The factory of new knowledge

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Every good journey starts with a map, and I can't think of a better map to start a journey than this one. This is the first published map of the surface rock formations in England and Wales. It was compiled by William Smith – 'the father of English geology' – and first published in 1815.

A version of it hangs here at Imperial College, in the School of Mines.

By coincidence, home for me is a village very close to Churchill in Oxfordshire, where William Smith was born and where as a young boy he found his first fossil – a 160-million-year-old sea urchin called 'Clypeus'.

These fossils were commonly known as a 'butter stones' in that part of the world, as they were used by milkmaids to weigh out pounds of butter.

It was this unassuming little creature that spiked William Smith's interest in geology and inspired him to figure out how the earth worked.

Thomas Henry Huxley, after whom this lecture is named, was himself a geologist – or more specifically, a palaeontologist – as am I. So it is fitting that I am here today to talk about how far geoscience and technology have come since the early pioneering days of Huxley and Smith.
Far from being a sunset industry – the oil and gas business is one of the most fascinating places in which any scientist or engineer could wish to work. The opportunities and technical challenges are still quite extraordinary.

Thomas Huxley himself spanned many scientific disciplines, from medicine and biology, to palaeontology and geology – and he coined the phrase I have borrowed for the title of my talk today.

Huxley described the universities of his time in the 19th century as the 'factories of new knowledge.'

Given the remarkable scale of multidisciplinary innovation by which I am surrounded in my work today, I think it is a phrase to which the modern oil and gas industry can also stake a claim.

I am very honoured to have been invited to Imperial College to deliver this year's Huxley lecture, and to join such a distinguished list of speakers.

In particular, I should like to thank Professor Jan Cilliers for this kind invitation.

My remarks tonight are divided into three sections.

Firstly, I will start by bringing us up to date from the early days of technology in oil and gas exploration.

Secondly, I'll talk about the challenges we face in the industry today.

And thirdly, I'll speak about the role of technology in finding solutions for those challenges.

History of the industry

The early days of oil exploration

So to start, with the history…..

In the early days of the 19th century oil explorers knew very little about what was going on underground. They were real exploration pioneers who also needed to be adventurers, experts in survival, mountain climbers and diplomats – in addition to being able to interpret the landscape and translate those observations into a three-dimensional picture of the subsurface.

We have many sophisticated exploration tools at our disposal today, but in the early days it helped enormously to come across a natural oil seep on the surface, like the one shown here on the right.

One of those places with plentiful seeps was Baku in Azerbaijan, known as the 'Land of Fire,' because of the perpetually burning rocks in the mountains around the city where gas seeped out from the subsurface.

Baku stakes a claim to be in the birthplace of the oil industry, the first oil well being drilled there back in 1846. This short film from Azerbaijan gives you a good impression of quite how primitive the technology was in those early days.

Early 20th-century well technology

As you can see, oil was a high risk business at the time – and not for the faint-hearted, or for those without very deep pockets. That continues to be the case today, although the industry's management of exploration risks has come a long way.

Also staking a claim as being the birthplace of the industry is Titusville in Pennsylvania, where the first discovery well was drilled in 1859, to a depth of just 71 feet.

It was drilled by an unemployed railroad conductor called Edwin Drake. But, to bolster his credentials as a prospector out in the backwoods, his city financiers addressed letters to him as 'Colonel' Drake – making this possibly the first recorded example of exaggeration in the oil industry.

Masjid-i-Suleiman, South West Persia

The industry really began to expand globally at the turn of the century, when oil was first discovered in the prolific oil province of the Middle East – by BP, as it happens.

In 1901 the millionaire speculator, William Knox D'Arcy, hired a geologist called George Reynolds to go to Iran – or Persia as it was known then – and prospect for oil. Conditions were extremely harsh, and records state, and I quote, that "smallpox raged, bandits and warlords ruled, water was all but unavailable, and temperatures often soared past 50°C."

