THE INTERNATIONAL MAGAZINE OF THE BP GROUP **ISSUE 2 2014**

BP MAGAZINE

14 SPOTLIGHT: BP-ICAM

MATERIALS WORLD

BP Magazine reports on the progress being made at the BP International Centre for Advanced Materials to advance the fundamental understanding and use of materials in energy.

Welcome. November is 'Think Technology' month in BP and throughout this edition we're asking the question 'where is technology taking us?' To help us answer that, BP's head of technology, David Eyton, kicks off things on page 6. On page 14, we meet some of the scientists working at BP's International Centre for Advanced Materials to find out how a 10-year research programme is going. On page 22, BP's chief scientist, Angela Strank, and graduate chemist Rachel Fort discuss their roles as women in science, and on page 34, we find out how dramatic increases in computing power are transforming data analysis across BP. We also take a look at some of the new technologies in wind and biofuels that are boosting production (page 48) and how unmanned aerial vehicles are changing the way in which BP equipment is checked (page 52). Technology aside, we visit Canada to learn more about BP's Upstream business there (page 54), mark the 20th anniversary of the signing of Azerbaijan's 'contract of the century' (page 62) and take a look at the new BP-supported Ming exhibition at the British Museum (page 74).

Lisa Davison> Editor

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BP MAGAZINE
The international magazine of the BP Group – ISSUE 2 2014

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Cover image: scientists at Imperial College, London, working on one of the projects for the BP International Centre for Advanced Materials.
Photograph by Richard Davies


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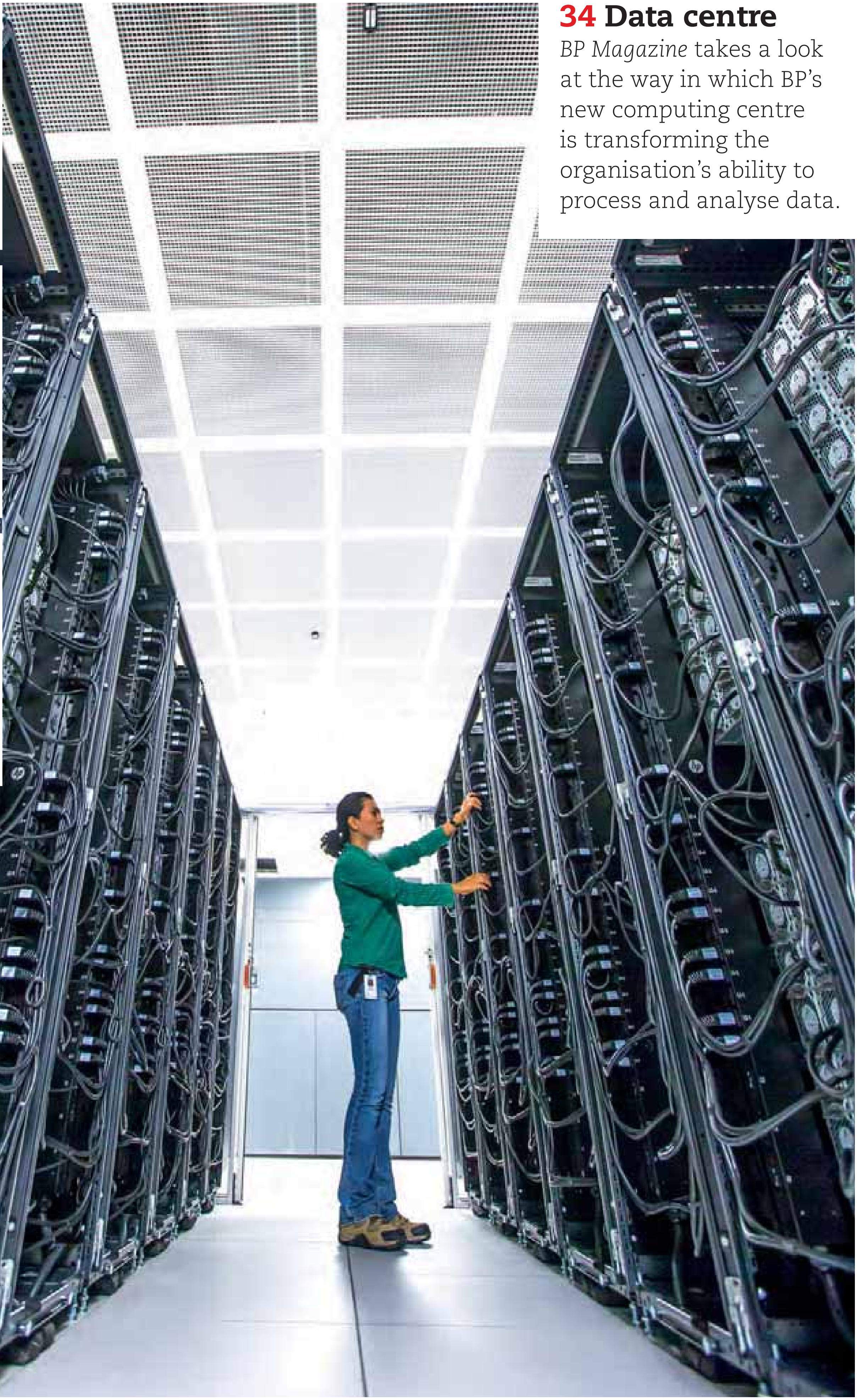


34 Data centre

BP Magazine takes a look at the way in which BP's new computing centre is transforming the organisation's ability to process and analyse data.

