology investment. Over the past three years, several state-of-the-art technology centers have opened worldwide, as shown here, with more on the way. This investment positions Halliburton closer to the customers, opening the door for better understanding their challenges for collaboration on in-depth solutions for the deepwater market. No matter where the client may have a deepwater challenge, Halliburton has the capability to deliver the innovation to solve the challenge.

Halliburton Houston Technology Center

Halliburton’s primary technology center in Houston continually attracts global clients seeking assistance in solving their specific challenges. The 215,000 sq. ft. (19,974 sq. m) Houston Technology Center officially opened in 2012 and is now home to 550 innovators focusing on fluids and chemicals, sensor physics, rock mechanics, and electronics that are primarily driven into five product service line solutions’ deliveries as well as some integrated asset solutions.

The Houston Technology Center clearly reflects the critical importance of Health, Safety, and Environmental excellence throughout Halliburton. The building is built to the

Fig. 1. Halliburton’s Strategically Positioned Technology Centers.
exacting Leadership in Energy and Environmental Design (LEED) Silver standards, making it cutting-edge in energy efficiency. Where required, the flooring of each room indicates the specific personal protection equipment (PPE) employees should use in that area. Cement flooring signals that workers should use eye protection and appropriate PPE. And the electrical dispersive floors help keep delicate electronics free of static buildup. Carpeted rooms mean no PPE is required.

Halliburton Brazil Technology Center
In 2013, Halliburton opened its Brazil Technology Center at the Federal University of Rio de Janeiro (UFRJ) Technology Park, located at the do Fundao, Rio de Janeiro. The center provides a collaborative setting, enabling Halliburton specialists to work closely with the country’s leading universities and customer research groups to establish a global center of expertise for deepwater and mature fields, particularly those characteristic of Brazil. The 7,062 sq. m (76,015 sq. ft.) technology center is located on three floors and includes specialized laboratories, a collaboration room, a testing area, and conference and training centers.

Halliburton Singapore Technology Center
In 2014, Halliburton Completions Tools (HCT) will open a new Technology Center in Singapore, similar to the one in Carrollton, Texas. The Technology Center will focus on specific markets, such as mature fields and shale assets. The new center will complement the HCT Singapore manufacturing facility that opened in 2013. The combination of the technology and manufacturing center enhances Halliburton’s capacity to serve the Eastern Hemisphere and will enable the rapid delivery of solutions to area clients.
The Halliburton Advanced Perforating Flow Laboratory
The current industry standard is to evaluate perforating charge performance in a cement target as documented in API 19B Section I Perforator System Testing. However, a perforating charge penetration in cement does not necessarily translate into actual penetration in hydrocarbon-bearing reservoir rock. Accordingly, the more in-depth API Section IV test can provide realistic flow performance data, validating the effectiveness of a perforator’s penetration in a porous media.

With Halliburton’s Jet Research Center (JRC) leading-edge evaluation techniques, reservoir inflow from a perforation tunnel optimization can be carried out for specific well conditions. Many of these tests have been tailored specifically for an operator’s requirement to help better understand actual downhole conditions and perforating system performance. This extensive library of laboratory testing knowledge and competencies showed the need to improve capabilities for tomorrow’s deepwater reservoir challenges to better serve the industry. It is this realized need that drove the creation of the new Advanced Perforating Flow Laboratory at Halliburton’s Jet Research Center in Alvarado, Texas.

The laboratory’s capabilities enable Halliburton to provide real answers to how a perforating system performs under actual reservoir conditions, accounting for overburden stress, reservoir pore pressure, wellbore pressure, and reservoir and wellbore response at reservoir temperatures. By doing so, the lab enables reservoir and completion engineers to more accurately appraise a well’s performance and can be used as a tool to identify the optimum solution to connect the wellbore and reservoir.

CASE STUDY: Formation-Specific Charge Development: Dominator® Charge Gives 21% Greater Penetration in Challenging North Sea Field
A major operator asked Halliburton to help improve project economics by optimizing the industry-leading 3¾-in., 6-spf, 25-gm gun system for an application in a marginal gas-condensate field in the North Sea. To meet specific field needs, charges were tailored to specific in-situ rock characteristics and reservoir conditions. In this particular situation, high jet-tip speed and an extra burst of power in the trailing elements were added to give deeper penetration and to create perforation-tunnel geometry conducive to complete tunnel cleanup for the operator’s specific underbalance condition.

These Dominator® shaped charges were developed at the Halliburton Advanced Perforating Flow Laboratory by firing perforating charges into real rock under simulated downhole conditions that included rock effective stress, wellbore underbalance, and rock pore pressure. By analyzing post-shot results from the testing program, it was possible to rapidly develop a charge with favorable jet characteristics. Using the perforation flow laboratory in the design process also avoided the pitfalls associated with translating data from surface concrete targets to productivity estimations in downhole reservoirs.

(Note: While the North Sea is not deepwater, some of the harder multi-layer deepwater formations are showing some of the same challenges.)
The facility includes three newly designed test vessels:

- The new 50,000-psi ultra-high-pressure test vessel is the only one in the world that is capable of simulating in-situ conditions with remarkable accuracy of supplying 50,000-psi overburden, 40,000-psi wellbore, and 40,000-psi reservoir pressure.

- The new cantilevered cell capabilities are 25,000-psi overburden, 20,000-psi pore pressure, and 20,000-psi wellbore. A Section IV test can be performed by rotating the cell to any angle desired and determine the effects, if any. This ability is unique to the industry.

- The third vessel’s capabilities are 25,000-psi overburden, 20,000-psi pore pressure, and 20,000-psi wellbore, with high-temperature capabilities up to 400°F (204°C).

The lab also includes a dedicated in-house Computed Tomography (CT) scanner to provide high-resolution 3D imaging of the perforation tunnels. In addition, the images provide definitive perforation geometry. Software enhancements developed in the medical industry are being implemented for better understanding of the crushed zone and identification of metal debris left in the perforation tunnel. The CT scan is a standard part of the work flow for charge performance evaluation and improvement.

The technological advancements of the perforation lab represent a significant innovation in developing reservoir solutions in challenging markets such as the pre-salt in Brazil and the deepwater Gulf of Mexico.

**Acoustic Test Facility Only One of Two in the World**

The characterization of wireline logging tools is essential to verify and validate tool response, and ensure superior service quality. Consequently, Halliburton’s Wireline and Perforating product service line made the decision to build its own acoustic test facility – one of only two in the world.

Previously, acoustic testing was dependent on third parties, which was a significant disadvantage. Recognizing that cement slurries can be designed to meet the precise specifications required for the characterization of sonic tools, the Wireline and Perforating team and Halliburton’s Cementing Product Service Line (PSL) came together in a joint collaboration to design and construct the unique Acoustic Test Facility at the Houston Technology Center.
Value-Added Procurement and Logistics

In large deepwater and ultra-deepwater projects, procurement of the needed materials and delivery of the needed materials to the location in a timely matter is critical since additional time translates directly into unnecessary cost.

Strategically positioned in more than 110 countries, Halliburton’s supply chain infrastructure has the flexibility, resources, and enterprise to deliver value-added products and services wherever and whenever they are required with unparalleled speed and reliability. Averaging in excess of 1.6 million moves every year, Halliburton’s Global Procurement and Logistics network comprises high-caliber personnel, processes, and technology that work seamlessly with a keen focus on complying with all HSE regulations and guidelines.

Halliburton’s team of dedicated and experienced professionals shares the same goals and employs a consistent methodology at both ends of the acquisition chain. Each professional completes the Company’s Global Procurement or Logistics Educational Program to ensure competency.

Even where others have failed, Halliburton’s infrastructure helps ensure the secure and timely delivery of all goods and services needed, especially with respect to high-demand solutions, such as drilling, formation evaluation, testing, and completion equipment and services. The Global Procurement and Logistics network also provides specialized transportation and handling services for critical components, including oversized deliveries, time-sensitive material, bulk air or ocean charters, and the safe shipment of hazardous mechanical and chemical cargo, including radioactive materials.

CASE STUDY: Liquid Mud Plant Meets Ultra-Tough GOM Batch Drilling Demand

The challenge was formidable: The operator planned to batch-set a group of Gulf of Mexico wells in just 75 days, requiring uninterrupted mixing and delivery of 350,000 bbl of 16.3 lb/gal SUPER SATURATED™ RISER-VIS™ riserless mud, while simultaneously providing 170,000 bbl of RISER-VIS mud to other operators. Halliburton mobilized its liquid mud plant at Fourchon, LA, where personnel mixed, stored, and delivered all the required volumes with no interruptions to its operations. Close collaboration with the operator was critical for designing a program and making sure the needed capabilities and procedures were in place. Logistical coordination with grinding plants helped ensure delivery of barite and identified primary and backup facilities. Meeting salt requirements involved planning with vendors as far away as New Mexico, Michigan, and Pennsylvania.

Fig. 1. No matter where a deepwater exploration is located, Halliburton logistics and procurement can supply the needs to the customer the fastest in the industry using the Speed, Reliability, and Visibility processes that have been put in place.
Heavy Emphasis on Local Content

Within all its global operations, Halliburton actively seeks collaborative strategic relationships with local suppliers, with emphasis on equal opportunities for residents and small businesses. These win-win supplier relationships enable Halliburton to effectively manage the purchase of commodities on a global scale, thereby delivering long-term value to clients. Sourcing and supply are conducted within strict guidelines to ensure compliance with the local laws and internal control requirements. Halliburton adheres rigidly to the U.S. Foreign Practices Act, the U.K. Anti-Bribery Law, all applicable local regulations, and “First World” ethics. These same standards also apply to third parties, including freight forwarders and brokers.

A Holistic Chain Streamlines the Process

All of the individual steps in the supply chain are combined into a holistic system that links procurement and logistics with all the processes streamlined to ensure accurate and on-time delivery. This methodology enables the Global Logistics and Procurement organization to provide customers with the unparalleled speed, reliability, and the visibility needed to enable better business decisions and greater efficiencies that can cut cost.

Exploration Infrastructure

The unknowns associated with an exploration project, particularly in virgin territory with zero infrastructure, make it difficult to justify the establishment of a permanent, full-scale service and supply facility. Halliburton addresses those limitations with a variety of portable facilities that can be set up quickly and equipped to deliver the maintenance and service required for the exploration program. The mobile set-ups even include capabilities to relay real-time data to the operator’s shore base to expedite decision-making for the offshore well.
CASE STUDY:
Dominant East Africa Position Begins With One-Well Setup

Halliburton responded to a client’s single-well deepwater exploration opportunity in Tanzania, East Africa, by being the first service provider to establish a local presence and infrastructure. The single-well opportunity mushroomed with Halliburton being the only service and equipment provider in position to deliver logistics and technical support for a first major deepwater gas discovery off Mozambique. With a number of operators having since made significant deepwater discoveries off Mozambique and Tanzania, and eyeing prospects offshore Kenya, Halliburton was the only provider locally established and capable of delivering the customized solutions to meet unique logistics challenges. Since that initial one-well project, Halliburton’s Pemba facility has grown to over 80 employees across several product service lines (PSL). Halliburton has established East Africa’s first fully equipped mud lab in Dar es Salaam, Tanzania, with the capabilities to perform operational and quality analysis.

Cost-effective mobile maintenance systems available to accommodate temporary exploration and small developments in remote locations can include:

- Mud plants
- Cement bulk plants
- Multifunctional formation evaluation units
- Data acquisition laboratories
- Fluid testing labs
- Equipment maintenance and repair facilities
- Completion test facilities, including special API test facilities
- Production test facilities

Using these facilities, Halliburton successfully supports all exploration activities, including the provision of advanced reservoir characterization tools; reservoir-fluid sampling tools; production analyses; and complete MWD/LWD, wireline, and other evaluation technologies. Established processes determine the mobile facilities required. The process begins with selecting a site as close as possible to the location and proceeding through identifying the specific building requirements, preliminary setup, safety processes, risk management, preparations for operations, and verification of operability. HSE and service quality audits are conducted throughout the process.

The selected site may be a floating drilling rig, an offshore structure, or a temporary onshore location. The goals of reliability, safety, and efficiency are built into the equipment and best delivered by a service provider that designs and manufactures its own equipment and uses it on a daily basis.

Logistically, Halliburton has engaged local resources to meet the growing activity demands. By focusing on improving shipping times and negating importation problems, the time from order to delivery to get materials and equipment into East Africa has been reduced from 160-180 days to the current average of 80-90 days. This has enabled better planning across all PSLs, enhancing service delivery to the growing client base.

Owing to this high level of performance, Halliburton was recently named winner of the Africa Oil and Gas Supplier Award 2013.
Plan, Develop, and Produce Deepwater Developments with Speed and Accuracy

While meticulous planning is certainly imperative in any E&P venture, the pressures rise exponentially when designing a plan for high-cost and risk-intensive deepwater developments.

Every deepwater development program presents a series of planning and engineering challenges that must be systematically addressed with the utmost accuracy and speed. Accuracy is critical as the decisions translate into extremely high-cost decisions that will affect the entire life cycle of the project.

A thorough development plan begins with the seismic investigations in the initial basin exploration program, and continues to determine the geological model, the drilling operations, and the development infrastructure to be built. Some of the most critical long-term decisions are made in these phases of a project.

Understanding Geomechanics Key to Successful Planning and Development

Before a field can be planned, drilled, developed, and produced, a thorough understanding of its geomechanics is necessary to ensure initial and long-term well stability. At well completion, and especially during stimulation, knowledge of geomechanical properties such as rock composition, strength, and stress field orientation helps operators avoid costly mistakes by implementing inappropriate well and completion designs.

During development, geomechanical programs have taken planning to a new level, delivering the industry’s most accurate suite of software that gives geoscientists and engineers the data they need to make critical decisions, from determining whether a reservoir is commercial and, if so, how it should be developed. The objective is to provide a strategy that will incorporate the optimum reliability, safety, and efficiency into the plan and deliver maximum bottom-line value.

Geomechanics cannot be ignored in a deepwater development. Here are some things to consider:
Geomechanics also plays a vital role in analyzing and optimizing production factors, from initial production to abandonment. From fracture gradient changes, to sanding, to compaction and subsidence, Halliburton’s geomechanical work flow analyzes production parameters and provides solutions to extend the life and ultimate recovery of a reservoir.
New Tools Take Guesswork out of Planning

In deepwater field developments, the initial challenge for the operator is to quantify fluid volume and properties and evaluate petroleum containment potential and emplacement patterns. Of course, in these environments, ultra-accurate data produced quickly are paramount.

Landmark’s highly sophisticated DecisionSpace® family of planning software is unique in that it seamlessly enables results from one software to flow in and out of another software module. The final outcome is analysis that is more integrated, resulting in a more optimized development plan delivered much faster than more conventional planning methodologies.

Special features are built into the software, including the capability to modify for the specialized parameters needed for subsalt and deepwater conditions.

Within the suite, the Permedia™ Petroleum Systems software models basin-scale processes over geological time, helping geoscientists evaluate source-rock potential, migration, reservoir trap and seal characteristics, and fluid-composition prediction, all with the aim of highlighting the “sweet spots.” The software includes a basin simulator to forward-model pressures and temperatures as input to the petroleum-migration simulator.

The integration of basin-simulation results and exploration data enhances the long-term vitality of exploration and production assets, while mitigating risks and highlighting the optimum carbon-content sweet spots.
Building Precise Geological Models Faster than Ever

Historically, creating the geological model critical for development decisions was a frustratingly slow exercise. Fault polygon digitizing and other conventional geological modeling was extremely time consuming, leaving development decisions hanging in the balance.

With its state-of-the-art DecisionSpace® Geology software module, Landmark set the benchmark for expedient geological interpretation, mapping, and modeling. The modeling software improves traditional correlation and cross-sectioning tasks by leveraging industry-leading topology technology, geologic conformance concepts, advanced fault prediction, and horizon geometry projection technology.

A traditional geologic interpretation tool in combination with Dynamic Frameworks to Fill® workflow technology provides a powerful workflow that represents a step-change advancement in efficiency for structure and property mapping. Geoscientists can build a sealed structural framework while they interpret, fill the framework with facies and deterministic reservoir properties, and then create accurate maps – in a matter of minutes. Auto-generation of fault polygons and dynamic grid updates accelerate the process.

**GeoShell Subsalt**

In addition, the GeoShell body likewise can be accessed and viewed from the DecisionSpace Geosciences platform. Extended data conversion options exist to convert standard horizons to GeoShells. Conversely, GeoShell bodies may be converted to single-Z horizon patches. This technology provides valuable assistance in helping geologists and geophysicists build their models more accurately and quickly.

GeoShell technology generates a sealed body for representing complex, multi-Z, and three-dimensional objects. The technology enables the geophysicist to interpret in three dimensions by creating objects that represent the most complex and largest of geological bodies quickly and easily. This technology is particularly valuable in salt body imaging and interpretation workflows.

Interpreters can use the GeoShell body reconstruction algorithm to “wrap” multiple input surfaces, such as a top and base of salt, to create a body. Any number of surfaces can be put into the algorithm to build a final sealed salt body. Surface tension properties can also be input to yield the most geologically meaningful and accurate output.

