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**Prepared for**

***Plug Company (fictitious company)***

Intelligent Valve for Oil and Gas Well Blowouts



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# INTRODUCTION

This report provides a recommendation regarding investment worthiness of a technology or invention. For the purposes of this report, investment is defined as additional time, money, or labor required to bring a technology closer to market readiness. To ensure an appropriate return and to mitigate risk, it is most beneficial if investments are made in inventions or early stage technologies that appear likely to achieve a competitive advantage in the market. Therefore, making investment decisions can prove difficult without first understanding market factors such as the presence of prior art which includes existing offerings, patents and research and development (R&D) activities as well as the presence of opportunities or barriers in the market. This report evaluates these factors and provides a simplified recommendation that is based on a traffic light. Unlike other types of market assessments, this report is structured to look for red lights or those factors that would limit the commercial potential of the technology and justify a non-investment. Working in this way, clear winners – or green lights – can be identified which helps to mitigate risk and increase investment returns.

## Non-Proprietary Technology Description

A non-proprietary description of the company/organization’s technology is offered below:

The technology is an intelligent valve used to plug oil and gas wells to stop blowouts. The valve can be inserted into a high-pressure stream in the open position allowing it to be positioned in the well pipe without being jettisoned. The valve is capable of accurately measuring well output, information needed to determine if a blowout can be safely plugged. The valve cage is set firmly against the pipe wall to prevent dislodging as the valve is closed. The valve can be reopened once the pipe/well head is repaired allowing for the resumption of oil or natural gas production.

## Industry Classification

The North American Industry Classification System (NAICS) is the standard leveraged by business and government in categorizing business establishments relevant to its type of economic activity in the United States, Canada and Mexico. The example technology is applicable under the following NAICS: 237120. Establishments under this NAICS are “primarily engaged in the construction of oil and gas lines, mains, refineries, and storage tanks. The work performed may include new work, reconstruction, rehabilitation, and repairs. Specialty trade contractors are included in this industry if they are engaged in activities primarily related to oil and gas pipeline and related structures construction. All structures (including buildings) that are integral parts of oil and gas networks (e.g., storage tanks, pumping stations, and refineries) are included in this industry.” [[1]](#footnote-1) Oilfield service companies with a large presence domestically and globally reported revenues of at least $14 billion in 2015. [[2]](#footnote-2)

## Search Scope

For the purposes of this report, all searches were conducted at a national scope.

## Section Summary

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| **Patent Recommendation:** | Green | Proceed. The all-in-one properties of the Intelligent Valve do not appear to be present in other patented well plug technology |

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| **Offerings Recommendation:** | Yellow | Proceed with caution. There are many well plug technologies available. |

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| **R&D Recommendation:** | Green | Proceed. The Intelligent Valve will have value when blowouts do occur. There is still a need for novel blowout kill technologies. |

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| **Market Recommendation:** | Green | Proceed. One can envision every oil and gas exploration rig carrying an Intelligent Valve in the event of a well blowout. |

## Overall Recommendation

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| **Overall Recommendation:** | Yellow | Proceed with caution. The value of the Intelligent Valve, particularly for well blowout prevention, will have to be demonstrated to gain commercial interest from the Oil and Gas services companies – including Schlumberger, Baker Hughes and Haliburton. |

# Patents & PATENT APPLICATIONS

A cursory search of existing patents and patent applications was performed within USPTO. Additional searches may be performed through Google Scholar & Patents and The Lens, a publicly available patent database that is based upon several datasets. This search is based on key words that are relevant to the technology including: blowout, plug, well, and borehole. Patent and patent applications that appear relevant have been included in the table below. Using keywords including blowout, plug, well and borehole in the full text field yielded 1,611 results for a total of 830 patent families. Top applicants include Halliburton Energy Services Inc., Shell Oil Co., Schlumberger Technology Corp., Weatherford/Lamb, and Baker Hughes Inc. From 1992 through 2017, the rate of IP has been steadily increasing in this area with a total of 137 publications filed in 2017 alone.