For the record

Highlights from around the globe > Autumn 2014

the quarter in numbers

18

Number of countries in which BP Ultimate fuels are now sold, following the launch of BP Ultimate 95 and 98 in Russia.

2,377

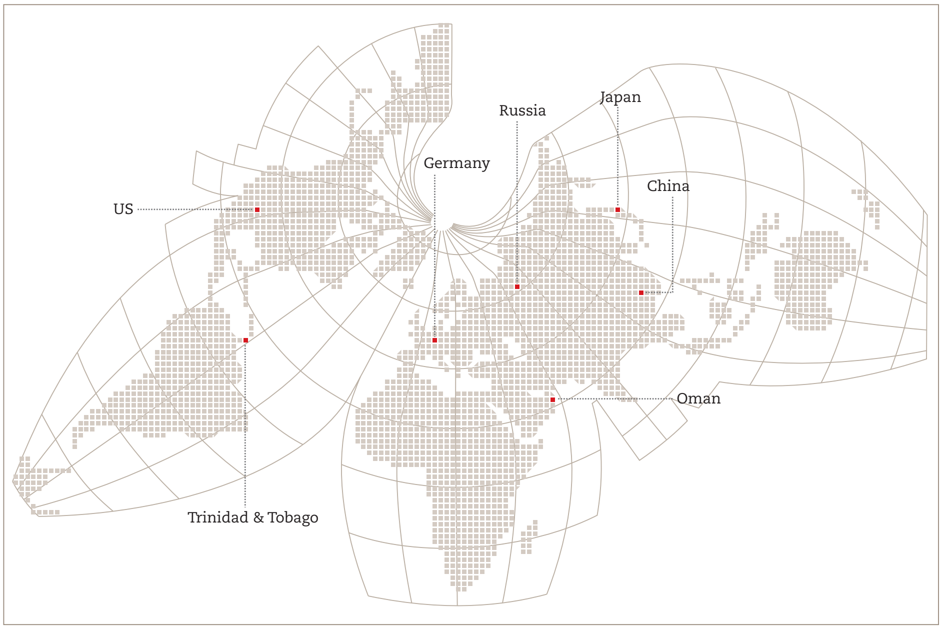
Record-breaking number of entries for the 25th BP Portrait Award. Entrants came from 71 different countries.

4,000+

Number of people who took the opportunity to learn more about Germany's Ruhr Oel refinery – a joint venture between BP and Rosneft – during the German Association of Chemical Industry's 'Day of Chemistry'.

90,000

Number of attendees at ONS 2014 – Norway's premier energy event. Attendance was up 50% on the previous record.



OMAN: DRILLING CONTRACTS

BP has awarded two long-term drilling contracts for the Khazzan project in Block 61. KCA Deutag has been awarded more than $400 million contracts for the construction and operation of five new-build land rigs for Khazzan. The rigs are being assembled in Nizwa to help maximise employment opportunities in Oman. According to the second agreement, Oman's Abraj Energy Service has been awarded more than $330 million contracts to supply three drilling rigs for the full-field development of the Khazzan project.

"We are pleased to announce these contracts, which continue to progress our development of the gas resources at Block 61. Abraj Energy Service and KCA Deutag will play important roles in the massive drilling programme ahead. The selection of Abraj Energy Services demonstrates once again BP's commitment to in-country value," said BP Oman general manager Dave Campbell.

Khalid Al Kindi, deputy general manager for BP Oman, stated: "Building local content into our supply chain is a key focus area in BP's procurement strategy. BP is committed to hiring and developing talented Omanis."

NEWS IN BRIEF

China
LNG agreement
BP and the China National Offshore Oil Corporation (CNOOC) have signed a heads of agreement for the supply of up to 1.5 million tonnes of liquefied natural gas (LNG) per year over 20 years, starting in 2019. BP's chief executive, Bob Dudley, said: "This is a significant deal for BP and China, but it also marks a step up in global connectivity in the gas market."

Global
Conn departure
BP has announced that Iain Conn, group managing director and chief executive for Downstream is leaving the company and is to step down from BP's board by the end of the year. Conn has worked for BP for 29 years, serving on the board for the past 10 years and in his current Downstream role for the past seven.

Global
Board appointment
Alan Boeckmann has been appointed a non-executive director of the BP board. Previously, he was chairman and chief executive of Fluor Corporation, the engineering and construction company. BP's chairman, Carl-Henric Svanberg, said: "Alan is a global leader in the engineering and construction industry. His deep experience of international project management and procurement will complement the skills and perspective of the BP board and I am looking forward to welcoming him as a director."

Trinidad and Tobago
Project sanction
BP Trinidad and Tobago (bpTT) has sanctioned its Juniper offshore gas project. The project will feature the construction of a normally unmanned platform, together with corresponding subsea infrastructure, a first for bpTT. The development will include five subsea wells and will have a production capacity of approximately 590 million standard cubic feet a day. Juniper will become bpTT's 14th offshore production facility. First gas is expected in 2017.

US
Court ruling
The US District Court for the Eastern District of Louisiana found BP grossly negligent in the lead-up to the 2010 Deepwater Horizon oil spill in the Gulf of Mexico. BP strongly disagreed with the decision and said it will appeal to the US Court of Appeals for the Fifth Circuit. The organisation said it believed that the finding was not supported by the evidence at trial.