A sealed salt body can also be constructed from extracted seismic attribute volumes generated with the patented GeoShell GeoAnomalies feature. GeoShell technology identifies connectivity within seismic attributes and then “wraps” these attributes to create the GeoShell object.

![Fig. 8. The sophisticated DecisionSpace® Geology software is a “step change” in geological mapping, a byproduct of framework construction.](image)

![Fig. 9. GeoShell technology enables for salt modeling by deepwater operators.](image)
Additionally, a GeoShell object can be created directly from TSurf objects. GeoShell objects can be consumed by the ezModel™ application for inclusion into a sealed structural model. To enable the interpreter to edit complex bodies without the overhead of reinterpretation steps, the GeoShell functionality also includes an interactive deformation feature. Interpreters can selectively edit GeoShell bodies by selecting the precise area they want to modify and “push” or “pull” the surface of the GeoShell body until the objective is achieved. This localized interpretation leaves the rest of the project undisturbed.

Taking Geological Mapping to the Reservoir Model

The geological map is only the first step and must be followed with an integrated reservoir and facility model to fulfill the holistic methodology of the entire asset development process.

The Nexus® Software optimized for the DecisionSpace environment provides solutions five times faster on average than other leading reservoir simulators, solving both surface and subsurface equations in a tightly coupled network model yielding more accurate results. The increased speed is a function of the unique volume balance formulation, which results in convergence with fewer iterations. A tightly coupled network model enables the surface and subsurface models to be solved simultaneously, leading to a faster and more accurate solution. What's more, several reservoirs that might come from dissimilar earth model data sources can be combined into a common downstream model. This capacity is particularly beneficial in a deepwater development with a combination of platform and subsea wells. New reservoirs in these areas are more complex and multi-layered, but the Nexus model can handle these environments with no difficulties.

The Nexus model enables modifications to individual parts of the production chain and shows exactly how the change will affect the total asset performance. Performance is realized out of the box with minimal tuning required. Nexus differentiators include: volume balance formulation, compositional formulation, multi-reservoir coupling, surface facility modeling, tightly coupled fully implicit surface-subsurface modeling, unstructured solver for faster computing, intelligent upscaling, direct-access modeling, and parallel computing.

Individualized Well Planning

After the holistic asset has been planned, one of the major remaining challenges is to optimize individual well planning as quickly as possible. Speed, however, must go hand-in-hand with design considerations, such as weather conditions and environmental impact that must be taken into account. This is imperative for deepwater developments.

DecisionSpace® Well Planning software helps asset teams reduce well-planning cycles by leveraging advanced automation techniques to quickly plan any combination of targets and well trajectories for single wells, relief wells, and field development scenarios. The software is the latest advancement in well planning, enabling geoscientists, well planners, and drilling engineers to work collaboratively in a single application and in the context of a shared-earth model. Algorithms optimize field development plans based on user-specified cost parameters, risk and uncertainty, and degree of difficulty.

Fig. 10. With DecisionSpace Well Planning software, asset teams work together more efficiently in a unified 3D visualization environment where well-planning decisions are made in the context of relevant geologic, geophysical, and GIS data.
By planning complete field scenarios in a unified plan, asset teams are able to maximize drainage while reducing drilling delays and eliminating hours of rework. In developing deepwater assets, the software can help drilling engineers and geoscientists rapidly iterate through field-development scenarios.

**Well Plans Recommend Rigs, Equipment**

Once the number of wells has been ascertained, the next challenge in the systematic approach is to decide how to deliver the individual wells as safely, efficiently, and reliably as possible.

DecisionSpace Well Engineering software provides project-specific recommendations on the rig and other equipment to use, the proper string components, and the appropriate fluid properties and parameters to drill the targeted asset safely and efficiently.

The easy-to-use software matches rig, equipment, and mud configurations for any deepwater well design, including high-pressure/high-temperature, 3D-directional profiles, horizontal, and extended reach.

**Special Focus on ERD, Horizontal Well Paths**

With the ever increasing number of ERD and horizontal deepwater wells, operators need more data to properly land the well.

For instance, drilling engineers require insight on the optimum geosteering that will help deliver maximum drainage and, in turn, reduce the costs and bring more value.

The Horizontal Well Correlation software within the DecisionSpace Well Engineering package correlates MWD/LWD data from the horizontal portion of a well to the vertical portion of the target well or nearby offsets. The software uses correlations to locate the stratigraphic position of the wellbore, and determine if the wellbore is on target. Additionally, the software provides real-time updates to the 3D subsurface model, and drives powerful geosteering workflows.

Leveraging the dynamically updated subsurface model and the visual context of seismic data provides a unique “look-ahead” capability that enables team members to quickly determine the bit location and make operational adjustments to stay within the most productive zones.

The Horizontal Well Correlation software correlates the predicted curve from offset wells and actual LWD/MWD data to create detailed inter-well XYZ control points. These control points fill the gaps between the offsets with new subsurface data, including dip variation, pinch-outs, or faults, which are interpreted in the well correlation.

The benefits of Landmark’s step-change advancement in well and development planning
Plan, Develop, and Produce Deepwater Developments with Speed and Accuracy

comes to the forefront in wells and full-field developments that are delivered with optimum performance in reliability, HSE efficiency, and maximum bottom-line value.

**Integration of Well Construction Planning**

Halliburton’s DrillingXpert™ software provides our experts the ability to design an entire drilling system in one advanced package that speeds up the planning process and improves decision making by providing access to all required information in a single location. With DrillingXpert software, the Halliburton team is able to deliver integration, efficiency, engineering, and standardization into a single planning process.

By consolidating the drilling modeling applications from Landmark in DecisionSpace Well Engineering and those from Sperry Drilling, Baroid, and HDBS into a single platform, Halliburton has created a well-engineering software tool kit that is unparalleled in the industry. The software also provides a common connection between the drilling PSLs and customers, thus increasing collaboration in the drilling process.

DrillingXpert™ engineering Modules include:

- DecisionSpace Well Engineering Torque and Drag
- DecisionSpace Well Engineering Hydraulics
- DecisionSpace Well Engineering Casing Centralization
- DrillingXpert™ DFG™ Hydraulics
- DrillingXpert™ DFG™ DrillAhead® Hydraulics
- DrillingXpert™ Direction by Design® Bit Analysis
- DrillingXpert™ MaxBHA™ Analysis
- DrillingXpert™ Whirl™ Analysis

DrillingXpert software supports any drilling services delivery by providing the capability to model all elements of the drilling systems required to meet the objectives of any hole section, in any well, and in any environment. By rapidly optimizing the design of the entire drilling system, DrillingXpert software delivers maximum performance to reduce overall drilling days and well AFE.

The DrillingXpert software development program has begun the consolidation of PSL engineering tools with the modules from the Landmark Wellplan software. Since it is one common application running on the Engineer’s Data Model™ (EDM™) database, DrillingXpert software can obtain the well trajectories developed in COMPASS™ software. This integration, which promotes engineering capabilities that are faster and of considerably higher quality, is continually evolving with further consolidation and enhancement of engineering applications on the horizon.

The planning stage of this standardized process comprises BHA modeling, vibration modeling, torque and drag analysis for each hole section, hydraulics analysis, surge/swab analysis with identified limits, pore pressure, and fracture pressure. DrillingXpert software supports all these calculations.

![Fig. 13. Gulf of Mexico Real-Time Operation Team](image-url)
Plan, Develop, and Produce Deepwater Developments with Speed and Accuracy

With Drilling Xpert software, Halliburton provides:

- A Drilling Performance Workflow process that is delivered in a single integrated software environment.

- Rapid development of complete drilling solutions rather than PSL- or product-specific items, reducing the time required to assemble data and increasing the time available for analysis.

- A common platform that connects the PSLs and customers, driving improved collaboration in the drilling planning process.

- Assurance that all engineering calculations across the company are performed using standard libraries maintained by PSL domain experts.

- Accelerated development of technical professionals by using one application for all calculations while standardizing and streamlining training and competency development; as a result, technical professionals do not have to learn many different software applications to perform their jobs.

Cutting Risks with Real-Time Shore-Based Monitoring

The remoteness and restricted working conditions of deepwater locations require that on-site personnel requirements be minimized wherever possible.

Halliburton has helped reduce the risks, while elevating the speed, efficiency, and reliability of the asset decision-making exercise, with implementation of its shore-based Real Time Reservoir Solutions (RTRS) for deepwater exploration and development operations.

Incorporating a revolutionary network of powerful computers, satellites, and other monitoring technologies, the RTRS bridges the distance between personnel and downhole data, in real time. Using RTRS, Halliburton and client experts can collaborate, share knowledge, and solve well problems almost instantly from anywhere in the world.

Well-matched for deepwater operations, the RTRS reduces HSE risks and helps maximize economic recovery with the delivery of timely and reliable data necessary to optimize investment decisions. Multiple deepwater regions have teamed up to save drilling costs.

Fig. 14. Halliburton’s strategically placed Reservoir Decision Centers (RDC) are the core of the RTRS and provide state-of-the-art visualization rooms that display real-time wellsite data to enable immediate multi-disciplinary collaboration to hasten asset decisions.
Addressing Reservoir Uncertainties

Uncertainties exist in any reservoir, but acquiring thorough formation and reservoir data is especially critical to making exploration and development in deepwater programs economical. For these projects, accurate and reliable downhole data is imperative to efficiently “right size” the development with respect to the subsurface, surface and infrastructure. Accurate insight from evaluation tools saves geophysicists, geologists, and petrophysicists time in making decisions that can strongly impact the life-long productivity, HSE performance, and the ultimate value of the asset.

Halliburton has assembled a holistic suite of advanced coring, testing, MWD/LWD, and wireline-conveyed data acquisition innovations. Halliburton separates itself as the leader in data collection and interpretation for HP/HT, complex lithologies, the pre-salt, and other equally extreme downhole applications with unparalleled accuracy and reliability between the data collection methods.

Delivering Value to Exploratory Assets

Perhaps more so than in any other E&P venture, the capture and analysis of comprehensive reservoir data is paramount for maximum exploitation of the pay zone in deepwater exploration prospects. This has spurred the development of highly advanced descriptive tools and techniques, designed to yield a wealth of data for reservoir characterization. Technologies, applied individually or in combo, generate superbly accurate data, images, and samples, which, in combination with interpretative techniques, help the explorationist make the decisions necessary for maximum asset value.

Full, Clean, and Cost-Effective Coring Solutions

Analysis of unaltered, native-state cores is fundamental to the exploration process. However, the excessive vibration on the BHA when coring in hard and abrasive rock, coupled with extreme temperatures and pressures, have frustrated many in the ability to achieve 100% recovery of uncontaminated cores using previous technologies. Halliburton's exploration suite extends to the industry's most robust and efficient coring solution (RockStrong™ system), engineered with a superior design and core barrel drive mechanisms that makes it effective for all coring applications, including extreme hard rock and deep water. Halliburton coring systems also includes the proprietary Full Closure System (CFCS) which completely seals the inner barrel and provides a coring system for deepwater unconsolidated formations. The Hostile Rotary Sidewall Coring (HRSCT™) Tool was designed for retrieving undistorted cores in temperatures and pressures up to 400°F (204°C) and 25,000 psi, respectively. The HRSCT tool has demonstrated its capacity to acquire up to 30 high-quality 1½-in. diameter core plugs in a single run – that are undistorted and easily analyzed, free of the micro-fractures typical of percussion cores.

Solutions for Enhanced Reservoir Characterizations

For both exploration and development, accurate characterization of reservoir rock and fluid properties is essential for gaining needed understanding of reservoir potential. These data sets provide the insight required to design a more efficient well that is landed perfectly and helps avoid the drilling hazards that can raise serious NPT and HSE issues.

Halliburton has an extensive portfolio of reservoir characterization technologies for deep water and equally critical applications. The portfolio ranges from the latest-generation borehole seismic services to advanced extreme HP/HT MWD/LWD sensors and sonic services, including azimuthal, ultrasonic LWD service and wireline.
Three-Pronged Solution for Defining the Pre-Salt

The emerging pre-salt basins of Brazil, West Africa, and elsewhere bring unique challenges to reservoir characterization, largely due to the limitations of conventional seismic images to clearly delineate salt horizons.

Halliburton’s Borehole Seismic Services portfolio includes a new generation solution (3D Salt Proximity) that delivers high-quality surveys that use X, Y, and Z salt exit points to clearly define the salt flank in 3D space. Using 3-component downhole geophones, Halliburton’s 3D Salt Proximity refraction technology in tandem with advanced vertical seismic profile (VSP) software helps operators drill around salt formations.

The descriptive quality of 3D Salt Proximity surveys helps minimize the inevitable risks and costs of drilling a salt body. Salt flank delineation surveys also enhance asset value by helping operators locate attic oil deposits and guiding the directional drilling program toward hydrocarbon accumulations trapped up-dip from producing horizons and trapped against the salt.

Fig. 1. RockStrong™ system for coring operations in extreme conditions.

Fig. 2. Using 3D Salt Proximity coupled with Offset VSP salt images helps provide assurance and redundancy of the salt flank interpretation.
Real-Time Reservoir Characterization

Until now, the acquisition of formation fluid samples was possible only on wireline. Sperry Drilling’s GeoTap® IDS sensor, for the first time, enables reservoir fluid samples to be recovered with LWD technology. Built on the acclaimed GeoTap® LWD formation pressure tester platform, the GeoTap IDS sensor delivers timely downhole capture, surface recovery, and identification of multiple samples of uncontaminated formation fluids.

By eliminating flat time associated with wireline sampling, the GeoTap IDS sensor can acquire multiple fluid samples within hours, rather than days, of drilling the formation. In addition, with the GeoTap IDS sensor Halliburton now provides true formation testing while drilling capabilities for optimizing wellbore placement to achieve maximum production over the life of the reservoir.

The GeoTap IDS sensor helps reduce risk and uncertainty in complex reservoirs, while reducing costs and limiting costly wireline trips and associated rig time. The GeoTap IDS also provides data within hours, not days, through reduced pump-out time and helps improve geocorrelation accuracy and geosteering capabilities.

In high-cost environments, such as deepwater exploration wells, significant value is found in eliminating trips for wireline sampling tools. When samples are taken while drilling, formation contamination from drilling fluids is considerably less and extended pump-out times for clean samples are reduced dramatically compared to wireline. Valuable data are more rapidly recovered, improving decision-making while drilling the reservoir, and enabling more timely solutions.
Meeting HP/HT, MWD/LWD, and Wireline Logging Challenges

Deep water alone can make the acquisition of complete and reliable downhole data problematic, but add in the extreme temperatures and pressures and the difficulties/costs escalate considerably. Extreme HP/HT adversely impacts wireline and MWD/LWD tool reliability and performance. High temperatures damage tool electronics, affect sensor accuracy and precision, and can lead to premature tool failure if equipment is ill-designed for this service.

Differentiating Halliburton is the development of high-temperature-rated downhole tools that enable the successful drilling and evaluation of deepwater wells. New tool designs and electronics provide greater control in extreme-temperature reservoirs, thus reducing the uncertainties of “drilling blind.” This capability is enabling access to reservoirs previously considered uneconomic.

Halliburton's one-of-a-kind suite of LWD and wireline-conveyed sonic and ultrasonic logging tools comprises the industry's most advanced technologies for acquiring reliable data in the most extreme service conditions, often in one pass. Among the best-in-class innovations is the Hostile Wavesonic® wireline tool for the consistent delivery of reliable formation property measurements in temperatures up to 500°F and pressures of 30,000 psi.

The Hostile WaveSonic® tool, like the companion WaveSonic® tool, measures fast and slow shear wave travel times, P-wave slowness, compressive fluids in pore space and anisotropy. The Hostile WaveSonic tool likewise calculates minimum and maximum stresses and field orientation. These measurements provide operators an inclusive characterization of formation properties in HP/HT wells, which conventional logging tools are unable to provide.

Fully compatible with all the tools in Halliburton's HP/HT Hostile Logging (HEAT™) suite, the Hostile WaveSonic tool can be incorporated in the same tool string for a single logging pass to reduce the trips required for complete formation evaluation. The all-inclusive logging portfolio also includes diverse LWD borehole imaging services to help identify structure dips, faults, and fractures and otherwise help target the sweet spot.

The LWD suite includes the Sperry Drilling ADR™ Azimuthal Deep Resistivity sensor that provides fully compensated, multiple-depth resistivity measurement and petrophysical evaluation for both precise wellbore placement and more accurate petrophysical analysis. Sperry Drilling also offers the AFR™ Azimuthal Focused Resistivity Sensor that produces high-resolution resistivity images for identifying dip, fractures, and borehole breakout.