## Relevant Patents & Patent Applications

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| **Capture method for flow back retrieval of borehole plug with a lower slip assembly** | | |
| **Patent or Patent Application Number**:  US20180023364 | **Assignee or Applicant:** Baker Hughes Incorporated | **Publication Date:** 1/25/18 |
| **Abstract:** A borehole plug or packer for treating is designed to be flowed back to a surface location after use. When the treatment is concluded pressure from above is relieved or lowered, and well fluid is flowed back, so that the plug or plugs disengages at slips designed to resist differential pressure from above. The application of differential pressure from below causes the lower slips to release one or more of such plugs in the hole into specialized sub surface or surface capture equipment so that well pressure is relieved before removal of the plugs from specialized subsurface or surface capture equipment. Packers or plugs are captured above, below or at a wellhead in a receptacle. Production ensues without milling with the captured plugs or packers in place or removed. | | |

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| **Borehole data transmission method for flowed back borehole plugs with a lower slip assembly or object landed on said plugs** | | |
| **Patent or Patent Application Number**:  US20170362914 | **Assignee or Applicant:** Baker Hughes Incorporated | **Publication Date:** 12/21/17 |
| **Abstract:** A borehole plug or packer for treating is designed to be flowed back to a surface location after use. When the treatment is concluded pressure from above is relieved or lowered, and well fluid is flowed back, so that the plug or plugs disengages at slips designed to resist differential pressure from above. The application of differential pressure from below causes the lower slips to release one or more of such plugs in the hole into specialized sub surface or surface capture equipment so that well pressure is relieved before removal of the plugs from specialized subsurface or surface capture equipment. Sensors to obtain and store data can be incorporated into the plugs or into objects landed on the plugs so that when brought to the surface the data can be processed and used in aid of production. | | |

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| **Cementing plug tracking using distributed strain sensing** | | |
| **Patent or Patent Application Number**:  US9222349 | **Assignee or Applicant:** Halliburton Energy Services Inc. | **Publication Date:** 12/29/15 |
| **Abstract:** Various systems and methods for cementing plug tracking using distributed strain sensing include a downhole cementing apparatus that includes a distributed strain sensor with an optical cable and a first downhole cementing plug coupled to a fixed point on the optical cable. The apparatus further includes a second downhole cementing plug slideably coupled to the optical cable between the first downhole cementing plug and a sensing end of the optical cable. The second downhole cementing plug causes a detectable feature in a strain profile along the optical cable's length that indicates a position of the second downhole cementing plug. | | |

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| **Downhole plug** | | |
| **Patent or Patent Application Number**:  US20130292119 | **Assignee or Applicant:** Welltools Limited | **Publication Date:** 7/11/13 |
| **Abstract:** A downhole plug for plugging and method of controlling fluids within a borehole in an oil and/or gas well. The downhole plug has a body having a throughbore for the passage of fluids. The plug also has a mechanical anchoring device that can radially expand an anchoring member on an outer surface of the body to lock the body in a fixed axial position within the borehole and an annular sealing device that can radially expand a sealing member on the outer surface of the body to seal an annulus formed between the outer surface of the body and an inner surface of the borehole. | | |

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| **Downhole plug** | | |
| **Patent or Patent Application Number**:  US7290603 | **Assignee or Applicant:** Interwell Norway AS | **Publication Date:** 11/6/07 |
| **Abstract:** Downhole plug, especially designed for closing an annular conduit in an oil or gas well, under high pressure and temperature. It has two radially expandable ring elements, which are arranged on a carrying cylindrical element, between two mutually axially movable pressure elements having an expansion sleeve in between. The ring elements can, by insertion of the downhole plug in a well, be expanded from an inner position, seen radially, to a sealing position against the wall of the well. The radially expandable ring elements, comprises a closed series of circumferentially overlapping seal elements. By the expanding movement they are mutually moved in the circumferential direction, thereby maintaining a seal against each other. They form an outer sealing surface, which can provide a seal against a cylindrical pipe wall, and they have an inwards facing sealing surface**.** | | |

## Analysis

The example patents and applications cited above describe technological advances in the development of borehole plugs with a focus on ease of removal, remote data transmission and durability. These are all properties of the Intelligent Valve. Moreover, the Intelligent Valve can remain in the pipe even after the blowout is repaired and can provide flow-rate as well as other information during production. The Intelligent Valve is designed not to impede oil gas flow when in the open position. All of the companies listed as assignees for these patents or applications are leaders in the oil and gas services business. The implication here is that they are doing research to improve blowout control as well as temporal well plugging methods. This is an indication that they are not satisfied with current well plug solutions.

Please be aware that when comparing the novelty of this technology to existing patents and patent applications, consultation with a patent attorney is recommended.

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| **Patent Recommendation:** | Green | Proceed. The all-in-one properties of the Intelligent Valve do not appear to be present in other patented well plug technology |

# Commercial Offerings

Offerings can include commercially available products and services. Competition can occur from offerings that are attempting to address the same issue in a similar manner (direct competition) as well as from offerings that are substitutable or address the same issue in a completely different manner (indirect competition). A search for similar and substitutable commercial offerings was performed using BCC Research, Frost & Sullivan, MarketsandMarkets, and Google. This search is based on key words that are relevant to the commercial application for your technology including: oil, gas, well, borehole, wellbore, plug, completion barrier, well abandonment, bridge plug, temporal, permanent, subsea, deep water, offshore.

