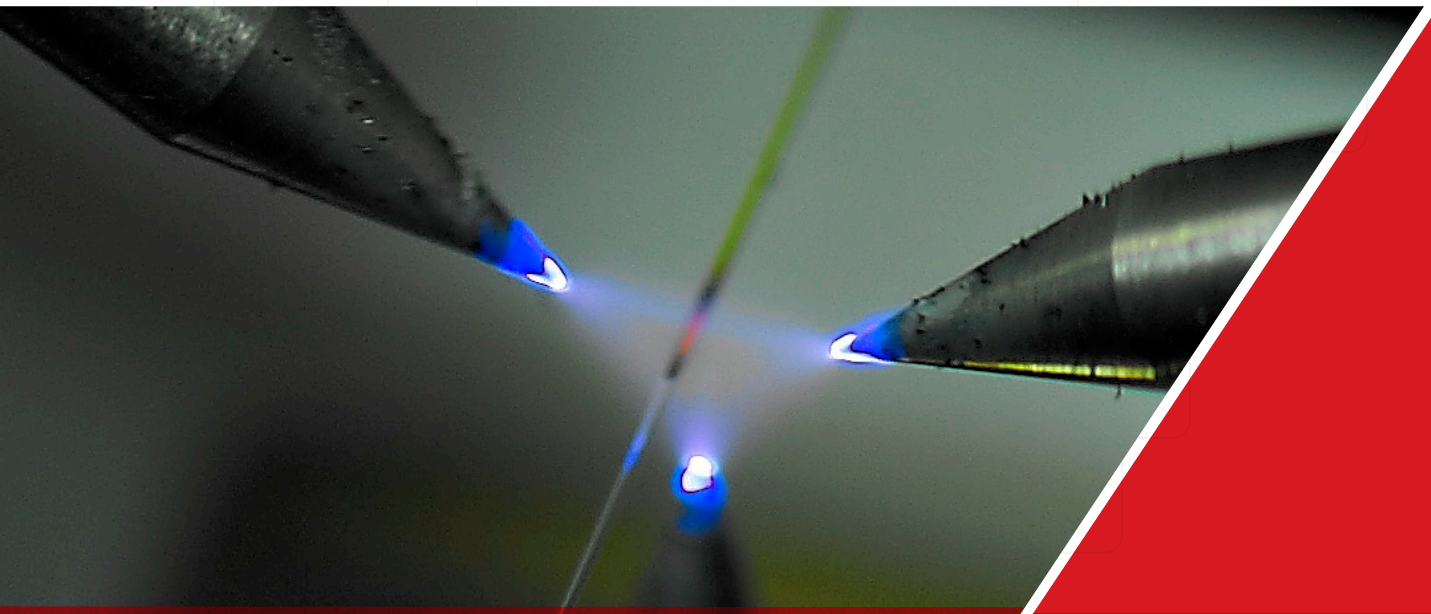


FIBER-OPTIC SENSING TECHNOLOGIES

FOR **WELL MONITORING** TO **RESERVOIR MANAGEMENT**

Solving challenges.™

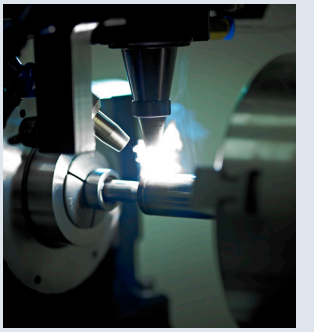
Pinnacle
A HALLIBURTON SERVICE

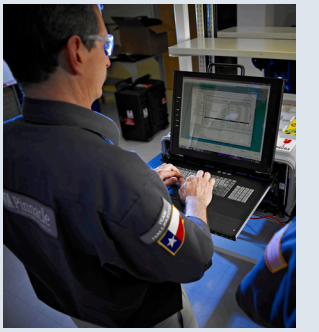
CUTTING-EDGE FIBER-OPTIC TECHNOLOGY FROM THE WORLD'S LEADING PROVIDER

Pinnacle, a Halliburton Service, is the industry leader in fiber-optic product development, deployment, and analysis. You already know us as an established leader in microseismic and microdeformation monitoring, and we are leveraging that same level of excellence and innovation to fiber-optic sensing technologies and solutions.

APPLIED PHOTONICS CENTER

At our Applied Photonics Center in Houston, we are continuously developing new and unique systems that improve the accuracy, longevity, and abilities of fiber and meeting or exceeding ISO 9001 standards. It is this dedication to pushing the limits of what is possible that has helped us become one of the industry's leading providers of fiber-optic services.





FIBERWATCH DISTRIBUTED SENSING

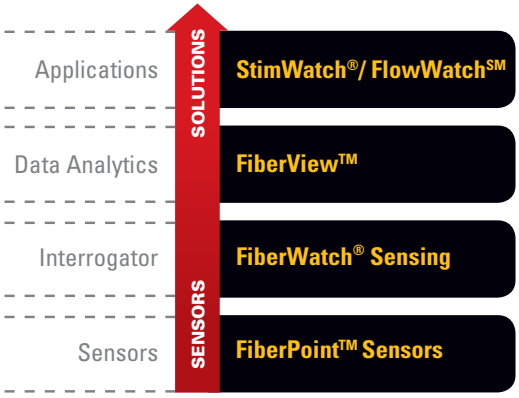
Distributed-sensing techniques such as distributed temperature sensing (DTS) and distributed acoustic sensing (DAS) enable the operator to fully monitor the wellbore during flow profiling or seismic mapping. Pinnacle is leading the industry in developing complete well-life solutions to improve asset optimization.

FIBERPOINT SENSING

Point sensing techniques such as pressure and temperature solutions provide improved value around long-term well characterization. Pinnacle is leading the industry in developing point sensing technologies to further define well performance.