Fig. 5. The AFR sensor acquires data in up to 128 discrete, azimuthal sectors, or “bins,” around the borehole. This fine delineation of the borehole wall translates into very-high-resolution images that provides the customers accurate dip and fracture analysis.
Table 1: State-of-the-Art Seismic, Logging, and Reservoir Characterization Services BHT <350°F

<table>
<thead>
<tr>
<th>Tool</th>
<th>Wireline</th>
<th>LWD / SDL</th>
<th>How Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quad Combo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistivity</td>
<td>ACR™ or DLL™, MSFLt</td>
<td>ADR™, AFR™, EWR™</td>
<td>Fluid saturation, TOC</td>
</tr>
<tr>
<td>Spectral Density</td>
<td>SDL™</td>
<td>ALD™</td>
<td>Porosity, GIP</td>
</tr>
<tr>
<td>Dual-Spaced Neutron Porosity</td>
<td>DSN-II™</td>
<td>CTN™</td>
<td>Porosity, Gas Identification</td>
</tr>
<tr>
<td>Compensated Array Sonic</td>
<td>BSAT™</td>
<td>QBAT™, XBAT™</td>
<td>Sonic Data Acquisition</td>
</tr>
<tr>
<td>Spectral Natural Gamma Ray</td>
<td>CSNG™</td>
<td></td>
<td>Lithology Correlation</td>
</tr>
<tr>
<td>Natural Gamma Ray</td>
<td>NGR™</td>
<td>ABG™, DGR</td>
<td>Lithology, Clay Typing, Geosteering</td>
</tr>
<tr>
<td>Azimuthal Gamma w/ Inclination</td>
<td>ICT</td>
<td>GABI™</td>
<td>Lithology, Geosteering</td>
</tr>
<tr>
<td>6-Arm Caliper</td>
<td></td>
<td>AcoustiCaliper™</td>
<td>Borehole Geometry, Log Correction</td>
</tr>
<tr>
<td>Elemental Analysis Tool</td>
<td>GEM™</td>
<td>LaserStrat™, LithoSCAN™</td>
<td>Mineralogy, Clay Typing</td>
</tr>
<tr>
<td>Formation Pressures and Samples</td>
<td>RDT™, ICE Core™</td>
<td>GeoTap™</td>
<td>Formation pressure and fluid sample analysis and extraction Downhole fluid analysis service</td>
</tr>
<tr>
<td>Advanced Logging Services</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3D Induction Resistivity</td>
<td>Xaminer™ MCI</td>
<td></td>
<td>Measuring Resistivity Anisotropy and Formation Dips</td>
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<tr>
<td>Crossed-Monopole/Dipole</td>
<td>WaveSonic*</td>
<td>QBAT™</td>
<td>Porosity, Geomechanical Properties</td>
</tr>
<tr>
<td>Acoustic Tool</td>
<td></td>
<td></td>
<td>Stress-Field Orientation (Anisotropy Analysis)</td>
</tr>
<tr>
<td>Nuclear Magnetic Resonance</td>
<td>MRIL* Prime, MRIL*-XL</td>
<td>MRIL* - WD</td>
<td>Porosity, and Free and Bound Water, Permeability, Fluid Typing</td>
</tr>
<tr>
<td>T1 and T2 Analysis</td>
<td>XRMI™, OMRI™, CAST-1™</td>
<td>AFR™, ADR™, ALD™</td>
<td>Lithofacies, Dip, Fracture ID, and Evaluation</td>
</tr>
<tr>
<td>Borehole Imaging</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulsed Neutron</td>
<td>RMT-I™, TMD-3D™</td>
<td></td>
<td>Mineralogy, Clay Typing, Hydrocarbon Saturation, Chi Modeling</td>
</tr>
<tr>
<td>Vertical Well, BHT &lt;350°F</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wireline</td>
<td></td>
<td>LWD / SDL</td>
<td>How Used</td>
</tr>
<tr>
<td>Sidewall Cores</td>
<td>RSCT™, HRSCT, SWC™</td>
<td></td>
<td>Mineralogy, Porosity, Permeability TOC, Kerogen Typing, Fluid Typing, Geomechanics, CST</td>
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<tr>
<td>Borehole Seismic Services</td>
<td>OMRI, XRMI, CAST-1</td>
<td></td>
<td>Reservoir Delineation, Fracture Evaluation, Reservoir Characterization</td>
</tr>
</tbody>
</table>
### Table 2: HP/HT Logging and Evaluation Services BHT >350°F

<table>
<thead>
<tr>
<th>Tool</th>
<th>Wireline</th>
<th>LWD</th>
<th>How Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hostile Triple Combo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gamma Ray</td>
<td>HNGR™</td>
<td>Quasar Pulse™</td>
<td>Lithology Correlation</td>
</tr>
<tr>
<td>Resistivity</td>
<td>HACRt™</td>
<td></td>
<td>Fluid Saturation, TOC</td>
</tr>
<tr>
<td>Spectral Density</td>
<td>HSDL™</td>
<td></td>
<td>Porosity, GIP</td>
</tr>
<tr>
<td>Dual-Spaced Neutron</td>
<td>HDSN™ (included with density/neutron tools)</td>
<td></td>
<td>Porosity, Gas Identification</td>
</tr>
<tr>
<td>Caliper</td>
<td></td>
<td></td>
<td>Borehole Geometry, Log Correction</td>
</tr>
<tr>
<td>HSFT-II</td>
<td></td>
<td></td>
<td>Formtion Pressure and Fluid Sample Analysis and Extraction</td>
</tr>
</tbody>
</table>

### Advanced Logging Services

<table>
<thead>
<tr>
<th>Wireline</th>
<th>LWD</th>
<th>How Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hostile WaveSonic*</td>
<td></td>
<td>Porosity, Geomechanical Properties</td>
</tr>
<tr>
<td>LaserStrat Chemostratigraphy</td>
<td></td>
<td>Mineralogy, Correlation</td>
</tr>
</tbody>
</table>

### Additional Formation-Evaluation Services

<table>
<thead>
<tr>
<th>Wireline</th>
<th>LWD</th>
<th>How Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRSCT, SWC</td>
<td>RockStrong™</td>
<td>Mineralogy, Porosity, Permeability, TOC, Kerogen Typing, Fluid Typing, Geomechanics, CST</td>
</tr>
<tr>
<td>Full Core</td>
<td></td>
<td>Full Core for Geological and Reservoir Studies</td>
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</tbody>
</table>

### Horizontal Open Hole, BHT >350°F

<table>
<thead>
<tr>
<th>Wireline</th>
<th>LWD</th>
<th>How Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEAT™ Suite II**</td>
<td>Quasar Pulse™</td>
<td>Lithology Correlation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fluid Saturation, TOC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Porosity, GIP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gas Identification</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Borehole Geometry</td>
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<tr>
<td></td>
<td></td>
<td>Log Correction</td>
</tr>
</tbody>
</table>

### Horizontal Cased Hole, BHT >350°F

<table>
<thead>
<tr>
<th>Wireline</th>
<th>LWD</th>
<th>How Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMT-Elite™, TMD-3D™ Tool</td>
<td></td>
<td>Mineralogy, Clay Typing, Fluid Satuations</td>
</tr>
<tr>
<td>Hostile WaveSonic*</td>
<td></td>
<td>Porosity, Geomechanical Properties, Stress-Field</td>
</tr>
</tbody>
</table>

Halliburton constantly innovates to solve deepwater and ultra-deepwater challenges. Please consult with your local Halliburton Sperry Drilling representative regarding Extreme HT-200™ sensors rated to 392°F (200°C) and 25,000 psi (172.4 MPa); and Ultra HT-230™ sensors, rated to 446°F (230°C) and 25,000 psi (172.4 MPa) solution developments.
Keeping Sensors Intact When the Heat’s On

When downhole temperatures increase, so does the failure rate of conventional MWD and LWD sensors. Standard MWD/LWD sensors are unable to hold up under extreme temperatures, resulting in a replacement trip, not to mention serious doubts over the validity of any acquired data.

Sperry Drilling is widely identified as the pacesetter in developing MWD/LWD sensors that continue to acquire the highest-quality data even in the face of downhole temperatures as high as 392°F (200°C). Designed to provide accurate and timely reservoir measurements while maximizing reservoir deliverability, Sperry Drilling’s full range of rugged SOLAR™ sensors withstand temperatures as high as 347°F (175°C) and pressures as high as 30,000 psi, depending on tool size and type.

The entire SOLAR suite of formation evaluation sensors, which includes directional, gamma, pressure, resistivity, neutron, density, sonic, and formation pressure testing, were developed to ensure quality information is obtained throughout the well. The SOLAR sensors help ensure accurate directional data and steering capabilities through harsh conditions, delivering wireline-quality reservoir data for effective, economical reservoir characterization while drilling or stored for later retrieval.

In extreme environments with temperatures that push 392°F (200°C), Sperry Drilling offers the unrivaled Quasar Pulse™ service that combines extreme-HP/HT directional, gamma ray, PWD, and vibration sensors in a single collar to accurately and quickly acquire the reservoir measurements necessary for precise and efficient wellbore placement. The Quasar Pulse service is the only M/LWD tool capable of consistently acquiring reliable data while drilling in temperatures up to 392°F and pressures of up to 25,000 psi (172 MPa).

Evaluation Technologies Help Enhance Production

Gathering the reservoir data can avoid future problems that can arise from a completion that has not been designed to properly match specific reservoir fluid and rock properties.

An advanced suite of reservoir-specific LWD and wireline-conveyed sonic and other tools has been developed to help in the completion design phase to maximize the bottom-line value of the asset. The Sperry Drilling QBAT™ multiple LWD sonic tool delivers shear and compressional velocity measurements to determine porosity and rock properties, while also providing input to numerous advanced calculations, such as synthetic seismograms and wellbore stability analyses. The QBAT tool delivers monopole, dipole, and quadrupole reservoir measurements over a wide range of formation types and velocities. The QBAT sensor is less sensitive to drilling noise that can compromise acoustic measurements and delivers reliable high-temperature performance with a rating of 175°C (347°F).

The Sperry Drilling XBAT™ azimuthal sonic and ultrasonic LWD service combines multipole transmitters, four azimuthal receiver arrays, and a 4-pinger acoustic caliper, which in combo have raised the bar in velocity measurements. The sonic-caliper combination of XBAT tool helps mitigate risk through pore pressure...
prediction and hole shape data for wellbore stability monitoring, while optimizing the position of the wellbore with synthetic seismograms that tie back to surface seismic data.

**Nuclear Magnetic Resonance Delivers Fluids Movement**

The solutions offering also include a suite of Nuclear Magnetic Resonance (NMR) tools that provide accurate and timely measurements to maximize reservoir deliverability. The MRIL*-WD magnetic resonance imaging logging-while-drilling tool provides important reservoir fluid information, such as water saturation, mobility, etc., delivering wireline-quality reservoir data for efficient, reliable, and value-added reservoir characterization. Wireline conveyance of NMR provides valuable reservoir information on production, depletion, and waterflood.

**Safe and Reliable Subsea Testing Solutions**

A reliable subsea safety system is vital for deepwater well testing, as well as collecting completion data and providing invaluable data as to how to design the infrastructure that will last the entire field life. Reliable subsea tests that are conducted with the highest level of safety are imperative for determining system performance.

As part of Halliburton’s suite of subsea safety systems, the premier 3-inch 15k Veto™ Subsea Safety System is designed to specifically provide well isolation and control during exploration and appraisal drillstem testing and well cleanup operations. An integral component of a full well-testing package, the Veto system provides the required BOP, wellhead, DST, and surface equipment interfaces for landing out in the appropriate position, while providing well control required during exploration testing and cleanup operations. The Veto subsea safety tree is a hydraulically operated, dual “fail-safe closed” valve system designed as a primary well-control barrier combined with a passively orienting latch mechanism.

By incorporating the latest advances in design and technology, the Veto system delivers comprehensive well control mandatory...
in today’s highly demanding and regulated deepwater environments. The Veto system is engineered with the very latest technologies, including:

- Standard single design rated to 15,000 psi (103 MPa) working pressure
- Lubricator valve that enables pressure testing against ball valve from above to full working pressure with applied control line pressure
- Retainer valve designed to fail-safe close in the event of a severing of the shear sub, if normal operations fail
- The Veto subsea safety tree designed with a passive latch orientation system that provides positive latching, removing the need to rotate the landing string to achieve engagement, thus helping to eliminate potential issues with landing weights and string torsion
- Dual sealing elements installed in critical areas of well isolation help increase reliability.
- All connections are locked from rotation with the Halliburton lock mechanism, which enables each connection to be fully shouldered out, thus increasing overall strength without the need to back off connections to get alignment.
- High tensile capacity helps enable safe deployment of heavy DST strings.

In deep water, serious weather conditions arise quickly, and sometimes the need to disconnect from the drillship is paramount. An integral component of Halliburton’s Veto subsea safety testing system, the Dash™ Emergency Response Module (ERM) has near-instantaneous well shut-in and landing-string disconnect. Also, the testing equipment capability is essential when conducting well-testing operations from a dynamically positioned deepwater rig where water depths can reach 10,000 ft (3,048 m).

Unlike conventional “rapid response” systems that rely on downhole nitrogen accumulators and complicated electrical systems to hydraulically deliver tool functionality, Dash ERM simply uses stored energy developed within the marine riser. Completely passive during operations, the Dash ERM requires no complex downhole electronics to effect immediate activation. An electrical signal is simply sent from the surface through the umbilical to a single solenoid valve mounted within the Dash ERM.

The solenoid valve is energized to open and allows a small volume of accumulated fluid within a hydraulic hose to enter the tool and release a mechanical lock that allows the upper section of the landing string to move through the BOP stack and clear the lower marine riser package (LMRP).

The Dash ERM also provides real-time displays of wellbore temperature and pressure to accurately predict hydrate formation. In addition, the sophisticated ERM displays real-time fault monitoring of internal pressures, as well as continuity verifications of actuators post-deployment. The surface control module is mounted within the frame of the electrical reel units, helping reduce space requirements.

The availability of pertinent and timely data from downhole sensors is paramount for making sound development decisions. Halliburton’s DynaLink® telemetry system...
operates as a real-time wireless sensor and actuator network using acoustic energy in the tubing string. Consequently, any activity that can be done downhole can now be done wireless. The DynaLink system helps reduce the cost of the operation while enhancing the economic value of the reservoir through flexible access to critical and accurate real-time data pertinent to the reservoir evaluation. This flexibility enables well-timed decisions to be made in drillstem testing and future sand control or stimulation applications.

**Downhole Analysis Delivers Lab Quality Results**

Halliburton’s subsea testing and evaluation solutions also include the wireline-deployed Armada® large-bore sample system and the Reservoir Description Tool (RDT™) tester. These tools are used for accurate PVT and fluid sampling in extreme-HPHT deepwater exploration wells. Effective up to 400°F (204°C) and 20,000 psi, the Armada was developed to solve the risks and difficulties of obtaining accurate fluid sampling in cased holes.

The RDT tester incorporates the very latest in microprocessor technology and best-in-class pump control to deliver up to 15 clean and representative reservoir fluid samples and up to 10 fluid and formation properties to be monitored during testing, including C₁–C₅, saturates, aromatics, resins, asphaltenes, and GOR. The system’s simple modular design reduces operation complexity, while enabling versatility of performing the job with wireline if necessary. For pressure and temperature monitoring, a dual memory gauge enables redundancy capability.

Halliburton has taken downhole fluids analysis to a new level with its ICE Core℠ service that delivers lab-quality results. Until the introduction of ICE Core service, downhole fluid analysis was limited in that optical analyzers could determine when the sample was pure enough to collect, but rarely could they identify the fluid components that were present and in what proportions. The revolutionary ICE Core℠ technology provides that information through its availability in the Integrated Characterization Section (ICS) of Halliburton’s proven Reservoir Description Tool (RDT™) tester.
In ICE Core service, light shines through downhole fluids and through sensors. Each sensor is programmed to recognize the chemical nature – or optical fingerprint – of a specific fluid component, such as methane, ethane, propane, aromatics, saturates, or water. Measuring the intensity of light passing through any one sensor indicates the presence and proportion of a particular chemical component within the overall fluid. Since ICE Core technology relies on rugged and simple photometric detection, rather than spectroscopy, it does not require a computer to perform calculations on an optical spectrum as with competing systems. Each ICE Core sensor is designed to respond specifically to the fingerprint of the selected analyte using all of the useful information in the optical spectrum.

Exploration data is unrivaled in the value that it brings to the operator as major decisions are made early on. Accuracy of the data is paramount. Halliburton collects the reservoir and fluid data with accuracy and reliability across all the various reservoir characterization, fluid analyses, coring analyses, and formation evaluation sampling methods. This data helps ensure the long-time economic vitality of these cost-intensive E&P ventures.

Managing Risks to Optimize Safety, Efficiency, Reliability

The well-documented risks inherent to deep water require meticulous and proactive identification of all potential hazards, followed by the development of reactive measures to mitigate the impact of any incident that may occur.

Boots & Coots, a Halliburton Service, provides comprehensive solutions that help ensure the possible risks are identified and understood, and pre-event contingency planning is established should the need arise. The Boots & Coots program for reducing the risks of the deepwater operations follows a systematic strategy that includes:

- Hazard Identification (HAZid)
- Hazard and Operability Study (HAZops)
- Emergency Response Plan
- Emergency Response Exercise
- Blowout Contingency Plan
- Relief Well Plan
- Safety Case
- Wellhead Audit

The components of the comprehensive Boots & Coots risk management solution are in line with the U.S. Offshore Safety and Management Systems (SEMS) and other federal and state regulations that might be applicable in the particular country.