Japan
LNG agreement
BP and Tokyo Electric Power Company (TEPCO) have signed a sales and purchase agreement for LNG. Under the agreement, TEPCO will purchase from BP up to 1.2 million tonnes of LNG per year for 17 years, starting in 2017. BP will supply TEPCO with LNG from its diverse portfolio of LNG sources. This is the first long-term portfolio contract for TEPCO. It is also BP's first long-term contract with TEPCO where BP is the sole supplier.

US
Paralympic donation
BP is to donate $160,000 and the necessary equipment for the creation of the first official US Paralympic training site for wheelchair racing at the University of Illinois at Urbana-Champaign.

"As a proud partner of the United States Olympic Committee, BP is honoured to support the establishment of what we believe will be the top Paralympic wheelchair racing training facility in the world," said Corey Correnti, BP's Chicago-based vice president of marketing, sales and supply.

Global
New chief economist
Spencer Dale has joined BP as its new group chief economist, replacing Christof Rühl, Dale joined from the Bank of England, where he was executive director for financial stability strategy and risk. In his previous capacity as the bank's chief economist, Dale served for six years on the monetary policy committee.

Europe
Aviation purchase
Air BP has announced its agreement to purchase the aviation fuel business, Statoil Fuel & Retail Aviation AS (SFR Aviation), from Canadian company Alimentation Couche-Tard Inc. The deal will add around 73 new airports in the Nordic countries and northern Europe to Air BP's 600-strong global fuels network. The deal, which is subject to regulatory approvals, is expected to close by the end of 2014.

Interview> David Eyton

Lubricant leader: testing a lubricant in a glass dish at BP's formulated products technology (FPT) centre in Pangbourne, UK. One of BP's business goals is to be the best at lubricant development.

the technical edge

As head of technology at BP, it's David Eyton's job to oversee technology strategy and execution across the organisation in support of its businesses. He talks to **BP Magazine** *about the growing importance of technology and adapting for the future.*

INTERVIEW> LISA DAVISON **PHOTOGRAPHY>** STUART CONWAY/RICHARD DAVIES/SIMON KREITEM/GRAHAM TROTT

"Often small changes today, when accumulated over time, can make significant differences in the longer term. So, BP is increasingly taking into account the long-term impact of technology on its portfolio choices."

What is BP's technology strategy?
BP's technology strategy has three elements: to manage safety and operational risk, capture business value, and differentiate us from the competition. Investment is aligned with the organisation's business goals: focusing on its strengths in exploration, deep water, giant fields, gas value chains, and high-quality downstream businesses. There is no point developing great technology where we do not intend to invest as a business.

Can you give some examples of where BP wants to lead the competition?
In the Upstream, we have decided that we want to lead in two areas with proprietary technology: seismic imaging and enhanced oil recovery. In the Downstream, we want to be the best at making the petrochemical products that are in our portfolio. On the customer-facing side, we want to be the very best at lubricants. These are all areas in which we believe we can bring extra value to the business.

How does BP assess future technology potential?
Over the past decade, we have studied global technology trends and asked ourselves 'where is the world headed?' Often, small changes today, when accumulated over time, can make significant differences in the longer term. So, BP is increasingly taking into account the long-term impact of technology on its portfolio choices. In 2013, we created a long-term technology view which indicates, for example, that the global potential of unconventional sources of energy is very significant and likely to become a growing part of the industry's focus. If we know that, we can develop skills and technologies today that will allow us to compete in the future.