## Overview

There are several methods to plugging and abandoning of oil and gas wells including cement plugs, specialty cement plugs, bentonite and drilling mud, and mechanical plugs such as bridge plugs and cement retainers. [[3]](#footnote-3)

## Relevant Commercial Offerings

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| Offering Name | Company | | Description | | Image | |
| [Evo-Trieve® Bridge Plug](http://www.halliburton.com/public/cps/contents/data_sheets/web/h/h06439.pdf) | Halliburton | | The Evo-Trieve® bridge plug is a high-performance retrievable monobore plugging device that does not require a predetermined setting restriction for locating or sealing within the production completion. Evolved from the industry-leading HE3®, TR0 / TR1 and Monolock® retrievable bridge plugs, the Evo-Trieve bridge plug blends past experience with future industry requirements.  The Evo-Trieve bridge plug is V0-qualified per ISO 14310 to 7500 psi and up to 325°F. Its robust design includes large slip and element footprints to provide improved pressure-holding capability in unsupported casing. Debris tolerance has been verified through a comprehensive flow loop testing program. | |  | |
| [SIMultra Retrievable Bridge Plug](https://www.slb.com/services/well_intervention/slickline/simultra-retrievable-bridge-plug.aspx)  [Brochure](https://www.slb.com/~/media/Files/slickline/brochures/simultra-retrievable-bridge-plug-br.pdf) | Schlumberger | | The SIMultra retrievable bridge plug delivers both proven sealing integrity and dependable retrievability, even in challenging downhole conditions. Fully certified to ISO 14310:2008 grade V0 and Quality Grade Q1, the SIMultra plug incorporates a unique proprietary hybrid metal-elastomer seal. This innovative seal design eliminates permanent elastomer setting and elastomer decompression—and their adverse effects on plug retrieval—while providing a full metal contact.  Available for industry standard tubulars ranging from 4 1/2 to 7 in, the SIMultra plug is performance rated to 350 deg F, 10,000 psi, and full sour service capability to readily meet the extremes of today’s energy production, including HPHT and gas wells. Bidirectional high-expansion and high-load slips ensure secure setting at any well deviation.  By using a proprietary nonexplosive tool for setting and retrieval, the SIMultra plug can be deployed in vertical and horizontal wells using all conventional conveyance methods. For slickline operations, the downhole intelligent decision module enhances setting assurance by using time, temperature, pressure, and tool movement measurements to identify the correct setting depth. | |  | |
| [CIW Bridge Plug](http://www.dloiltools.com/products/service-tools/ciw-bridge-plug)  [Brochure](http://portal.dloiltools.com/product_detail/download?file_name=ciw-bridge-plug-76409794.pdf&_ga=2.166676279.86408856.1537886475-2062552798.1537886475) | D&L Oil Tools | | The CIW Bridge Plug is designed to have excellent running characteristics and secure sets. This plug can be set on different types of Wireline Pressure Setting Tools as well as with Hydraulic Setting Tools. This plug is designed for rapid drill-out while maintaining sufficient strength during the set. It is designed for high differential pressures and temperatures up to 250° F with standard nitrile element and o-ring. Different elastomers are available for higher temperatures.  The short, compact, interlocked construction assures the CIW Bridge Plug will provide faster, safer run-in, dependable set and pack-off, and hold pressure that is safe for the casing weight and grade. The interlock construction and compact size requires minimal material removal during drill out. | |  | |
| [LastLock®](http://archerwell.com/content/uploads/2014/10/LASTLOCK-product-sheet.pdf) | Archer | | As part of the LOCK™ series to provide gas-tight barriers for wells, LASTLOCK brings total security and maximum protection for permanent plug and abandonment (P&A).  **Benefits**   * Permanent barrier (VO protection) * Easy and rapid deployment * Safer and lower cost operations * Flexible set depths and angles   **Features**   * ISO 14310 V0 certified gas-tight seal with enhanced seal technology * High performance elastomer (NORSOK M-710 approved) * No set weight needed below * High differential pressure elements * Multiple sets without tripping * Sizes 7” – 14” | |  | |
| [SRP Wellhead Plug with added back pressure valve](http://www.halliburton.com/public/cps/contents/Presentations/Subsurface%20Flow%20Controls_External.pdf) | Halliburton | | * Deepwater development has created demand for wellhead plugs * Used primarily in subsea trees * Ultra-compact design allows for use in horizontal trees * Available in equalizing and non- equalizing models * High-pressure rating above and below * No-go design with minimum restriction   **Design Features**   * Redundant seals along all leak paths * OD leak path is through two full packing stacks * Equalizing plug leak path is through a static MTM seal and an O-ring * Valve leak path is through a MTM seal and a packing stack * Multiple shear pin hold down mechanisms for redundancy * Only three moving parts: keys, expander sleeve, and valve * Can hold pressure from above with the addition of a test prong * Cannot be pulled until equalized * Two options for equalizing prongs. One engages the knock-out plug and one pushes the dart off seat | |  | |
| [PlugCemTM](http://www.halliburton.com/public/cem/contents/Chem_Compliance/web/H05835.pdf) Cement | | Halliburton | | With Tuned Cementing Solutions™ cementing systems, Halliburton has created a set of innovative fit-for-purpose solutions with the flexibility required to allow each system to be tuned specifically for a given set of wellbore conditions. PlugCem cements form one of these families of fit-for purpose solutions. With PlugCem cement you receive a conventional cementing solution designed to form an effective cement plug in either cased or open hole intervals using specially tuned systems. PlugCem systems are ideal for temporary and permanent abandonment plugs, lost circulation, or kickoff and whip-stock plug | |  |
| [PlugSealTM](http://www.halliburton.com/public/cem/contents/Chem_Compliance/web/H05857.pdf) Cement | | Halliburton | | With Tuned Cementing Solutions™ cementing systems, Halliburton has created a set of innovative fit-for-purpose solutions with the flexibility required to allow each system to be tuned specifically for a given set of wellbore conditions. PlugSeal cements form one of these families of fit-for-purpose solutions. With PlugSeal cement you receive a foamed cementing solution designed to form an effective cement plug in either cased or open hole intervals using specially tuned systems. PlugSeal systems are ideal for temporary and permanent abandonment plugs, lost circulation, or kickoff and whip-stock plugs. PlugSeal cement can provide the additional benefits of increased compressibility, bridging, and elasticity gained through the introduction of stable, well-dispersed small N2 bubbles. | |  |