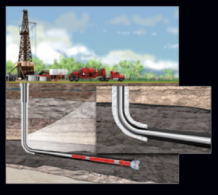
FiberWatch[SM]

A comprehensive solution

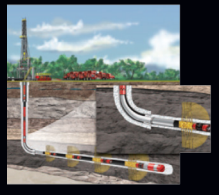


OPTIMIZE THE WELL THROUGHOUT ITS LIFECYCLE

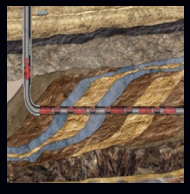
WELL CONSTRUCTION → COMPLETION/ STIMULATION → PRODUCTION/ INJECTION → WELLBORE INTEGRITY → RESTIMULATION



Cement Monitoring
Well construction monitoring service

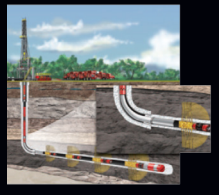


StimWatch®
Stimulation monitoring service



FlowWatch℠
Production/injection monitoring service

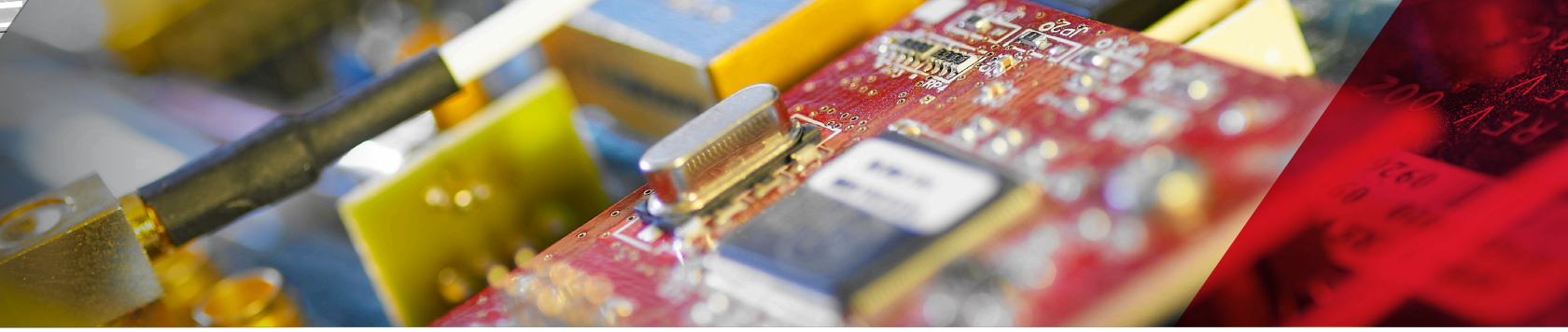
FlowWatch℠
Wellbore integrity monitoring service



StimWatch®
Stimulation monitoring service

Additional Applications for Fiber-Optics

Fiber-optic monitoring is used in many industries where temperature sensing is critical. Pipeline companies often use fiber optics to detect a sudden drop in temperature or an increase in acoustic vibration, which may indicate a leak. Power companies use fiber-optic technology to monitor heat along electrical lines to ensure users don't overload the system. Fiber optics allow operators to measure fluid flow in refineries and liquefied natural gas (LNG) plants, detect fires in industrial plants, and monitor temperature and vibrations in deepwater completions.

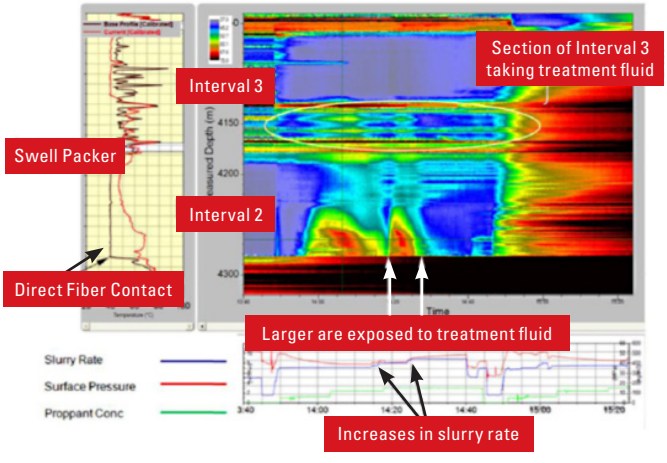


REAL-TIME STIMULATION MONITORING

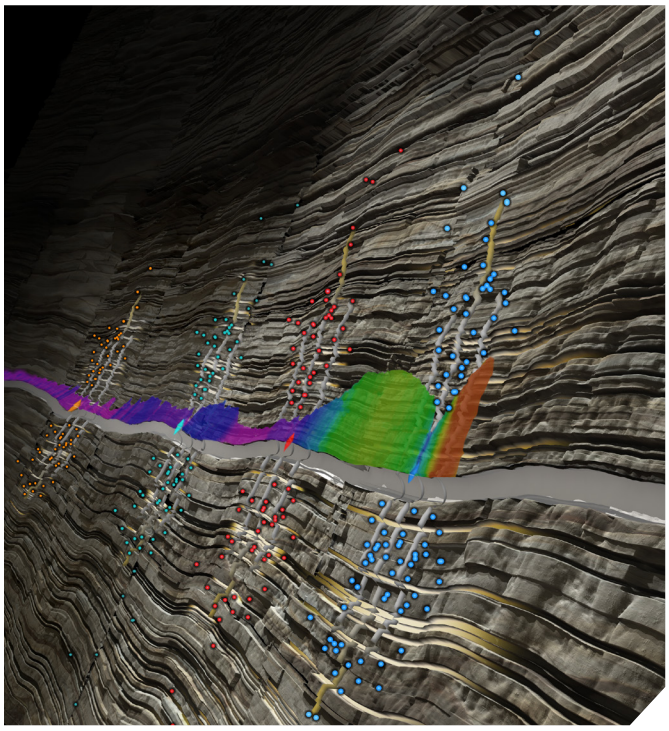
STIMWATCH® SERVICE

StimWatch service is Pinnacle's injection profiling service. By closely monitoring the conditions in every part of the well, an operator can determine exactly where stimulation fluids are flowing from the wellbore into the formation. This information is especially useful in multi-zone completions, as it enables operators to determine whether the entire targeted interval has been stimulated. Providing results in real-time, StimWatch service has many benefits that cannot be obtained using any other monitoring system:

- **Cluster Efficiency** – Fiber-optics allow operators to qualify and quantify fluid distribution, helping operators understand how to improve completion efficiency and treatment designs.
- **Improved Economics** – An accurate understanding of where fracture initiation is occurring enables operators to change a treatment design in real-time to divert fluid into understimulated parts of the reservoir.
- **Risk Mitigation** – Real-time information allows operators to detect malfunctioning packers, plugs or casing lines.