Despite all the visible signs of oil seepage and flaming rocks – and place names like 'the plain of oil' – Reynolds and D'Arcy came within a whisker of failure, despair and financial ruin. After seven years searching and over £500,000 spent – an enormous sum over 100 years ago and equivalent to about £50 million today – the money had run out.

A disappointing end?

In early May 1908 D'Arcy sent Reynolds this letter.

He was instructed to complete two final wells at Masjid-i-Suleiman, and if no oil was found, Reynolds was to "cease work, dismiss the staff, dismantle anything worth the cost of transporting to the coast for re-shipment, and come home."

It seemed like their last chance was slipping away.

But then – just days later – Reynolds struck oil. At 4am on the morning of 26 May, the well reached 1,180 feet and a fountain of oil gushed out into the dawn sky.

Success from the jaws of defeat

This is the telegram that took the news from Persia to London. It marks the start of the oil industry in the Middle East and also the birth of the Anglo-Iranian Oil Company – the company that eventually became BP.

Reynolds's original rig would have looked something like the one in the video clip we saw earlier – a heavy, steam-powered percussion drill which essentially hammered a hole into the ground.

But by 1922 the first rotary drilling rig was in use in Persia – and this was one of the first really major technical breakthroughs for the industry.

Rotary drilling meant that it became easier to drill wells much deeper and with much greater control because the pressure in the well could be managed with the use of mud and cement.

Oily Rocks, Azerbaijan

Those first decades of the industry were mainly spent onshore – but there were also the first signs of today's offshore industry, with wells in California being drilled from piers over very shallow water from as early as 1896.

And this extraordinary place, known as 'Oily Rocks' began to grow out into the Caspian Sea from the Baku coast in 1948.

Oily Rocks has since grown into a city on the sea with 190 miles of streets, shops and restaurants and a population of 5,000 – it is amazing, and no wonder it made a cameo appearance in the James Bond film, 'The World is Not Enough'.

At about the same time as Oily Rocks was growing out into the sea, the industry was starting to develop another new frontier, fully offshore, out of sight of land. In 1947, engineers from a US oil company called Kerr McGee drilled a well 10 miles of the coast of Louisiana in the Gulf of Mexico.

Successive generations of rigs have enabled exploration into deeper waters, and in the 1960s the first semi-submersible rigs were introduced. These floated on the surface whilst maintaining their position with anchors and tension chains.

The Forties field – UK North Sea

Let's fast forward to 1970 and – using one of those early semi-sub rigs – the discovery of the giant 2.5-billion-barrel Forties field in the North Sea.

BP discovered Forties 110 miles off the East Coast of Scotland in water depths of 400 feet – very deep water at the time.

This was another frontier breakthrough – not due to the size of the field, but due to the technical know-how that had to be developed to cope with some of the most severe weather conditions ever experienced by the industry, anywhere in the world.

With only a short window of good weather to work in during the summer, a new approach had to be developed for constructing and installing platforms offshore.

Platforms had to be twice the height of any built by the industry before to withstand waves that might reach 90 feet at their most extreme.

And the export pipeline to the onshore terminal in the Firth of Forth was, at the time, the largest, deepwater pipeline ever built.

At peak production the North Sea was supplying a quarter of the UK's total energy requirements.

Today, the industry is still developing projects that will be delivering oil and gas from the North Sea for many decades to come.

The journey into deepwater

Now let us move into the deeper water story offshore.

Over the past few decades the demand for oil and gas has grown relentlessly, and to supply this demand, oil companies have had to set their eyes on more challenging frontiers.

As I said, back in early 1970s – Forties, in 400 feet – was considered very deep water.

But since then the industry has developed the technology to work at water depths of 6,500 feet – and also to drill complex directional exploration wells that go as deep as 35,000 feet – or about 6.5 miles – below the seabed.

35,000 feet is further below ground than the summit of Mount Everest is above it.