## Analysis

The offerings presented above represent a small fraction of the well plug solutions currently available. Either mechanical or cement, these have been utilized to temporarily or permanently stem oil or gas flow from wells. Drilling mud or cement is commonly used to quench a well blowout. However, in some cases, such as the Deepwater Horizon oil spill, the blowout pressure is so strong that traditional remediation methods fail. Here the Intelligent Valve has the advantage of allowing maximal outflow as it is inserted into the pipe. Once set in place, it can be closed gradually unto flow is stopped. Cement can be placed over the Intelligent valve to complete a plug and abandon operation. It should be noted that most wells have blowout preventers attached to the well head. These automatically shut of gas and oil flow when a blowout is detected. In the case of the Deepwater Horizon oil spill and other blowouts, the blowout preventer failed.

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| **Offerings Recommendation:** | Yellow | Proceed with caution. There are many well plug technologies available. |

# Research and Development Activities

Understanding similar R&D activities relevant to a technology provides insights as to intended direction of not only competition, but also the market being considered for entry. Relevant R&D activities have been identified below using a search performed on BCC Research, Frost & Sullivan, MarketsandMarkets, Google Scholar, and The Lens’ Scholarly Works. In most cases, R&D efforts are limited to the current year plus one, although on lesser occasions, information may be collected from publications produced before this designated timeframe. This search is based on the following key words including: oil, gas, intelligent, well, borehole, plug.

## Relevant R&D Activities

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| **Case study on remotely operated intelligent plugs to eliminate multiple wireline runs in offshore completions** | |
| **Authors**:Zac Arackakudiyil Suresh, Linh Nguyen, Bharathwaj Kannan, Oh Huyn Jung, Yi Jae Seok, and Truyen Luu | |
| **Organization:**Halliburton and KNOC | **Date:**November 2016 |
| **Abstract/Relevance:**This paper introduces a novel application of intelligent completions using remotely operated intelligent plugs that can eliminate multiple wireline runs. This case study outlines completion of two wells in offshore Vung Tau, Vietnam using intelligent plugs. The plugs were used to test tubing, set the packer, and later act as deep-set barriers for christmas tree installation.  The wells were completed with two intelligent plugs preinstalled and run-in-hole (RIH) open. One was installed above the production packer and the other below. Use of such intelligent plugs allowed opening and closing the plugs remotely; this feature is attributed to the plugs' onboard decision-making electronics to monitor well conditions programmed to either open or close whenever a specified condition (known as a trigger) is detected. This allowed the operator to communicate to the tool remotely from the surface using applied-pressure commands.  The upper plug was closed initially to test the tubing string. It was later opened and the lower plug was closed to set the packer. The lower plug was then opened to test the packer. Both plugs were later closed to act as barriers when the blowout preventer (BOP) was removed and the christmas tree was installed. Both plugs were then opened and pulled out of hole (POOH) on wireline.  The use of remotely operated intelligent plugs helped the operator successfully eliminate eight wireline runs, saving approximately 15 hours of rig time. Considerable monetary savings were gained by removing intervention runs. Additionally, health, safety, and environment (HSE) risks associated with rigging up and running wireline were also eliminated in this case.  The industry is striving to perform completion and intervention activities in a safer and more economic manner. This case study of remotely operated intelligent plugs can be a timely addition to existing intelligent completion solutions. [[4]](#footnote-4) | |