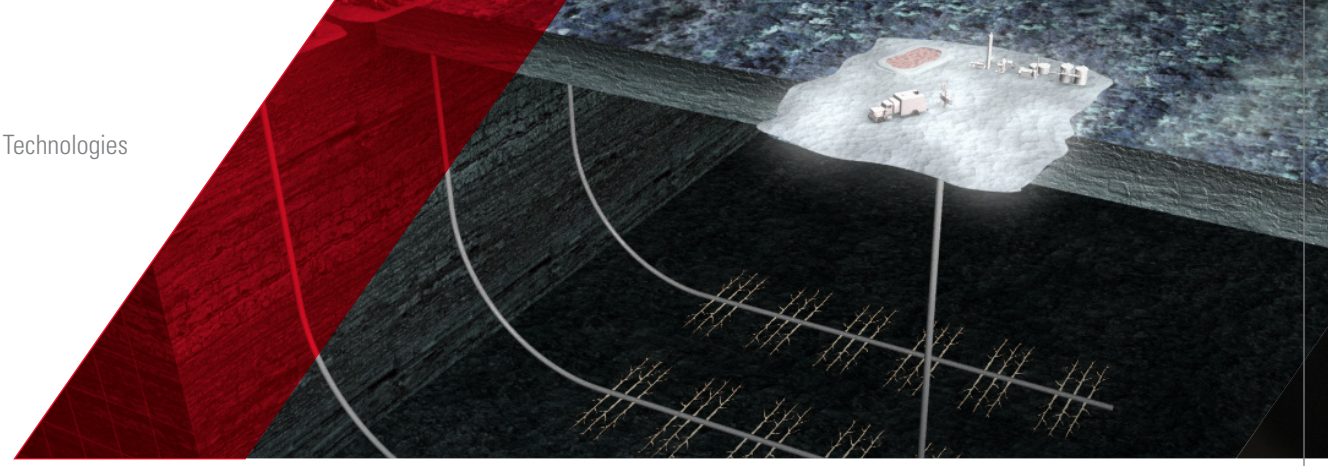
Real-time distributed-temperature-sensing (DTS) StimWatch service indicates fluid movement in the near-wellbore, the under-stimulated portion of a wellbore interval (white oval) and a leak during stage 3 of the fracture treatment.



CASE HISTORY

Barnett Shale Stimulation Monitoring

A Barnett Shale operator deployed a dual-array microseismic monitoring solution as well as a permanent fiber-optic line along the outside of production casing. StimWatch service was used to monitor the points of fluid entry into the reservoir in real-time and microseismic was used to compare those results to the hydraulic fracture geometry. This gave the operator a full-scale understanding of completion effectiveness at the near-wellbore, and how it will impact the fracture extension into the reservoir.

