The Hinton Lecture

Bob Dudley

BP CEO

Engineering Challenges at the Energy Frontiers

Thank you John, and good evening everyone. It is an honor to be here tonight and deliver a lecture that tracks the history of some of the great engineering challenges of the energy industry right through to today's challenges.

I appreciate that this is a significant event in the Academy's year and I hope that what I have to share with you tonight about the challenges of the energy frontiers is worthy of the occasion.

I believe that the subject matter it is certainly appropriate because Lord Hinton of Bankside – the first President of this Academy - for whom this lecture is named - was himself a pioneer of engineering at the frontiers of energy.

Engineering makes progress through small steps as well as by step changes driven by events such as research breakthroughs, technologies developed in wartime and the lessons from specific incidents.

In Lord Hinton's case, the challenges were those of moving from the development of atomic weapons in the second world war to providing energy for post-war Britain. And one way in which those challenges were met was by the engineers who made nuclear based power a reality.

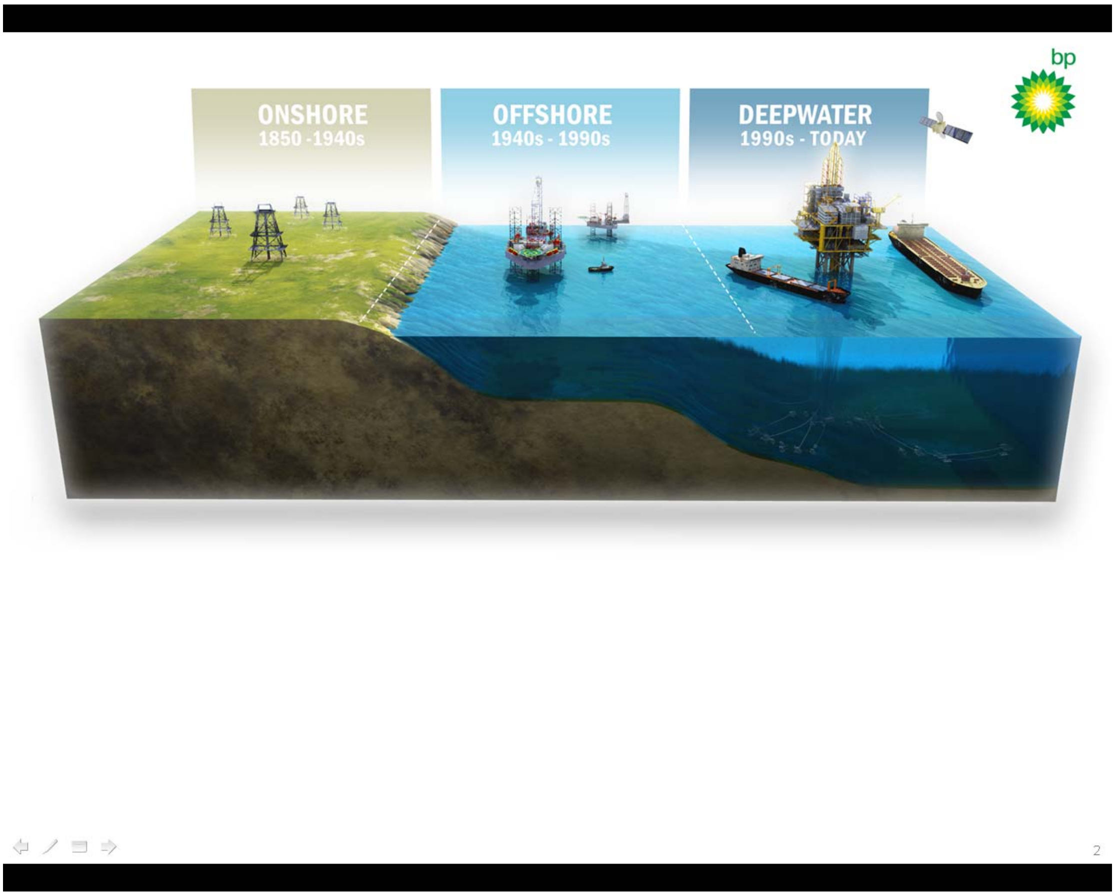
Hinton led the development of nuclear power in the UK and that included the construction and operation of the Windscale Nuclear Reactors.

In 1957 one of these reactors had a serious accident and that led to important changes in the regulation of the industry. In particular, it became incumbent on operators to provide a 'safety case' for each facility.

So ladies and gentlemen, the experience of your first President could not be more relevant to what I want to say tonight, because I want to look at the way engineering and technology have helped our industry to meet demand as well as to manage risk – which includes implementing the lessons learned from accidents.

You are aware that we experienced a very serious accident last year in the Gulf of Mexico. In fact its anniversary falls next Wednesday. We deeply regret what happened and I will explain the changes we are making in BP – and commending to the industry - in the way we manage risk on the energy frontiers.

I am going to look at the evolution of engineering challenges over three distinct eras in the industry.



I'll start with the early days of onshore exploration and production; then move to offshore drilling and the progression to deepwater activity.

In that context I'll cover the Deepwater Horizon accident and its lessons. I'll then conclude by looking beyond these three eras to the next frontiers and the next generation of engineering challenges.

What we will see is:

- first, how demand has driven the industry to operate at more and more testing frontiers;

- second, how engineering – making best use of emerging technologies - has delivered more and more ingenious solutions to find and produce oil and gas at those frontiers;

- and third, how new challenges and new operating environments, as well as setbacks, have increased our risk awareness and caused us to add more and more levels of protection in our work.

In all of this what we are examining is ‘frontier engineering’. From an engineering perspective, the term ‘frontier’ implies more than simply geographic remoteness – such as we see in the Arctic for example.

It can also simply mean being the first to work in an uncharted natural environment – such as the deep water or complex rock formations. This introduces a unique element of engineering risk. The essence of frontier engineering is the way in which that risk is managed and, in particular, the extent to which it requires the use of newly created technology.

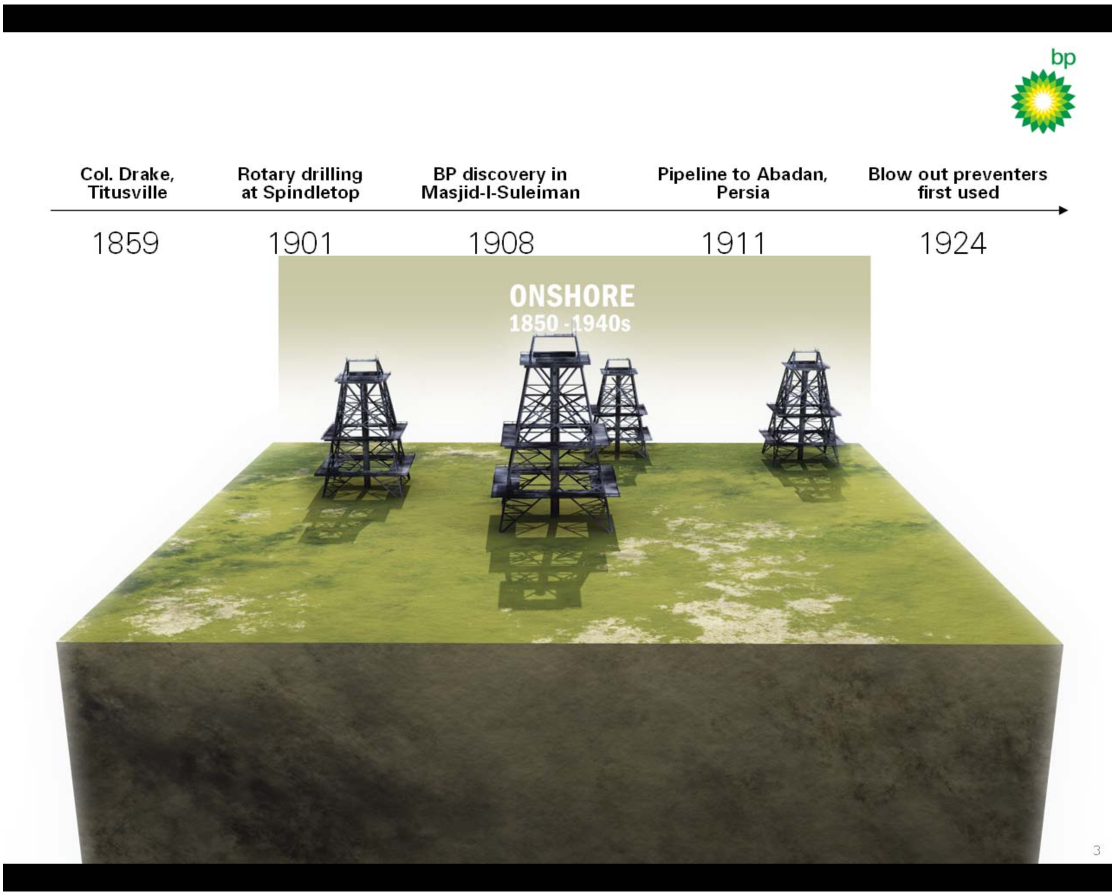
For some industries, crossing new frontiers is a matter of choice. They could if they wished choose to continue to work with current technologies.

But for oil and gas, crossing new frontiers is a matter of necessity. To get the energy we need as a society, our industry needs to go to new places and face new challenges.

That means we have to design new technologies and standards using our experience and what we can learn about the new environment before we start operating. Sometimes we find we have built in more safeguards than are needed. At other times we discover something we did not know and we have to create a new and better design.

1. The early days

So let's start with a brief look at some milestones from the first era of oil production, for BP and for the industry. I'm going to look in more detail at some of these in a moment.



It all began in 1859 with the oil well commonly regarded as the first of the industry in Titusville, Pennsylvania. This was drilled to the stunning depth of 71 feet by Colonel Edwin Drake – who incidentally was not a Colonel at all but an unemployed railroad conductor.

In fact, Drake did not "discover" oil. It had been used for thousands of years by native peoples around the world, primarily as a medicine. What Drake developed was a method for producing large quantities of oil.

And once the oil was found, the business of drilling oil wells was not for the faint hearted or those without deep pockets.

Back then explorers knew very little about what was going on under ground. They typically relied on what they could see – oil seeping out of the ground. When they drilled they had little idea whether they were hitting the edge or the center of the reservoir. And that was only the beginning. Developers had to think about building the roads and pipelines, often across deserts and in hostile areas, to get the oil to refineries and processing units.

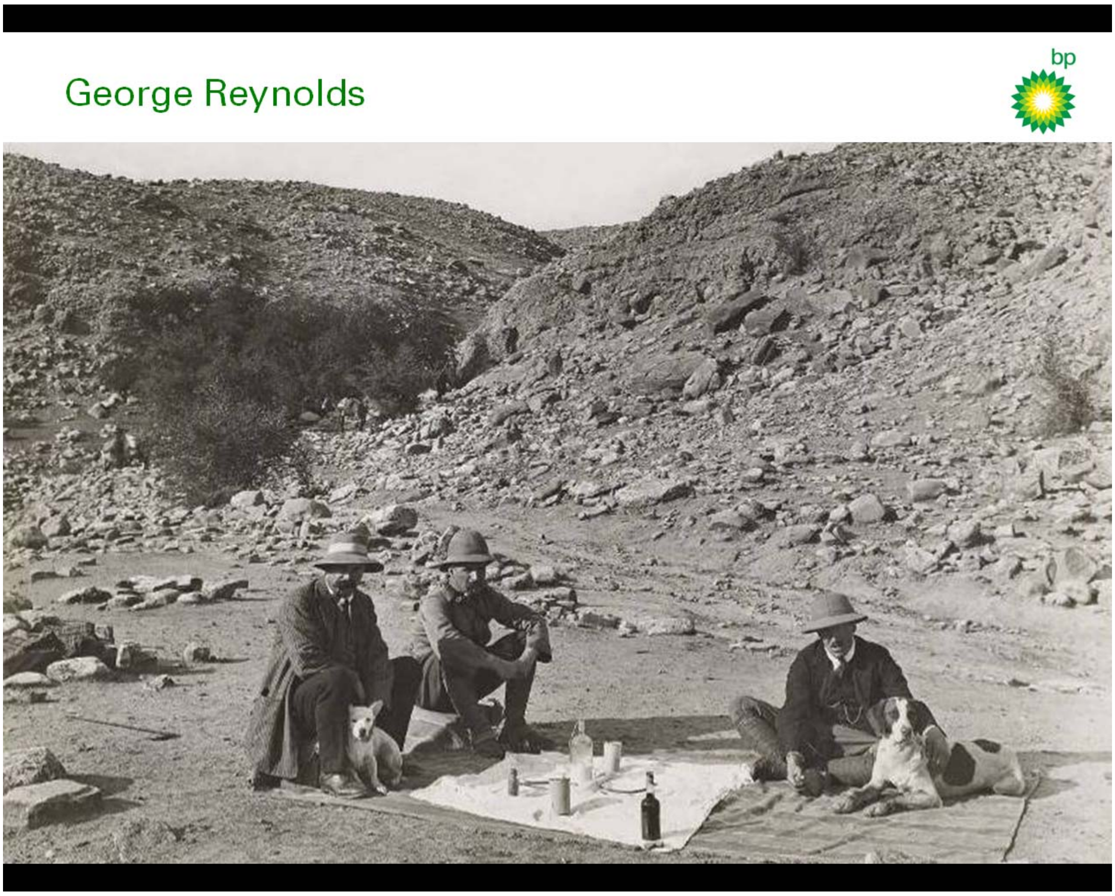
These are the early days of drilling in Azerbaijan. And here is a person being winched out of a well, covered in oil where he has been working without any protective clothing.

The conditions were primitive with oil seeping sloshing around on the surface.

Initially, the operators used percussion drilling in which you just punch a hole in the ground with a heavy bit.

Rotary drilling was introduced around the turn of the last century and gradually became the industry standard.

Once a field was opened up wells were sunk all over the place and you ended up with forests of wells.



BP’s UK heritage goes back to an industrialist called William D’Arcy who made his fortune in the Australian gold mines and then poured a considerable amount of it into searching for oil in Persia – modern day Iran. By 1908, things were looking bleak but he had an engineer called George Reynolds who didn’t want to give up and on the 26th May that year, this happened.