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| **Maximizing completion efficiency using remotely operated barrier valves** | |
| **Authors**:Barry Thomson, Zac Suresh Arackakudiyil and James Todd | |
| **Organization:**Halliburton and Chevron | **Date:**November 2016 |
| **Abstract/Relevance:**The paper introduces an application of intelligent completions that uses remotely operated barrier valves to improve completion efficiency. The case study outlines the completion of a well in the UK North Sea. The valves were used to set the packer and to test tubing; later, they functioned as shallow and deep-set barriers for the removal of the blowout preventer (BOP) and the installation of the christmas tree.  The well was completed with two barrier valves deployed in the open position; one was installed for use as a shallow-set barrier above the safety valve and the other as a deep-set barrier below the production packer. The valves used onboard decision-making electronics that monitor well conditions and that are programmed to open or close in response to the detection of a specified condition (known as a trigger). This configuration enabled the operator to communicate with the tool remotely from the surface by using applied-pressure commands. The use of remotely operated barrier valves made it possible to open and close the barriers multiple times.  The deep-set valve was initially closed to set the packer and test the tubing string. It was later opened to test the packer on the annular side, and it was closed to act as a deep-set barrier. The shallow-set valve was later closed to act as a second barrier to enable the removal of the BOP and the installation of the christmas tree. Both valves were then remotely opened to begin production.  The use of remotely operated barrier valves helped the operator to successfully eliminate eight wireline runs, which resulted in the elimination of approximately 59 hours of rig time. The health, safety, and environment (HSE) risks associated with rigging up and running wireline were also eliminated in this case.  The industry is striving to perform completions and intervention activities in a safer and more economic manner. This case study demonstrates the new use of remotely operated barrier valves will provide a timely addition to existing completion solutions. [[5]](#footnote-5) | |

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| **A case study on remotely operated intelligent bridge plugs for plug and abandonment operations** | |
| **Authors**:Zac Suresh Arackakudiyil, Barry Thomson and Carl Henning Forde | |
| **Organization:**Halliburton | **Date:**September 2016 |
| Abstract/Relevance: This paper demonstrates a new method of using remotely operated intelligent bridge plugs to replace conventional plugs, thereby eliminating the need for multiple wireline runs. This reduces operational expenses and eradicates potential health, safety, and environment (HSE) challenges resulting from additional personnel involvement in the pressure control equipment rig up and testing.  Use of traditional plug-and-prong barriers and retrievable bridge plugs is integral in plug and abandonment (P&A) operations. However, multiple wireline runs are required in wells with considerable gas buildup.  The well in this paper had a considerable amount of gas buildup in the annulus that required periodic circulating. Use of an intelligent bridge plug offered the potential to open and close the plug remotely because the plug uses onboard decision-making electronics that monitor well condition. The plug is programmed to either open or close whenever a specified condition (known as a trigger) is detected.  The intelligent bridge plugs allowed the operator to communicate with the tool remotely from the surface using applied pressure commands, and the plugs were opened and closed periodically to circulate the gas buildup out of the annulus. The plugs were later closed remotely to act as a barrier while the christmas tree was removed and the blowout preventer (BOP) was installed. The plugs were finally opened and pulled along with the tubing, saving further wireline runs. [[6]](#footnote-6) | |