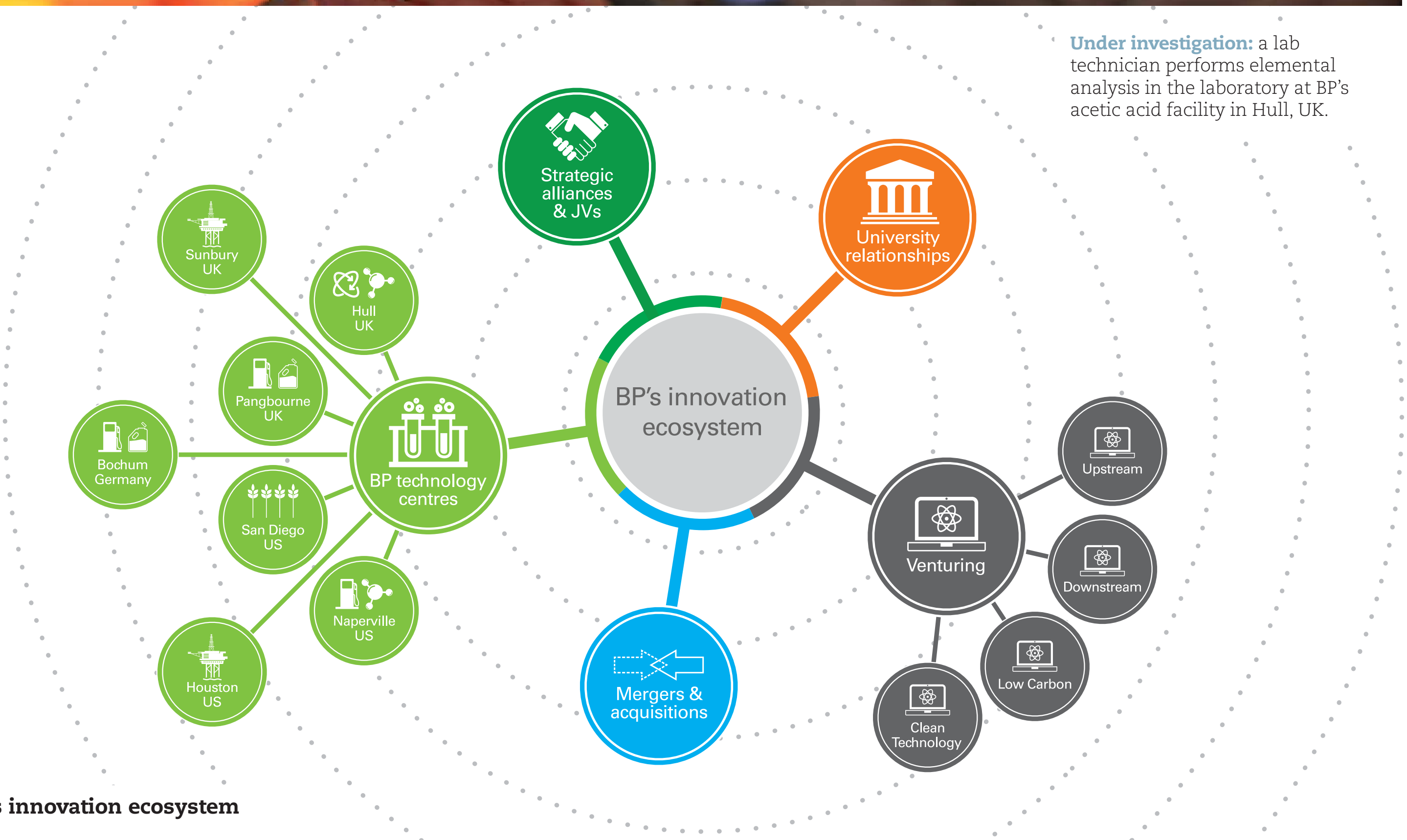
BP's *Energy Outlook 2035* indicates that demand for energy will be 41% greater than in 2012. How does the technology that we are developing today help us to meet that demand in the future?
First and foremost, technology can improve the standards with which we operate – we must find and produce the resources safely. Second, it can help us to access new frontiers – either new regions or new forms of energy. Digital technology is a good example of how we are already making progress in these areas – technologies such as remote sensors help us to monitor and manage corrosion in our assets, and our new Center for High-Performance Computing in Houston is revolutionising the way in which we process and analyse seismic data, allowing us to make faster decisions on new and existing reservoirs [see page 34 for more on the computing centre and data analytics]. The third thing technology can do is help us to improve efficiency. The reality is that today's global energy systems are incredibly inefficient. It is a fact that only 12% of the energy captured at its source ends up as useful heat, light and motion. So, there is a very big prize in terms of improved efficiency and that includes everything from the internal combustion engine, to smart electricity grids, to enhanced oil recovery. The fourth area it can help with is sustainability. Technology can deliver lower carbon solutions over time.

How important is policy and social behaviour when making technology decisions?
It's critical. There is only so much industry can do to influence the debate about genetically modified organisms, or hydraulic fracturing, or the Arctic, or drilling in deep water. But, clearly, in different parts of the world, people remain divided over activities that might be techno-economically attractive. That is the big difference between Europe and the US when it comes to shale gas; the US has alignment between land ownership and mineral rights ownership, which has enabled the shale revolution.

Do we have a sense of which technologies would be most important for accessing resources in the future?
It depends on the timeframe, but we do know that right now, across BP, the application of digital technologies is changing the way in which we operate. The clock speed of digital technology evolution is very rapid.

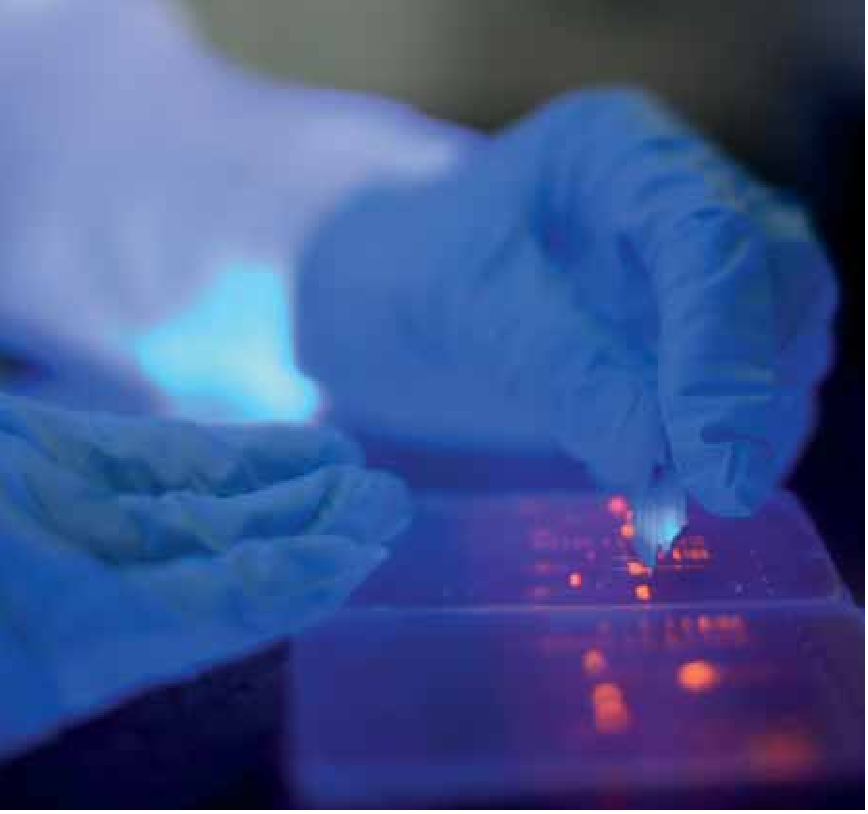
What role might power generation play within BP and more generally?
Although BP has a large US wind business, it is not the company's strategy to grow as a merchant power generator. If you look at power more generally around the world, coal-fired generation is probably the fastest growing source right now, particularly in China. It is easier to reduce the carbon »