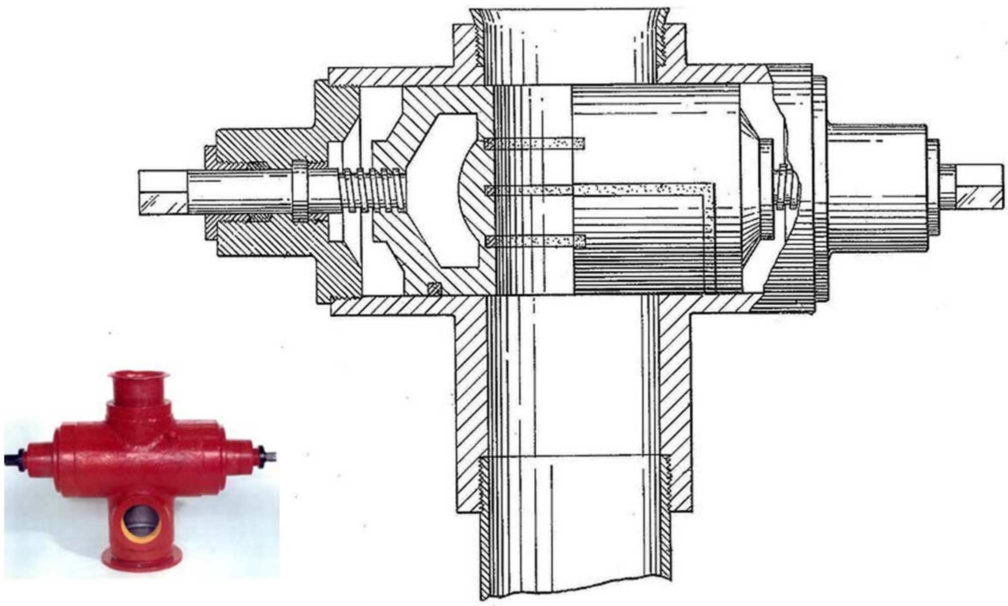
Masjid-i-Suleiman

Despite being symbols of new-found wealth, blow outs, or ‘gushers’, were dangerous. They killed workmen, destroyed equipment, and coated the landscape with thousands of barrels of oil.

Initially drilling in this field was carried out by using a steam powered cable tool percussion rig. We have a replica of a percussion drill bit here tonight in fact.

And then in 1922 – quite early for the industry - the first two rotary rigs were used in the field. This reduced the risks of gushers as mud and cement could then be used to control the pressures in the wells.

Early Cameron blowout preventer (BOP)



In 1924 along came an example of an innovation driven by risk management. This was the world's first successful blowout preventer, or BOP. It was a ram-type device, with simple hydrostatic pistons, fixed to the wellhead.

These could be closed on the drill stem to form a seal against escaping well pressure. As the technology developed, blowout preventers became standard equipment.

Modern BOPs have Automated Mode Function or Deadman circuits that are designed to cut in without human intervention if needed – an example of how engineering has sought to design out risk.

One of the first frontier engineering challenges in BP's history was the building of the pipeline from the first discovery at Masjid-i-Suleiman to the site of the new refinery at Abadan, 220 kilometers to the south, also in Persia, or Iran.

The pipeline was built through two ranges of hills and across a desert plain using up to 6,000 mules and over 1,000 local and Indian labourers. 140 miles of pipe in 20 foot lengths were imported from New York and transported to the site by river barges.

So even at this early stage, we can see that our industry really involves three sets of processes - or three phases

Phases of activity

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Exploration	Development	Production
		

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- exploration to find the oil or gas;
- development – to drill the wells and build the projects;
- and production – to bring the reserves from the reservoir to the market.

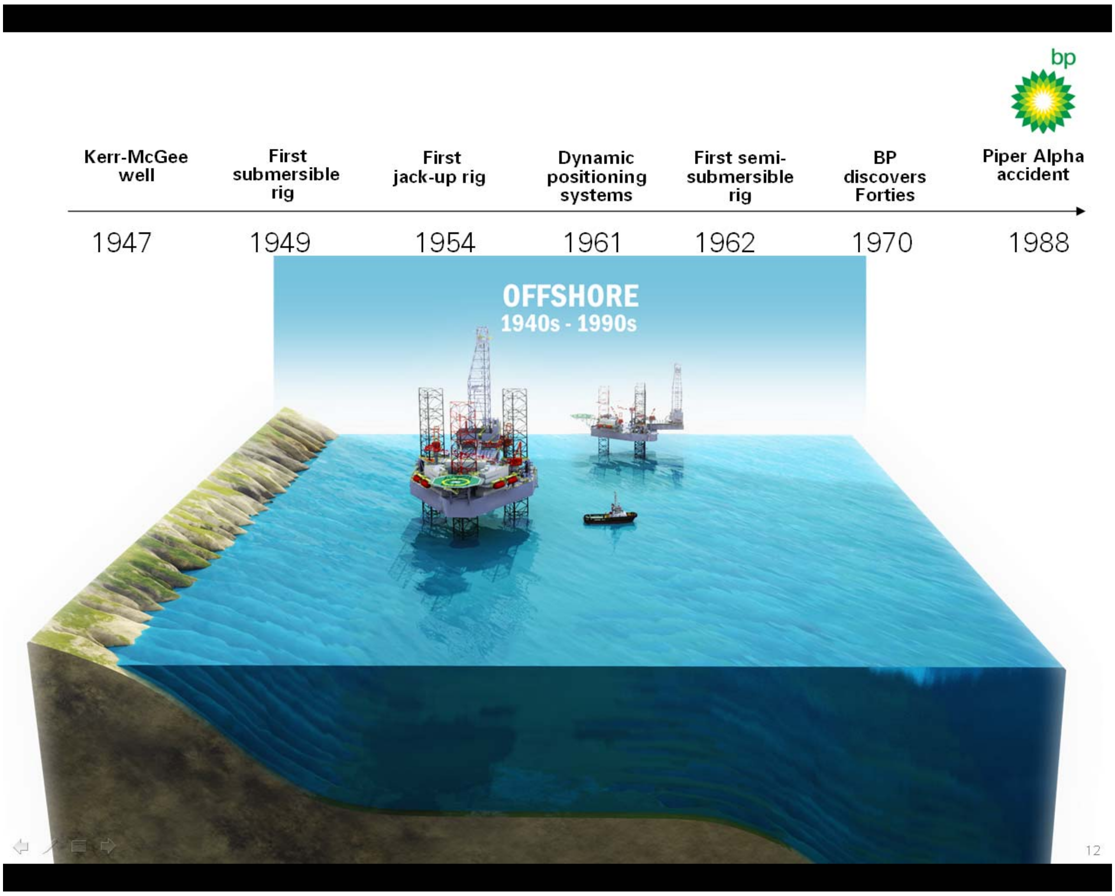
And there are diverse technologies involved in each of these phases.

We're always exploring ahead of production. And this often means creating new technologies, standards and design codes to meet the challenges presented by each new frontier.

We assess the risks and design our equipment and practices using a combination of experience, calculation, sound engineering and science.

But the basic components of drilling have remained similar for over 150 years.

2. Going offshore

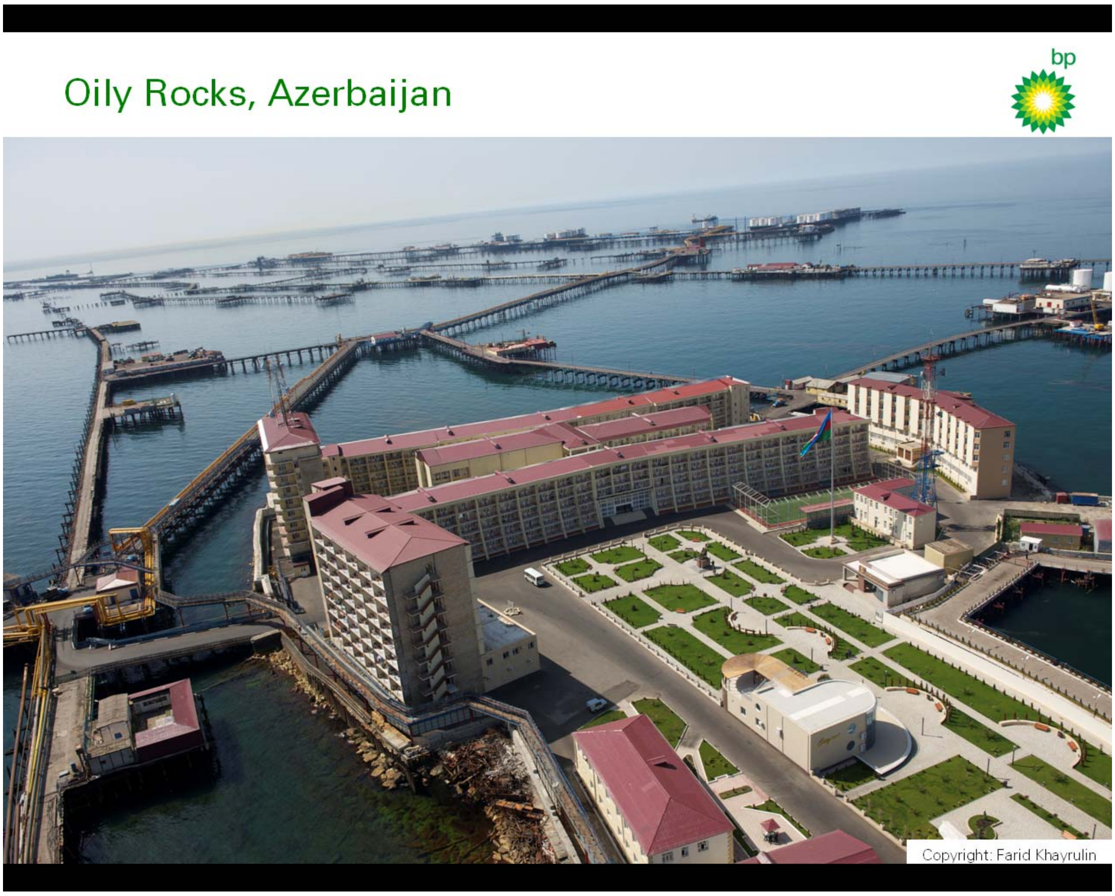


Let's now move on to the second of the eras I want to discuss this evening. This is the progression from onshore to offshore drilling.

Here we can see a number of significant milestones from the first era of offshore drilling running from the post war years up to the late 1980s.

And these include developments in the North Sea, which was a real frontier for the industry.

The potential to recover oil from beneath the ocean had been understood for decades. Indeed wells had been drilled from piers in California as early as 1896.



The concept of using piers was taken to a totally new level in Azerbaijan in a place known as Oily Rocks near Baku. This extraordinary development started with a single path out over the water in 1948 and grew into an entire city at sea.

It has 190 miles of streets and its population has been as much as 5,000 people.

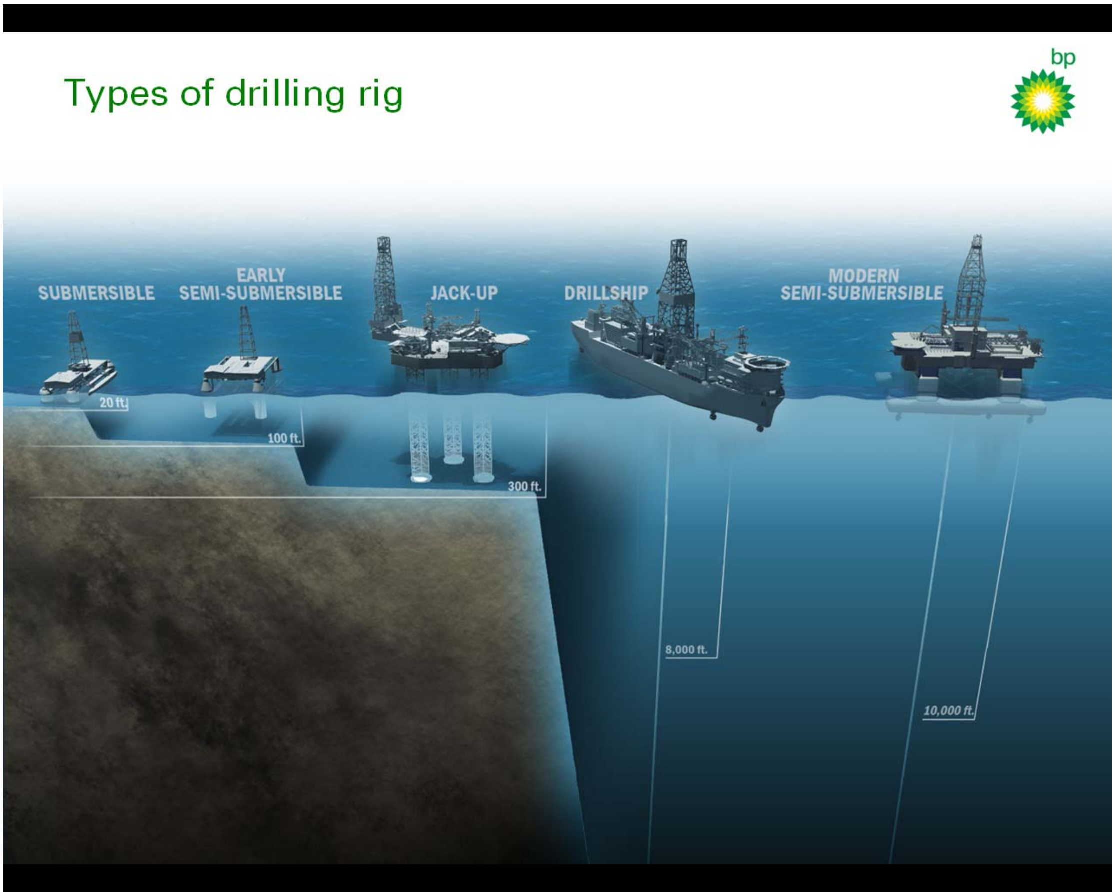
It includes houses, schools, libraries and shops. It is amazing and it is no surprise that it was used as a setting in a James Bond film.

But a definitive frontier was crossed in 1947 when engineers from Kerr-McGee, an American oil company, drilled the very first well that was completely out of sight of land.

It was located 10 miles off the coast of Louisiana in the Gulf of Mexico and the drilling deck was no bigger than a tennis court. Alongside, it had refurbished navy barges which served for storage and sleeping quarters. The well was drilled from a single derrick into the seabed just 15 feet below the surface.

By this time, firms were choosing steel over wooden structures. They recognized that the metal had greater structural integrity and lower costs over the life of the well.

The history of the offshore industry has been marked by successive generations of drilling rigs able to operate at greater depths and harsher conditions.



The first offshore rigs were submersibles with pontoons that were flooded with water and literally sat on the seabed.

In the 1950s jack up rigs were developed. These were towed to the drill site and then jacked up so their legs rested on the seafloor. They could operate in around 300 feet of water.

The 1960s saw the introduction of the first semi-submersible rigs. These floated on the sea surface while maintaining their position using anchors and tensioned chains.