Scale of deepwater drilling

The New York Times once described exploration at these depths as "like flying 30,000 feet above New York City and aiming a drill bit the size of a coffee can, at the pitcher's mound at Yankee stadium – in the dark."

Thunder Horse, Gulf of Mexico

And just to give you some idea of the scale of these developments – this is one of our deep water platforms – Thunder Horse, being towed by barges out to its final location in the in the Gulf of Mexico.

PSVM (Pluto, Saturn, Venus and Mars), Angola

I've included this slide to show that the large scale and technical complexity isn't just what you see above the waves.

In a previous role I was involved in the negotiations with the Angolan government for the licence to drill in a block about 180km off the west coast of Africa.

Our block turned out to contain a series of oil and gas fields in water deeper than six Eiffel Towers standing on top of each other.

PSVM – or Pluto, Saturn, Venus, Mars – the individual names of the four fields – was discovered with the help of the largest marine seismic survey we had ever undertaken and the resulting development project is the largest sub-sea operation in the world.

That complex sub-sea system of wells, manifolds and flowlines spans an area approaching the scale of Greater London – and delivers an average of 150,000 barrels of oil and gas a day to a floating vessel anchored at the surface.

Prudhoe Bay, Alaska

We shouldn't leave the history of frontier exploration without mentioning one of the toughest frontiers – the Arctic – which demands its own set of technological innovations to withstand extreme conditions and protect the environment.

BP found oil in Prudhoe Bay on Alaska's North Slope in 1969 – 1,200 miles from the North Pole and 250 miles north of the Arctic Circle. It is the USA's biggest oil field and one of the largest fields in the world.

Building the 800-mile Trans-Alaska Pipeline to transport the oil from the frozen North Slope to the ice-free port of Valdez in the South was the largest civil engineering project ever undertaken in North America – and involved a number of technical solutions to address environmental concerns.

It included long stretches above-ground – to prevent hot oil melting the permafrost.

Some stretches were raised higher to accommodate the migration paths of the native caribou.

Trans-Alaska Pipeline

And a zig-zag design was employed to absorb movement generated by temperature changes and local seismic activity.

That concludes my brief personal selection from the history of technical frontiers innovation so far. And it brings us to the energy challenges ahead.

The energy challenge

Energy demand is growing

So what are the challenges?

They are summed up neatly in this image…and in this series of charts.

Firstly, the world's population is growing. Anyone over 50 has already seen the global population double in their lifetime – and it is set to increase from more than 7 billion people today to around 9 billion by 2035.

Secondly, the world's economy is growing. Global GDP has been increasing by an average of about 3.5% a year since 1970 and that's expected to continue up to 2035.

And thirdly, energy consumption is growing. In the last two decades energy demand grew by about 50% - and in the next two decades we expect a further 40% growth.

Technically that's a slowdown, but it won't feel like one – because 40% by 2035 means adding roughly one more US and one more China to today's energy consumption.

Meeting that demand begs three questions, or challenges.

The first is sufficiency – is there enough energy to meet demand?

The second is security – can different countries access the energy they need?

And the third is about sustainability – can energy demand be met without an unacceptable impact on the planet's ecosystem?

Let me expand briefly on these.

The sufficiency challenge is whether there is enough energy to meet this demand – bearing in mind that the world is over 80% reliant on fossil fuels for energy today?

The answer is a very straightforward 'yes'.

Our analyses show that the world has abundant technically recoverable resources to meet global energy demand through to 2050.

There are 45 trillion barrels of oil and gas equivalent discovered today – a number that has almost doubled due to the emergence of the ‘unconventional phenomenon’ that includes shale oil and gas. This is mostly onshore and only 1.7 trillion barrels of oil equivalent have been produced to date.

We have moved on from the days of the ‘peak oil’ debate – and we will not run out any time soon.

Moving to the second challenge of energy security, this relates to the fact that big energy consuming nations or blocs, like Europe, are not all big energy producers – and therefore rely on supplies from elsewhere.