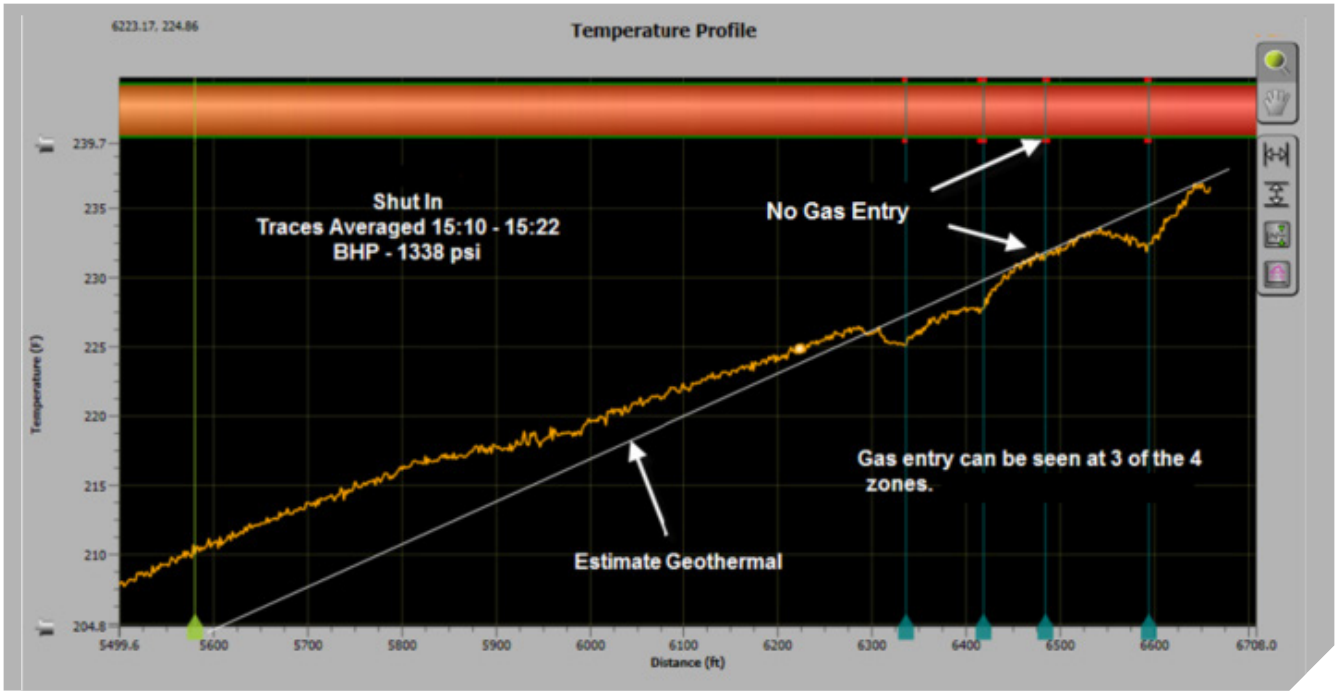


REAL-TIME PRODUCTION MONITORING

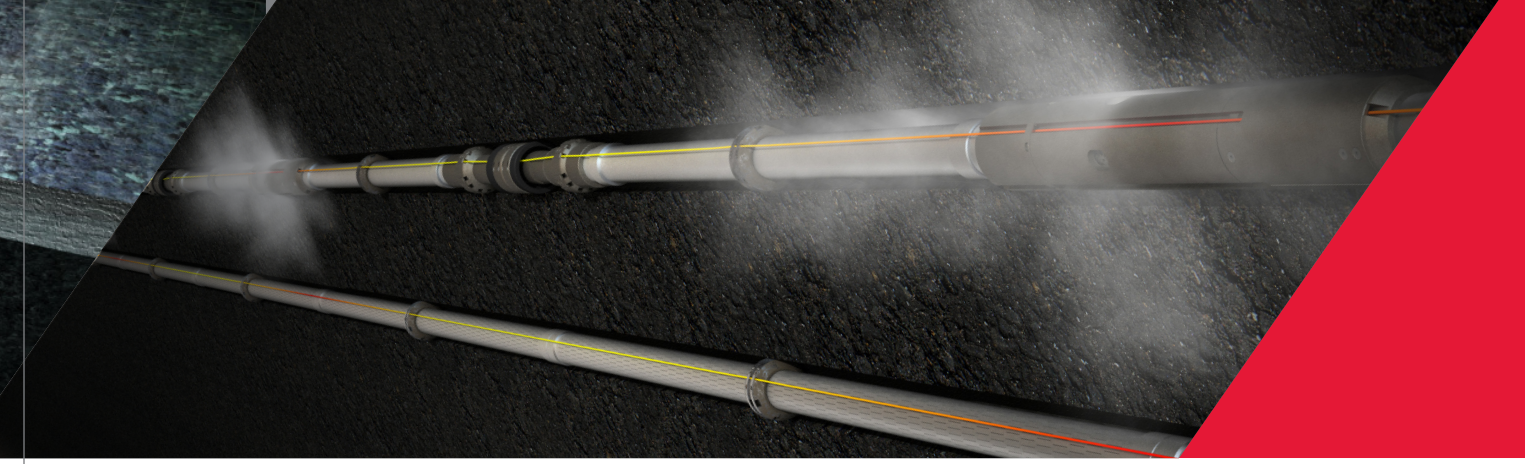
FLOWWATCH℠ SERVICE

FlowWatch monitoring and diagnostics service utilizes distributed sensing to monitor dynamic wellbore conditions during production. This helps operators understand well performance by identifying zonal contribution, monitoring artificial lift systems, and identifying scaling or deposit build-up inside tubing. We can accurately correlate downhole temperature and acoustic changes with the location and volumes of liquids and gas exiting each zone. This provides a solid foundation for operators regarding critical decisions about well performance, completion effectiveness, and reservoir quality.

- **Identify zonal contribution** – Understanding how each interval contributes to the overall production after well completion enables operators to relate this information back to treatment designs, geology and reservoir properties.
- **Improved economics** – Fiber-optic cables may be inserted inside tubing to acquire production profiling information. With Pinnacle's retrievable "dip-in" services, an operator can deploy a fiber-optic cable without the need for a workover rig, dramatically lowering the overall cost to obtain a production log.
- **Production decline over time** – How does production change as the reservoir depletes or when the well is put on artificial lift systems? With distributed monitoring, an operator can determine how flow dynamics, zonal contribution, and fluid phase change during the production life of a well.



A real-time DTS logging program inside flowing production wells helps identify where to land new horizontal wells by identifying the highest producing intervals.



SINGLE POINT AND DISTRIBUTED SENSING

Fiber-optic sensing falls into two categories: distributed sensing and single point sensors. Distributed sensing uses the fiber-optic cable itself to monitor temperature, acoustics, and strain across the entire length of the well. Pinnacle's FiberPoint™ single point sensors are small, durable, and highly accurate sensor units, which are placed in the well and attached to a high-bandwidth fiber-optic cable. These single point sensors can be multiplexed and placed at strategic locations along the fiber to construct a quasi-distributed measurement.

FIBERWATCH DISTRIBUTED SENSING

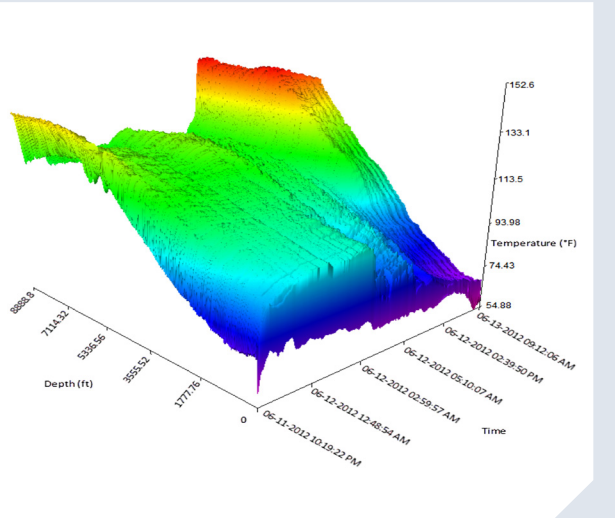
Distributed sensing transforms the fiber optic cable itself into a the sensor. Physical properties, such as temperature, pressure or tensile forces can temporarily alter the way light is backscattered. By sending a pulse of light down the fiber and analyzing the attenuation of backscattered light, Pinnacle can accurately measure these physical properties. Distributed sensing has the advantage of collecting thousands of points of data along the entire length of the wellbore.

TYPES OF DISTRIBUTED SENSING

Distributed Temperature Sensing (DTS) is the most widely used form of distributed sensing. It can precisely measure temperatures up to 300°C (570°F) every meter along the fiber to an accuracy of +/- 1°C (1.8°F) and a resolution to +/- 0.01°C (0.018°F).