Initially these could only operate in shallow water but now the industry is using 5th and 6th generation semi-submersibles in combination with advanced dynamically positioned systems.

These allow the floating structures to hold and adjust their position using thrusters – which are essentially sophisticated propellers. And this currently allows drilling in water depths of up to 10,000 ft or more.

In addition the industry uses drill-ships. These are most often used in deep water and have the advantage of being able to move from place to place rapidly. They currently have a typical reach of around 8,000 feet.

In October 1970, BP discovered the Forties Field, some 110 miles east of Aberdeen, using the company's first semi-submersible rig called the Sea Quest, seen here.

Forties – exploration

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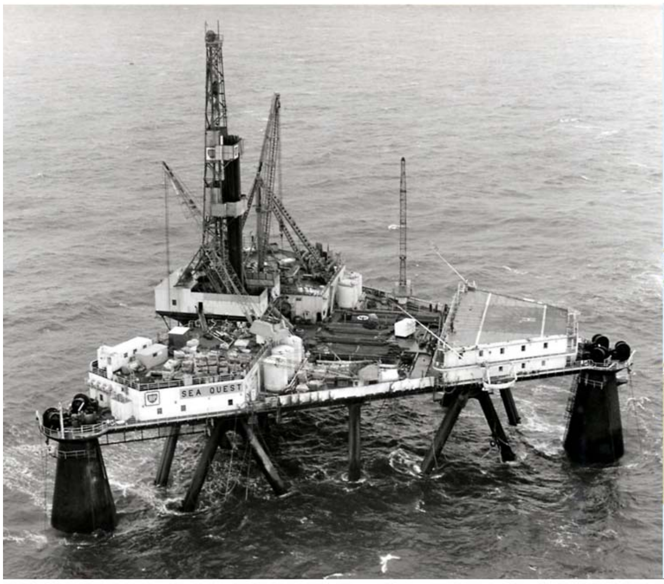

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The Forties had 2.5 billion barrels of recoverable reserves and was the largest field in the UK sector.

From an engineering perspective, what made Forties challenging was not so much its size as its location. It was located in a water depth of 400 feet and in an area with much more severe weather conditions than the industry had experienced anywhere in the world.

The 100 year maximum design wave height exceeded 90 feet, almost twice the design height used previously in offshore engineering. Persistent bad weather throughout most of the year meant that metal fatigue became an over-riding design consideration. With only a brief summer season for offshore construction, a new approach was required for platform and topside installation.

Ladies and gentlemen this was truly the frontiers of our industry. Many of you will remember those days and I know some of you were directly involved.

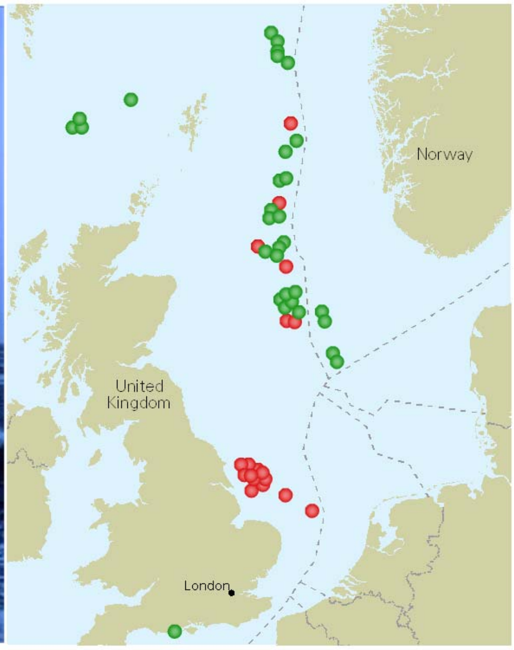
Everything about Forties was on a giant scale for its time, often exceeding the then current industry practice by a factor of two or three times. any of the existing codes and design rules no longer applied and new ones were created from first principles, along with new technologies.

The field was developed using 4 massive steel jackets, built in a specially constructed fabrication yard in Scotland.

The export pipeline back to the beach also broke all industry records in terms of water depth and size. It was the first offshore pipeline to be constructed using fully automatic welding and the first to be designed to resist propagating buckles.

Over the next 15 years, BP and other companies continued to develop fields in the North Sea. They expanded beyond the Forties field and produced both oil and gas. This shows how BP’s own fields grew over the years.

North Sea production



Oil field Gas field

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Oil and gas production in the UK peaked in 1999 at around 4.5 million barrels of oil and gas per day. Today production is running at around 2.4 million barrels a day.

I remember all this very well because I started working in the North Sea in 1985. I spent three years based in Aberdeen, mainly working offshore at that time, and it really was the most exciting place to work in our industry.

Over the years, platform design became more sophisticated and the jackets no longer needed to be quite so massive.

Let's end this section by moving ahead to 1988 when one of the defining events of the offshore industry took place. Sadly it was a dreadful accident.

The Piper Alpha platform was located on the Piper oilfield, approximately 120 miles northeast of Aberdeen in 474 feet of water. On July 6th 1988, Piper Alpha suffered a massive leakage of gas condensate. The leaked gas ignited, causing an explosion which led to large oil fires and a fireball that engulfed the platform.

This tragic accident killed 167 people and only 62 workers survived.

An inquiry under Lord Cullen made over 100 recommendations and led to widespread changes in industry practices and regulation.

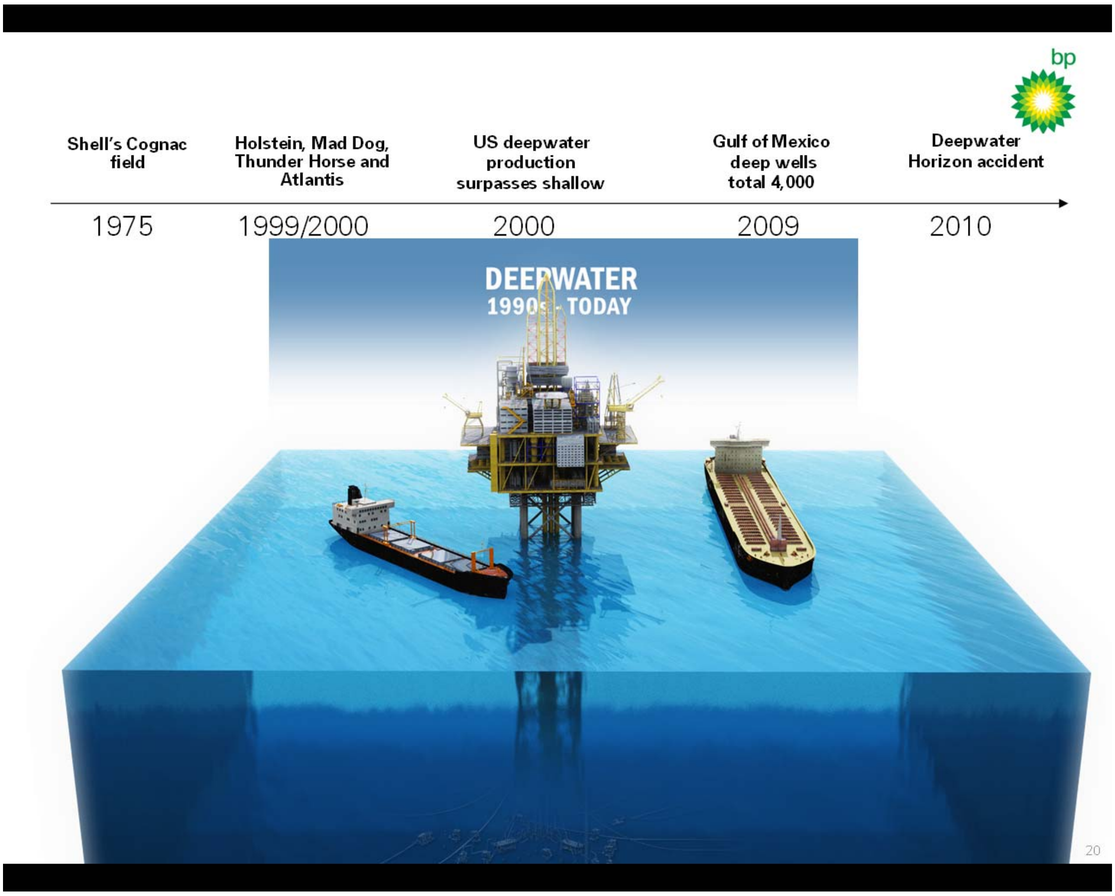
Responsibility for safety was transferred from the government's energy department to the Health and Safety Executive – the HSE. That separated oversight of production from the oversight of safety.

The disaster led to energy companies conducting wide-ranging assessments of their installations and their systems for integrity management. Operators invested around £1 billion in safety measures such as 'permit to work' management systems.

As a result of the report, the Offshore Installations Safety Case Regulations came into force in 1992. These applied the same 'safety case' principle for the UK offshore sector as had been applied to the nuclear sector after Windscale.

And by the following year, a 'safety case' for every UK offshore installation had been submitted to the HSE.

3. Deepwater



Let us now move onto the deepwater story of the past two decades. Over that period, demand for oil and gas has grown relentlessly. In broad terms the world's oil consumption has risen from around 30 million barrels of oil a day in 1965 to 60 million in 1980 and 85 million barrels per day now.

Early fields have become mature and production from some basins has peaked – the North Sea is one example.

Geo-political factors have also been at work. National oil companies in many countries have dominated the easier fields onshore.

Meanwhile the international oil companies have had to set their sights on more challenging environments.

In 1970, over 80% of global reserves were controlled by international oil companies. Today the figure is close to 8%. So companies like BP have had to develop their skills at the difficult frontiers.

We are now increasingly moving back into partnerships with the national oil companies as they start to work at new frontiers and we can contribute what we have learned.

In 1975 Shell found the Cognac field in the Gulf of Mexico – the first to be discovered in over 1000 feet of water. But progress in developing deepwater fields was slow due to the challenges of locating reservoirs and developing rig and riser technologies.

The challenges the industry has faced in deepwater are tremendous. The sea can be over 5,000 feet deep and the oil itself can be as much as 35,000 feet below sea-level, through miles of hard rock, thick salt and tightly packed sands.

We are operating hundreds of miles from shore, at subsea pressures of over 2,000 pounds per square inch and water temperatures below 40 degrees Fahrenheit.

Exploration at these depths, to quote the New York Times, is like flying 30,000 feet above New York City and aiming a drill tip the size of a coffee can at the pitcher’s mound at Yankee Stadium - in the dark.

Scale of deepwater drilling

Yet these are the challenges that the industry has surmounted through technology breakthroughs and engineering expertise. By 2009 the industry had drilled some 4000 wells in over 1000 feet of water in the Gulf of Mexico alone.

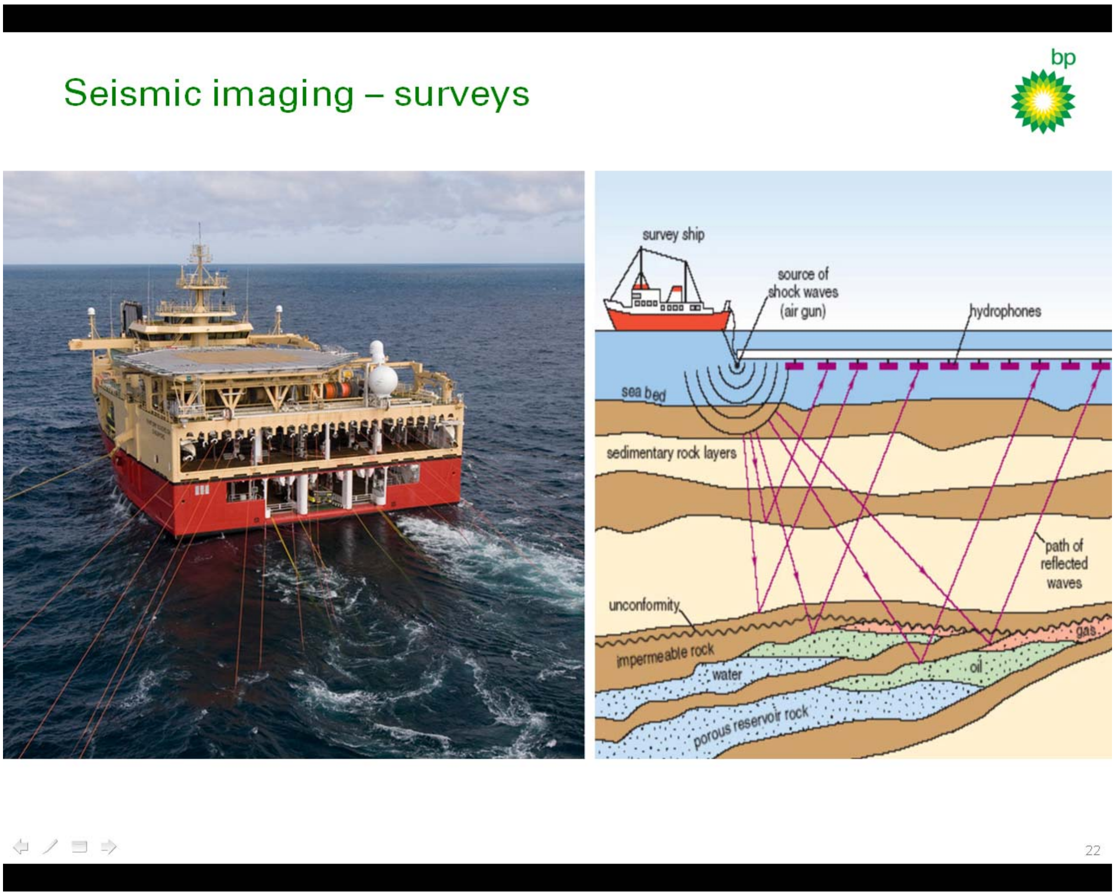
In the year 2000, deepwater production in the US surpassed shallow water production and by 2008 more oil had been found in the deepwater than the shallow water and onshore combined.

This progress has been driven by engineering and technology – including some massive new floating rigs.

Equipment has to be installed and maintained at depths no human diver can reach.

As a result a whole new sub-sea engineering sector has grown up in making and operating the robot submarines that act as our hands and eyes. In the industry we call them remotely operated vehicles or ROVs.

However, one of the most important advances for deepwater activity was not in the hardware of production - but in the software of exploration.



This advance concerned seismic imaging. Seismic technology involves sending sound waves into the ground from so-called shot-points where they are reflected off rock layers with the resulting signals being picked up using receivers called geophones or hydrophones.

By analysing the way the signals bounce off the various geological layers beneath the surface, seismologists can identify patterns that indicate potential oil and gas reservoirs.