So, the energy security challenge is predominantly one of geopolitics, and there’s no doubt that the world is currently in a period of considerable geopolitical turbulence.

And yet oil prices are falling.

This is a reflection of the complexity of supply and demand. The market is resilient and has continued to supply the world with energy for many years through major disruptions such as wars, sanctions and extreme weather events.

This suggests that – rather than the world being divided into countries that are energy dependent and energy independent – the real situation is that the world is energy-interdependent.

And that brings us to the challenge of sustainability.

The key point I’d like to make here is that BP has long been in favour of action to address the risk of climate change.

We are in favour of a stable long-term policy framework with a carbon price that harnesses market forces to incentivize emissions reductions in three ways

- The first is via increased energy efficiency.
- The second is via switching from higher carbon energy to lower carbon energy.
- And the third is through incentivising low carbon innovation.

That includes switching from coal to gas as well as from fossil fuels to non-fossil fuels.

For some time we have included a carbon cost in our investments for major new capital projects in order to drive efficiency and prepare for a more carbon-constrained world.

The challenge ahead then, is not just one of meeting substantially growing demand.

We have to do so in a way that is safe and reliable.

And we have to meet global aspirations for a more prosperous future while minimising the consequences for the planet.

How will technology address those challenges?

Technology across the value chain

I’m optimistic about how we do that – for reasons that I will now come to in this third and final part of my talk – which is all about the role of technology in finding solutions to the energy challenges.

Technology underpins everything we do in the oil and gas business, right across the value chain.

It enables us to discover, recover, process and market energy safely and efficiently to provide heat, light and power to communities around the world and drive economic growth.

So let’s start by looking at some examples of how technology supports discovery, or exploration – the finding of oil and gas.

Seismic imaging

Advances in seismic

The fundamental technology in this area is seismic imaging – using sound-waves to create a picture of the sub-surface. And it’s a technology that has seen extraordinary advances in the last two decades.

In the 1980s, seismic imaging gave us simple cross-sectional profiles of the subsurface using a few hundred sensors.

Today we are creating advanced three-dimensional images using data from hundreds-of-thousands of sensors.

This series of figures shows how that works in practice. They come from our Mad Dog field offshore in the deep water Gulf of Mexico.

The picture on the left is what was possible at around the turn of the 20th century. In this case we are left with very little information in detail on the middle of the field, which is the large ‘hump’ shape in the visible layers. That’s because the sound waves were being dispersed by a large salt body – the feature at the top of the image.

This image was not great, but it was good enough for our geoscientists to determine that there might be hydrocarbons there – and convince us to drill a successful exploration well.

The next two pictures – show the degree to which imaging has improved though the technical advances in data acquisition and processing.

The key development is moving from a two dimensional approach to a 3D process using data from many sources. We achieve this by using multiple vehicles on land and at sea, with boats towing streamers that can be as long as 8 kilometres.

These subsurface images are still not perfect, but have come a long way. Now the structural features of the field are much clearer and – most importantly – gathering data from different angles means we can effectively ‘see’ the layers beneath the salt. That reveals a level of details that was totally impossible a decade ago.

Thunder Horse - 3D

This is our most recent image of the Thunder Horse field in the Gulf of Mexico. You’ll see that the image is a complete ‘volume’ – not just a few cross sections that then have to be mentally stitched together.

The salt canopy is the feature shaped like a bird’s head. We can create much more coherent 3D images of the formations below the salt and so get a much improved understanding of all the subtleties of the field.

Time lapse seismic takes things a step further – also known as 4D seismic. Here we undertake repeated surveys over different time periods to see how the reservoir changes as oil, gas and water move through the subsurface during production.

Another breakthrough has been the phenomenal growth in the computing capacity required to process the data.

Last year we opened a new computing centre in Houston, Texas that houses the world's biggest commercial supercomputer dedicated to research. Currently it gives us access to 3.8 petaflops of processing power – meaning it can make nearly four-thousand-trillion calculations per second.