Under investigation: a lab technician performs elemental analysis in the laboratory at BP's acetic acid facility in Hull, UK.

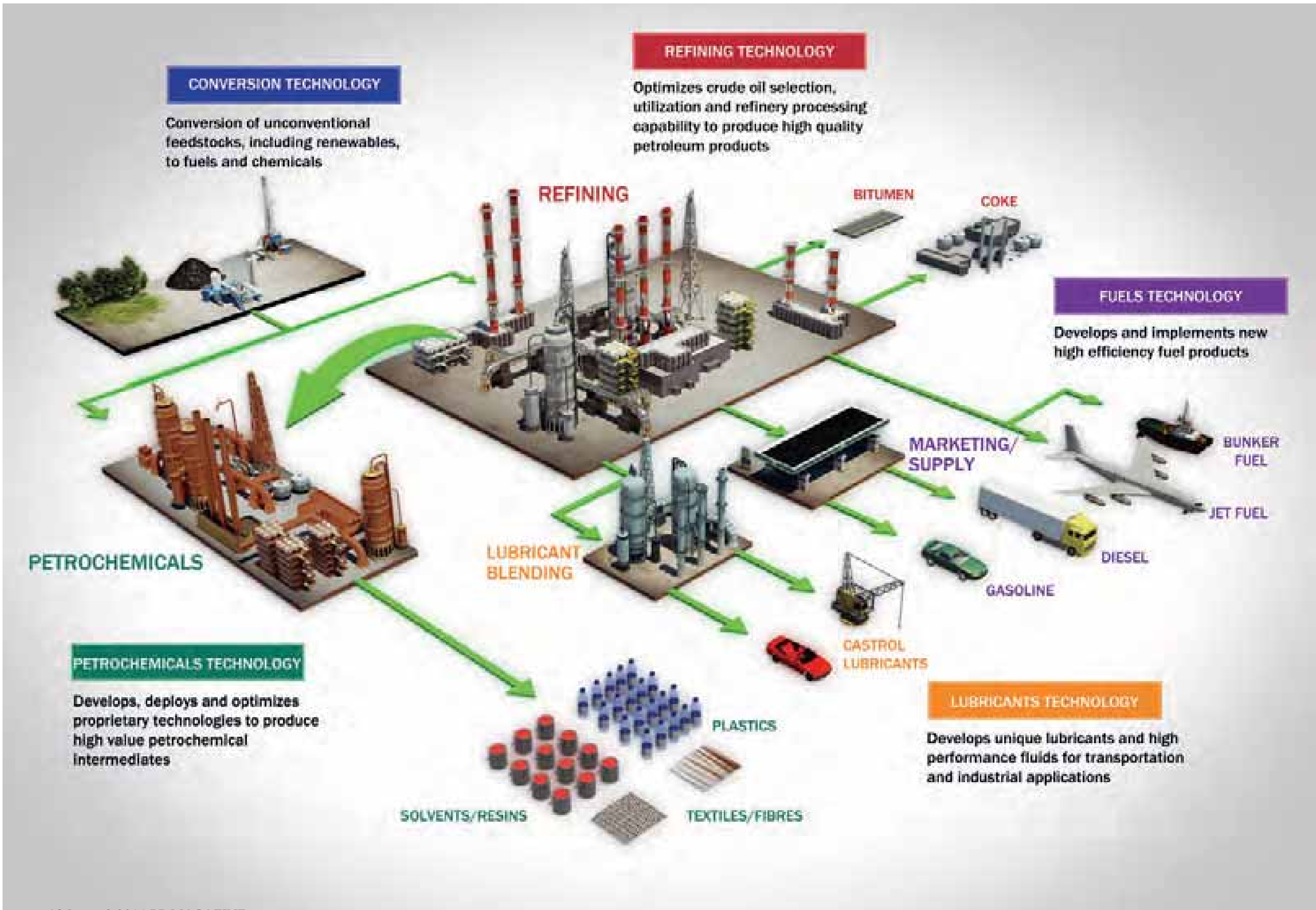


BP's innovation ecosystem

BP spends more than $600 million on research and development each year and employs more than 2,000 scientists and technologists at seven major technology centres. This internal expertise is part of a larger global innovation ecosystem, as seen in this graphic. As well as working with world-leading universities on long-term research and development programmes, the organisation is part of a number of strategic alliances and joint ventures. BP also has a thriving venturing business, identifying and investing in entrepreneurial companies to accelerate the development of technology, from oil and gas to renewable energy and can access new technology capabilities via mergers and acquisitions. This ecosystem gives BP a 'bigger brain' to create innovative solutions to industry challenges.