Early seismic surveys on land used dynamite to create the sound waves and operated in straight lines, producing two dimensional images.

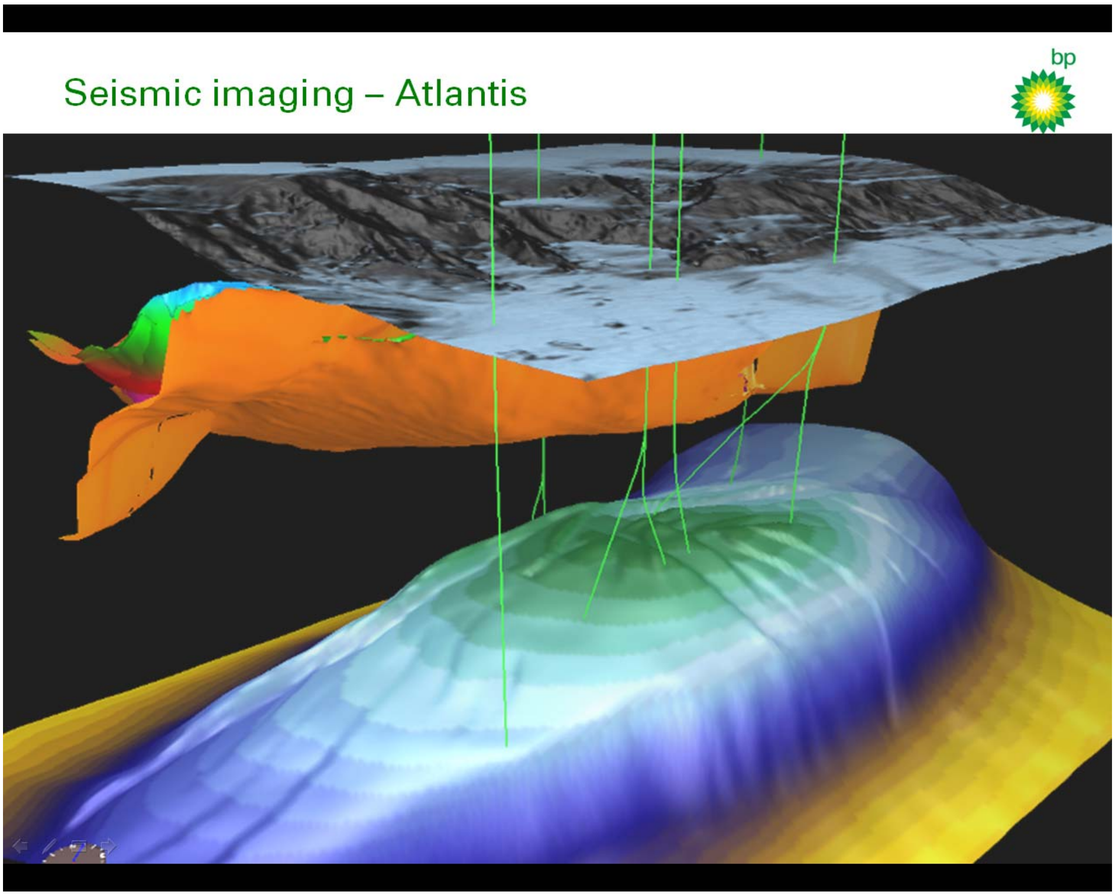
Seismic imaging came into its own in the 1980s and 1990s with the emergence of 3D seismic methods that use shot points arranged in grids. This coincided with dramatic increases in computer power for data processing.

At sea, 3D Seismic surveys have been typically carried out using a vessel towing eight to ten parallel streamers, each several kilometers long. The vessel has a seismic source that creates sound waves using blasts of compressed air. These signals are detected by hydrophones incorporated into the streamers.

In basins such as the Gulf of Mexico and offshore Brazil or Angola, this process can be impeded by the salt canopies that cover many of the reservoirs. The salt surfaces have irregular shapes and the seismic reflections go in many directions, creating a confusing picture.

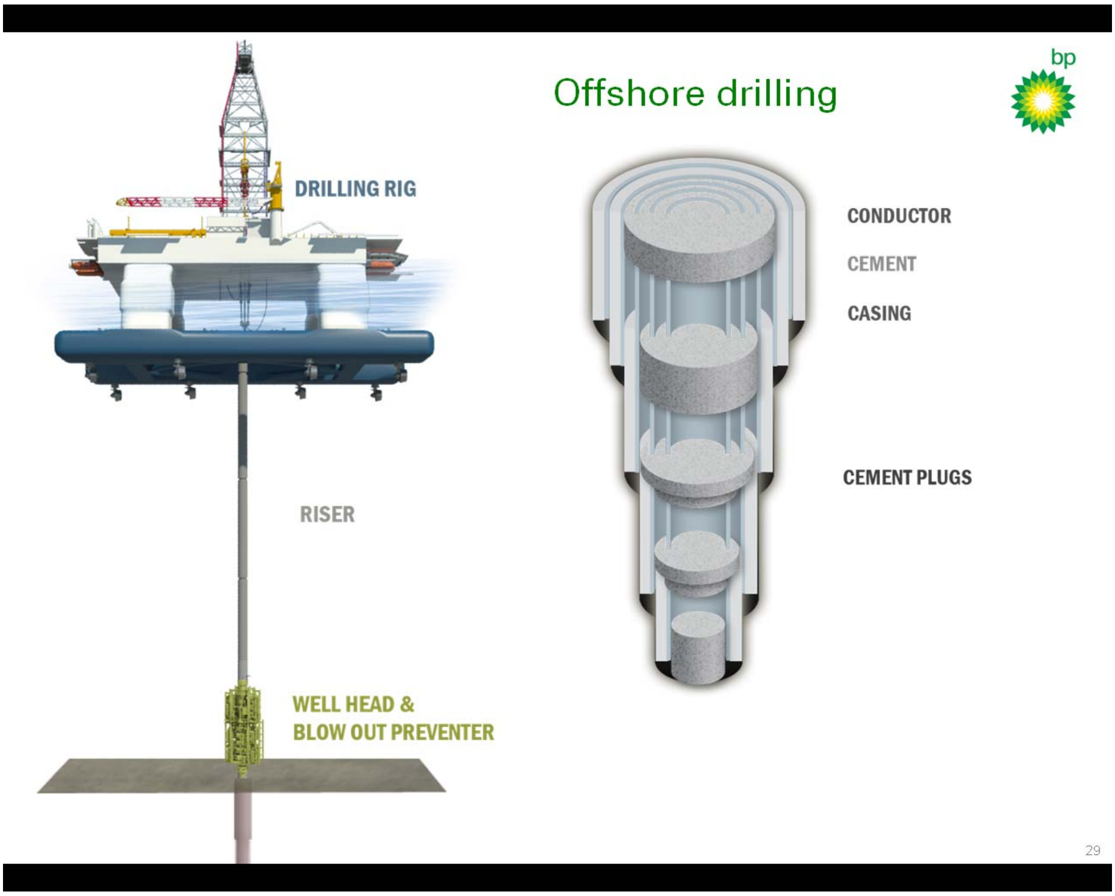
This issue has been overcome by acquiring 3D data in a so-called "wide-azimuth" survey. This involves multiple seismic source and receiver vessels which illuminate reservoirs below salt.

This method was pioneered by BP in 2005 on the Mad Dog field in the Gulf of Mexico.



This is the kind of image we produce. It shows the Atlantis reservoir in the Gulf of Mexico lying beneath the salt - which is the orange area. You can also see the paths taken by wells.

At this point I think it may help to remind ourselves of what is involved in drilling a deepwater well. Some of you will be very familiar with this but it helps to provide the terms of reference for what I will cover in the remainder of my remarks.



First we deploy a large diameter drill bit to the sea bed and drill the first section of the well.

We then sink a cylindrical conductor into the first section of the well. Cement is pumped down this conductor which then rises up to fill the annular space between the well and the rock.

Drilling then starts again using a smaller diameter bit and another section of hole is drilled. Then a steel casing is inserted into the conductor and the new well section and cementing is repeated, closing in the spaces between the casing, the newly drilled rock and the conductor.

A well head and blow out preventer are then fitted at the top of the first section of casing on the sea bed. A riser pipe is connected to the top of the blowout preventer connecting the well to the drilling rig.

The drilling, casing and cementing process is then repeated using narrower and narrower casings in a telescopic structure until the reservoir is penetrated. The result is a closed system designed to have full integrity.

If the well is to be used for production, the bottom of the casing is perforated to enable hydrocarbons to flow into the well from the reservoir.

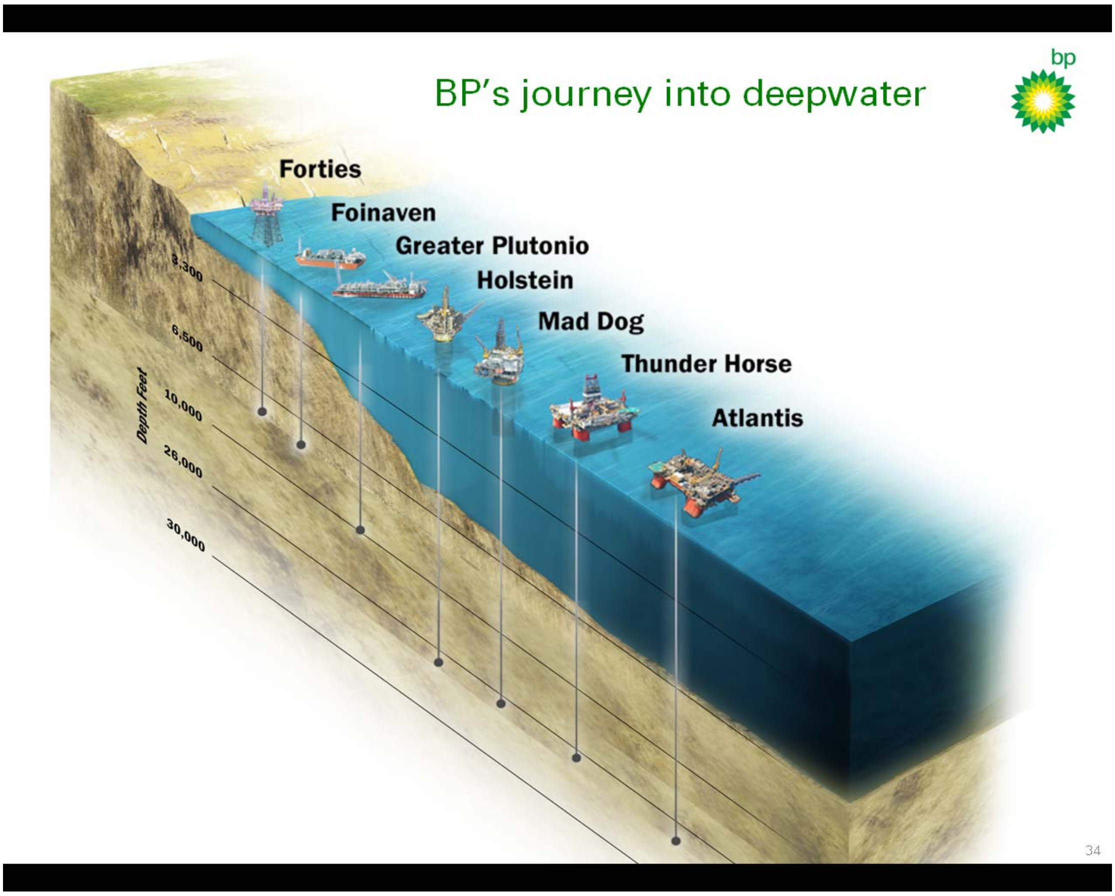
Alternatively the well can be abandoned, either permanently or temporarily for future use. In this case cement is pumped to various locations within the well to create multiple effective seals. Pressure tests are carried out to ensure that the system has integrity.

Over the past few decades in BP, we have been moving to deeper and deeper water with more powerful rigs and platforms.

BP’s journey into deepwater began as we built on what we had learned in the Forties field.

We took a major step forward with the development of the Foinaven field, West of the Shetlands. Foinaven remains the largest subsea development in the UK sector with over 30 wells.

This kind of experience then gave the company the confidence to tackle the giant fields off Angola and in the Gulf of Mexico.

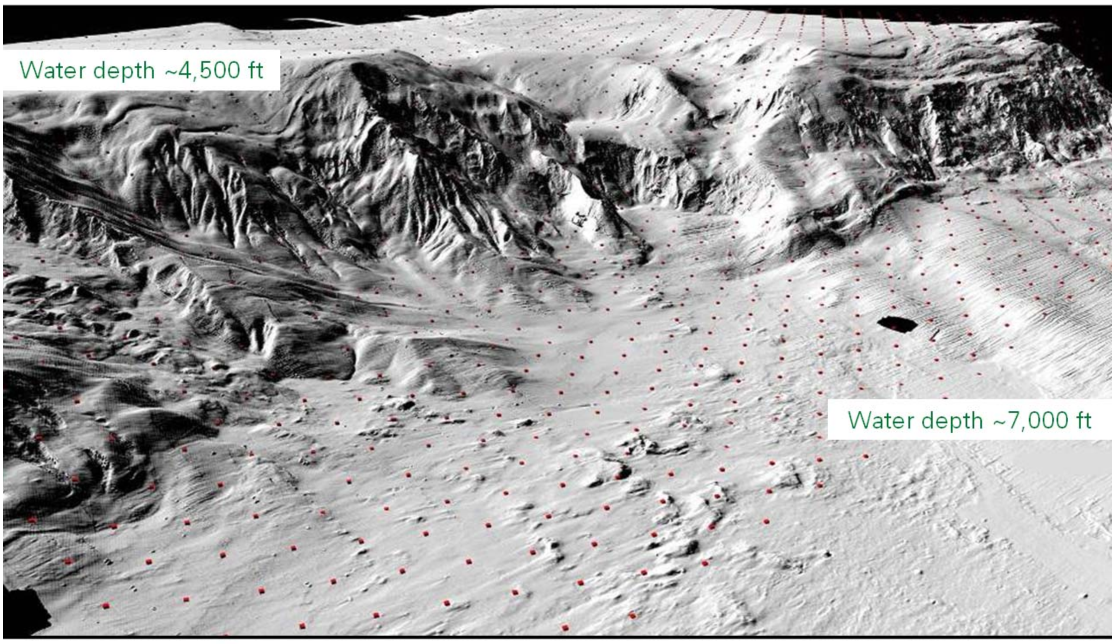


The strategy paid off in the 1999-2000 period, when BP made four world class discoveries in the Gulf of Mexico - Holstein, Mad Dog, Thunder Horse and Atlantis – each of which set a number of world firsts.