It now takes a geophysicist a single day to carry out analyses that would have taken four years only a decade ago.

BP Well Adviser

Now let's take a look at how technology is improving recovery, and this is an example of how big data is transforming the way the industry drills, completes and operates wells.

BP Well Adviser is a technology that collects real time 'down-hole' data – in other words from within wells that are being drilled or operated. It then combines real-time data with predictive capability from an ever-increasing amount of historic data from hundreds of wells around the world.

As mentioned in the film, well operators access data via a series of consoles that are much easier to see and act on than previous systems.

Consoles monitor critical well activities and equipment, from drilling and cementing to blowout preventers – such as the one shown here.

Enhanced oil recovery

The next step in our value chain is oil and gas production – how do we maximise the amount of oil we extract from the reservoirs.

Picture an oil reservoir like a solid sponge with the hydrocarbons trapped in tiny pores between sand grains – as just as in this model. Under pressure, roughly about 10% of the oil in the reservoir will flow to the surface, but the majority is held in the pores

A further 20 to 25% of the oil can usually be brought to the surface by a process known as waterflooding – pumping water into the reservoir to maintain pressure.

Even with conventional waterflooding, the average oil recovery factor from a reservoir is only 35%– meaning that almost two-thirds is left behind in the pore spaces.

Technologies that improve on this recovery rate are known as Enhanced Oil Recovery and BP has made this an area of leading-edge expertise in recent years.

We have developed a number of enhanced oil recovery technologies specifically for different kinds of reservoirs and situations, and I have two examples to show you.

Bright Water ®

Bright Water® was developed with our partners, Nalco and this video explains it does in the reservoir.

The Bright Water polymer is added to the injection water and it expands like popcorn when it is exposed to the right temperature conditions, blocking the already well-swept channels.

This blockage diverts injection water down poorly swept areas of the reservoir where there is more oil to recover.

LoSal® Enhanced Oil Recovery (EOR)

LoSal® is my second example of enhanced oil recovery.

Historically, it has been assumed that injecting low salinity water – lower than seawater – would damage the reservoir and impede production.

The 'light bulb moment' was understanding that lowering the salt concentration of the water could shift the electrolytic balance in the reservoir in a way that weakens the bonds between oil molecules and rocks, allowing more oil to be released.

This clip explains the chemistry of the process.

The potential of EOR then is enormous, and longer term breakthroughs in microbial and nano-particle technologies could raise recovery factors even further.

So much so, that we now think more oil may be recoverable from the reservoirs we currently know about, than from potential new discoveries.

Improving energy efficiency

Most energy is lost

We are now going to move from the upstream – where energy is discovered and recovered – to the downstream, where it is processed and marketed.

And the technology story here is largely one of improving energy efficiency.

Only 12% of primary energy is converted into useful motion, heat, light, cooling and sound. The rest – 88% - is lost, largely as low grade heat.

Technology and efficiency

I have another video here which show just some of the areas where BP is working to improve efficiency.

I want to just pick up on a couple of those examples from the film that are of particular significance to us all.

One of these is transport, where many of the products from the oil and gas industry are used, and where there are three important and related trends to consider.

One trend is increasing vehicle numbers – with consequences for fuel consumption and emissions.

A second is increasing regulation in many countries to reduce fuel consumption and CO_2 and particulate emissions.

And the third trend, is the increasing efficiency of vehicle fleets.

In Europe by 2015 the average CO_2 tailpipe emissions target for the new vehicle fleets will be at 130g CO_2/km. In 2021 it is going to be even more stringent and reduce to 95g CO_2/km.

Automotive manufacturers have to meet these strict targets or face steep fines. So in recent years they have embraced innovation on a huge scale – with hybridisation and batteries, downsized engines with turbo-charging, variable valve timing and direct fuel injection, as well as light-weighting vehicles and using advanced materials – but without loss of power and performance, and also continuing to meet their customers' needs.