The HAZid is a key element that provides a systematic process that breaks down the targeted project into component parts with each subjected to detailed analysis. This analysis precedes the HAZops that provides a structured and systematic examination of a planned or existing process or operation to identify and evaluate problems that may represent risks.

All the data assembled is used in the development of a project-specific emergency response plan, followed by emergency response exercises meant to realistically demonstrate that the risks have been mitigated to as low as reasonably practicable. Data provided by the respective operators also is incorporated into the Blowout Contingency and Relief Well Plans that are customized for each specific well.
A unique component of Boots & Coots integrated risk management solutions is a quantitative Wellhead Audit that evaluates five elements to help mitigate overall impediments to safe and efficient operations, including:

- Well data
- Wellhead condition
- Property liability
- Impact liability
- Pressure/volume risks

Further details on the risk management approach for deepwater operations are available from your local Halliburton Boots & Coots representative.

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### Reducing Drilling NPT

Given the daily spread costs of deepwater floaters that can run upwards of $1 million with consumables, avoiding any unplanned events that wastes valuable rig time that could be spent drilling new formation is a predominant criterion.

Besides the challenges of operating in extreme water depths, the subsurface of deepwater and ultra-deepwater wells holds distinctive drilling risks – high pressure, deeper horizons, low overburden, and tight pore pressure-fracture gradients with narrow drilling windows – that must be considered and addressed early in the planning stage.

Befitting its holistic approach to well construction, Halliburton considers all aspects of the drilling process with an ultimate objective of eliminating NPT and delivering bottom-line value to operators. From planning to execution, this multidisciplinary approach considers all the variables that drive a safe and efficient drilling operation, including lithology, geomechanics, pressure, temperature, and targeted depth. With innovations that include state-of-the-art rotary steerable systems and motors, advanced geosteering, high-performance drill bits, environmentally friendly drilling fluids, and formation evaluation innovations, Halliburton offers NPT reducing solutions that deliver reliability, efficiency, and HSE stewardship in the most challenging applications. These solutions reduce NPT and maximize the value of the cost-intensive deepwater and ultra-deepwater assets.

### Planning NPT out of the Well Plan

Failure to identify potential drilling hazards up front and plan accordingly not only reduces efficiencies throughout the process, but can seriously increase NPT and possibly threaten the ability to drill the well. The risks, for instance, begin in the top hole, which must be drilled riserless to compensate for the lack of overburden. Drilling the riserless section can generate shallow water flows that can cause erosion and even wellbore collapse. The risks magnify as the well deepens and the narrow drilling window comes into play.

While previously discussed, it is important to repeat that the new Drilling Xpert™ software considers the well from a reservoir perspective, combining automation and optimization technology to reduce well planning time up to 80%. Using the collaborative DecisionSpace 3D visualization environment, well design teams generate well trajectories, BHA designs, and reservoir targets, using data to help conceive and evaluate development scenarios, and quickly respond to risks, or changes to scheduling or capital expenditure constraints.
It also can be integrated with the Reservoir Real Time Operations data system, further optimizing drilling on an ongoing process.

**Reliable Equipment for Turning to the Right Longer, Faster**

A thorough well plan is only as good as the reliability of the equipment selected to execute without having to trip to replace a prematurely destroyed bit or motor. Running a bit that lacks the mechanical integrity to drill harder rock of deeper intervals can seriously restrict efficiency, but also elevates NPT risks. Halliburton's response is a reliable and efficient suite of bit-motor combos and rotary steerable systems (RSS).

Halliburton Drill Bits & Services has augmented its fixed-cutter drill bit line with the state-of-the-art MegaForce™ PDC bit, incorporating the latest-generation cutter technology. The MegaForce™ bit is field proven in deepwater applications and contains all the latest material and cutter technologies to reduce bit erosion, extend bit life, improve hydraulics, and increase average ROP.

The efficiency of MegaForce bit to drill long intervals in a single BHA run is attributed largely to the state-of-the-art and continuously improving SelectCutter™ PDC technology. In various hard-to-drill applications, the MegaForce-SelectCutter tandem has delivered field-record ROP and cumulative footage drilled with appreciable cost-per-foot reductions. The step-change advancement in PDC cutter technology features individual cutting elements that stay sharper longer, enabling operators to drill more footage faster, even in highly abrasive formations. Owing to its reduced shank length, the MegaForce bit reduces bit-to-bend distance by up to 14%, improving directional control and extending fatigue life in the connection.

Along with MegaForce, Halliburton offers the SteelForce™ drill bit, which is recognized as the industry's most advanced steel body bit. The SteelForce bit is manufactured with a patented anti-balling coating and higher blade standoff to increase face volume for improved cuttings evacuation and higher ROP. The SteelForce body bits generally are used for larger-diameter applications in top and intermediate hole sizes and are highly effective in formations with more than 40% shale, and with water-based muds.

**Efficiency Gained by Matching Bit Design to Well Architecture**

Halliburton DBS also offers the FX Series™ performance fixed cutter bits that were designed specifically for Sperry Drilling's Geo-Pilot®. FX Series drill bit cutters are customized for specific applications and engineered to provide the correct degree of steerability, walk rate and torque control for accurate and cost-effective wellbore placement. FX Series bits combine the most advanced and robust materials and design technology to deliver precise directional control.
Reducing Drilling NPT

control and help operators meet their directional objectives faster and at less cost.

The portfolio also includes the IQ Series™ bits that combine increased ROP over longer intervals for enhanced drilling performance in a wide range of hard rock and HPHT applications, safely and at a lower cost. These reliable impregnated diamond fixed-cutter bits feature high blade standoff and high diamond volume of the utmost quality.

Combining sophisticated design capabilities with the most advanced cutter technology, Halliburton DBS created a series of PDC bits perfectly matched to the most daunting application, including:

- Geo-Pilot® PDC Bit Design that uses a modified extended gauge (MEG) sleeve to give the box connection and fulcrum point necessary for the Geo-Pilot® rotary steerable tool. The MEG sleeve gives consistent fulcrum point locations while maintaining a flow area from bit face to sleeve.

- Directional PDC Bit Design employs different gauge and cutting structure geometries calculated from Direction by Design® software to help ensure that adequate DLS and tool face can be achieved without sacrificing bit performance or life reliability.

- Turbine PDC Bit Design uses special cutter layouts and optimized Depth of Cut (DOC) to give maximum ROP in high-RPM applications. Bits may utilize sleeves and extended gauges for stability or specialized gauge designs for directional applications.

- Geo-Pilot®EDL Bit Design is designed with a standard point-the-bit cutting structure with a unique gauge design to enable high doglegs to be achieved.

Reducing Rathole Length While Saving Rig Time

In a traditional reaming-while-drilling BHA, the reamer is placed above the Rotary Steerable Systems (RSS) and LWD tools, creating a long rathole and requiring an extra trip to enlarge the hole to TD. Challenged to design a tool to increase efficiency, Halliburton has responded with a solution that has the added benefits of optimized steerability and fluid flow, and reduced tool length based on the proven reliability of the NBR® reamer technology. Run in conjunction with a traditional reamer, TDReam™ tool is Halliburton’s newest downhole innovation designed to significantly reduce rathole length and reach TD in one run.

Fig. 4. Balanced Concentric TDReam™ Tool – Substantially reduces BHA vibration compared with eccentric tools or bi-center bits, improving steerability and stability.
Advanced Steering for Reducing Downtime, Optimizing Efficiency

In highly deviated and horizontal deepwater wells, achieving the performance benefits of a drill bit with exceptional mechanical integrity and longevity depends largely on the steering mechanism designed to reach the target quickly, safely, and efficiently. The last thing operators need while drilling a deepwater well, for instance, is unproductive time dealing with a stalled motor or rotary steerable, at worse, tripping to replace a motor or rotary steerable with prematurely destroyed internal components.

Sperry Drilling services has developed a comprehensive portfolio of dependable high-performance directional drilling innovations, including high-torque motors and point-the-bit rotary steerable systems. Matched perfectly to the targeted lithology and designed well path, these steerable systems consistently maximize ROP while reducing NPT.

The SperryDrill® and GeoForce® XL and XLS series motors represent the most reliable and powerful motors in the market, delivering higher torque output and designed with a rugged mud-lubricated or sealed bearing assembly. Compared to a standard motor, the XL and XLS series motors deliver up to 80% more power, 65% higher torque load, 50% increase in operating differential pressure, and a shorter bit-to-bend distance for improved build rates. The result is longer motor runs, fewer trips, and increased rate of penetration.

Oftentimes, downhole problems are occurring that you never notice, and while they may not result in NPT, they nonetheless put the brakes on optimum drilling efficiency, accounting for up to one-third of well delivery time and costs.

With its innovative time/depth, MaxActivity™ rig floor monitoring software package, Sperry Drilling minimizes so-called invisible lost time (ILT) by using advanced surface sensors to collect data during well operations. A key component of the Sperry Drilling Optimization software suite, the performance-enhancing MaxActivity surface sensors collect depth, hook load, RPM, and flow-in data to track rig floor activities, such as trips and circulating, as well as drilling and connection operations. By calibrating the sensor data, MaxActivity software enables operators to precisely pinpoint and address issues that consume time and profits.

Conventional directional drilling systems often encounter efficiency-restricting problems in extended-reach and similarly complex well geometries, including orienting the tool face during sliding. The Sperry Drilling DrillDOC® drilling downhole optimization collar tool helps minimize vibration and wasted energy transfer from surface to bit and in the process maximizes efficiency.

The DrillDOC tool incorporates multiple sensors that deliver real-time measurements of weight, torque, bending moment, and bending moment direction at the tool. In addition, the incorporation of a new-generation vibration sensor provides a full suite of vibration measurements to further enhance performance. The integration of weight, torque, and bending values with vibration ensures the full movement of the BHA is measured throughout the drilling process. Available in 4¼, 6¼, 8 and 9½-in. sizes, the DrillDOC tool often is used in tandem with the Geo-Pilot® GXT rotary steerable system.

The advanced Geo-Pilot® XL RSS avoids the problems of conventional directional drilling assemblies. The Geo-Pilot XL RSS sends more RPM to the bit, resulting in comparatively higher drilling rates while reducing stick-slip.

The Geo-Pilot® GXT RSS delivers a new level of drilling performance by integrating a GeoForce® motor power section between the rotary steerable system and the LWD system. Delivering increased horsepower and revolutions per minute directly to the bit, the Geo-Pilot GXT system overcomes challenging formations while reducing the occurrence of stick-slip. The system provides the ability to achieve higher penetration rates while minimizing casing wear by decoupling the bit speed from the drill-string speed.
The Sperry Drilling suite of RSS innovations also includes the revolutionary Geo-Pilot® Dirigo system, which gives operators all the benefits of point-the-bit rotary steerable drilling, with higher build rates previously possible only with conventional mud motors. Being able to provide consistent high build rates in large hole and soft formations often encountered in deepwater formations enables more flexibility in designing wellbore trajectories, with the ability to achieve higher inclinations earlier in the well, such as those required in subsea or drilling pads. The sail angle for extended-reach drilling (ERD) also can be reduced. Improving ERD capabilities, the RSS is driving access to reserves from existing platforms and reducing development costs. The variable-deflection point-the-bit RSS provides maximum ROP while at the same time delivering gun-barrel hole quality, reducing torque and drag associated with challenging profiles. This capacity enhances project economics particularly in the high-cost deepwater applications.

The reduced profile of the RSS helps improve hole cleaning and tripping efficiency. The shorter tool enables movement of LWD sensors closer to the bit for improved and faster formation evaluation, critical for ERD applications.

Like any component of the drilling process, the higher temperatures and harder rock of many contemporary deepwater wells can shorten the operational life of conventional drilling systems, increasing the NPT risks.

The Turbopower™ Turbodrill line was designed for steerable and straight-hole applications and is capable of delivering

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**CASE STUDY:**
Geo-Pilot Dirigo Rotary Steerable System Sets New Build-Rate Off Angola Deepwater

An operator drilling an extended-reach deepwater exploration well off Angola in 1,428 m (4,685 ft) of water wanted to drill the 12¾-in. section from shoe to shoe in one run and do so using a rotary steerable system. The plan called for building angle in a very soft unconsolidated formation at 6°/30 m immediately below the 13¾-in. shoe, reaching up to 86° prior to hitting the geological target where angle would be dropped to 46° at TD. A Geo-Pilot Dirigo 9600 series RSS system was matched with an HDBS 12¼-in. PDC bit; the BHA also comprised a penta-combo MWD/LWD suite that included a GeoTap formation pressure tester. The assembly drilled the entire section in 132.25 circulating hours at an average ROP of 20 m/hr (66 ft/hr), achieving up to 7.25°/30 m dogleg – the best RSS build rate to date in the block.

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**CASE STUDY:**
Turbodrill Helps Cut 12 Rig Days in Brazil Pre-Salt Exploration Well

After average ROP dropped to 1.1 m/hr (3.7 ft/hr), the operator pulled the RSS from a pre-salt exploration well in 1,943 m (6,375 ft) of water offshore Brazil. An alternative solution to the previous PDC bit-RSS assembly was required that would deliver faster drilling rates in the very hard formation while also maintaining excellent directional control. Sperry Drilling recommended running a 9¾-in. T245 Turbopower™ Turbodrill turbine with 1° bent housing and an impregnated bit in the 12¼-in. intermediate section. The Turbodrill went on to drill 552 m (1,811 ft) from 4,512 to 5,064 m (14,803 to 16,614 ft) while building a hold inclination from 14.6 to 37° and simultaneously changing azimuth from 326 to 303°. Despite a poor-performing rig compensator, the tool face remained steady, and in the 266 m (873 ft) sliding mode, the Turbodrill assembly achieved a sliding-mode average ROP of 3 m/hr (9.7 ft/hr). The Turbopower Turbodrill delivered rotating-mode average ROP of 3.2 m/hr. (10.4 ft/hr.) over 286 m (938 ft). The Turbodrill efficiently drilled the hard rock without compromising steerability or hole quality. The exceptional performance saved 12 days, rig time, encouraging the operator to use the Turbodrill assembly in the next section.
more power to the bit for faster and easier drilling in hard rock formations. Sperry Drilling’s Turbodrills are continually reducing drilling times and establishing new field records in deepwater pre-salt and other hard, abrasive formations.

**Solutions for Reducing Mud Losses**

Studies have shown that a main culprit to NPT in deepwater wells is wellbore instability brought on by severe losses. Consequently, drilling new formation efficiently with zero NPT or HSE impact begins with a properly formulated and maintained invert emulsion or aqueous-based drilling fluid system incorporating the highest degree of fluid-loss control. In the ever-changing temperatures and pressures of deep water, it is imperative the mud system maintain stable properties. The challenge is magnified in ERD and horizontal wells drilled in deeper horizons, requiring an even higher fluid-loss control and sag resistance.

One of the problems with maintaining fluid properties is that downhole conditions can change repeatedly, and with only two mud checks typically taken each 12 hours, decisions all too often based on rheology that may not reflect the real-time fluid condition. The lack of up-to-the-minute rheological data can make it extremely difficult to optimize the fluid-loss control properties of the active mud system.

Baroid has taken a major step in enhancing the monitoring of drilling fluids with the fully automated Real Time Density Viscosity (RTDV) technology that measures fluid density and rheology in real time. The compact RTDV unit is installed near the mud tanks and uses automated sensors to continually collect data on fluid properties. The subsequent measurements are then recorded and archived with Halliburton’s InSite® data acquisition software, with the data displayed just as the measurements are made and transmitted to a real-time shore-based operations (RTO) center for immediate evaluation by off-location personnel serving as expert advisors.

Baroid has long been recognized as an industry leader in developing synthetic-based drilling fluids that provide the highest level of efficiencies within regulatory HSE requirements. Formulating and maintaining excellent fluid systems is vital to long-term success.
fluid-loss control must be balanced with the HSE requirements of any mud system used in the “zero” discharge deepwater environment. An optimum high-performance drilling fluid is one that reduces losses, meets strict discharge requirements, reduces waste disposal costs, and prevents potential bottlenecks.

The ACCOLADE* and companion ENCORE* synthetic-based muds (SBM) consistently reduce overall well costs in deepwater wells, while complying with low-toxicity environmental regulations worldwide. These SBMs are formulated with an ester-internal olefin (IO) blend comprising a combination of fully biodegradable esters – recognized as the least toxic base fluid available.

Complementing their environmental fitness, the organophilic clay-free gel ACCOLADE (up to 300°F BHT) and ENCORE (>300°F BHT) drilling fluids are customized to meet specific formation characteristics and targets, ensuring the delivery of exceptional value-added performance. The systems provide operators fluids that maintain stable viscosities through a wide range of temperatures and pressures and are highly resistant to contaminants and sustain exceptional rheologies in low equivalent circulating-densities (ECD) environments often encountered in deepwater formations. A Case History on Page 43 demonstrates how the drilling fluids optimize Brazil pre-salt drilling.