Over the same period, a series of important deepwater discoveries were also made in Angola including the Greater Plutonio field.

Here's a seismic image of the Atlantis field in the Gulf of Mexico. As you can see it lies on a subsea cliff which drops from approximately 4,500 feet to 7,000 feet. So that cliff face is over five times the height of the UK's white cliffs of Dover.

Atlantis – subsea cliff



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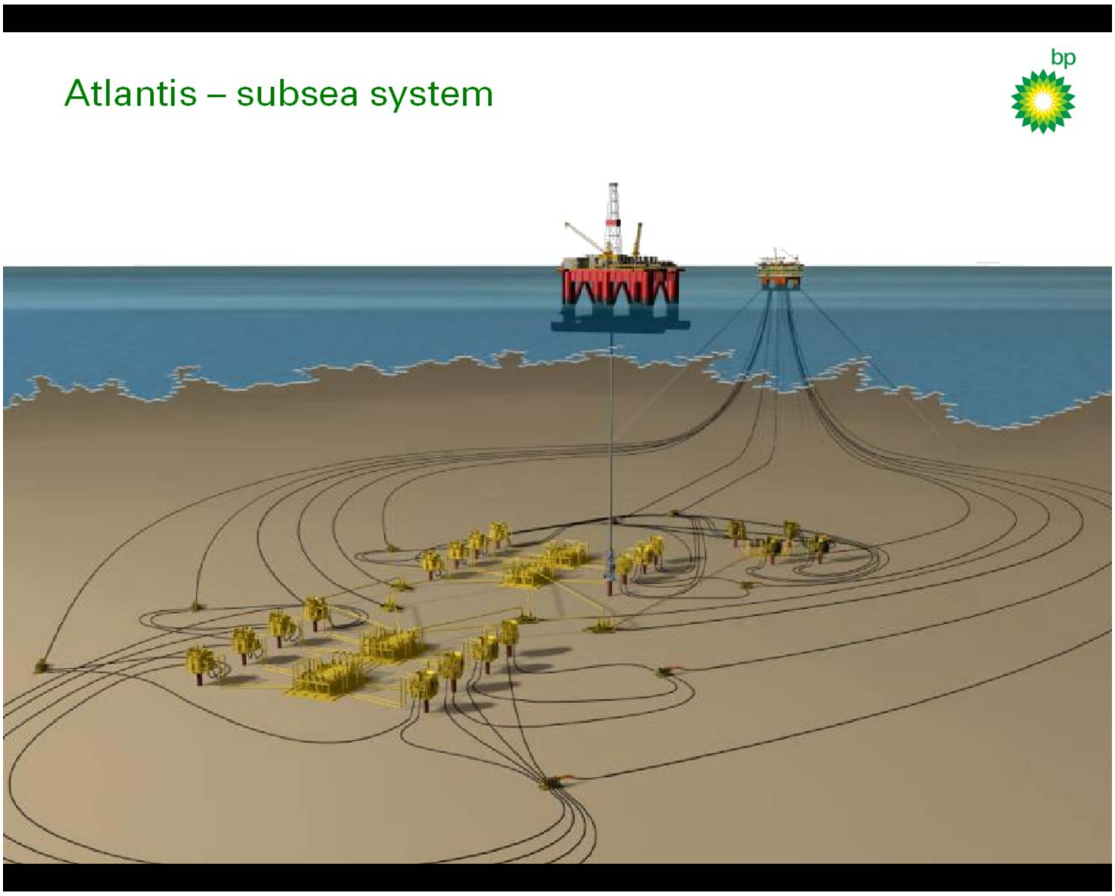
The task for engineers was to drill wells at a variety of depths in this topography and then link them together, tying all of them back to one platform.

Atlantis has no less than 150 separate substantial subsea components – including flowlines, manifolds, trees and umbilicals.



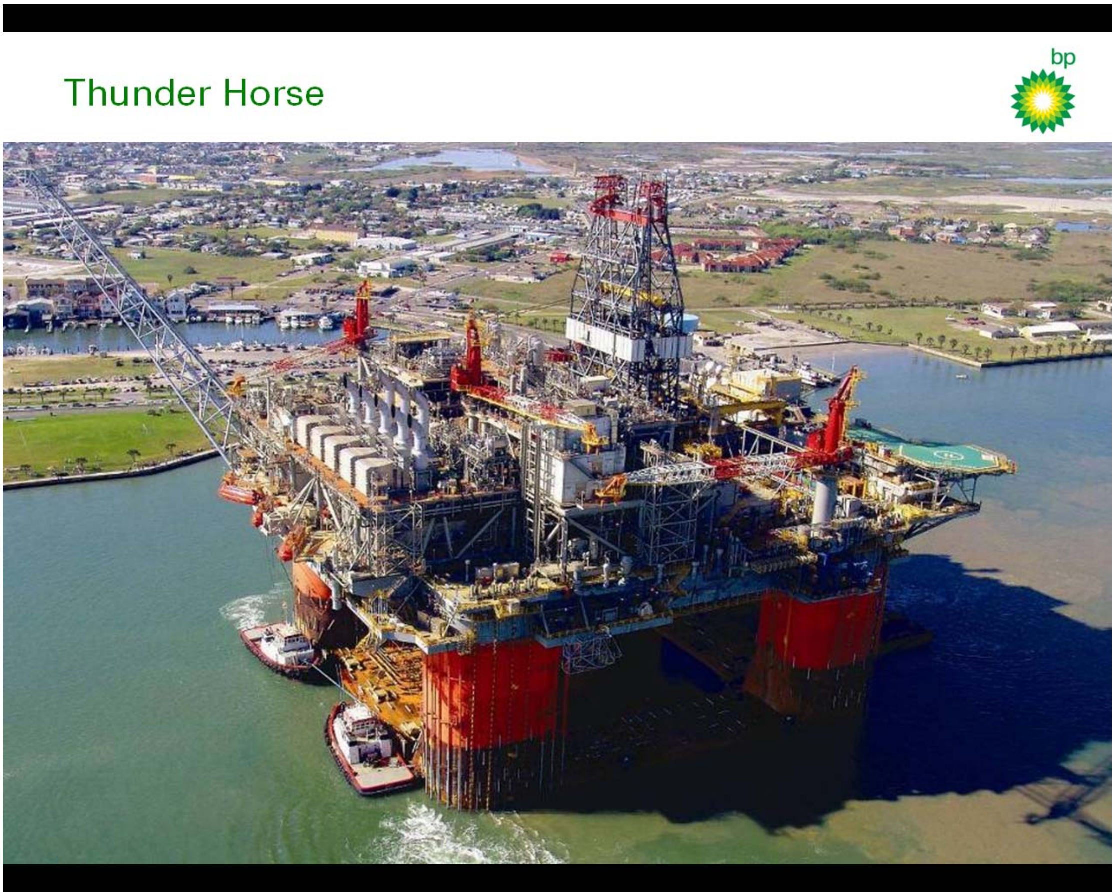
The production rig fabricated to produce oil from Atlantis is a 58,700-tonne semisubmersible platform which is tethered to the seabed over 7,000 feet below. For a few months in 2007 Atlantis was the deepest moored platform in the world.

But the record did not last long. In 2008 Shell's Perdido spar, in which BP has a stake, was chained to the seabed nearly 8,000 feet down.

But the depth of the water is only one frontier. Another is the depth of the reservoir – which can be several miles below the seabed. Other factors include the high pressures and temperatures.

If you have a very deep reservoir, and you are planning to use a series of complex systems, then you need a very large platform to carry the weight.

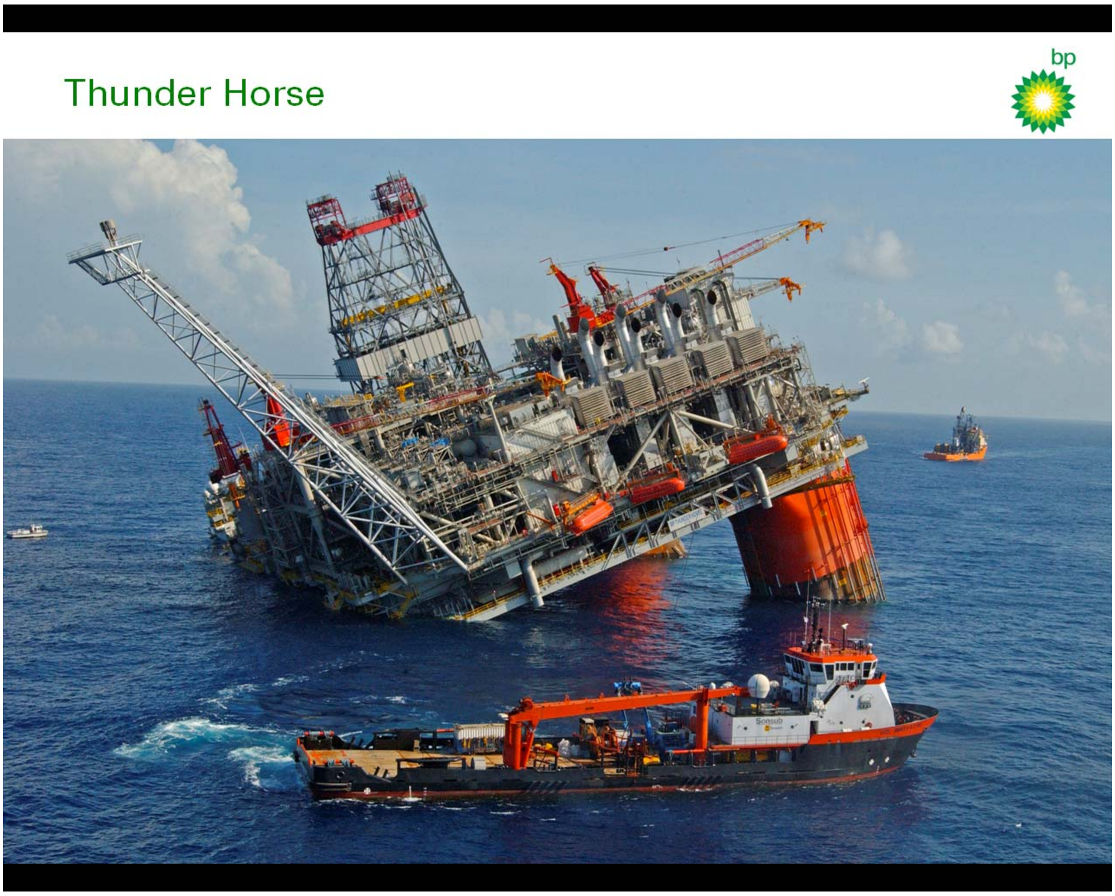
So meet Thunder Horse. What made the Thunder Horse field unique was not the depth of the water – at around 6,300 feet – but the depth of the oil which was a further 20,000 feet or so below the seabed, where the reservoir pressures were as high as 18,000 pounds per square inch.



To produce oil from this field BP constructed the largest production semi-submersible ever built. The platform's topside area is the size of three football fields. It contains equipment and systems capable of processing a quarter of a million barrels of oil equivalent per day from over 20 wells. It involved many new technologies and their design, testing and construction required a whole new generation of subsea equipment.

Just as in the Forties and other situations, there was a strong emphasis on design standards for the new technology – building in very high safety thresholds and levels of redundancy.

So when Hurricane Dennis hit the rig in July 2005, there was no damage to the hull. But a failure in the ballast system allowed water to freely flow among the ballast tanks and caused the platform to list.

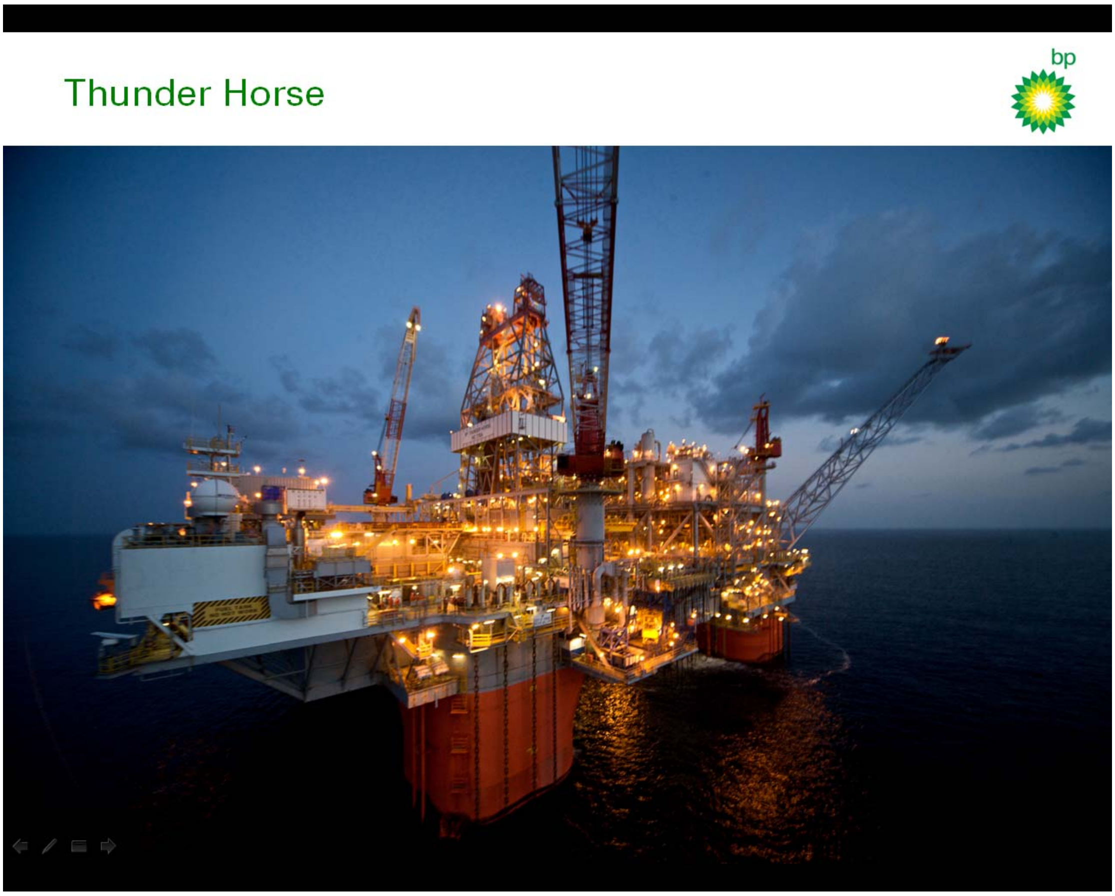


It was righted within a week, and when it was hit by Hurricane Katrina shortly afterwards it weathered the storm.