Distributed Acoustic Sensing (DAS) effectively turns the fiber cable into a series of geophones (or microphones) to identify near wellbore injection and production, cross well monitoring, fluid densities, fluid migration, and casing leaks, and/or for early detection of equipment wear or failure. In addition, DAS is a cost-effective alternative to traditional vertical seismic profiles (VSPs). DAS offers thousands of sensor points and repeatable time-lapse imaging.

Distributed Strain Sensing (DSS) can help to determine casing deformation location and severity, or provide insight into stresses produced at perforations during stimulation.

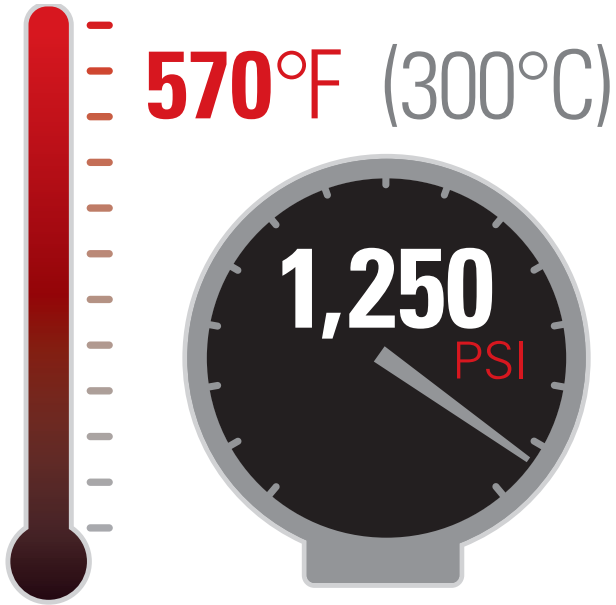


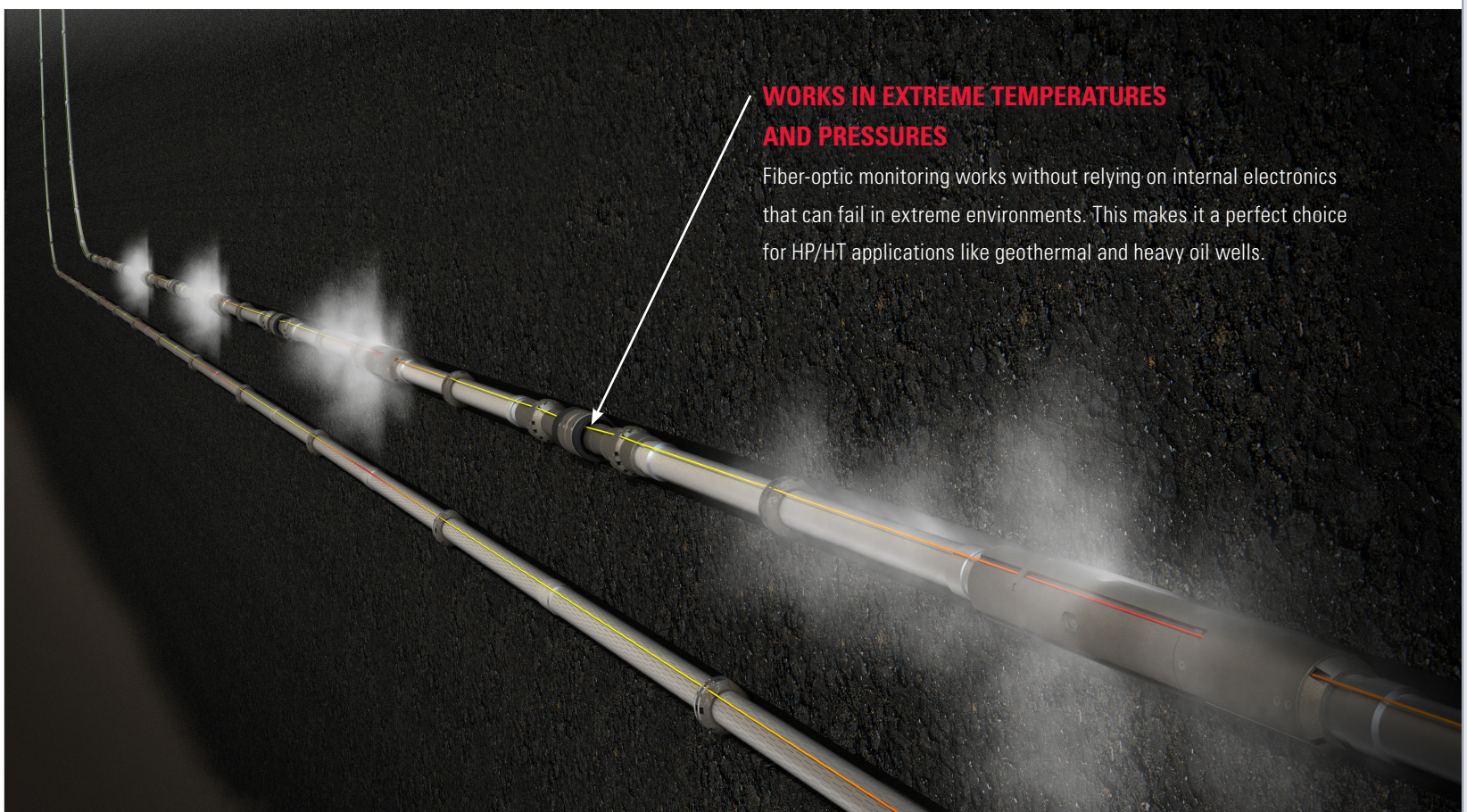
Real-time DTS data

FIBERPOINT™ SENSORS

FiberPoint sensors are some of the most precise measuring tools that are designed to enter into some of the most hostile environments on Earth. Unlike traditional sensors, FiberPoint sensors have no internal electronics that can fail in extreme environments. That means they can reach up to 570°F (300°C) 1,250 PSI (8,600 KPa) in steam-assisted gravity-drainage (SAGD) applications. This opens new possibilities for measurements in a much broader range of downhole conditions.

The FiberPoint sensors accurately measure temperature and pressure, two of the most critical pieces of information for operators.