Baroid also built off the ACCOLADE technology with its INNOVERT* paraffin/mineral oil-based system, which, unlike conventional paraffin-based muds does not require excess mud thickening to prevent sag. The INNOVERT mud consistently demonstrates its capacity to dramatically reduce whole mud losses over a range of temperatures of more than 450°F and mud weights of more than 18 lb/gal. The fragile gel strengths of INNOVERT SBM not only prevents barite sag without having to thicken the mud, but have been shown to reduce downhole losses up

**CASE STUDY:**

**ENCORE** Eliminates Wiper Trip, Saves $1.2 Million

The operator of a Mississippi Canyon well in the deepwater Gulf of Mexico planned to evaluate the formation, prior to running casing requiring a fluid solution that would avoid having to run a wiper trip in the S-shaped hole at a more than 6125 m (20,095 ft) TD. A maximum 12.6 lb/gal ENCORE SBM was used to drill to casing depth at 4984 m (16,352 ft) MD, where the well was wireline-logged for 94 hrs, after which the liner was run to bottom and cemented with full returns while not requiring a wiper trip. The ENCORE SBM proceeded to drill the entire 9½-in. interval, which logged for 101 hrs, and the 7½-in. liner was run to bottom and cemented successfully, also without a wiper trip. The fluid system was credited with cutting 24 hrs of rig time for an estimated bottom-line saving of $1.2 million.

**CASE STUDY:**

**ACCOLADE** Synthetic-Based Mud Cuts $1 Million in Lower Tertiary Well

The operator selected the ACCOLADE drilling fluid for its demanding Lower Tertiary well in the deepwater Gulf of Mexico, where temperatures typically can vary widely. The primary objective was to drill the well, programmed for a 56° deviation, as quickly and safely as possible with a maximum allowable flow rate, minimal ECD, and maintain excellent hole cleaning conditions. The constant rheological profile of the ACCOLADE SBM enabled Sperry Drilling to pump a maximum flow rate and reduce by 21 days the programmed time for drilling, directional work, tripping, logging, and running casing, reducing costs by more than $1 million.
to 80% with less cost and environmental impact compared to conventional invert emulsion fluids.

Baroid further extends the ACCOLADE clay-free technology with its high-performance INTEGRATE® diesel-based mud with a CaCl₂ internal phase, employing the specially formulated RHEMOD™ L viscosifier for rheology control and the ADAPTA® filtration reducer for HPHT fluid-loss control. Where regulations permit the use of diesel-based mud, the INTEGRATE drilling fluid system, through the omission of organophilic lignite and minimal organophilic clay additions, delivers excellent performance in any oil-based application.

Fig. 7. Deepwater fluids must meet all environmental regulations as well as deliver drilling efficiency performance which includes reduced NPT and minimization of mud losses.

Fig. 8. Collaboration and monitoring of the well can drive improved efficiencies.

Fig. 9. Collaboration drives improvements to the design, manufacturing, and maintenance of the facility.
CASE STUDY: Customized Drilling Fluids Optimize Brazil Pre-Salt Drilling

The pre-salt of deepwater Brazil comprises halite and anhydrite with layers of carnallite and tachydrate, which bring distinctive drilling challenges. Brazil’s salt has low mechanical strength and becomes semi-plastic at 220°F (104°C) and plastic at 400°F (204°C). An important consideration, especially when formulating the drilling fluid system, is the tendency of the salt to creep, or flow, either vertically or horizontally, with the creep rates varying widely from the top to bottom of the interval. Consequently, it was critical that torque and drag be monitored closely. After carefully defining the most important pre-salt drilling fluids issues, Baroid developed a multi-pronged solution to customize the high-performance synthetic-based fluid system to optimize well construction for the pre-salt drilling:

- **Lost circulation.** To increase the hoop stress around the wellbore to cut losses, the system was designed to achieve low gel-breaking pressure, reduced ECD and minimal cold-water rheology effect.

- **ECD management.** The hydraulics-related conditions were modeled in the plan and monitored in real time while drilling.

- **Cold-water rheology.** Running the high-performance invert emulsion drilling fluid reduced the downhole pressure loss and high ECD ramifications of cold water.

- **Wellbore stability.** For drilling the pre-salt layers containing anhydrite, modifying the system with strong emulsion and salinity properties and constant monitoring of cuttings integrity maintained wellbore stability.

- **Barite sag.** As an organophilic clay-free system, the drilling fluid did not require the increased clay concentrations typically used for suspension, which tended to elevate rheology and ECD, resulting in sag. Thus, circulating.Conditioning of the fluid was no longer necessary.

- **Hole cleaning.** Drill solids were monitored continuously to ensure the cuttings bed remained below 3% and the open-hole circulating pressure did not exceed the fracture gradient.

- **ROP.** Running a drilling fluid with low colloidal solid content based on polymers and surfactants helped increase the drilling rates.

- **Stuck pipe.** Stuck pipe risks were reduced in the salt layers by displacing with seawater pills and operating a drilling jar.

- **Shallow hazards.** Large volumes of high-density fluids helped prevent flows and achieve hole stability.

- **Lubricity.** The drilling fluid was formulated with excellent lubrication properties to prevent high torque and drag, and vibration while drilling the salt and carbonate layer.

- **High temperature.** Customizing the mud with excellent rheological properties maintained stability in the high temperatures and pressures.

In addition, for the pre-salt, the high-performance invert emulsion drilling fluid was formulated to resist contaminants, avoid formation damage, mitigate corrosion, enhance well control, and help control hydrates while drilling.
Enabling Riserless Drilling
Serious risks also lie in the deepwater riserless drilling section, which requires higher-weight muds to provide the hydrostatic density necessary to avoid shallow water flows. Most rigs, however, do not have the storage capacity for high volumes of the more than 10 lb/gal riserless mud sometimes required.

A key component of Baroid Surface Solutions™ is the easy-to-install and -operate OTF Mixer that effectively blends high-weight mud and seawater at rates up to 2,000 gpm, providing even mixing with consistent fluid properties, and relaxing on-board storage requirements for the deepwater riserless section.

Balancing Drilling, Environmental Challenges
While the often young and highly reactive deepwater sediments require optimal drilling fluid performance, tightening regulations and the exorbitant costs associated with waste disposal mandate an ideal balance between drilling effectiveness and environmental acceptability.

Along with its suite of environmentally sound SBM, Baroid also responded to the challenge with the development of its advanced Hydro-Guard® high-performance water-based drilling fluid that delivers the performance closely mirroring that of an oil-based mud with the intrinsic environmental benefits of an aqueous-based fluid.

The clay-free Hydro-Guard water-based fluid is formulated to deliver maximum shale inhibition in highly reactive formations. The high-performance aqueous-based mud relies on polymeric chemistry to deliver superb inhibition while providing wellbore stability, high penetration rates, and acceptable rheologies over a wide range of temperatures. The system includes the proprietary polymeric Clay Grabber® flocculant and the Clay Sync II® shale stabilizer. In addition, as a water-based fluid, Hydro-Guard cuttings can be discharged where regulations so permit.

CASE STUDY:
Hydro-Guard WBM Inhibits Shale, Cuts Drilling Time in West Africa Wildcat

In planning an exploration well in an environmentally sensitive area offshore West Africa, the operator initially specified an invert-emulsion drilling fluid. However, the requirement for an onshore mud plant and the additional infrastructure needed posed a host of logistical challenges. The operator decided to change the mud program and use the Baroid Hydro-Guard high-performance water-based mud (WBM), which would effectively address the environmental and logistical challenges while delivering the ROP and gauge hole the operator needed to drill the well successfully while reducing nonproductive time (NPT). The HYDRO-GUARD WBM drilled the 17½-in. section that included 3,975 ft of reactive shale formation with outstanding results. The high-performance water-based fluid produced virtually no swelling in shale formation and, as a result, produced a gauge hole in the critical section with only 0.11% washout. Additionally, the section was drilled faster than the operator’s original time estimate based on the use of an invert-emulsion fluid.
Reducing Drilling NPT

Integrated Solutions for Promoting Wellbore Stability

Unstable wellbores and the ensuing lost circulation often encountered in the fragile zones of deepwater wells precipitate a host of downhole problems, including stuck pipe, which can not only increase drilling costs appreciably, but in some cases actually threaten the completion of the well. To address the extreme NPT costs of an unstable wellbore, Halliburton developed WellSET™ wellbore stress management service that combines specially engineered software and lost circulation material (LCM) to prevent lost circulation by strengthening the wellbore.

The fully engineered service is designed to increase the wellbore pressure containment ability, known as the hoop stress, in the near-wellbore region. Placing a specially selected plugging material in an induced fracture helps prevent further pressure and fluid transmission to the fracture tip, while at the same time widening and propping the fracture.

Essential to a successful WellSET treatment is the simulation of actual wellbore conditions, through the proprietary DFG™ hydraulics modeling software with the DrillAhead® hydraulics module. The DFG engineering software predicts the equivalent circulating density (ECD) over an interval, calculates the width of a fracture that may be initiated, and proceeds to select and design a proper material and particle size distribution (PSD) that can efficiently prop and plug that fracture. The DFG program is then able to model the change in rheology resulting from the addition of the specialized lost-circulation materials. The changes in rheological properties are cycled back to update the ECD calculations and enhance the accuracy of the WellSET treatment.

The DFG software models key wellbore parameters, including:

- Wellbore geometry
- Hole angle and size
- Drilling mode: sliding, rotating, or mixed
- ROP while sliding and/or rotating
- Downhole fluid densities based on dynamic or static profiles
- Pump rates
- Rotary speeds
- Circulating and static intervals (drilling, sliding, making connections, etc.)
- Downhole rheology
- Fracture generation
- LCM PSD
- Effect of LCM on rheology

The engineered DFG software suite delivers an effective WellSET treatment service through the design and proper application of correctly sized lost-circulation material (LCM), usually consisting of the SteelSeal® resilient graphitic carbon and BARACARB® 600 ground marble bridging agent.

SteelSeal® LCM, which helps plug fractures continuously under changing pressures, is widely recognized as one of the most effective solutions for not only preventing, but also treating lost circulation. SteelSeal LCM comprises resilient, angular, dual composition, and carbon-based particulate additives designed to compress with an increase in downhole pressures. The compressive property of the uniquely resilient SteelSeal particulate allows it to “mold” itself into the fracture, thus promoting screen-out. Given downhole pressure fluctuations, the material “rebounds” and
continues to isolate down to the fracture tip.

Complementing solutions for preventing lost circulation, Baroid also provides a wide range of LCM for remediating losses once they occur. When encountering zones prone to moderate to severe losses, LCM are available that can be applied as stand-alone treatments or in combination with other Baroid solutions. The DUO-SQUEEZE® H-engineered composite lost-circulation material provides an optimized bi-modal solution to lost circulation that is able to seal fractures and manage fluctuations of downhole pressure. The LCM can be applied conventionally in a pill formulated from the drilling fluid and pumped through drill strings equipped with PWD and mud motors.

The LCM portfolio also includes the HYDRO-PLUG® lost-circulation material, which comprises a combination of products and contains a key component that hydrates and swells to form a compliant treatment. It is a simpler system than one that chemically cross-links, and has minimal changes in reaction rate with temperature. HYDRO-PLUG lost-circulation material also contains a combination of resilient graphitic carbon and other sized components. In addition, the STOPPIT™ particulate-based lost-circulation material is an engineered, composite solution designed to mitigate partial to severe drilling fluid losses. STOPPIT LCM works by isolating the tip of the fracture, which it seals with its unique composition designed to increase the material’s toughness to resist swab/surge, wellbore breathing, and other pressure fluctuations that commonly occur downhole.

Solutions for Avoiding Wellbore Collisions

Typically, especially in multi-well locations, wireline gyro was used to orient the pipe and survey the well, which is time consuming and raises a host of HSE issues. The time lapse between gyro shots also means the downhole tool is being steered without real-time orientation, increasing the potentially catastrophic risks of drilling into a nearby well.

Sperry Drilling addressed the collision risks with the Evader® MWD gyro while-drilling service that consistently provides faster, safer, and more accurate drilling in the presence of adjacent or nearby wellbores. The Evader service optimizes orientation, eliminating the costly and risky use of wireline gyros to orient or steer the drilling assemblies while affecting accurate wellbore guidance to avoid collisions and deliver precise trajectory placement. The Evader sensors are not affected by magnetic interference, which also enables them to be run closer to the bit in the MWD string, eliminating the need for non-magnetic spacing collars. The modular design enables it to be placed anywhere in the drill collar, and it may be run with either positive-pulse or negative-pulse telemetry systems.
**Real-Time Pressure Measurements Cut NPT**

Owing to ever-changing temperatures and pressures in deepwater wells, optimizing mud densities and managing equivalent circulating densities (ECD) are constant challenges. Acquiring real-time formation pressure while drilling is invaluable to the overall efficiency and safety of the drilling process and plays a key role in minimizing NPT risks.

Sophisticated PWD formation pressure innovations provide operators the critical real-time data required to fully optimize deepwater well construction and help with making cost-effective decisions. The capacity to collect while-drilling formation pressure data can reduce the time and costs of wireline testing as well as the risks of well control issues.

An integral component of the Sperry Drilling PWD solutions suite is the advanced GeoTap® formation pressure tester sensor that provides early recognition of potential lost-circulation zones, influx situations, or well control issues. Today, the ability to test formation properties in real time, while drilling, helps guide the well to the most productive reservoir sweet spots in the first attempt, while avoiding geohazards, faults, or salt lenses. Since the GeoTap formation pressure tester measures absolute pressure gradients to determine the position of the wellbore relative to fluid contacts in the reservoir, its value is magnified in deepwater exploration projects, where typically wellbore position uncertainties are greater than the actual geometrical dimensions of the reservoir.

Moreover, the timeliness of while-drilling measurements ensures the data acquisition while the borehole is stable and not contaminated by mud filtrate invasion. Accordingly, real-time measurements contribute to lower rig costs by significantly reducing the time required for pressure data collection.

More importantly, GeoTap tester is an essential component in safe drilling. In the event of changing pore pressures, real-time pressure data enables the drilling crew to take immediate action to maintain well control. Early on, Halliburton recognized the importance of this capability, which is pronounced in the imperceptible pressure regimes within the subsalt and pre-salt drilling environments of the deepwater Gulf of Mexico and Brazil, respectively, where the structure and stratigraphy of salt bodies are difficult to interpret from seismic imagery. The technology has advanced to the point that many deepwater operators run the GeoTap tester as an integral part of the standard deepwater BHA, particularly on subsalt exploration wells, where it meets the goals of defining the reservoir as well as reducing the non-productive time.

![Fig. 13. The GeoTap® formation pressure tester helps drillers detect potential well control issues prior to their becoming an issue.](image)
Drilling Optimization

The more efficient the drilling, the less time and money spent getting the operation back on a productive track. Excessive shock on the drillstring, annular pressures that are outside the wellbore boundaries, drilling with mud weight higher than the optimum-density window and a non-direct drilled pathway to the reservoir sweet spot are some of the problems that can elevate NPT.

The ADT® Optimization Service considers three of the most important areas for drilling optimization, with the overriding objective to improve drilling performance and, hence, lower NPT and achieve maximum value. With the ADT service, Sperry Drilling experts consider drillstring integrity, hydraulics, and wellbore integrity that can increase efficiency and decrease NPT.

After the three-component analysis, the Sperry Drilling specialist provides project-specific solutions to optimize drilling rates, improve operational efficiency, and minimize the impact of unplanned events. The Model, Measure and Optimize process leverages Sperry Drilling’s specialized software, surface, and downhole measurements to achieve the desired objectives.

Halliburton’s drilling optimization solutions also include the XR™ reamer, the only tool that can be deactivated after enlarging for drilling ahead with the original pilot hole size and allowing full-flow circulation while tripping out. The XR reamer tool provides concentric and simultaneous hole enlargement with on-demand activation/deactivation systems where tool reliability, durability, and hole quality of the enlarged hole are important. The tool minimizes BHA vibration, macro-doglegs at formation transition interfaces, and the tendency to initiate “whirl.”

LWD Solutions for Optimizing Drilling, Targeting the Pay Zone

In deep water, inadequate formation data not only can increase drilling problems, but can frustrate development plans going forward.

Sperry Drilling’s M5™ Integrated LWD Services combine five state-of-the-art solutions that provide formation evaluation answers from resistivity, azimuthal gamma ray, drilling optimization sensors, vibration sensors, and pressure sensors. These fully

CASE STUDY:
ADT Solution Delivers Long GoM Salt Run under Ultra-High Pressures

The 16,887-ft (5,147 m) salt body in a Gulf of Mexico well in 4,132 ft (1,259 m) of water was expected to encounter pressures higher than 30,000 psi. The operator required an MWD/LWD combo that could drill at least 60% of the salt section in one run and mitigate vibration without compromising ROP. The Sperry Drilling ADT Applied Drilling Technology optimization services incorporated all pre-planning data into the MaxBHA™ modeling software to identify the critical RPM and weight-on-bit parameters, along with torque and drag analysis. The real-time surveying and logging data provided by the AGR (azimuthal gamma ray), EWR-M5™ resistivity, PWD, and directional survey sensors enabled the section to be drilled with a 16½-in. bit to 10,685 m MD (35,055 ft) in a single run, despite up to 32,433 psi internal pressure. Average ROP in the interval ranged from 80 to 100 ft/hr (24 to 30.5 m/hr).