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| **Plug and abandonment solution for oilfield decommissioning in the North Sea** | |
| **Authors**:P. Aguilar, C.R. Johnson, J. Salazar and M. Bogaerts | |
| **Organization:**Schlumberger | **Date:**April 2016 |
| **Abstract/Relevance:** When wells have come to the end of their lives, it becomes necessary to plug and abandon them and return the seabed to its original condition. In the UK sector of the Central North Sea (CNS), an operator managed 6 fields comprising a total of 30 subsea wells in 7 clusters, required to be plugged and abandoned. These fields are among many that are coming to the decommission stage, with the over-riding requirement from the UK government being that of no leakage of hydrocarbons to the environment or between separate permeable geological zones.  The operator standards required the placement of two cement barriers of a minimum of 100-ft each for zonal isolation. The preferred route was to find the annular portion of the barrier by interpretation of ultrasonic imaging tool in combination with the cement bond (CBL) wireline logs used for cement evaluation service, then to set a 500-ft plug inside the casing opposite that zone. In the case that no barrier quality cement was identified in the annulus, section milling of the casing was undertaken to expose 100-ft of formation over which cement was placed.  A number of challenges were faced to design the cement slurry prior to the logging results. The setting depth may only have been confirmed a few hours before the cement job. To cover the possible setting depths and temperature ranges, laboratory testing consisted of performing temperature sensitivity tests on base slurries designed with a wide temperature range retarder, but still optimizing the system to minimize wait on cement (WOC) time.  **A specialized high magnesium resistance (HMR) cement system that provides long-term zonal isolation and protects against cement degradation was identified as being best solution.** The HMR cement is a blend of blast furnace cement and fly-ash, which reduces the cement permeability and limits the effect of alkaline brine corrosion.  Optimal plug placement was also required for long-term isolation. Specialized plug placement software that accounts for in-pipe and annular contamination, and fluid interface matching during pulling out of the plug was utilised. The slurry design and emplacement best practices will be summarized in this paper.  **These subsea wells have been successfully plugged and abandoned by laying temporary, primary, secondary and environmental cement barriers by several different methods: inside casing, across section-milled windows, multi-annular, through scaled production tubing and through coiled tubing according to each particular well's condition.** Success ratio was exceptionally high with all the long-term barrier themselves being flawlessly placed and verified without any repeat job being required. [[7]](#footnote-7) | |

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| **Plug and abandonment solution for oilfield decommissioning in the North Sea** | |
| **Authors**:Mahmoud Khalifeh, Helge Hodne, Arild Saasen and Torbjorn Vralstad | |
| **Organization:**University of Stavanger, Det Norske Oljeselskap ASA, and SINTEF | **Date:**May 2013 |
| **Abstract/Relevance:** Plug and Abandonment (P&A) can easily contribute with 25% of the total costs of drilling exploration wells offshore Norway. The costs of running a P&A operation on some offshore production wells may have a cost impact similar to the cost of the original drilling operation. Therefore, cost efficient P&A technology is necessary to reduce cost. In this paper, qualified technology and materials for P&A is reviewed to act as a basis for P&A planning. This paper describes in detail requirements for P&A operations offshore Norway as well as normal practices for P&A. Well construction issues related to minimising the need for later P&A operations like proper primary cementing planning is discussed. P&A techniques and materials for P&A operations are reviewed to act as background information for future P&A planning on the Norwegian continental shelf. These techniques include operations ranging from milling to washing and squeezing cement or other materials. **The materials being reviewed include swollen shale, concentrated sand, metal plugs like bismuth, as well as improved conventional cement systems.** This work presents an overview of the well plugging and abandonment challenges, innovative potential barriers and case histories on the Norwegian continental shelf.  **Introduction** Oil and gas wells at some time in their life will be plugged and abandoned. Improperly abandoned wells can become a significant threat to the environment if they are not constructed or sealed properly. Plugging material (barrier) may fail during or after placement. Barrier failure can be caused by: natural fractures/faults, tectonic stresses, improper plug placement or materials used. In brief; isolation outside casing, collapses and sustained casing pressure are main well integrity challenges with respect to Plug and Abandonment (P&A). **The quality and performance of a P&A operation may be investigated by two points of view; type of plugging material and plug placement technique.** **Barriers may be categorized as cementitious or mechanical barriers. It should be noted that mechanical barriers are used as temporary P&A barriers and not allowed to be used as permanent barriers.** Type of material used defines the type of plug placement technique. There are several cement plug placement techniques that are used in the abandonment process (Smith 1993; Nelson 2006): 1) Balanced method, 2) Dump-bailer method, 3) Two-plug method, and 4) Jet grouting. The following tools are used for placing cement plugs: 1) Flexible bags, 2) Inflatable through-tubing packers, and 3) Umbrella-shaped membranes (Nelson 2006). Local practices, government regulations, company policies and well conditions lead to variations of the above-mentioned tools and methods. [[8]](#footnote-8) | |