BP'S DOWNSTREAM TECHNOLOGY MAJOR PROGRAMMES



Advanced knowledge: (far left) high-powered ultra violet light is used for research into developing advanced biofuels technology by Du Pont/BP. Biofuels is one of two key alternative energies in which BP invests – the other is wind; (left) a chromatography specialist, part of the investigational analysis team, loads a sample vial to perform gas chromatography mass spectrometry (GC-MS) at BP's FPT centre in Pangbourne; (right) and BP's head of technology, David Eyton.

"Across BP, the application of digital technologies is changing the way in which we operate. The clock speed of digital technology evolution is very rapid."

footprint of power than in, for example, heating or transportation, and our analysis shows that renewables will penetrate the world's power systems. However, switching from coal to natural gas-fired power has a more immediate benefit in cutting emissions.

What about transport fuels?

We did a big study in 2009 and we found that if a driver is concerned about his or her carbon footprint, then the most cost-effective way of reducing it is to make the internal combustion engine more efficient. This is already happening – think about the miles you get per gallon that a car can do now compared to 10 years ago – the progress is extraordinary. In Europe in particular, car manufacturers are driven by European Union standards for tailpipe emissions. The second thing you can do is hybridise, by capturing more of the energy of braking. That will make the car more efficient in terms of miles per gallon, but it comes at a slightly higher cost. The next thing you can do is use biofuels. In Brazil, for instance, 50% of transport fuel is now biofuel. Electrification is also an option, but the money spent per unit of carbon saved depends very much on your source of electricity. If you are in France and the source is nuclear, then that clearly is a very low-carbon source of electricity. In the US and China, though, it's likely to be coal. If you are particularly concerned about emissions in very big cities, though, then electric vehicles can help, especially relative to particulate emissions from diesel engines.

BP's *Energy Outlook 2035* also states that renewables are growing at the fastest rate of all energy sources. What does that mean for BP?

The rate is high, but they are growing from a very small base. However, the world has not done much to put a price on carbon, which remains one of the prerequisites in making some of these renewable energy options commercially viable. They simply don't compete without support. BP made a commitment in 2005 to spend $8 billion on alternative energy and by the end of 2013, we had passed this target, spending $8.3 billion. Today, we have two gigawatts of wind capacity spinning in the US, and are focusing on biofuels, where we think that BP has a lot of natural advantages. Biofuels production is simply a different form of catalysis, something we're already very experienced in and we have the retail networks to supply the products.

Why does a big multinational such as BP need policy incentives to invest in renewables?

BP is a business. Our shareholders invest in us and expect a return on that investment. Many of the alternative sources of energy do not compete today with the fossil equivalent and they need subsidies to do so. BP looks to invest in the more competitive renewables, such as Brazilian sugarcane ethanol and US wind power. Even then, returns are often » not as high as for fossil fuels. Incentives, mandates, regulation and taxation are expressions of national desires – often designed to advance or deter particular forms of energy – and we live within those frameworks. We make no secret that within that set of policy levers, we favour a widespread carbon price to incentivise lower-carbon energy and discourage the higher-carbon fuels. But until it exists, it is difficult for us to invest in these products at scale.

How easy is it for an organisation of BP's size to adapt to changes in technology development?