Later another problem arose when a failed weld was discovered in the subsea metallurgy. The decision was taken to replace all of the subsea equipment, a major exercise requiring 14 vessels in operation simultaneously.

The learning from this incident led us to upgrade our monitoring of parameters such as wind speed, ocean currents and vessel movements.

The restoration work was completed and first oil was received on Thunder Horse in June 2008. These issues again demonstrated the challenges and the achievements of operating beyond previous frontiers.



There were also major advances in the scale and sophistication of subsea pipeline systems developed to carry oil and gas from the fields to the processing hubs onshore. The Mardi Gras deepwater transportation system in the Gulf of Mexico is the largest capacity deepwater oil and gas pipeline system ever built, capable of transporting over 1 million barrels a day of oil equivalent through 800 kilometres of pipeline.

Mardi Gras pipeline system

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This brings us to The Deepwater Horizon rig and the tragic accident that occurred last year.

In September 2009, the rig had drilled the deepest well in the history of the industry at the Tiber field. That well was about 35,000 feet – or nearly seven miles - below the earth’s surface.

The Deepwater Horizon had also drilled wells at the Atlantis and Thunder Horse fields in the Gulf of Mexico.

Then in April 2010 the Deepwater Horizon was drilling at the Macondo prospect approximately 50 miles off the coast of Louisiana when a blowout took place.

Deepwater Horizon incident

Hydrocarbons escaped from the well resulting in explosions and a fire that burned for two days until the rig sank. 126 people were on board. Tragically, 11 men lost their lives and others were injured. Hydrocarbons continued to flow from the well for 87 days, causing a major oil spill.

As I said we deeply regret this accident. Several investigations have been conducted, some of which have already published reports. These include our own BP investigation – in which external experts participated – the report of the President's National Commission and a specific report for the US government on the blow out preventer.

Both the Presidential Commission and our own internal investigation concluded that the accident was the result of multiple causes, involving multiple parties.

Several factors stand out in the findings of these reports.

The cement at the bottom of the well did not seal off the hydrocarbons in the formation.

The negative pressure test carried out to check that the well was sealed was misinterpreted.

And the blow-out preventer did not seal the well at the seabed. It is clear that the blind shear rams failed to close.

The precise cause of that failure was still being discussed last week at hearings in New Orleans. It is the subject of additional testing for which a framework is being discussed with the court.

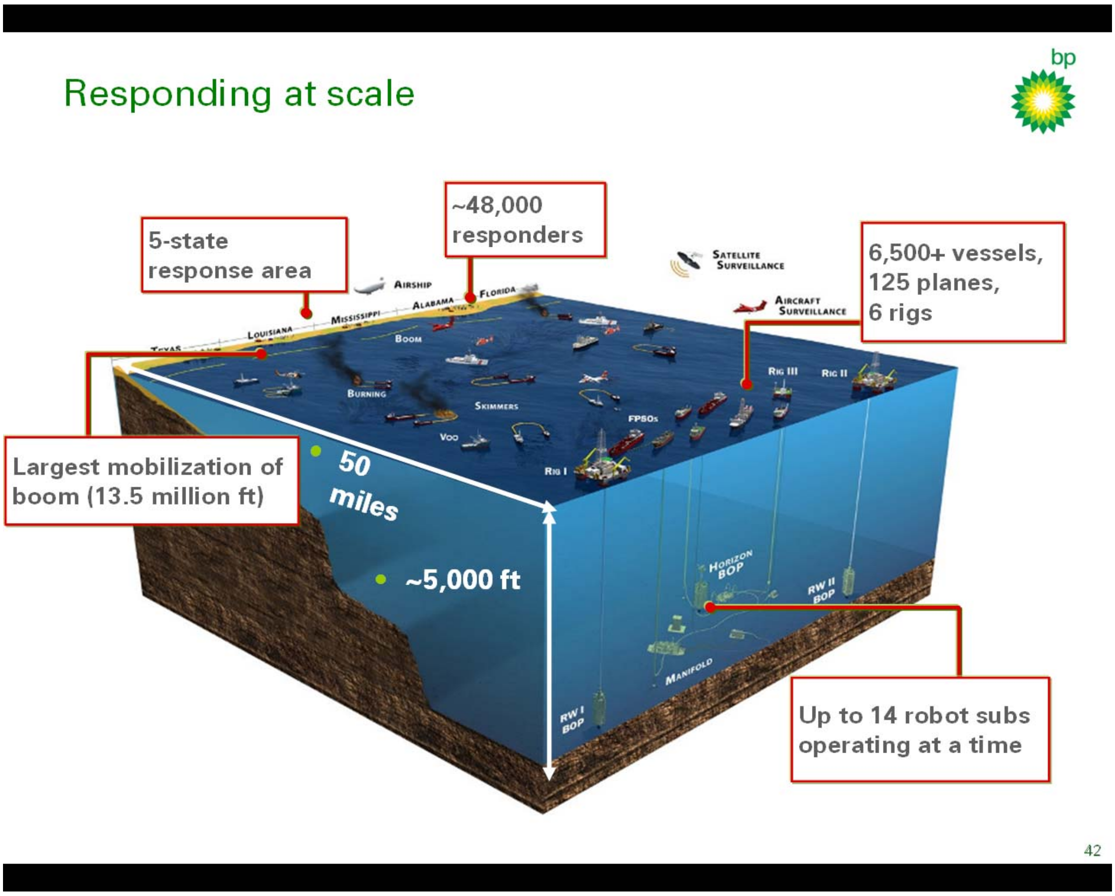
Our own investigation made 26 recommendations covering issues including BOPs, pressure tests and cement testing.

And the Presidential Commission made wide ranging recommendations for government and industry on areas ranging from risk management to planning for oil spill responses.

We are now systematically implementing the lessons we have learned from the incident.

Clearly the event left us in a state of shock and grief. But the imperative was to respond – to seal the well, to tackle the oil spill and to help all those affected.

That meant that together with the US state and federal government departments and agencies, we mounted a major crisis response. At its peak it involved around 48,000 people, 6,500 vessels and 125 aircraft.



That phase is now over but we are still very much in action in the Gulf, meeting legitimate claims and fulfilling our commitments to the Gulf Coast communities.

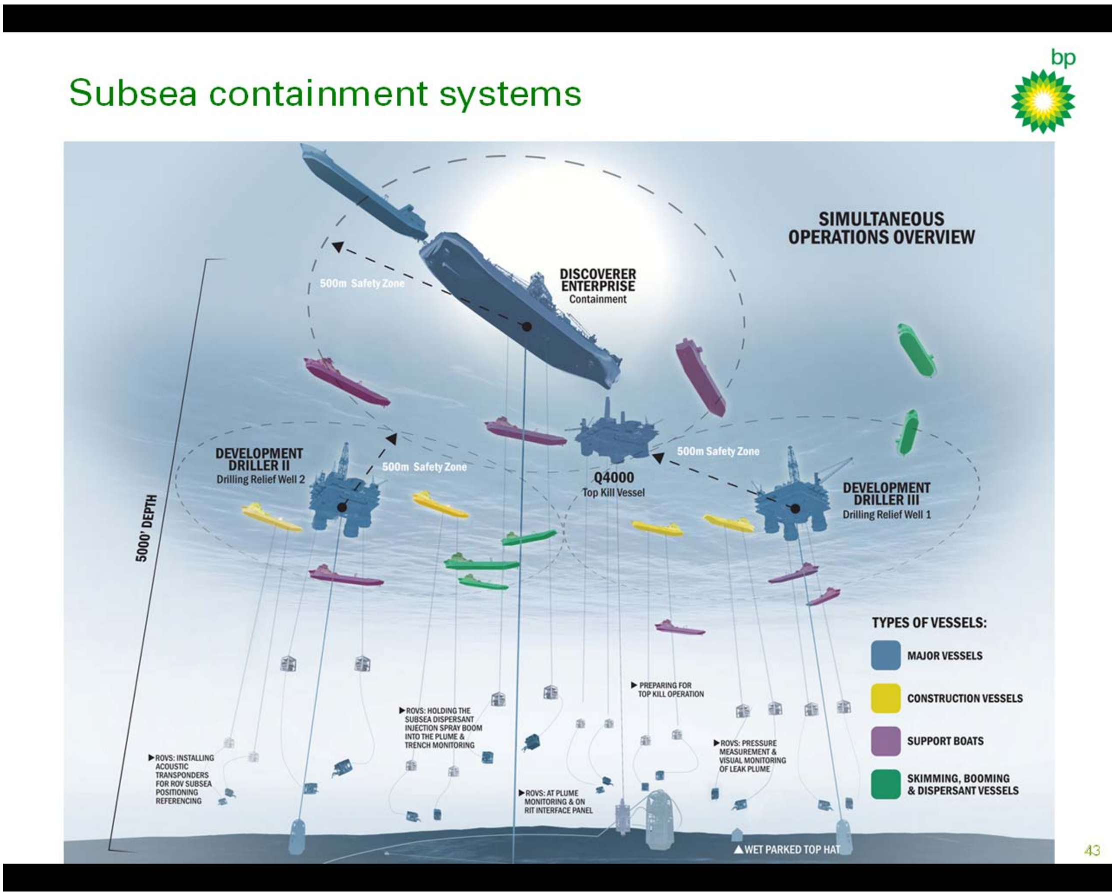
In terms of engineering, the effort to stop the flow of oil meant working fast to enhance existing technologies and develop new ones.

Never before had anyone experienced a blown-out well at a depth of more than 5,000 feet and over $200 million was spent on research and development by BP alone during the response.

We deployed a range of measures with increasing success. Within 12 days of the accident, we had begun work on a drilling a relief well that would permanently stop the leak. And a back—up relief well was started two weeks later.

We employed multiple techniques to contain the leak, collecting oil in open water, using containment systems that piped oil to vessels on the surface, and ultimately sealing the well by fitting a capping stack on top of it.

This graphic shows the complexity of the operation. You can see the two rigs drilling the relief wells and two vessels collecting oil.



You can also see robot subs suspended from vessels at the surface. These were often moving around performing complex operations which had to be carefully choreographed in advance.

These technologies were developed at extraordinary speed – the containment systems, for example, were created in three months when the norm would have been around two years.

In order to make containment and then the sealing cap work, we needed to cut the broken riser pipe. As you can see from this film clip it involved using a giant pair of shears, operated by ROVs, exerting massive pressure at exactly the right spot. There you can see the oil flowing out at the moment the riser was cut.

Once the riser was cut we were able to capture a large volume of oil and pipe it to vessels on the surface. You can see them here. They are the Discoverer Enterprise and the Q4000.

And then when we had built an effective capping stack we first placed a transition spool over the wellhead and then lowered the stack into place.

Here we see video footage of the moments when the well was finally capped. Here we can see the sealing cap being lowered onto the spool and ultimately stopping the flow. You can see the mechanical arm of the robot sub guiding the stack into place. The robot sub operators were some of the real heroes of this response. That was on July 15 last year.

Meanwhile we continued with the drilling of two relief wells. The relief well had to be drilled with precision to intersect the Macondo well at exactly the right point deep beneath the seabed.

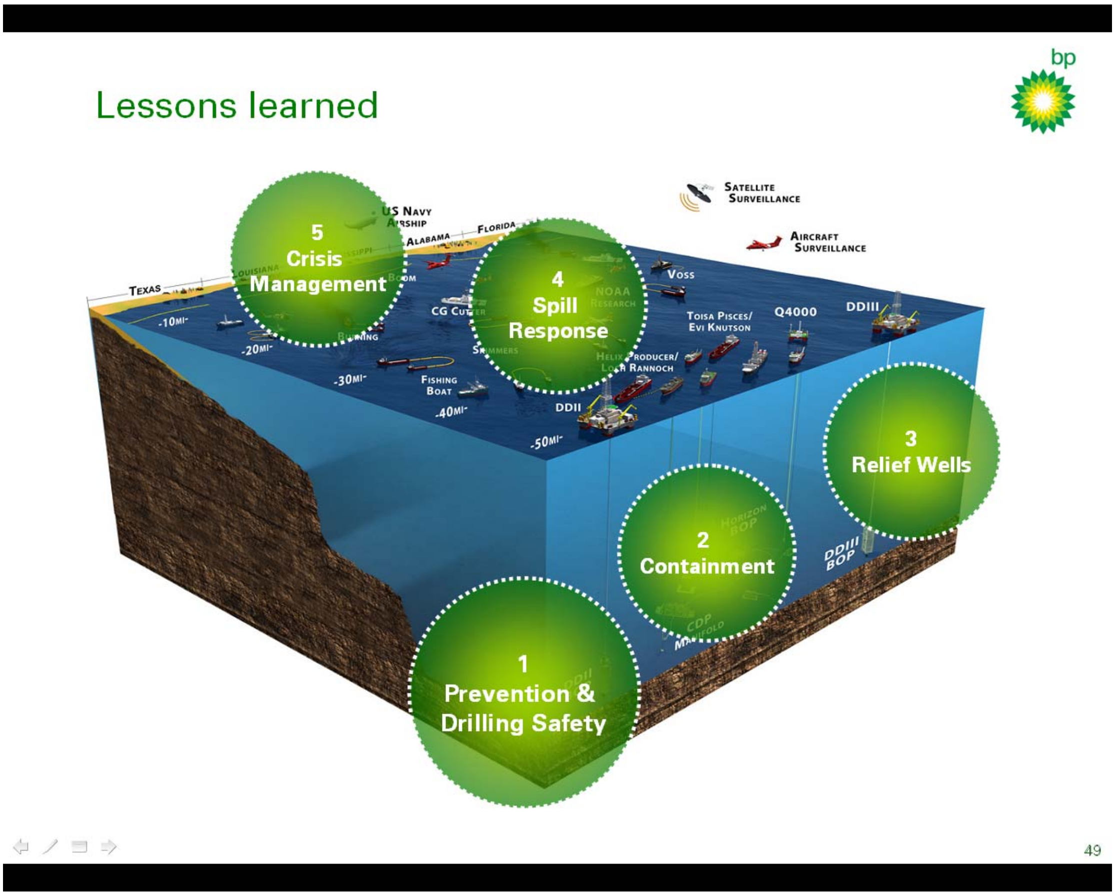
With oil leaking for 87 days, there was a large scale effort to prevent it reaching land and then to find it and clean it up where it did come ashore.

The response involved applying dispersant onto the oil at the surface, applying dispersant underwater, skimming oil from the surface, burning oil on the sea, laying nearly 13 million feet – or 2500 miles - of boom and deploying thousands of people to clear oil from beaches and marshes.

In the communities we set up claims centres to reimburse those who had suffered losses and we have now paid out over $5bn to individuals, businesses, governments and for environmental restoration.