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| **Challenges in setting cement plugs in deepwater operations** | |
| **Authors**:Martijn Bogaerts, Alia Iza Kanahuati, Polina R. Khalilova, Fabricio Moretti, Eric Voon and Shailesh Dighe | |
| **Organization:**Schlumberger Tech Services and Schlumberger | **Date:**June 2012 |
| **Abstract/Relevance:** Offshore cementing poses many challenges across the world as drilling operations move towards deep-water and ultra-deep-water. As a new initiative of continuous improvement, a deep-water cementing peer review process was started early 2011. To this date, this team has reviewed more than 1200 deep-water cementing jobs in more than 30 countries worldwide.  **Plug cementing makes up nearly 53% of all the deep-water jobs reviewed**. **The majority of the cement plugs placed are for plug and abandonment purposes;** however a significant part is for loss circulation, kick-off, or squeeze. Although plug cementing comprises a big portion of deep-water cementing, it often does not get the same level of attention as primary cementing.  Specialized plug cementing software is used to design all cement plugs set in deep-water operations. The software simulates fluid interfaces, contamination during placement (both when the fluid is travelling down the pipe and when it is being placed in the annulus) and while pulling out of hole. As a final result, it provides the top of uncontaminated cement. Aside from proper job placement, good slurry design is very important. Cement slurries used for plug cementing need to be designed according to the objectives of the job. Several case histories will show lessons learned from the analysis of plug cementing operations in deep-water operations.  As the industry and local regulations gets more stringent on the evaluation and acceptance of the barrier for well integrity, the success of setting a cement plug the first time is becoming ever more critical. Getting it right the first time easily saves several days of NPT resulting in savings of millions of dollars, especially in this deep-water environment. Appropriate focus on sound engineering practices and the use of the specialized software has improved reliability of setting cement plugs in deep-water and helps operators avoid costly remedial operations. [[9]](#footnote-9) | |
| Ultra-Deepwater Blowout Well Control and Abandonment Operations Through Relief Well Under Capping and Containment Scenario After Worst Case Discharge | |
| **Authors: F. Terra. A. Large, et.al.** | |
| **Organization:** Petrobras and Schlumberger | **Date:**2015 |
| **Abstract/Relevance:** or ultra-deepwater wells, the ability to control and plug the blowout well is more and more important as regulatory agency has more strict rules to issue a drill permit. After the blowout well is killed, cement plugs need to be placed in the borehole to prevent migration of fluids between the different formations. Because of the mixing and contamination process of the cement slurry pumping through relief well, to ensure required cement height and good quality for blowout well, is more challenging than the topside intervention well plugging operations.  In this study, dynamic simulations are carried out to assess the difficulties faced during blowout well control and abandonment. In the selected scenarios, the capping stack system is installed on the wellhead of the blowout well and three vessels are used to capture the oil with risers connected to each vessel separately. Through the relief well, sea water is pumped to the blowout well, increasing the hydrostatic pressure and reducing the rate of production. The injection of sea water together with the manipulation of choke outlet pressures on the vessels provides proper conditions for controlling the blowout well, keeping the liquid flow rates within the limits imposed by the processing capacity at surface. As sea water accumulates in the blowout well, reducing oil production rate, each vessel is shut down accordingly. Once the blowout well is completely filled up with sea water, kill mud is used to replace sea water to ensure static kill. Cement slurry is then pumped to blowout well to set the cement plug. The displacement is specially studied when the cement slurry is flowing into the blowout well. In the sensitivity analysis, borehole enlargement, cement slurry rheology, and flow rate are considered to investigate the contamination of the cement slurry.  The presented outcomes allow engineers to better understand the operation procedures for blowout well control with capping, containment and zero discharge to the environment under capping and containment scenario after worst case discharge, and the methods to mitigate cement slurry contamination and ensure good cement plug for well abandonment.[[10]](#footnote-10) | |

## Analysis

Research on oil well control covering plug and abandonment and blowout kill procedures shows the greatest emphasis on prevention of blowouts by recognizing the signs of an initiating event and taking active measures to mitigate the event before the blowout occurs. Much of this is based on training and SOPs. Failure to recognize the signs of “kicks” (changes in overpressure that can cause a blowout) were considered to be the root cause of the Deepwater Horizon oil spill. It is important to note that in spite of improved training and procedures, blowouts still do occur. Technologies such as the Intelligent Valve that can successfully kill a blowout while still allowing the later recovery of the oil and gas will have value to the Oil and Gas Services industry. It will be important to generate data showing that the Intelligent Valve can indeed, kill a well blowout. Petroleum Engineering schools may offer test bed opportunities. The Louisiana State University College of Engineering’ Petroleum Engineering Research & Technology Transfer (PERTT) Laboratory has facilities for testing the Intelligent Valve.[[11]](#footnote-11)

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| **R&D Recommendation:** | Green | Proceed. The Intelligent Valve will have value when blowouts do occur. There is still a need for novel blowout kill technologies. |

# Market Opportunity

A technology may be unique when compared with existing commercial offerings, patents, and R&D activities. However, if a market opportunity does not exist, the ability to license or to gain a competitive advantage may be limited. For the purposes of this report, given time and budgetary constraints, the market opportunity will be scoped via an examination of relevant markets and the aggregate size of those markets as well as balancing market drivers and barriers. The review of the market opportunity should be considered cursory and be viewed as trying to answer the macro level question, are there favorable market conditions for the introduction of this technology? Please note that the market data offered in this section may not be at the niche level.