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Hernando Jerez, Rafael Dias, and Jim Tilley, Halliburton, “Offshore West Africa Deepwater ERD: Drilling Optimization Case History,” presented at 2013 SPE / IADC Drilling Conference and Exhibition, March 5-7, Amsterdam, The Netherlands
digital sensors are bundled together in one short, integrated collar, reducing the number of connections and yielding a significantly more reliable design. The service includes the third-generation Sperry Drilling EWR-M5™ resistivity sensor, as well as azimuthal gamma ray, mud resistivity, temperature, PWD, and dynamic motion sensor measurements.

The dual challenge for operators in highly cost-intensive deepwater wells is reducing NPT while efficiently landing the well for maximum reservoir exposure. Unidentified faults, dips, and other deformities in the geological structure can make that challenge even more daunting.

As part of its borehole imaging services, Sperry Drilling offers the latest advancements in LWD resistivity sensors (ADR™, AFR™, ALD™) that provide operators deeper insight into their reservoir geology to optimize well placement, which maximizes production and extends field life while, in the process, mitigating hazards that can induce NPT.

The AFR sensor, in tandem with the StrataSteer® 3D geosteering service, provides fully compensated, multiple-depth resistivity measurement, petrophysical evaluation, and stratigraphic navigation solution in one package. The deeper readings improve reaction time, increasing drilling speed and decreasing drill-out risks.

The AFR™ (azimuthal focused resistivity) sensor provides high-resolution borehole images while drilling that deepen insight into the reservoir. Coupling the visualization of AFR sensor data with the StrataSteer geosteering model facilitates precise and efficient positioning of the well within the sweet spot. In addition, the sensor improves interpretations with accurate resistivity values in highly conductive muds and high formation resistivities and elevates the confidence of real-time decisions with at-bit measurements that provide early alerts of changes in fluid properties and lithology. Some complex geologies require supplementary data to achieve greater insight into reservoir properties and characteristics. The AFR azimuthal focused resistivity sensor delivers four additional types of data in fractured and otherwise complex formations, including:

- Omnidirectional, laterolog-type resistivity data
- Azimuthal laterolog-type resistivity data
- Electrical images of the formation
- At bit resistivity (ABR) measurements

Developed specifically for use in electrically conductive muds, the AFR sensor complements the EWR and other propagation-type sensors. The AFR at-bit resistivity measurement uses the BHA below the sensor as a measurement electrode. Consequently, the AFR measurement is particularly useful for detecting conductive beds as they are penetrated by the bit.

**CASE STUDY:**

Sperry Drilling Suite Cut Costs by $30 Million in Risk-Laden Well

The deepwater well off Mexico was fraught with risks, beginning with highly faulted upper sections with the serious risk of total drilling fluid losses and stuck pipe with the strong probability of washouts and cave-ins. High pressures in the producing formation also would make it difficult to control the well in the 6-in. hole. Compounding the difficulties was the presence of H₂S. Sperry Drilling provided an optimized drilling solution that included a Geo-Pilot RSS, a GeoForce® motor, an advanced PDC bit, as well as an MWD/LWD and PWD package to continuously monitor pressures and ECD while drilling. The integrated solution helped the operator drill the well trouble-free, reducing drilling time by 121 days and cutting more than $30 million in drilling cost.

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Also, the Azimuthal Lithodensity Tool (ALD™) sensor measures formation density and lithology and provides borehole images for geosteering, determination of structural dip, and borehole stability applications.

Managing the Low-ECD Challenge

The narrow margin between fracture gradient and pore pressures intrinsic of deep water, pre-salt, and the depleted zones in mature assets generate low Equivalent Circulating Densities (ECD). Uncontrolled low ECD can increase the risks of fracturing pressure-sensitive formations and induce lost circulation that can raise the risks of wellbore instability, pack-offs, stuck pipe, well control issues, formation damage, and even the inability to complete the well. The problems are especially magnified when circulating mud, running casing or liners, and cementing in high-angle extended-reach and horizontal-well geometries.

Halliburton’s holistic Low-ECD Solution can deliver safe, reliable, and efficient solutions that help maximize the value of your asset by:

- Maintaining well control, while avoiding formation damage
- Reducing NPT, while improving well integrity
- Improving efficiency and cost-effectiveness
- Tapping into the reservoir safely

Managing Fluid Properties to Resist Sag, Control ECD

Many of the solutions to low-ECD margins begin with the drilling fluids. In these environments, unstable fluid rheologies may lead to NPT and threaten the project success.

For drilling narrow fracture gradient/pore pressure margins, Halliburton Baroid offers an engineered mud system formulated to
reliably and cost-effectively address low-ECD conditions. The BaraECD™ high-performance invert emulsion drilling fluid is designed to maintain ECD control in narrow drilling window intervals. The exceptional rheological profile drilling fluid delivers low viscosity to minimize ECD, while providing superb and customized suspension properties to optimize hole cleaning and resist barite sag, even during prolonged static periods.

**CASE STUDY:**
Low-ECD Fluid Solution Avoids Losses in Depleted GOM Zone

At 5182 m (17,000 ft), the slim-hole high-angle Gulf of Mexico well encountered a depleted and permeable zone that was being drilled at 3,000-psi overbalance, elevating the risks of lost circulation, stuck pipe, and well control issues. The slim hole diameter raised the risks of elevated ECD, which could not be tolerated, given the 14.8 lb/gal fracture gradient and 13.7 lb/gal surface mud density. Halliburton responded with its BaraECD Low ECD fluid solution that enabled the operator to successfully reach bottom without HSE issues, indications of sag, mud losses, or stuck pipe while drilling, tripping, logging, or running casing. A safe ECD window was maintained below the safe 4.8 lb/gal operating window.

The BaraECD system uses the very latest emulsion and polymer technology to maintain superb rheology and robust, yet fragile gels and can be customized to deliver ECD control based on temperature requirements, environmental restrictions, and logistic limitations.

In addition, before a low-ECD fluid is delivered to the wellsite, it is run through Baroid’s Hydraulic Shearing Unit that helps produce a drilling fluid system with significantly higher levels of stability, yield point, and low shear rheology without relying on rig pumps or rig time.

**CASE STUDY:**
BaraECD™ Fluid System Eliminates Squeeze, Saves $1 Million

Baroid used the BaraECD fluid system in a deepwater Gulf of Mexico well to enable the production string to be run and cemented, while avoiding excessive losses that would require a squeeze in the liner top. Owing to the 11.6 lb/gal equivalent sand pressure and surface mud density of 15.0 lb/gal, the pressure difference across the sand was 3,786 psi. The drilling fluid enabled the operator to successfully run the production liner with full cement coverage, thus avoiding a squeeze and saving an estimated $1 million in rig time.

**Reducing Stuck Pipe Issues During the Running Liner Deployment**

Excessive pressure drops across the liner top in tight margins can dramatically hinder the efficiency, long-term reliability, safety, and ease of running liner hangers.

A key component of the holistic expandable liner hanger solution includes the VersaFlex® Low ECD system that specifically handles low-pressure formations and narrow fracture gradients. Independent field analysis routinely verifies the capacity of the system to reduce pressure drop across the liner top during circulation and cementing in the well construction design process. Due to an outer diameter (OD) smaller than industry-standard, the VersaFlex Low ECD system reduces pressures within a wide range of mud densities. The resulting increase in the bypass area promotes faster trip-in speeds. This enhanced flow-rate helps optimize the cementing process, especially when integrating its reciprocation and rotation capability, thus increasing cement integrity. The VersaFlex Low ECD system also carries an improved operating envelope without inner diameter (ID) restrictions.

The high-torque rating of the VersaFlex Low ECD system permits aggressive reaming and drill-in capabilities, which are especially beneficial in sloughing formations, swelling clays, and cave-ins.
Reducing Surge During Casing Run In
Pressure surges restrict the operational efficiency of running casing through low-ECD zones, reducing running speed and potentially damaging the formation.

Halliburton developed the SuperFill™ Surge Reduction System specifically to help manage surge pressures and enhance run-in efficiencies. The SuperFill system provides reliable self-filling of the fluids into the casing to minimize the ram effect on the formation caused by casing running operations. The SuperFill suite works seamlessly to provide reliable casing auto-fill to minimize the surge and swab effects and maximize the running speed into the well.

Complementing the surge reduction system are the Protech CRB® Centralizers, which help minimize blade embedment into the formation while running in. The low friction coefficient helps minimize the drag forces between the casing and the formation to enable smoother casing or liner running operations. The modular blade design increases the flow area to reduce the frictional pressure drop across each centralizer and, in turn, reduce pressure on the formation, minimizing Low-ECD damaging effects.
Ensuring Long-Term Well Integrity

The investment required of a deepwater development mandates optimal reservoir drainage, often up to 30 years or longer.

To help operators achieve lifelong reliability and realize maximum asset value, Halliburton employs a holistic strategy for wellbore integrity assurance with a portfolio of solutions employed systematically during planning and continuing to production.

Engineering Integrity Up Front

A cement design matched for specific wellbore characteristics and downhole conditions is critical to maintaining integrity.

Halliburton’s iCem® service was developed to do just that. The predictive-analysis software, which is based on computational fluid dynamics and finite element analysis, consistently delivers independently verified simulations of the slurry during placement. Simulations that once took days to develop and execute can now be completed in two to three hours.

Using iCem service, Halliburton evaluates the effects of variable changes, including mud displacement, slurry properties, casing/pipe movement, centralization, fluid volumes, pump rates, and temperature/pressure differentials. Three-dimensional models simulate fluid-flow interaction and displacement phenomena, while prognostic models evaluate stresses in the cement. The iCem service provides predictive input on material selection and volumes that help achieve long-term wellbore integrity.

The iFacts™ laboratory management system provides engineers immediate access to collective data from thousands of cement fluid tests. Data centralization promotes information sharing and collaboration among the global technical professionals for the optimization of spacers, flushes, and cement slurries for specific formations.
Well Integrity Provided from Design, Cement Slurry, and Equipment

As wells age, the cement sheath is subjected to stresses from formation and pressure changes. Upon investigating the root cause of potential damage, Halliburton developed the three-tier WellLife™ III cementing service, comprising iCem service for modeling, analysis, and cementing operations design; ElastiCem® and LifeCem™ cement systems; and Swellpacker® isolation systems based on proprietary Swell Technology systems. This trio works synergistically to preserve cement integrity while reducing or eliminating costly remediation.

Meeting the Challenges of Salt Creep

Salt creep generates thermo-mechanical loading that if not addressed can instigate a host of serious and cost-intensive problems, including closure, lost circulation, borehole instability, casing failure, and even a loss of well control. Halliburton developed the IntegoCem™ cement system, specifically to withstand the distinctive stresses of squeezing salts, like those encountered in the Zechstein Basin of the North Sea.

Unlike conventional cements that shrink during curing, IntegoCem cement is designed to expand to minimize load points on the casing and more evenly distribute the formation load to help mitigate casing deformation, or at worst, failure. This capacity is a function of the specific properties of both the slurry state during placement and the set state as a cement sheath. Consequently, the IntegoCem cement helps facilitate full coverage and efficient displacement during cementing operations, and afterwards quickly withstands the forces created when pumping stops, effectively stabilizing both the casing and formation.

The IntegoCem cement is designed with tight control of fluid loss, thus helping avoid compromise to the slurry system as well as the salt formation. Additionally, the early static gel strength development of IntegoCem cement shortens the transition time to a set sheath. At the same time it contributes to the integrity of a hydraulic seal and minimizes fluid influxes that can induce salt creep, to reduce non-uniform load points that can cause casing failure and costs.

CASE STUDY:

In earlier Zechstein wells, applying the IntegoCem™ cement technology helped produce the most recent offset.

In earlier Zechstein wells, the operator had lost a cumulative $3 billion in unsustainable production, but applying the IntegoCem cement technology helped enable the client to successfully drill and produce the most recent offset.

Safety and Reliably Executing Cementing Operations

For any offshore operation, especially deep water, safety and reliability are fundamental to the success of the cementing process.

Developed to support cementing and liner operations, the Commander™ 1000 cement head is designed to surface launch balls or darts to operate subsea plugs. When used with wireless remote control (WRC), the cement head can eliminate the need for personnel in the derrick or red-zone safety area during pumping.

The Commander™ 1000 cement head is well suited for offshore well construction, including the pre-salt, low-ECD, extended salt formations or any application requiring heavier casing and work strings. Compliant with all Lloyds and DNV regulations, the cementing head enables cement
Ensuring Long-Term Well Integrity

plugs to be loaded offshore and in a basket without breaking the tool apart, thus enabling ultra-efficient pumping of the cement, reducing rig time, in a safer environment.

Reducing Drag and Heavy Load
Running casing to setting depth in highly deviated wells can prove extremely problematic as drag forces often exceed those for running the casing. The result can be slow casing run-ins or inability to land at the desired depth.

Halliburton’s response is the Buoyancy-Assisted Casing Equipment (BACE™), recognized as a major breakthrough in flotation technology. Used in conjunction with Super Seal™ II floating equipment, BACE traps fluids or air at the lower end of the string, effectively reducing the casing weight. The reduced weight lowers drag forces, significantly extending the potential running depth and minimizing buckling or sticking risks.

Late-Life Well Integrity
Casing leaks or micro-annuli can occur over the life of a well, and remediation usually is costly and challenging, especially in very narrow annuli or micron-sized fissures.

Halliburton’s WellLock® resin system readily penetrates and blocks small casing leaks, micro-annuli, or gravel packs without requiring acid cleanups. The system’s excellent mechanical properties of high ductility and compressive strengths up to 18,000 psi, capable of withstanding pressure differentials up to 100 times more than required within the wellbore, helps to preserve well integrity.

CASE STUDY:
WellLock® Resin Blocks Leaks in Gulf of Mexico P&A

The presence of bubbles after the initial casing cut during decommissioning of a Gulf of Mexico well prevented continuation with conventional P&A methods. Pressure could not be held on the cement plug, which raised concerns over having the bubble stream channel through the cement. The WellLock resin system was used in a squeeze, effectively stopping the annular leak and allowing a 15 m (50 ft) resin plug to be set and the permanent abandonment completed.

SPE 50680


Fig. 2. WellLock® Resin can be used in multiple applications – (a) during the initial well construction, for the prevention of gas migration into the annulus, (b) during a remediation operation, such as gravel pack remediation and (c) during plug and abandonment operations.
Ensuring Long-Term Well Integrity

Wellbore Cleanup Assures Well Production Reliability
No activity can have more of a damaging effect on productivity than failing to efficiently remove all drilling fluid and other contaminants during the wellbore cleanup.

The appropriately named CleanWell® system offers a mechanical solution for pre-completion wellbore cleaning. CleanWell system employs a number of cleanup innovations, including the Vac Tech® educator system, Vali Tech® mechanical filter, and Mag Tech® magnet to remove more metal debris than competitive systems, often in single runs.

Reducing Completion NPT
Delivering a usable wellbore safely, efficiently, and with zero NPT means little if the completion fails or otherwise restricts optimum production. The weight placed on designing and maintaining a reliable and fully functional completion intensifies with the multiple zones being completed to produce deeper horizons, such as the Lower Tertiary Wilcox formation of the Gulf of Mexico. For these ultra-deep and HP/HT multi-zone reservoirs, superb zonal isolation control, equipment reliability, and minimizing remediation trips are critical to maximizing asset value.

Halliburton long ago recognized the opportunities for innovative solutions to reduce rig and intervention costs for efficient completions in these demanding environments. Through collaboration with numerous operators, Halliburton addressed the NPT and completion efficiency issues, and developed an all-inclusive new solution comprised of technologies and processes. These advancements are combined synergistically in a holistic strategy to reduce the NPT and production-restricting issues that can affect the completion and the production.

CASE STUDY:
West Africa Operator Cleans Up, Saves $1.6 Million
The CleanWell system was employed for a single-trip drill-out, cleanout, and displacement for a deepwater well, where the operator needed a safe, cost-effective method to remove debris and establish total depth of 3,467 m (11,375 ft). The system established the desired depth in a single run, cleaning both the well and BOP, performing the negative pressure test to ensure integrity and displacing the mud with brine while drilling through cement stringers. More than 90 lb of debris was removed, mitigating any well control issues or completion remediation runs, saving the operator approximately $1.6 million in rig and fluid costs.

CASE STUDY:
Single-Trip Drill-Out, Clean Up Cuts $1.5 Million in Gulf of Mexico
The CleanWell® system was used to drill out and clean out a deepwater Gulf of Mexico well in a single trip, establishing depth at 5,730 m (18,799 ft) and displacing mud with brine. The job included drilling out more than 34 m (110 ft) of cement and washing/reaming 396 m (1,298 ft). The system recovered 165 lb of debris in the initial run, while a subsequent crown plug and post-perforation cleanout run recovered more than 280 lb of debris – four times that of conventional systems. The CleanWell system saved two days rig time, and at least $1.5 million.