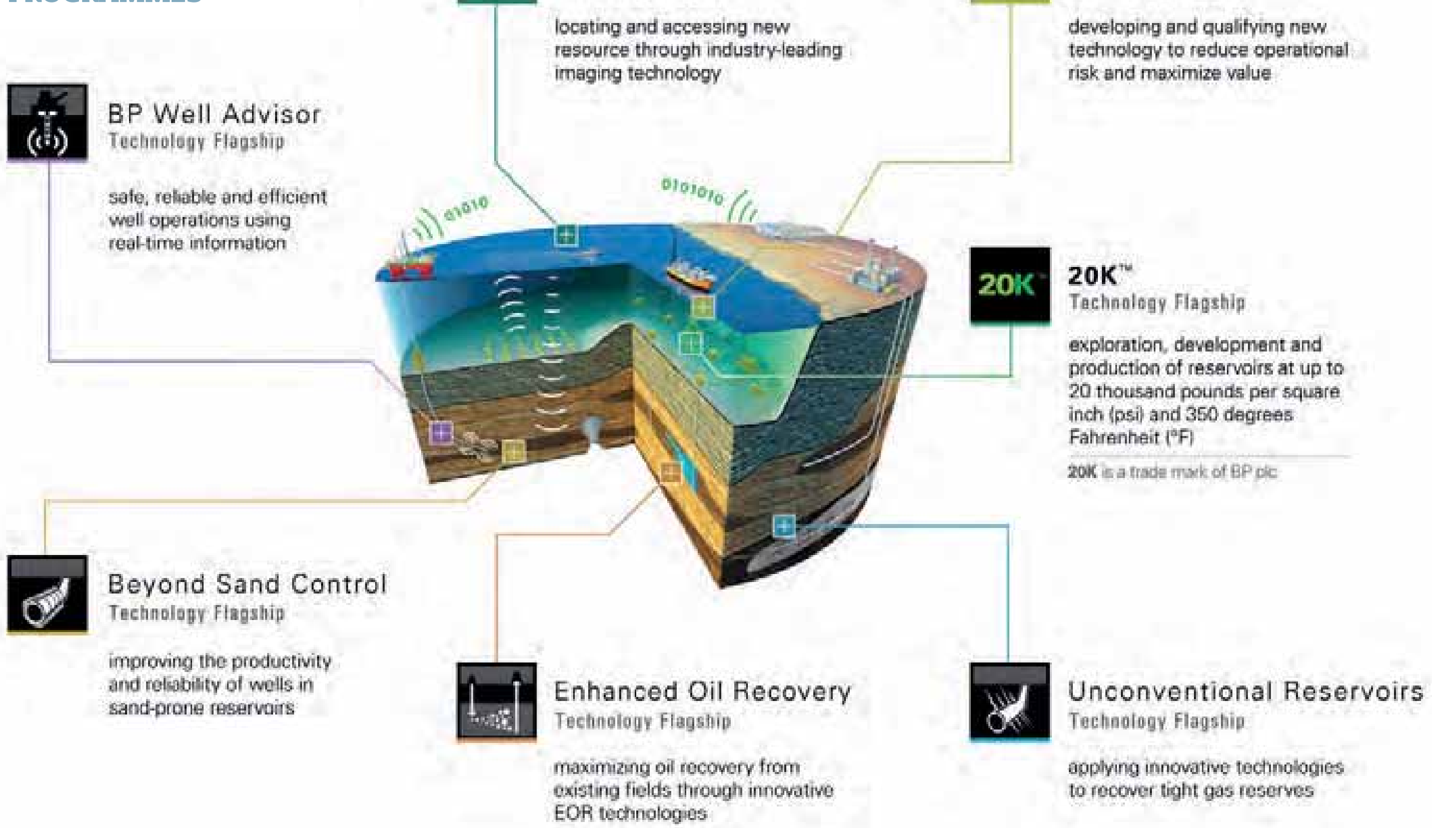
Some things in this industry can change quickly and some cannot. To give you an example, we renew our Upstream portfolio on average every 13 years, which gives you a sense of our timescales. We can choose to invest somewhat differently over that kind of decadal wavelength.

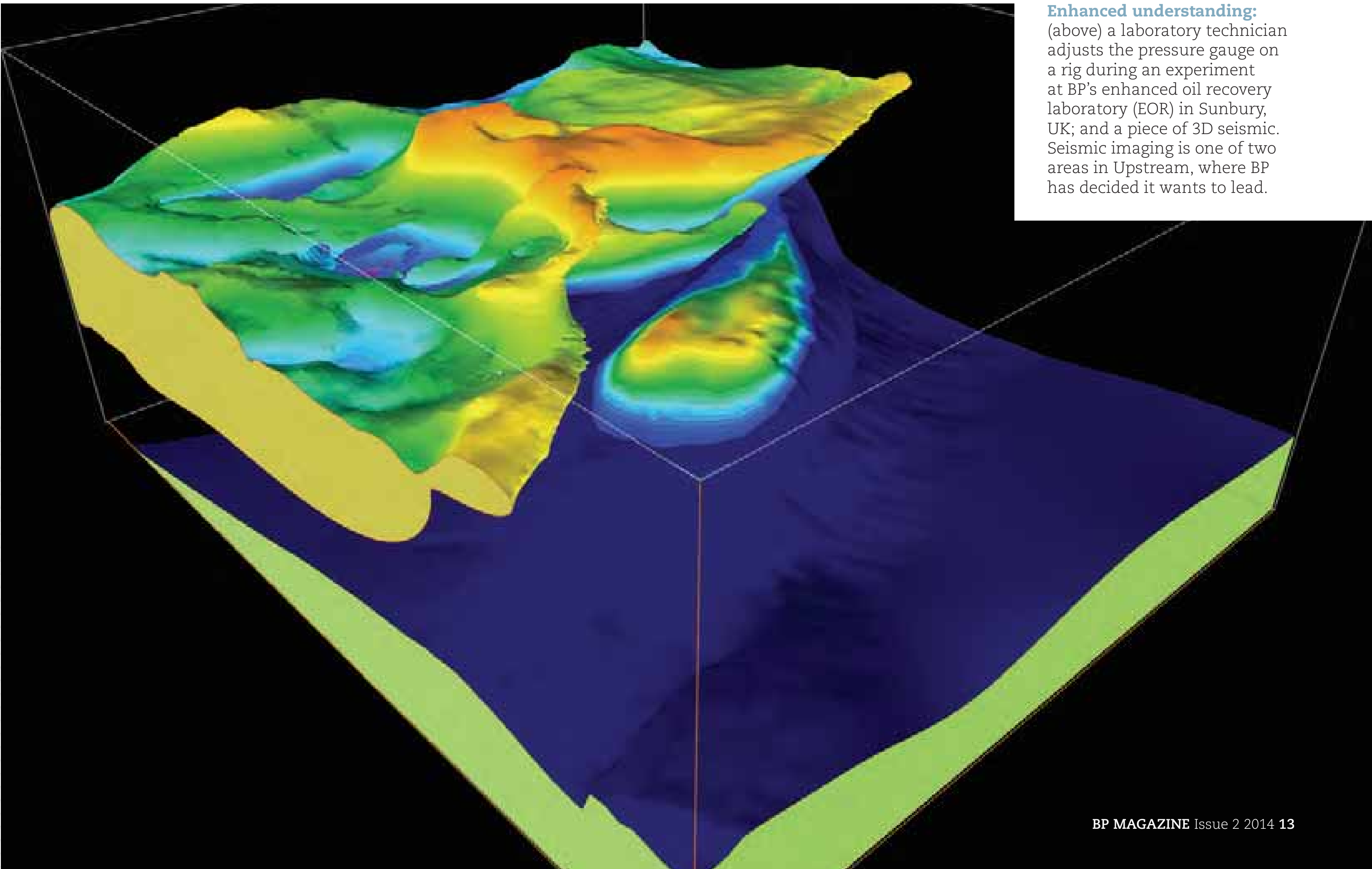
The key thing is that to supply energy requires enormous amounts of capital. Even if you develop a brilliant technology, it is very difficult to change the world's energy system rapidly because there is an awful lot vested in the existing system. Even if you take shale gas, which has taken everyone by surprise in the US, its roots are actually back in the 1940s, when hydraulic fracturing was invented by BP's forebear, Amoco, and even now it makes up less than half the US energy mix. I think it's also important to note that we don't have to invent something to be able to use it. BP is selective about the proprietary technologies we want to develop and we concentrate on areas that we think will give us a competitive advantage.