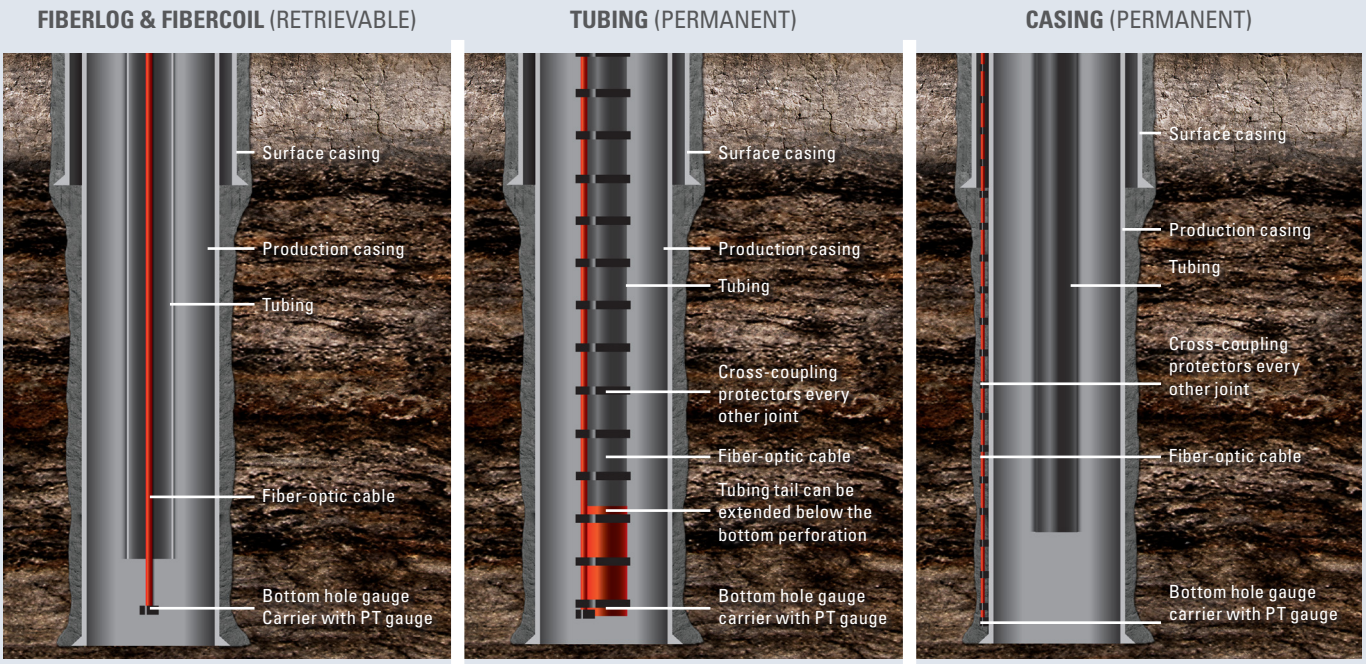
WORKS IN EXTREME TEMPERATURES AND PRESSURES

Fiber-optic monitoring works without relying on internal electronics that can fail in extreme environments. This makes it a perfect choice for HP/HT applications like geothermal and heavy oil wells.

HIGH PERFORMANCE CABLE DESIGN

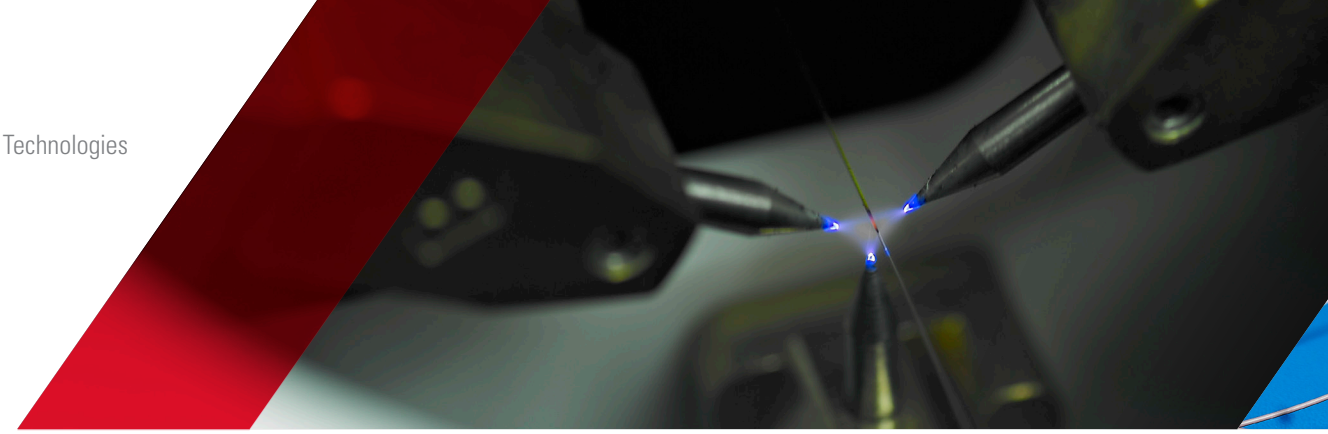
Optical fibers are transparent glass, with a diameter that is approximately the size of a single strand of human hair, that transmits light between the two ends of the cable. Unlike the fiber cables used in the communication industry, fiber optics designed for oil and gas wells utilize specialized glass chemistry, coating, and construction to withstand downhole conditions. Pinnacle has dedicated years of research and testing to create and refine the optical fiber that we use in oil and gas wells. That is the fiber-optic cable advantage.

Advanced cable design and installation techniques help protect the fiber while running into a well. To help ensure reliable operation over the life of the well, Pinnacle matches each fiber cable with the proper FiberWatch brand interrogator and calibrates the entire system using our in-house engineering and manufacturing facilities, which meet ISO certification standards. Operators trust Halliburton's technology, experience, and dedication to help them select the right fiber for use in heavy oil, unconventional, or deepwater applications.



CONVEYANCE OPTIONS

Fiber optic cables and sensors can be placed into the well using a wide variety of conveyance methods, depending on the type of job. Permanent deployment with casing or tubing installation is the best option for life-of-the-well monitoring. Short-term monitoring can be achieved when fiber is inserted into the well with slickline, FiberCoil℠ service (an instrumented coiled tubing solution), wireline enabled FiberLog Service, or even with a pump-down solution.