## Applicable Markets

Casing and cementation equipment are necessary functions in the well completion process. Casing is done to prevent the formation of fragments from entering the wellbore while cement fills and seals the annulus between the casing string and drill hole to form an extremely strong and almost impermeable seal of thin slurry. The casing and cementation hardware market, which includes liner equipment, float equipment, centralizers, wiper plugs and others (stage tools and casing packers), was valued at an estimated $1.78 billion in 2014, and is expected to reach $2.59 billion by 2019, growing at a compound annual growth rate (CAGR) of 7.8% from 2014 through 2019. Casing equipment is expected to reach $1.46 billion while cementing equipment is expected to reach $1.13 billion by 2019. Wiper plugs equipment is projected to hit $64.8 million by 2019 at a 6.53% CAGR, while stage tools and casing packers are expected to reach $32.9 million by 2019 at a 4.53% CAGR. [[12]](#footnote-12)

## Potential Market Barriers

Key market restraints for the global casing and cementation hardware market include access to reserves; falling oil prices; and local content requirement. [[13]](#footnote-13) Another market barrier is that national and state standards exist for plug and abandon and temporary plug operations. These standards regulate the types of plug materials (mechanical and cement), location of the plugs, depth of the plug and capping procedures.[[14]](#footnote-14) The Intelligent Valve will need to be recognized as a suitable plug by government regulatory agencies to gain broader use within the Oil and Gas Services area.

## Potential Market Drivers

Key market drivers for the global downhole tools market include the continuous increase in drilling activities worldwide; increasing demands from emerging countries; and the shale boom in the U.S.[[15]](#footnote-15)

## Analysis

Petroleum and natural gas exploration will continue to grow as a function of the demand for fossil fuels. Ironically, as more oil and gas reserves are discovered, they are being found in environments in which safe extraction is difficult (deep water, shale beds, formerly unproductive wells). Part of the extraction difficulty lies in the potential for loss of well control and subsequent mitigation. Blowouts, although rare, have the potential to cause death, bodily harm and extensive environment damage. Technologies that can rapidly mitigate oil and gas well blowouts will continue to be in demand.

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| **Market Recommendation:** | Green | Proceed. One can envision every oil and gas exploration rig carrying an Intelligent Valve in the event of a well blowout. |

# Conclusion

## Section Summary

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| **Patent Recommendation:** | Green | Proceed. The all-in-one properties of the Intelligent Valve do not appear to be present in other patented well plug technology |

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| **Offerings Recommendation:** | Yellow | Proceed with caution. There are many well plug technologies available. |

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| **R&D Recommendation:** | Green | Proceed. The Intelligent Valve will have value when blowouts do occur. There is still a need for novel blowout kill technologies. |

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| **Market Recommendation:** | Green | Proceed. One can envision every oil and gas exploration rig carrying an Intelligent Valve in the event of a well blowout. |

The Intelligent Valve has commercialization potential. No plug technology identified in a patent and R&D searches was able to provide all of the benefits of the Intelligent Valve. Compared to other plugs and plug methods, the Intelligent Valve offers can remain in place during the plugging operation; then be opened to allow oil or gas extraction once pipeline repairs are completed. Well control research is focused on preventing blowouts, not on how to quickly kill them. The Intelligent Valve can be an alternative to current methods – particularly in high pressure or inaccessible blowouts. An additional feature of the Intelligent Valve is its capability to measure gas or oil flow, critical information needed to determine by what method a blowout should be mitigated. As the demand for fossil fuels grows, exploration grows as well, as does the opportunity for blowouts. The need for the Intelligent Valve will grow too. With the number of plug technologies available today, it will be necessary to demonstrate the utility of the Intelligent Valve to the Oil and Gas Services community, particularly with respect to blowout prevention. It is recommended that a petroleum engineering center such as PERTT be engaged as a test bed for validation of the Intelligent Valve’s value in blowout mitigation.

## Overall Recommendation

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| **Overall Recommendation:** | Yellow | Proceed with caution. The value of the Intelligent Valve, particularly for well blowout prevention, will have to be demonstrated to gain commercial interest from the Oil and Gas services companies – including Schlumberger, Baker Hughes and Haliburton. |

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