Engines are shrinking
I think this video shows just how far downsizing of modern engines has come.
We work closely with many vehicle manufacturers on the development of our fuels and lubricants to achieve continuous improvement in engine cleaning, protection from wear and tear, and improved fuel economy – all of which help to reduce emissions.

For example, when we test our premium lubricants we have been able to demonstrate up to 4.5% reduction in fuel consumption in some engines – the less friction in the system – the better the fuel economy.

Fuel economy is improving
The efficiency gains resulting from these various developments are illustrated here.

Whilst the global vehicle fleet is set to rise by well over 100% over the next 20 years, demand for fuel will only increase by 29%.

Permasense® - corrosion management
That brings me to one last efficiency example – and it is one we developed here with our partners at Imperial College.

Permasense is an ultrasound technology that can measure changes in the thickness of pipelines with a very high degree of accuracy and sensitivity.

It is a non-invasive way of continuously measuring corrosion and internal erosion of pipework, and we can deploy it on pipes that are otherwise highly inaccessible for inspection.

When you consider that in North America alone there is something like 2.5 million miles of pipelines carrying hydrocarbons, the potential safety and efficiency gains from deploying Permasense are enormous.

We already have Permasense in place at all BP-operated refineries around the world and some upstream facilities – and we have plans to roll it out across our offshore platforms.

Looking Ahead

Emerging technology
I hope I have managed to convey the sense of the surge of innovation that is happening in the oil and gas industry at the moment.

This is bringing together digital and big data, nano, bioscience, robotics, advanced materials, computational modelling, energy storage and many other disciplines,

And technology is coming from many sectors and more countries than ever before as we assimilate innovation from the aeronautics industry, mining, pharmaceuticals, automotive and elsewhere.

It is far beyond the resources of any one company or organization, regardless of size, to excel and innovate in so many different disciplines.

BP's innovation ecosystem
As a result, R&D models have moved from big, in-house corporate laboratories to co-operation with academia, and to a diversity of collaborative partnerships.

At BP we develop in-house expertise in our core areas. That involves approximately 3,000 scientists and technologists in our research centres around the world – focussing on key strengths. We also have a strong venturing business that invests in entrepreneurial companies that are accelerating the development of promising new technologies.

Externally, we work closely with our partners and suppliers – and particularly important are our world class university partners - including a very long-standing relationship with Imperial College, working on a wide-range of scientific research and development.

Conclusion

So now for some brief concluding thoughts.

The first is that energy is abundant. There is no urgent concern about shortage or decline – as was once forecast. But there is a vital role for innovation in ensuring that we are able to meet the growing demand for energy safely, efficiently and reliably – and in a way that facilitates a sustainable future for the planet.

My second reflection is a contrast. When I joined the energy sector, innovation was mainly undertaken within the industry, inventing our own technologies – in our own research centres. Today the energy industry needs a whole range of technologies from many different disciplines and sectors.

Being a polymath himself, I think Thomas Huxley would have been ideally suited for a career in today's oil and gas sector.

Thirdly, is the importance of strategic relationships – when innovation is happening so fast, we stand or fall through the strength and quality of our technical partners.

Finally, oil and gas is a business that offers the opportunity to live and work all over the world, to work at the very forefront of scientific research and development, human knowledge and endeavour, and importantly to help provide people with the energy, heat and light they need for economic and social development.

As a very young girl I used to hunt around in the garden getting muddy, searching for odd stones, bugs and anything unusual in the soil. Like Smith and Huxley, I would hope to find some fossils.

As a young geologist, I got to do that for a career.

And today I have the privilege to talk to this audience of learned people in a darkened room and tell you all about doing that for a living.

The oil and gas industry has had an utterly fascinating journey so far, and there is more to come.

If I was setting out again now – as many of you are on your careers – I would definitely join this extraordinary industry again without hesitating for a second.

And I hope many of you will make the same decision.

Thank you.