Fig. 3. Halliburton’s StimStar completion vessels assist during the cement to completion fluid switch over and assist in operations through the completion operation.
Improving Reliability of Deepwater Subsea Complex Installations

In the complex well conditions intrinsic to deepwater subsea installations, Halliburton’s VersaFlex® Big Bore expandable liner hanger (ELH) system was designed specifically for the complexities of the deepwater and subsea markets, where it reduces both risk and capital costs.

The VersaFlex Big Bore system does not require landing in a predetermined profile or require liner-top cement integrity to achieve a liner-top seal upon setting. The system incorporates casing-placement flexibility that helps eliminate related liner installation issues, and the elastomeric seal technology is unmatched in the industry.

With its ground-breaking clean-form design, the VersaFlex® Big Bore system is an all-in-one integral hanger/packer with no moving parts, thereby helping eliminate costly tool failures associated with conventional liner hangers.

Owing to its “set and forget” reliability, the CAPEX savings from the VersaFlex Big Bore continue throughout the life of the well. The redundant leakproof design helps eliminate sustained casing pressure, while rotation and reciprocation also help ensure the best possible cement placement and cement bond. Surge and ECD risks are greatly reduced with an optimized OD and lack of a profile ring.

One of the biggest payoffs for operators is the reduced cost due to ease of installation. Also, liner overlap is greatly reduced with the VersaFlex Big Bore system because pressure-bearing tieback strings are not required. The VersaFlex Big Bore system also minimizes many of the operating steps required to set the liner hanger/packer, compared to conventional systems, while virtually eliminating remediation costs.

Fig. 1. The VersaFlex Big Bore system on location.

Fig. 2. The VersaFlex Big Bore illustrated in a deepwater well.
Reducing Completion NPT

Cutting Trips, Optimizing Isolation in Multi-Zone Completions

Historically, installing frac-pack, multi-zone completions not only increased rig days considerably, but once production commenced, operators faced the tremendous challenge of maintaining complete and reliable zonal isolation throughout the life of the well.

Obviously, for instance, multiple-zone completions heighten the risks of sand production that if uncontrolled can result in hardware erosion, sand bridging, and otherwise restrict production and increase NPT for remediation.

Halliburton has revolutionized multi-zone deepwater completions with its award-winning, technologically advanced and NPT-reducing Enhanced Single-Trip Multizone (ESTMZ™) Frac System, engineered specifically for the distinctive challenges of deep and ultra-deepwater reservoirs. This ground-breaking innovation enables single work string deployment of a frac pack completion that provides unmatched isolation and efficient separation of long reservoir intervals to optimize fracturing design. In addition, the ESTMZ system gives operators a cost-effective solution for accessing marginal reservoir intervals that typically would be bypassed as uneconomical.

The ESTMZ system consistently demonstrates its capacity to save up to three work string trips
Reducing Completion NPT

per zone in a typical Gulf of Mexico Tertiary Completion. Compounding the savings for the completion itself, deployment on a single string likewise reduces the costs of the deepwater rig as well as the stimulation vessel mobilization and demobilization.

The ESTMZ system offers other distinguishing advantages that further contribute to optimum reliability, reduced NPT, and increased and sustained production, including:

- Exceptional pre- and post-treatment formation isolation with access to each zone provided with the frac circulation sleeve and optional production sleeve.
- The system’s full 10,000-psi differential pressure rating increases the operating envelope for deeper wells and facilitates optimum frac designs.
- The industry’s highest ratings for frac pumping (45 bbl/min) and proppant volume (750,000 lb/interval) provide opportunities to optimize frac designs for up to five individual reservoir intervals.
- Offers the industry’s largest 10K ID system, which maximizes stimulation rates, reverse flow and production rates while being fully compatible with SmartWell® zonal flow control equipment.

Halliburton has successfully deployed nearly 20 ESTMZ systems worldwide, from the Gulf of Mexico to the Asia Pacific region.

SPE 116245


A major operator chose the ESTMZ Frac System for a three-well completion in the lower tertiary of the deepwater Gulf of Mexico. Compared to the plan, the ESTMZ system reduced the time required to complete each well by 18 days, on average, for a cost savings of approximately $22 million. While none of the wells have yet been put on production, the first well tested in excess of 13,000 BOPD. Contributing to the success of the three-well completions were wellbore assurance initiatives that combined all the critical operations, including wellbore cleanout, completion services, pumping, and fluids.

The ESTMZ enables four to five zones to be pumped in a week on a single well. With conventional methods, only two zones could be pumped. Previously, boats spent time reloading at the dock for different frac pack interval jobs. This is becoming a larger issue with the larger proppant volumes required in the Lower Tertiary completion market.

Halliburton offers a solution in the form of its offshore proppant transfer system that enables
Intelligent Completions

- No Dedicated Personnel Required
- Extensive Run History
- Run Open or Closed
- Remotely Operated Time-after-time

Features & Benefits

- Dramatically reducing rig-time and associated risks.
- As a downhole barrier or flow control device. With each use of the eRED® valve, subsea intervention is eliminated, saving time, money and helping to reduce risk.
- The eRED® valve is a retrievable, computer-controlled ball valve that is deployed below either a lock or bridge plug and can be used as a barrier or a flow control device. It is remotely operated, eliminating the need for any surface intervention.
- The eRED® valve can be used to facilitate interventions for a number of operational activities, including technical testing, temporary barrier closure during placement operations, and abandonment operations or as a flow control device.
- The offshore proppant transfer system enables Halliburton to pump ESTMZ system jobs with a single frac vessel fleet without the non-productive time (NPT) incurred with having to return to shore. The client's existing supply vessel is used to supply additional proppant and fluid, while the frac vessel is reloaded in between the pumping stages. The transfer station is designed to meet the volume and time requirements, thus offering more operational efficiency to the ESTMZ system.

Solutions to Help Reduce Completion Interventions

Most deepwater completions are designed to facilitate interventions for a number of post-treatment activities. Any activity that can be carried out without requiring a high-cost subsea intervention reduces precious rig time and helps enhance the overall economic profile of the asset.

One such activity required during the completion operation is the mandatory installation of a temporary barrier for the setting of the production packer and integrity testing of the production tubing. Typically, a barrier is deployed for the setting of a deep-set plug. Halliburton’s eRED®-HS remotely operated circulating valves provide high circulation rates without the need for any interventions during completion deployment—saving time and helping to reduce risk. The eRED®-LV remotely operated isolation barrier valves help save time and money and reduce risk by eliminating all wireline runs from completion placement operations.

eRED®-FB computer-controlled full-bore barrier valve provides the necessary barrier without the need for any follow-up intervention run. Permanently deployed as part of the tubing string, the innovative eRED-FB valve can be opened and closed repeatedly by remote command. This unique downhole barrier technology operates on a closed-loop hydraulic circuit powered and controlled by the integrated electronics. The unit requires no surface connections, and more importantly, eliminates the significant HSE risks and interventional costs in mechanically deploying and retrieving each plug required for the pressure-testing exercise.

At the foundation of this integrated NPT-reducing strategy is the delivery of optimized efficiency, reliability, and HSE superiority to maximize the bottom-line value of these premium assets.
Reliable Completions

An ill-designed completion with hardware lacking the mechanical integrity to handle the flow rates or reservoir characteristics can severely impact the economic performance of the asset. The stakes rise considerably in deeper, hotter, and multi-formation completions, where complete zonal isolation, hardware dependability, and effective stimulation are essentials.

Halliburton’s holistic solutions for a deepwater completion consider every variable that drives an effective and long-functioning completion, from wellbore clean up to sustaining production once online. Reliability is engineered into the design of the completion, using the very latest planning technologies. In execution, reliability is ensured with completion hardware carrying the highest mechanical integrity ratings, a full suite of high-performance and non-damaging fracturing fluids, and new-generation technology for keeping sand production and excessive water-gas cut to a minimum. All this and more is supported by the industry’s largest and newest-generation fleet of stimulation vessels, strategically placed to quickly deliver fracturing, acidizing, and sand control treatments anywhere and anytime in the world.

Fig. 1. Stimulation vessels placed strategically around the world in deepwater regions can quickly deploy to the customers’ wells.
Maximizing Production from Multilaterals

Multilateral wells are essential to the commercial success of reservoirs worldwide, particularly in subsea applications where the high infrastructure and rig costs continue to drive the utilization of multilateral technology. In reservoirs where maximum reservoir contact is required to reduce reservoir drawdown, control water production, or delay gas breakthrough, multilateral technology has dramatically extended the life of oil fields. The need for multilateral junctions with sand-control technology in many of these subsea applications has led to the development of reliable TAML Level 5 multilateral systems.

The Halliburton FlexRite® Multibranch Inflow Control (MIC) system is the world’s first multilateral completion system that provides the ability to individually control each branch of a multilateral well with three or more legs without costly subsea intervention. The MIC enables a multilateral well to be completed with sand screens, swell packers, Inflow Control Devices (ICDs), and Interval Control Valves (ICVs) to help maximize production from each multilateral leg. The MIC solution enables individual branch control of stacked (three legs or more) multilateral wells; a single-trip completion system consisting of multiple slim-hole ICVs is deployed through the stacked TAML Level 5 junctions to achieve individual branch control.

Using the FlexRite MIC system, multiple sealed junctions can be constructed from the mother bore in a given well. With the junction’s large main bore pass-through inner diameter (ID), a 3½-in. completion, including remotely controlled inflow valves, can be installed with an ICV controlling each junction. As a result, production can be managed and controlled at each lateral completely independent of all other lateral legs.

In applications where more than two multilateral junctions will be stacked in a single well, the inability to provide intelligent control from each leg has become critical for reservoir management. With the FlexRite MIC, operators can individually control one branch of a stacked multilateral junction well through a single ICV, while the remaining branches can be co-mingled through a shared ICV. In the past, if the need arose to throttle back production on any of the co-mingled legs, production of each of the co-mingled legs was throttled back as well. Even worse, if gas breakthrough occurred on any of the co-mingled legs, all of the legs had to be shut off.

As the first multilateral completion system that provides this solution without costly subsea intervention, this new and innovative technology will enable operators to improve well management with greater flexibility, optimize production rates and increase oil recovery. In addition, the MIC enhances safety by reducing well drilling and well intervention operations as compared to multiple wells.

Completion Design Solution for Maximum NPV

The biggest challenge in designing a reliable deepwater completion is identifying early on all the specific reservoir characteristics, and an advanced 3D, four-component, non-isothermal numerical reservoir simulator. The simulator helps design effective well treatments, including fracturing, conformance, and sand control and is even designed to predict production from complex wells and reservoirs.

As part of its “intelligent” approach to completions, Halliburton relies on the industry’s most advanced design innovations, taking all variables into consideration to reduce the uncertainties and deliver maximum value.

Landmark’s one-of-a-kind AssetConnect™ Enterprise distributed technical workflow automation software is the foundation of this strategy for designing deepwater completions. AssetConnect workflow considers all aspects of well construction, deepwater fracturing, and completion operations, including the critical path time line, and overall well costs, to create multiple customized completion scenarios.

The capacity to enable distributed execution with centralized model management ensures
consistency and the complete automation of the multidisciplinary workflows. This new-generation approach incorporates all the elements within the asset’s value chain, from the reservoir through production. The result is a more thorough, efficient, and cost-effective completion designed solely to optimize value.

The suite includes the multi-phase QuikLook® software, an advanced 3D, four-component, non-isothermal numerical reservoir simulator. The simulator helps design effective well treatments, including fracturing, conformance, and sand control and is even designed to predict production from complex wells and reservoirs.

SPE 150455


SPE 155867


SPE 151754

Reliable Zonal Isolation Solutions
Over time, high differential pressures, formation shifts, and similar events can weaken packer sealing, not only increasing NPT, but jeopardizing the integrity of the zonal isolation network.

The robust Swellpacker® isolation system makes it the ideal option for the unique challenges of deepwater, multi-zone completions. Compared to conventional packer systems, Swellpacker systems provides a simpler, safer, and much more stable solution for complete and long-term zonal isolation. Swellpacker systems demonstrate their capacity to cut rig time and reduce costs, all the while delivering absolute isolation of producing zones. In some open-hole completions, Swellpacker systems may even eliminate cementing and perforating altogether.

Well suited to cased or open-hole completions, Swellpacker systems is based on the swelling properties of rubber in hydrocarbons and/or water. With the ability to swell up to 200%, it effectively seals the annulus around the pipe and achieves unprecedented zonal isolation.

Once deployed, the rubber retains its flexibility, enabling the Swellpacker system to adapt to shifts in the formation over time and retain seal integrity.

CASE STUDY:
Swellpacker System Ensures Upper/Lower Completions Interface Off Brazil

After extensive validation testing, the operator chose the Swellpacker isolation system to help address the host of challenges in the completion of 10 wells in more than 1,000 m (3,218 ft) of water off Brazil. Among the challenges, the wells were to be completed with a semi, requiring sealing off the closing sleeve on the lower completion, which needed to be accomplished while avoiding use of a travel joint or mechanical telescoping device to achieve space-out when landing the tubing hanger. The multi-well project also required mechanical continuity and integrity between the lower and upper completions. In addition, the production packer had to be hydrostatically set and tested from below, thus necessitating temporary communications between the tubing and casing before the Swellpacker could be swelled to affect sealing.

The first of the completions was completed ahead of schedule and on budget, as were the two following wells. Six more wells will be completed using the same Swellpacker design. Both high pressure and high rates were possible once the Swellpacker system entered into the packer bore of the Versa-Trieve® VCA packer.
**Controlling Unwanted Water and Gas via Inflow Control Solutions**

Multiple-zone completions, especially in unconsolidated reservoirs, heighten the risks of sand production, as well as increased water and gas cuts that if unrestrained can severely impact completion functionality. Sand production specifically often erodes hardware and causes sand bridging and other problems that can restrict production and increase NPT.

Halliburton bolstered its completions portfolio with the advanced EquiFlow® Automatic Inflow Control Device (AICD). Typically installed in tandem with the PetroGuard® or other premium sand control screens, the EquiFlow AICD dramatically minimizes the production of water and gas at breakthrough.

To maximize oil production, EquiFlow AICD employs groundbreaking dynamic fluid technology to differentiate between fluids flowing through the device. The reservoir fluid flows from the formation, through the sand screen, and into the flow chamber, where it continues through one or more tubes managing the water through the fluid differentials.

**Fluid Solutions for Safe Fracturing of HP/HT Reservoirs**

The enormous challenges of deep water and ultra-deep water extend to pre-production fracturing stimulation, requiring considerably higher bottomhole treatment pressure. Conventional fracturing fluids, however, are unable to provide the required pressure without exceeding the safety limit ratings of the rig’s surface treatment equipment or downhole tubulars. Whether the pressure-generated failures occur on the surface or downhole, the result is increased HSE risks and costs.

Halliburton addressed those risks with high-density fracturing stimulation fluid systems (DeepQuest® and DeepQuest® HT) formulated specifically to safely and efficiently fracture HPHT reservoirs. These high-density systems enable fracture stimulation of HPHT reservoirs without exceeding the safety limits of treating equipment or tubulars or compromising the optimum fracture treatment design.

The DeepQuest HT service reduces surface treating pressure without the costs of higher-pressure equipment. The DeepQuest HT fluid system is effective in bottomhole temperatures up to 375°F (191°C) and provides improved performance with treating pressures higher...
than 15,000 psi. The weighted system takes advantage of gravity and is an ideal option when the availability of 20,000 psi fracturing equipment is limited.

Also, SeaQuest® HT service is an advanced proprietary fluid system that enhances performance, while promoting more flexible service delivery. Designed for seawater mixing, SeaQuest® helps reduce delays caused by the stimulation vessel scheduling issues that occur often when freshwater-based fluid systems are used.

The complementary InstaVis™ mixing system helps reduce and even eliminate the NPT traditionally associated with preparing the frac fluid. The proprietary fluid mixing technology enables simple on-the-fly rheology modifications with on-line quality control to assure desired fluid properties are being maintained.

Engineering a completion that clears the way for full and sustainable production is one more example of Halliburton’s commitment to deliver the highest reliability, safety and efficiency to produce maximum asset value.

**Precise Stimulation Treatments for Optimum Drainage**

Deepwater wells drilled and completed in low-permeability formations can sustain formation damage that can limit productivity. Consequently, to increase reservoir drainage and improve overall asset value, these wells must be stimulated with acidizing or hydraulic fracturing treatments.

Beneath its Pinpoint Stimulation umbrella, Halliburton has developed a range of fracturing technologies that have been used to effectively stimulate and enhance production from horizontal open-hole wells in the post-salt of Deepwater Brazil and elsewhere. With the aid of advanced techniques such as microseismic fracture mapping, pinpoint stimulation treatments can be customized for optimum performance in specific reservoirs and formations.

The SurgiFrac® Service enables dynamic fluid diversion for precise stimulation. The SurgiFrac uses the momentum of the fluid to create dynamic diversion that directs the fluid precisely into specific points along the wellbore.

![Fig. 7. The SurgiFrac service opens up a host of new possibilities, including for wells completed open-hole that may have hydrocarbon shows in multiple areas. With SurgiFrac, it is theoretically possible to create large and small acid fracs in the limestone areas and place large and small propped fractures in the sandstone/chert areas. A sand frac with acid could also to stimulate production from lenses.](image-url)
Sustainable Production

Hand-in-hand with designing and maintaining a reliable and high-performance completion is the challenge of sustaining production and ideally, extending the life of the production asset. Key elements in meeting that challenge are to have the capacity to remove formation damage and monitor production.