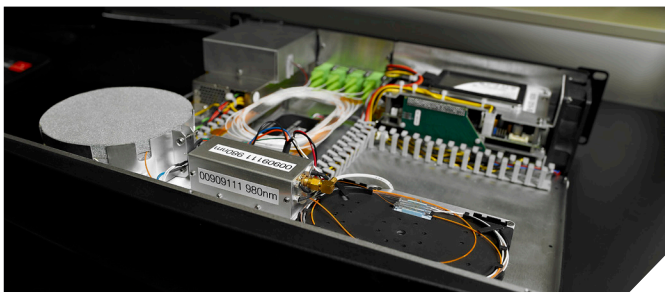
FIBERWATCH INTERROGATORS

The sensors and cables make up two important components of a fiber-optic system, but the interrogator is where the action—and the analysis—really takes place. The interrogator pulses laser light through a fiber-optic cable and records the amount and type of light backscatter, which is reflected back to the unit. Using sophisticated software algorithms, this light backscatter is translated into measurement data. Our FiberWatch interrogator units do not use telecom system lasers; we utilize specialized single- or multi-laser systems optimized to specific wavelengths for oil and gas applications. We engineer and manufacture all fiber-optic interrogators to ISO 9001 standards.

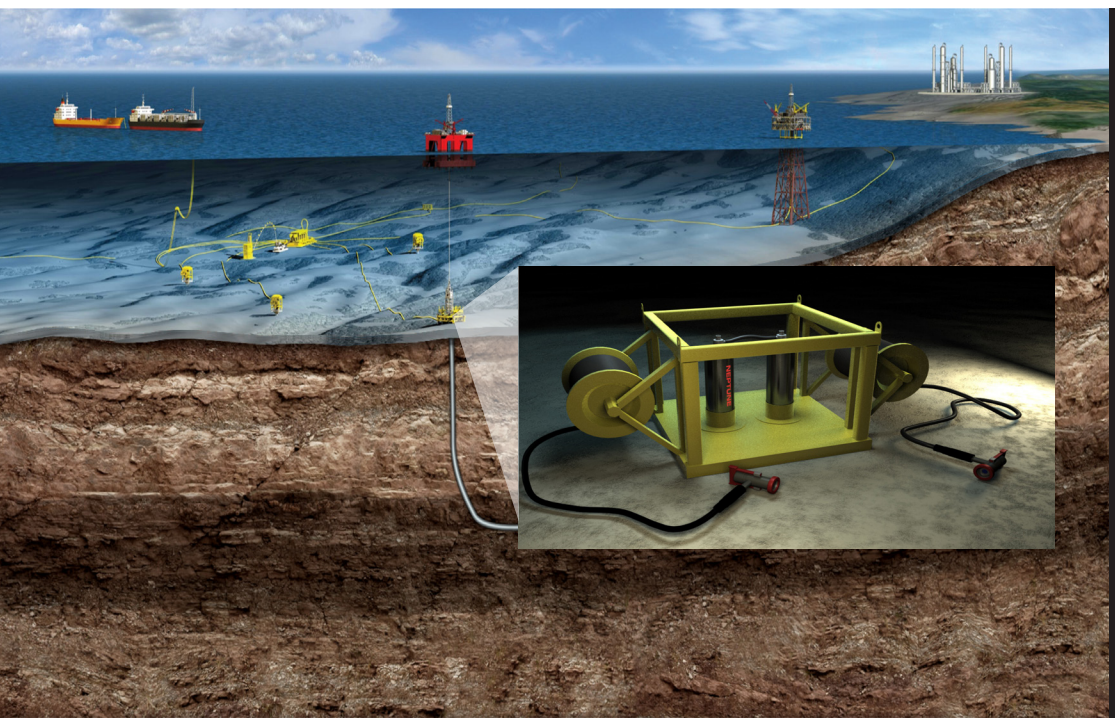
When operators need to ensure long-term operation without the detrimental effects of attenuation losses caused by bending losses or hydrogen darkening, dual-laser interrogators help them achieve their goals. Halliburton's proprietary dual-laser system operates on specific wavelengths that can compensate for hydrogen darkening.

FIBERVIEW™ SOFTWARE

With so many data points along the fiber cable, collecting, storing and analyzing information can be an incredibly complex task. Our FiberView™ software is designed for both distributed and single point sensor data. FiberView software is built to organize huge amounts of data into a visualization platform and to algorithmically interpret the data so that engineers can focus on decisions.

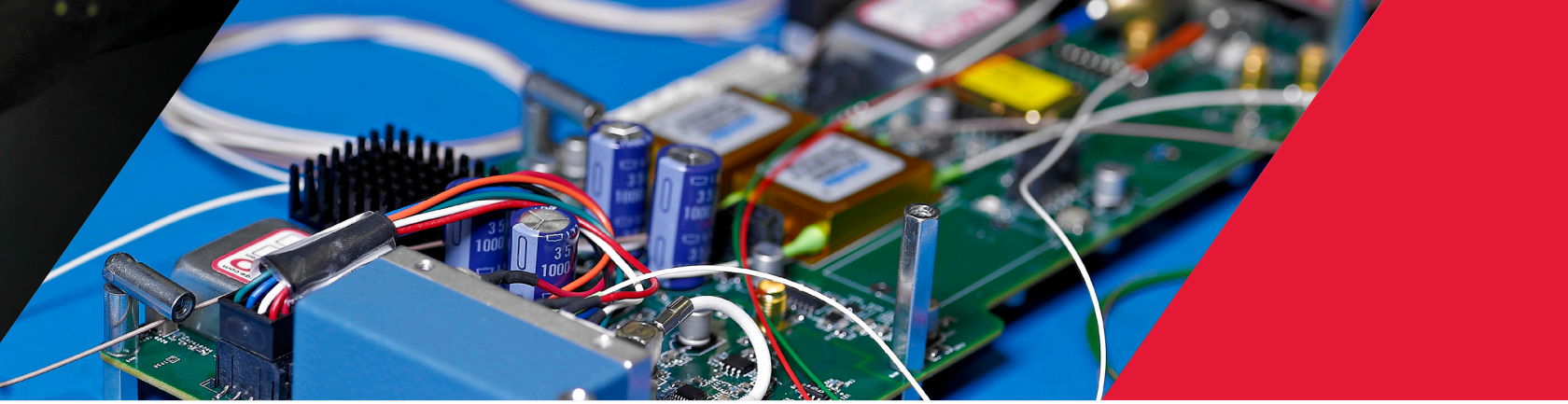


Our FiberWatch SL interrogator uses a traditional single-laser system to achieve accurate fiber optic monitoring at a fraction of the price of more complex solutions.