We have learned a tremendous amount from our experiences and the findings of the various investigations over the past 12 months. We would not wish the same on anyone ever again and that is why we are accepting the invitations we have been offered to share what we have learned. We have shared the lessons with industry and regulators in 20 countries.

And we have organized the lessons into five areas: prevention, containment, relief wells, spill response and crisis management.



In terms of prevention, for example, we have been systematically reviewing risk management plans for every one of BP's wells and enhancing our practices in areas such as cementing and well integrity testing.

Aside from the practical and engineering lessons, we are responding to the events of last year in ways that will embed change within all of BP's business, worldwide.

Let me just outline some of the main elements of this program.

We have formed a powerful, central safety and operational risk organization headed by Mark Bly, who led our internal investigation of the accident. Mark reports directly to me and sits on our executive team.

His organization has the resources and the mandate to drive safe, reliable, and compliant operations. This includes the ability to intervene in BP's operations anywhere in the world to bring about corrective action.

We are already seeing results. We have halted operations where concerns have been raised and we have turned away drilling rigs or required modifications, where they would not conform to our new standards.

The new organization has over 500 safety and risk specialists who work alongside our operational managers.

We have appointed people with deep experience in safety and risk management to key roles in this organization. For example, John Baxter, our Group Head of Engineering & Process Safety is here tonight in his capacity as a Fellow of this Academy. John is a former director of the UK Atomic Energy Authority's Dounreay and Windscale sites – two of the sites Lord Hinton built.

We have also made changes in our structure, introducing three divisions in the upstream: exploration, developments and production.

This creates greater clarity and accountability as well as bringing specialists together into teams where they can build their capability.

All of our wells are now drilled by a single Global Wells Organization to drive standardization of process and consistency of implementation to drilling worldwide.

We are conducting a major review of our risk management system and we are linking our performance management and reward systems even more directly to safety and risk management, compliance with standards and long term goals.

In taking these initiatives, we are drawing on lessons from other industries where safety and risk management have been developed to a world-class level.

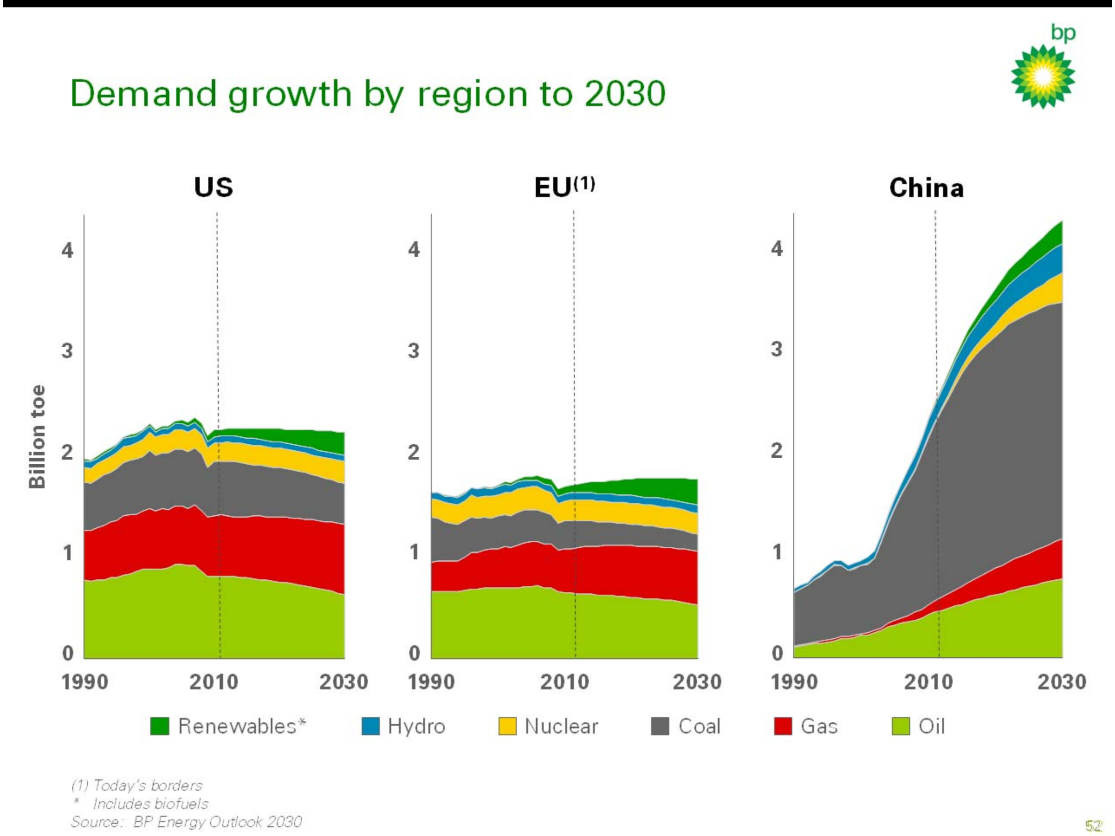
One of these is the US nuclear navy, which was identified by the Presidential Commission on the Deepwater Horizon accident as a leader in safety. And I am very pleased that we now have as a board member Admiral Skip Bowman, who served as director of the US naval nuclear propulsion program.

Strengthening safety and earning trust are the foundations on which we will build a new value proposition for BP, designed to create value for the long term, in a manner that is safe and sustainable.

So let me conclude with a look ahead to our wider task as an industry which is to provide the energy needed to meet the world's growing demand for fuel and power.

By 2030, according to our analysis in BP, we estimate that the world could be consuming around 40% more energy than today. This represents our best estimate according to current trends in demand and supply as well as policy and economic factors.

In this scenario, an incredible 93% of the increase in demand is set to come from emerging economies while consumption in the OECD world remains relatively flat.



This slide shows how that plays out in the cases of North America, Europe and China. As you can see the projected growth in Chinese demand is staggering while the mature industrialised economies show little growth in consumption.

And that pattern you see on the right is characteristic of many fast growing emerging economies as well as China.

Whatever happens, energy will have to come from many different sources. We expect continued reliance on oil, but with new growth met increasingly by gas and renewables. We also have to recognise that on current trends a lot of China's energy growth will come from coal.

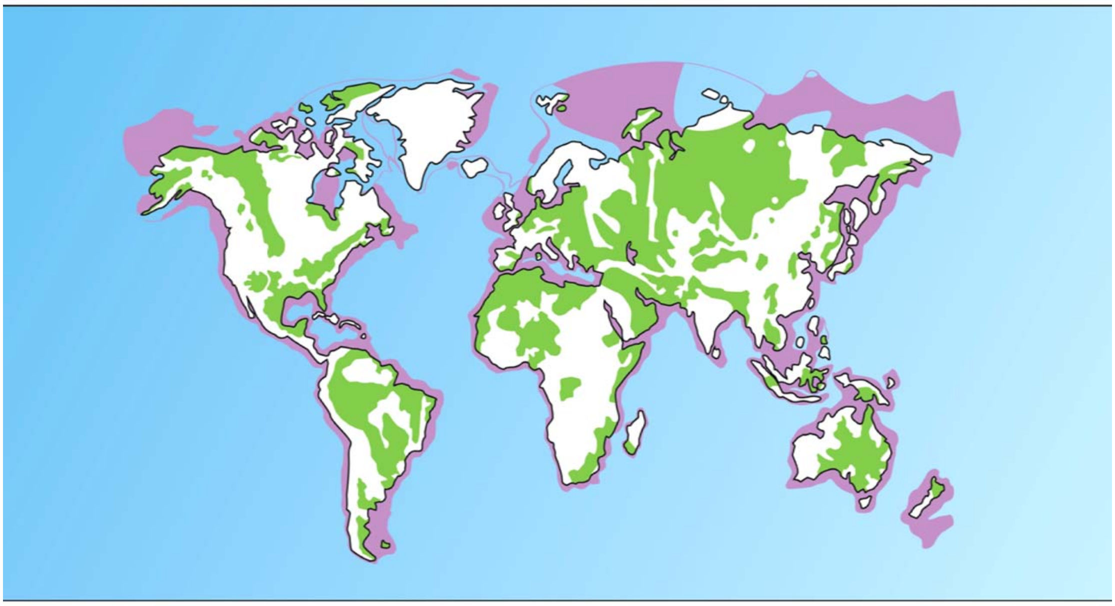
Many of you will note that such as trajectory implies significant greenhouse gas emissions and we have described it as a wake-up call to policy-makers.

As you may know, BP supports policy action to address climate change and encourage low-carbon energy. That action would include a widely applied carbon price and transitional incentives to help low carbon technologies compete with fossil fuels.

4. The next frontiers

So there we have the demand. But what about the supply to meet it? Let's look at fossil fuels first.

Oil and gas resources



This map indicates what we currently know about onshore oil and gas basins around the world. These basins are noted in green. And here we see the offshore basins in purple.

Some of these resources have been exploited, while some have not. Many of the basins shown here are already mature or declining now.

So the industry faces a series of challenges here.

First we need to maximise production from developed fields. Despite all that the industry has achieved, recovery rates for existing fields are still typically under 50%.

Second, much of the undeveloped resource is located in the Arctic. And that poses some unique challenges for engineers.

Third, we will need to continue to probe the deepwater. As you can see, hydrocarbons are often situated in continental shelves and around the mouths of river systems where fossils have accumulated.

And I'll come back to those points in a moment.

Fourth, we need to look beyond the so-called 'conventional' resources to the 'unconventional' resources that require very different production techniques.

Unconventional oil includes the heavy oils found in Canada and Venezuela. These can be extracted by surface mining or – as in the businesses we invest in – through a technique called 'steam assisted gravity drainage' which has a minimal environmental footprint.

Unconventional gas includes shales and 'tight gas' which is trapped in complex formations. Producing this gas requires advanced technologies such as 3D seismic, horizontal and angled wells and new ways of fracturing the rocks. Advances in this area have revolutionised America's gas production in the past decade.

Then beyond fossil fuels entirely, we have low carbon energy, including renewables.

With fossil fuels, Mother Nature has done us a huge favour of concentrating sunlight into accumulations underground - which is why oil, gas and coal have a huge cost advantage over the alternatives.

Renewables have a relatively high cost of collection because the sources have low energy density and require large areas of smaller scale facilities, such as wind turbines and solar panels.

However, we are now seeing significant technology advantages with certain renewables which are now making them cost competitive with fossil fuels, such as ethanol made with Brazilian sugar cane, for example.

BP is focussing its low carbon investments in areas where we can build competitive and material businesses such as biofuels and wind.

Wind power has been a great success story for engineers as they have created bigger and more powerful turbines – often incentivised by supportive policy.

Back in 1998 the American government projected that the country's wind capacity would be 4 gigawatts by 2020. Last year – 2010 – it already stood at ten times that capacity – over 40 gigawatts. And BP is playing a role in that, building a fast growing wind business in the US.

The renewable sector can make use of capabilities developed in the oil and gas sector. For example, geothermal energy and carbon capture both require subsurface capability.

And biofuels have a similar physical supply chain to gasoline, except they begin with a field of hydrocarbons above the ground rather than basin of fossilised hydrocarbons below it.

Biofuels vary in terms of how sustainable they are. Our policy in BP is to focus on what we call "Biofuels done well". And that means developing biofuels that are low carbon and sustainably produced, as well as capable of being delivered at scale and being competitive with other liquid fuels.

For example, BP is planning to strengthen is already significant position in sugarcane ethanol in Brazil and is developing a position in the Southeastern US for the production of lignocellulosic ethanol.

Nuclear power of course has its own set of opportunities and challenges – being much debated in the light of the Japanese crisis. A subject for another presentation I think.

So in this last part of these remarks I want to look at the first three of the challenges I just referred to.

First I mentioned the need to increase recovery rates from existing fields. This is not about new developments but about introducing new technology to well-established fields.

Worldwide, approximately one trillion barrels of oil and gas has been produced so far, but roughly twice that amount has been left behind in the reservoirs.

If recovery factors could be increased by 5%, we estimate that would provide enough resources for 10 to 20 years consumption at today's production rates.

So enhanced oil recovery – or EOR - is very important. One major location where they have been tested and used is BP's Prudhoe Bay operation in Alaska, part of which you can see here.

EOR technologies have increased the recovery factor from an original estimate of around 40% to more than 50%.

These technologies include horizontal drilling, coiled tubing drilling and gas cap water injection. And we now anticipate that we can push the rate above 60%.

The new generation of EOR technologies work in new ways. Reservoir management over the past 100 years has been mainly about large scale physics — drilling wells and displacing fluids in porous media.

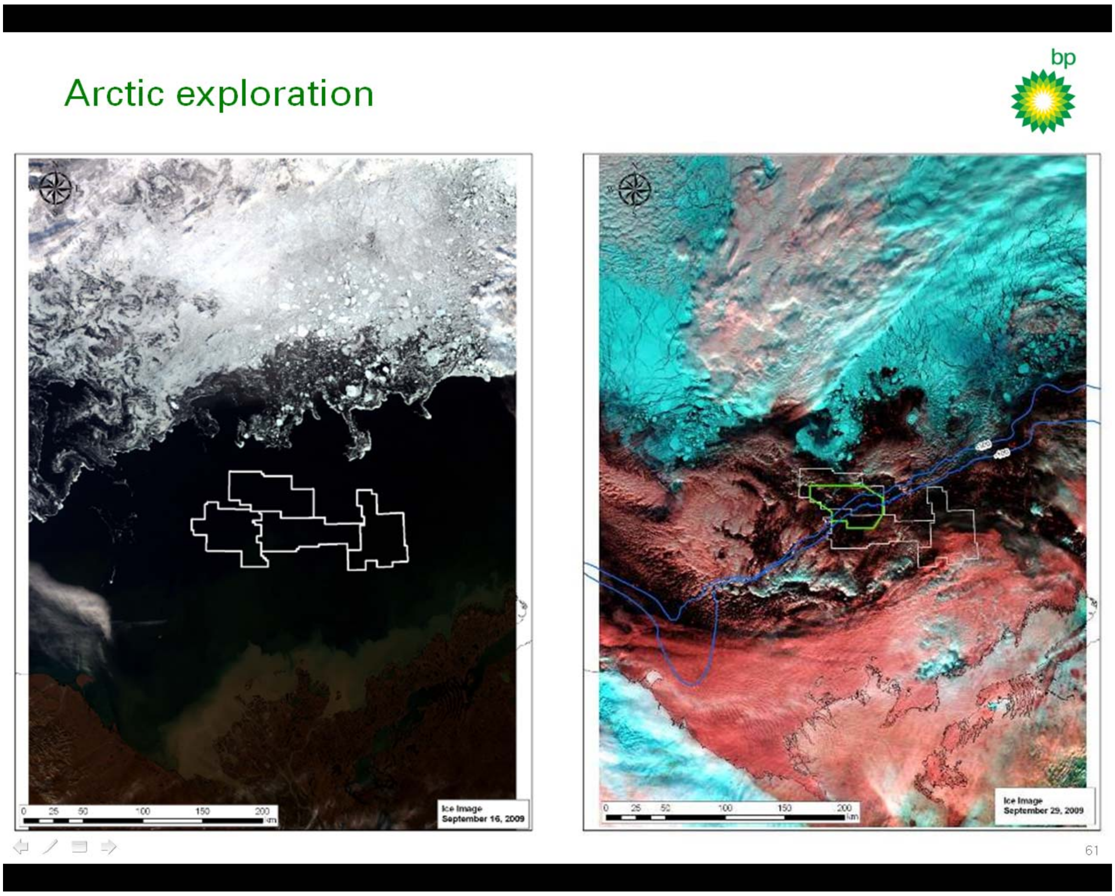
But now we are developing mechanisms that work at the molecular scale. One example is BP's Bright Water™ technology, developed in partnership with Nalco and Chevron.