Removing Formation Damage

For stimulating high-temperature carbonate or mixed carbonate/sandstone reservoirs, the environmentally benign KelaStim℠ chelant-based stimulation service, winner of the 2013 World Oil Best HSE award, provides a non-acid method for increasing production. The KelaStim fracturing fluid reduces the risk of rock deconsolidation that can occur with high-strength HCl acid stimulation fluids. KelaStim service provides reliable fracturing stimulation in higher than 300°F bottomhole static temperature.

In high-temperature formations with high carbonate content, Halliburton offers the safe SandStim℠ acidizing service that uses a chelant-based fluid system for stimulating sandstone formations. The SandStim fluid system provides a safer and simpler HF acidizing fluid than traditional HF acid blends.

The service is specially designed to be able to be used in high-temperature formations, wells that cannot be treated with HCl-based, HF fluids, or wells with a high or uncertain carbonate content.

SandStim service is a simple system that uses fewer pre-stages and minimizes blend components, as well as posing less HSE risk than traditional HF acid blends. SandStim system also helps minimize potential damage when stimulating formations of uncertain mineralogy and reduce the potential of de-consolidating friable formations. The system contains readily biodegradable components and is easier to work with operationally. By reducing the number of pre-flush stages, the SandStim service saves considerable time and costs. Since the SandStim service can be used in wells with a high carbonate content, the service is forgiving when treating uncertain mineralogy, simplifying treatment design.

Proppant packs can become unstable and weaken over time and, in the process, restrict optimal reservoir drainage. Halliburton reduced that risk with the introduction of the SandWedge® ABC aqueous-based conductivity enhancement system that helps improve long-term production by stabilizing and strengthening the proppant pack. SandWedge ABC system’s aqueous-based carrier enables it to be used as part of the fracturing fluid, used either in pre-treatment or in remedial treatments. The aqueous base also provides improved HSE performance and reliability.

SandWedge ABC conductivity enhancement system provides all the well-proven benefits of Halliburton's proprietary conductivity enhancement technology plus new capabilities, including helping maintain a high production rate over a longer period of time. The aqueous-based solution also enhances frac fluid cleanup. The SandWedge ABC is highly effective for primary or remedial applications in both hard rock and unconsolidated formations. The technology minimizes premature proppant settling and enables treatment of existing proppant packs to help prevent further damage caused by fines invasion.
New Age Real-Time Monitoring Solution

Historically, real-time monitoring of downhole conditions and determining actual oil and gas volumes being produced required high-cost intervention.

Pinnacle, a Halliburton service, has capitalized on its leadership position in fiber-optic sensing technology with FiberWatch® well monitoring and reservoir management service that requires zero intervention. With its revolutionary FiberPoint™ sensors, this step change in fiber-optic monitoring accurately correlates downhole temperatures and acoustic changes with the location and exact volumes of both oil and gas being produced from each zone.

With the fiber optics installed inside the well, operators can avoid having to run production logs, tracer surveys, or geophones to obtain vertical seismic profiles (VSPs). The fiber, optic distributed temperature sensing service delivers multiple diagnostic measurements on a single fiber-optic cable that reduces both the risks and operating costs of acquiring precise downhole data. Since it includes no internal electronics that can fail in HPHT applications, FiberWatch is effective in the most hostile downhole applications. Incorporating a complete portfolio of fiber-optic technologies, software, diagnostic systems, and services, the technology has shown its capacity to collect measurements from reservoirs up to 392°F (200°C) and 30,000 psi – well above the limits of electronically driven monitors.

Reducing Undesirable Water/Gas Production

The production of unwanted water or gas can restrict productive well life, while increasing lifting costs and environmental issues and related costs. Halliburton’s Conformance technology portfolio offers a variety of processes applied to reservoirs and boreholes to help reduce production of unwanted water and/or gas to efficiently enhance hydrocarbon recovery and/or satisfy a broad range of reservoir management and environmental objectives. While water management may not consistently increase petroleum, application of applicable technologies often can improve an operator’s profitability by helping achieve a longer productive well life, reduce lifting costs, and reduce environmental concerns and costs.

A broad range of causes exist for excess water production. The Halliburton conformance package offers a broad variety of solutions to help mitigate these water problems, varying from in-situ crosslinked water-based polymers, swelling/superabsorbent polymers, relative permeability modifiers, to cement-type materials.

One of the key solutions in the conformance portfolio is the WaterWeb® service which uses unique polymer chemistry to help create oil-water separation in the reservoir, impeding water flow and enhancing hydrocarbon flow to the wellbore. With the WaterWeb service, the resulting improved oil/gas recovery stems from a reduced water column giving improved natural lift for the residual oil and/or gas. In addition, it helps justify prolonged and sustained production by enhancing reservoir drainage.

Fig. 2. FiberWatch service works in extreme temperatures, up to 570°F (300°C) and pressures up to 30,000 psi.

Fig. 3. Utilize logging to verify WaterWeb® has stopped excess water production.
Flow Assurance

The distinctive deepwater build-up of production-restricting hydrocarbon solids, namely asphaltene, wax, and hydrates, has made flow assurance one of the most intensely investigated disciplines ever since operators first ventured into deeper waters. Hydrates, which form in cold deepwater temperatures and high pressures, are especially problematic, as they not only can plug the production line, but also the BOP stack and choke and kill lines, raising serious well control issues.

Addressing the Risks Pre-Production

Multi-Chem, a Halliburton service, has been a key player in preventing and removing obstructions for the free flow of hydrocarbons, and maintaining the overall integrity of the production system, including the subsea pipeline network. From analysis to deployment of innovative chemical remedies, highly experienced Multi-Chem deepwater technical teams provide meticulously engineered and cost-effective solutions that keep deepwater production flowing.

Of course, the ideal and less costly approach to mitigating problems is identifying the risks during planning and developing contingencies. Issues that can undermine maximum hydrocarbon flow are certainly no exception.

Well before first oil or gas hits the sales lines, Multi-Chem engineers analyze the specific flow assurance parameters and model flow through the production system. Based on the analysis, the Multi-Chem flow assurance specialists provide the operator process and procedure reviews, as well as recommendations and assistance in field design to help resolve potential flow assurance risks and develop the best mitigation solutions for the targeted asset.

Much of the analytical work is undertaken at Multi-Chem’s global R&D technology center, which houses some of the most sophisticated analytical tools in the industry, including cross polarized microscopy (CPM), differential scanning calorimetry (DSC), high-pressure cells rated to 14,600 psi, among others.

The Multi-Chem analytical tool set also includes the first and only purpose-built rocking cells for testing low-dosage hydrate inhibitors (LDHI). These ultra-advanced cells are designed to withstand \( \text{H}_2\text{S} \) gas to effectively replicate the conditions of a client’s actual deepwater production system. Specifically, these one-of-a-kind analytical rocking cells and specialized procedures offer:

- Fully automated protocols
- Proprietary seal and center-ported design with double sapphire windows
- Proximity sensors, P/T transducers, and CP and CV capability with pressure rated to 3,000 psi
- 18 total cells, 12 of which are \( \text{H}_2\text{S} \) compatible

The results and recommendations developed better simulate the conditions in a deepwater operator’s sour reservoir and provide safe and optimized solutions, without any damage to the production system equipment.

Chemical Solutions to Revive Steady Flow

Extricating hydrate plugs, getting rid of wax deposits, or otherwise dealing with any naturally occurring solid obstacle once they have built up can be difficult. When it comes to hydrate plugs, however, complete remediation is imperative to prevent potentially catastrophic HSE issues.

Fig. 1. Once a well has been completed, it is critical that problems do not arise with corrosion, issues, Multi-Chem pro-actively engages with the client to prevent flow reduction issues.
Halliburton’s Multi-Chem suite of Low Dosage Hydrate Inhibitors (LDHI) includes multiple and continuous applications with Kinetic (KHI) and Anti-Agglomerate (AA) inhibitors employed in site-specific applications. The unique LDHI has been shown to extend production beyond that of conventional methanol or glycol-based thermodynamic inhibitor treatments. In addition, they provide faster start-up time and the low dosage required reduces transportation and equipment costs.

The Multi-Chem chemical solutions package also includes new generation:

- Scale inhibitors and removers
- Paraffin and asphaltene inhibitors, dispersants, and solvents
- Foam-assisted lift to resolve liquid loading issues
- Biocides, corrosion inhibitors, sequestering agents, as well as the AcroClear™ and traditional line of H₂S scavengers
- Full water treatment solutions

Post-deployment, Multi-Chem deepwater experts monitor system data and flowline performance parameters in real time as needed to ensure optimum product performance.

**CASE STUDY:**

**Multi-Chem Water Solution Assures Compliance**

Owing to high oil and grease levels in overboard water, the platform operator faced the risk of regulatory non-compliance and potential downtime. Multi-Chem stepped in with a cost-effective chemical solution that ensured the discharge water remained in compliance. By optimizing the chemical program and treatment rates, the oil and grease content dropped to around 12 ppm, well within regulatory standards.

**OTC 21836**


**E&P Magazine 21836**

**CASE STUDY:**
**LDHI Prevents Hydrates in Gulf of Mexico 20-Mile Tieback**

The 20-mi tieback flowline in 1,463 m (4,800 ft) of water in the Gulf of Mexico encountered hydrate formation that methanol alone was unable to resolve. After rocking cell tests, Multi-Chem recommended a specially formulated low-dosage hydrate inhibitor (LDHI) that would control hydrates at the 60% produced water cut of the production. Treatment with the anti-agglomerate technology combined with methanol supplementation enabled the operator to continue to produce the well at the high-water cut, effectively controlling hydrates and increasing the production life.

**CASE STUDY:**
**Production Restored on Paraffin-Blocked Flow Line**

After losing production when an inter-field flow line became plugged with paraffin, the operator spent nearly $8 million in unsuccessful attempts to completely remove the plug. Multi-Chem suggested the best option was paraffin dispersant blended into seawater at a 5% concentration and pumped into the line. The 5% MX 3-1450 mixed in seawater was pumped in and the line cleaned completely with a chemical expenditure of less than $20,000.

**CASE STUDY:**
**Defoamer Clears Separators, Restores Production**

Foaming issues were causing the IP and LP separators to experience liquid carryover, raising the risks of damage to the gas compressor downstream of the separators. Multi-Chem recommended a 30 ppm treatment of DF-7190 oil-based, silicone defoamer. The foaming issues virtually were eliminated following a treatment of 22 ppm, and the separation system has since operated for eight months problem-free.

**Biocide-Free Water Flooding Remedy for Older Producers**

Bacteria growth over time has caused severe water flooding issues in many mature deep-water producing wells that, if untreated, could generate hydrogen sulfide (H₂S) production. Historically, the only remediation was in the form of high-dosage biocide treatments that could carry a number of environment considerations.

Halliburton has addressed those concerns with its award-winning CleanStream® ultraviolet light bacteria control process. The UV light technology provides an on-the-fly solution that significantly reduces the volume of biocides needed to control bacteria. Overall, the use of the ultraviolet solution can significantly reduce the use of larger quantities of biocides, which can be costly from logistics and quantity standpoints. CleanStream services is a new technology first originated in the unconventional shale operations, but now utilized in offshore waterflood operations.

**Offshore Magazine**


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> Flow Assurance
Certified Solutions to Serve Growing Deepwater Market

Multi-Chem further expanded its infrastructure to serving the growing needs of the deepwater Gulf of Mexico and surrounding markets with its new state-of-the-art Arcadiana chemical blend plant in Maurice, LA. The blend plant incorporates advanced design, technology, and processes to optimize safety and maximize efficiency in this challenging and highly regulated environment, including:

- Computer-controlled, batch logic chemical processing
- Instrumented blenders and high-flow filters
- Umbilical-qualified DeepSeal™ Engineering Assured Leadership certified solutions and MultiClean™ product inspection verification
- Dedicated bulk-loading facilities for smoother logistics

To ensure safety and consistent manufacture of our products, Multi-Chem’s new blend plant incorporates PLC-controlled operations using batch logic processing, and meets or exceeds all regulatory requirements and design codes, including NFPA 30, Process Safety Management (OSHA CFR 29 1910.119), API 650, and others. The 3,000 sq. ft regional lab includes a 1,000 sq. ft dedicated QA/QC lab which provides confirmation of quality for products coming out of the plant.

Acadiana is equipped for quality production, with two 8,000- and two 3,000-gal-capacity blenders instrumented for weight, temperature, pressure, recirculation flow, and specific gravity, with water-based blenders also instrumented for pH. To ensure that products meet or exceed the deepwater particulate specification ASE 4059/NAS, the plant employs 3M Cuno High Flow Filters, and a polishing filter helps to ensure the product is free from any haze.

In addition, at the Arcadiana plant, Multi-Chem dedicates the time and technology needed to assure every treatment will continue to flow through every umbilical every time, no matter how long the deepwater line runs. This is accomplished with the Multi-Chem DeepSeal Engineering Assured Leadership line of umbilical-qualified products that exceeds strict standards for quality, purity, and application compatibility, with a certification process that includes rigorous testing of materials compatibility, particulate content, low-temperature and high-pressure viscosities, and long-term product stability.

As part of the DeepSeal Engineering Assured Leadership certification process, candidate chemicals undergo rigorous material compatibility testing as well as extensive stability testing. The process goes beyond industry standards of excellence to require 30-day hot and cold static stabilities, and high-shear, surface film fouling test. The result is exceptional quality, every time.

To help ensure each product remains as pure as it was made, all DeepSeal Engineering Assured Leadership certified products receive special handling through Multi-Chem’s exclusive MultiClean™ process. This helps to ensure the chemicals and containers are of the exceptional quality and cleanliness required for capillary/umbilical delivery.
The MultiClean process includes verified inspections, multiple sample retentions, and multiple filtering to stringent specifications, which provides a chain of custody for each batch and container, documented by serial number.

In addition, the Multi-Chem’s Chemical Inventory Management System (CIMS) tracks all chemicals at each step of the process, providing the operator greater control over all aspects of the chemical program, from monitoring inventories and usage to remotely regulating chemical injection rates. Providing remote observations of tank levels, and confirmation of chemical injection rates and deliveries, Multi-Chem’s Web-based CIMS facilitates efficient scheduling, optimizing the treatment program, and reducing the total man-hours required to perform routine chemical inventory and pump integrity tasks.

On location, system sensors collect and transmit data on fluid levels, pump operation, and chemical delivery, automatically transferring the data to Multi-Chem’s secure CIMS website. The website can be accessed 24/7, remotely providing the operator with all the chemical program information, including pre-set alerts that deliver instant notification of abnormally high or low chemical usage to facilitate timely corrective action.

**Keeping the Flow in Subsea Flowlines**

Subsea flowlines, especially the scores of tiebacks laid to connect with primary production facilities, can ill-afford hydrate, paraffin wax, or other deposits that block steady production. The ultimate economic ramifications are particularly glaring with the tiebacks used for producing otherwise marginal reservoirs.

Halliburton Pipeline & Process Services’ heat-driven SureTherm™ service was developed solely to treat deposits, such as paraffin wax or hydrate, to return blocked subsea flowlines to full production. The services uses a proprietary time-delayed exothermic chemical technology to generate sufficient heat that consistently restores flow without requiring mechanical scrapers in a reduced ID or restricted pipeline. The treatment can be applied either during production flow or during shutdown.

The SureTherm service technology provides a cost-effective alternative to conventional solvents, which are unable to remove significant quantities of paraffin in the low internal temperature environment of subsea pipelines. The service can be applied singularly or synergistically with the highly effective Paragon™ paraffin solvent.

Complementing SureTherm service are Halliburton’s subsea pigging unit (SPU) and subsea hydrostatic testing units (SHU), which are proven technologies for the remote and safe flooding and testing of newly fabricated pipelines in water depths up to 13,123 ft (4,000 m).

The subsea pigging unit is engineered to filter and chemically treat water that fills the pipeline during the flooding operation. The water is continuously and autonomously regulated and monitored during the flooding and pigging operation without the need for umbilical cables or constant attendance by a support vessel. The ability to independently complete pipeline flooding and pigging operations offers distinct advantages. Plus, it typically brings significant value to offshore projects by enabling more flexible and efficient vessel usage.
The companion subsea hydrostatic testing unit provides a step-change improvement in the overall safety of subsea hydrostatic testing operations. The SHU enables hydrostatic testing operations to be completed entirely on the seabed, moving the risks posed by high-pressure fluids far away from personnel. The SHU utilizes the power available from an ROV to operate pumps within the SPU/SHU unit. The remotely operated vessel controls the rate of pressure increase in the pipeline by varying the flow rate provided by the ROV-driven pressurizing pump. Once the pipeline reaches its hydrostatic test pressure, the ROV may be disconnected and used for other activities, such as “flying the line” for visual location and confirmation of any suspected leaks indicated by the ongoing hydrostatic testing operations.

Fig. 5. Halliburton collaborates with our customers to develop a solution, and we create value for our customers, ourselves, and the global community.
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