WE DEPLOYED THE WORLD'S FIRST SUBSEA DTS INTERROGATOR

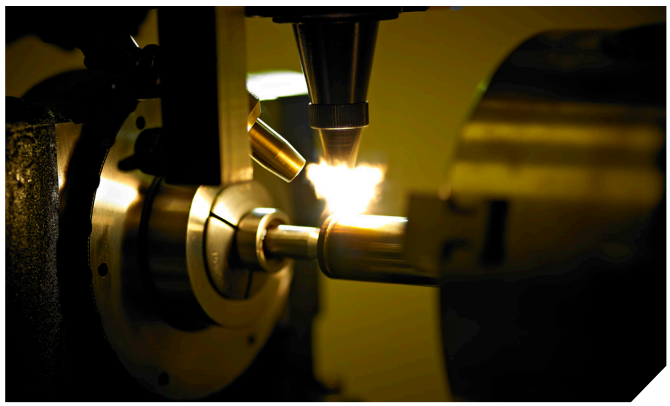
The FiberWatch DTS Subsea is certified for operation up to 10,000 feet of water. This gives operators a clear picture of the well, even where other systems cannot reach.

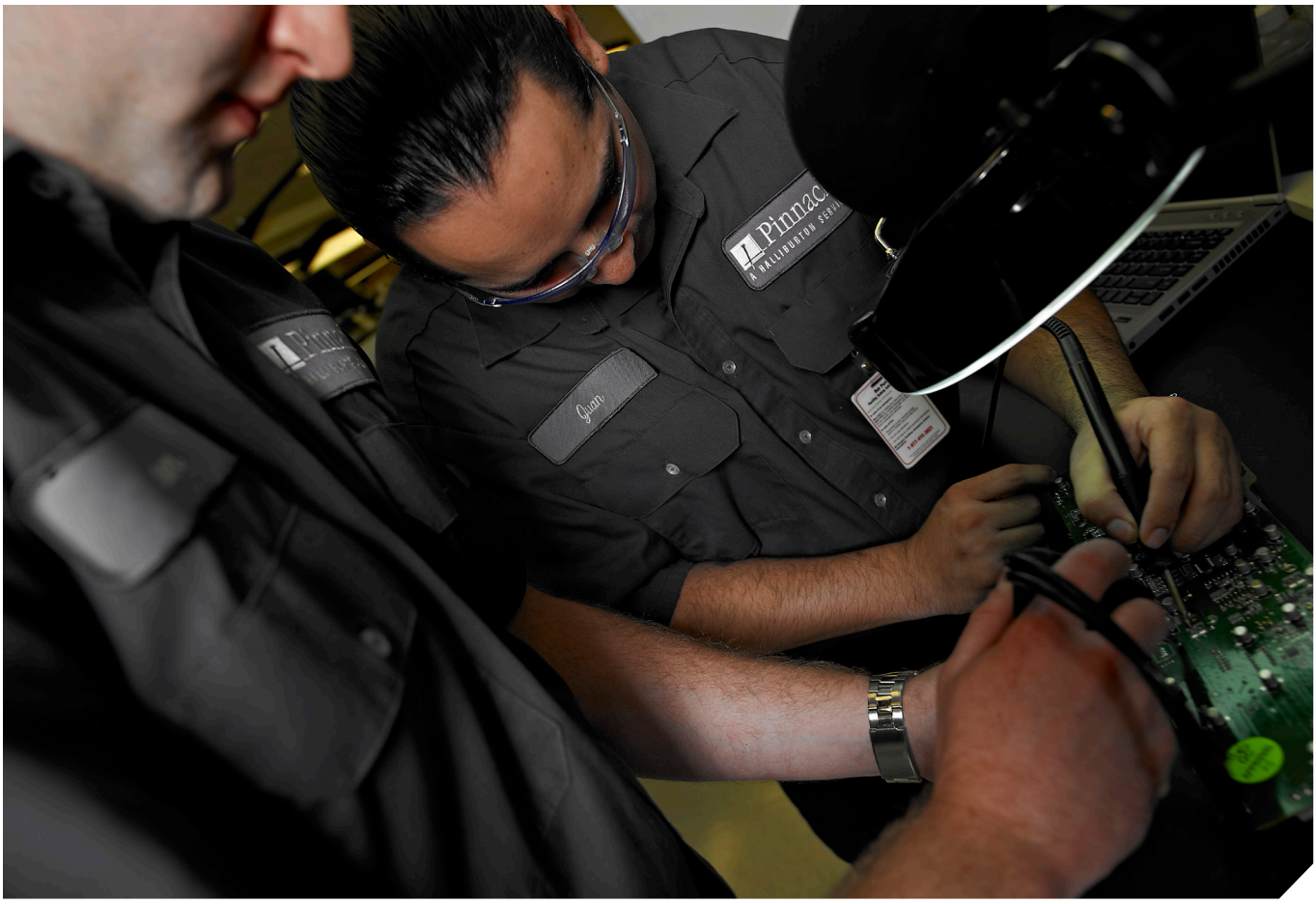


THE FUTURE OF FIBER

Halliburton is dedicated to finding new solutions that will shape the industry for years to come, and fiber-optic technology will play a key role in that future. At our Applied Photonics Center, we're developing the next generation of fiber services and applications.

Halliburton's goal is to lead the way in fiber-optic development to help solve our industries most pressing upstream challenges.





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