This technology improves the impact of injecting water into reservoirs to recover more oil. The problem with this has been making sure that the water doesn't simply channel along a few high permeability pathways.

Bright Water™ is a polymer which we add to injection water. It blocks the zones that have been swept already and it diverts the water into the unswept zones. Simple but effective.

Looking at the second challenge, Arctic drilling takes place offshore and that creates numerous challenges relating to ice.

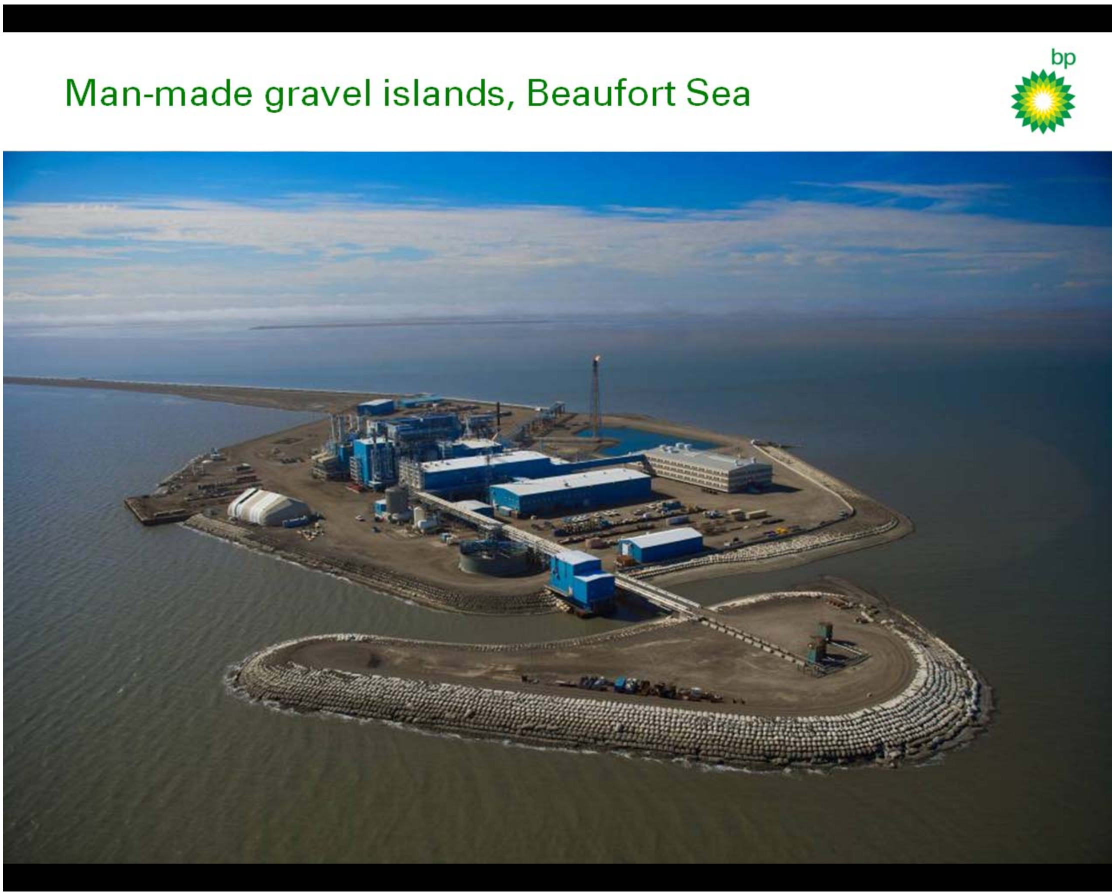
These images show the narrow band of water that exists between the land – in this case Alaska and Canada – and the ice sheet. Seasonally this opens up wider but it closes off completely during many months of the year.



That means that projects have to be built rapidly and then secured so that they can be left during the months when they are surrounded by ice. There is also an environmental concern because a spill could lead to oil being trapped in the ice for months.

One solution has been to drill from gravel islands, for example in the Beaufort Sea off Alaska. Joint industry engineering development programmes have been undertaken here. They have covered ice mechanics, the design of the islands, the construction of mobile drilling units and techniques for installing pipelines through the ice.

This is the Endicott Island development which was the first continuously producing offshore oil field in the Arctic. Drill-ships are also used in these conditions



The North Star development in the Beaufort Sea came on stream in 2001. This was the first, all year round, offshore Arctic production with no causeway link back to the shore.

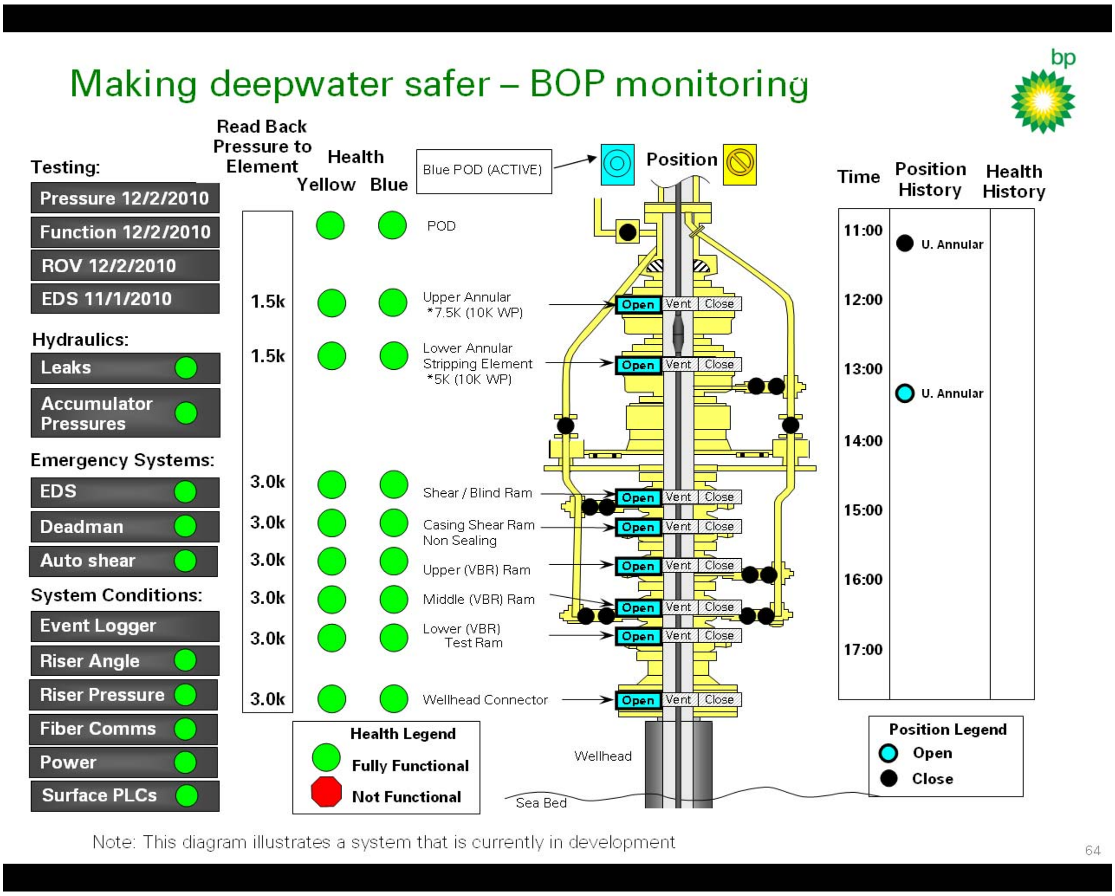
Man-made gravel islands, Beaufort Sea

But this is only a start. There is much to do, and we will make further advances in drilling and production and manage the risks required to help us protect the Arctic environment.

The third challenge I mentioned was moving to deeper water and the need for advances to make the deepwater sector safer and more efficient.

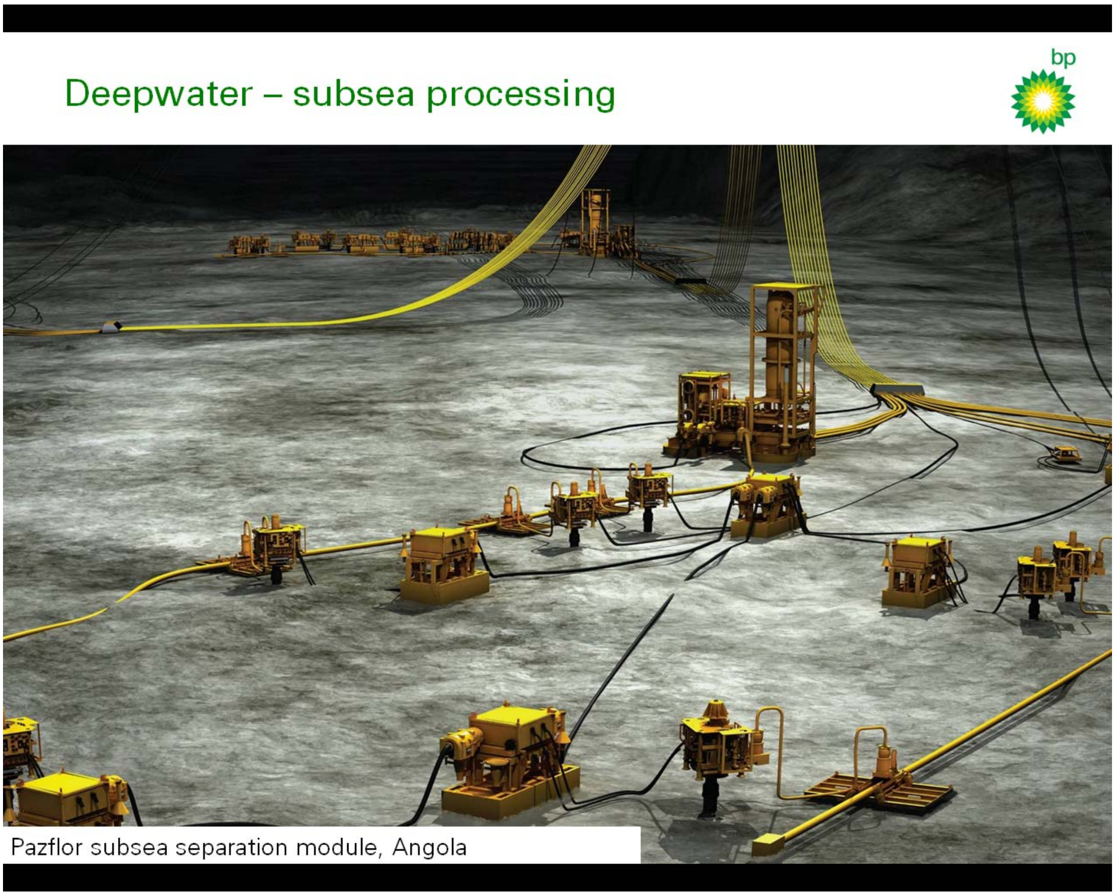
In BP as you might expect, we have a comprehensive program of activity underway on deepwater activity. This ranges from creating new standards and practices to assessing people’s capability and recruiting new specialists.

Let me just highlight one area that we are doing a lot of work on. This is about monitoring blow out preventers.



On deepwater rigs the status of each element of the BOP is monitored and we are now working on how that data might be presented using advanced diagnostic tools and an interface along the lines of the one shown here. This makes the data accessible in a new way to well site leaders and managers on shore as well as the engineers on the rig.

We are also working to make deepwater activity more efficient by expanding the scale of the subsea systems we use. These systems separate oil and gas at the seabed rather than the platform. They can also pump the resources from point to point underwater. This image shows the complex system designed for the Pazflor project that we are operating in Angola.



So let me conclude by drawing together the key points that arise from this story of a century or more of frontier engineering.

First demand has driven energy production to frontier after frontier. Given that fossil fuels are a naturally declining resource and the unrelenting growth in demand, we would expect that process to continue.

Second, sound technology innovation, driven by the market, has generated a stream of new opportunities accompanied by new engineering standards and design codes.

But third, risk has been ever present. We have an over-riding commitment to excellence in operational risk management and the safety that results from it. This is all the more important in an industry that faces a succession of new frontiers where we have to learn as we progress. Generally we have been both innovative and successful in managing the risks involved, but in some cases, accidents have been the driver for change.

After the Piper Alpha disaster, the United Kingdom introduced a “safety case” regime modelled on the one which Lord Hinton was instrumental in developing for nuclear projects in the UK.

After the Exxon Valdez spill, the United States introduced the Oil Pollution Act of 1990.

In a similar way, the *USS Thresher* submarine disaster led to the nuclear navy’s SUBSAFE system. And as I mentioned, the US nuclear navy has been a source of learning for BP in the safety initiatives we have put in place over the past year.

Changes that have been made after accidents and disasters have often been about creating independent and expert scrutiny and challenge - and that is exactly what we are now doing in BP following last year’s accident.

As the legendary US Admiral, Hyman Rickover said, “You get what you inspect, not what you expect.”

Given this history – and in no way minimising BP’s particular responsibilities - I think it is time for our whole sector to consider whether we need to take a collective step forward in instituting stronger systems of checks and balances, scrutiny and challenge, at an industry level.

But that is another discussion for a different forum. For tonight, I hope this brief journey through the history of the oil industry has provided some food for thought for you and the industries that you come from.

And in particular I hope that I have left you in no doubt that BP is determined to implement the lessons of the past year and to play our part in enabling our industry to continue to meet the challenges of engineering at the frontiers of energy.

Thank you.