For more on technology in BP, visit bp.com/technology

> *"BP is selective about the proprietary technologies we want to develop and we concentrate on areas that we think will give us a competitive advantage."*

BP'S UPSTREAM TECHNOLOGY FLAGSHIP PROGRAMMES





Enhanced understanding: (above) a laboratory technician adjusts the pressure gauge on a rig during an experiment at BP's enhanced oil recovery laboratory (EOR) in Sunbury, UK; and a piece of 3D seismic. Seismic imaging is one of two areas in Upstream, where BP has decided it wants to lead.

Formed just two years ago, a research partnership between BP and four universities is making progress on materials science challenges that have dogged the oil industry for decades. *BP Magazine* spoke to some of the scientists involved to understand how their collaborative approach is paying off.

Material difference

REPORT> SAM NUTTALL **PHOTOGRAPHY>** RICHARD DAVIES / JOSHUA DRAKE

Academic partnership: students at Imperial College, London – one of four universities involved in BP-ICAM.

With terms such as 'aerosol-assisted chemical vapour deposition', 'inhibitor molecules' and 'suspended aggregates' featuring in the project descriptions, it can be difficult at first glance to see how the work being carried out at the BP International Centre for Advanced Materials (BP-ICAM) is relevant to everyday problems.

But as Professor Erich Muller, a scientist at Imperial College, London, explains, the centre has some of the biggest challenges facing the energy industry firmly in its sights. In his case, along with scientists from three other universities and colleagues in BP, he is part of a team investigating why carbonaceous deposits – asphaltenes, soot, cokes and other materials – build up in places ranging from oil wells to car engines.

"We're talking about the cholesterol of the oil industry," he says. "Asphaltenes are a certain constituent of oil that can separate and stick to the walls of pipes and process equipment. Little by little, these deposits grow and grow and can eventually block pipes and equipment."

Muller's colleague at the University of Cambridge, Dr Colm Durkan, says that this is a problem that all oil companies face. "To my knowledge, this is a billion-dollar problem," he says. "These sticky deposits form at nearly every stage, from when the oil is dug up to when it gets into a car engine. Ultimately, they can cause refineries and wells to close down."

Problems like these led BP to set up BP-ICAM two years ago. The $100 million research centre is leading research aimed at advancing the fundamental understanding and use of materials across a variety of energy and industrial applications.

"There is a need for advanced materials right across BP and the industry," says Bob Sorrell, BP's vice president for public partnerships and associate director at BP-ICAM. "We're drilling in deep water, with well pressures of up to 20,000 pounds per square inch [psi] and in temperatures in excess of 175 °C [347 °F]. To put that in perspective, the average car tyre is around 40psi. So, we're operating under pressures 500 times greater than this. We're drilling with a steel riser suspended from a floating rig 3,000 metres [10,000 feet] above the seabed and to depths greater than the height of Mount Everest. This places huge demands on materials and requires an enormous degree of innovation in how we deploy them."

Recognising the need for dedicated research capacity and a pool of global talent, BP decided to create the BP-ICAM partnership using a collaborative 'hub and spoke' model. The BP-ICAM hub is based at the University of Manchester and there are three primary collaborating centres at Cambridge and Imperial, also in the UK, and the University of Illinois at Urbana-Champaign in the US. Each BP-ICAM project has a BP mentor and the research projects are overseen by a management board formed of senior university and BP staff.

"Partnerships with single universities are fairly common," says Sorrell, "but the collaboration with four universities and BP is a unique model, certainly in the field of materials. It allows us to undertake advanced research, stay at the leading edge of science, and create a pool of expertise."

Despite being set up only two years ago, BP-ICAM has already made significant steps forward. Seventy researchers, including doctoral and post-doctoral students, are now working on 20 projects across four of BP-ICAM's main research areas – structural materials, functional materials, smart coatings, and membranes.

The partnership has won funding from the UK's Engineering and Physical Sciences Research Council (EPSRC) to establish centres for doctoral training – centres of excellence in PhD-level training and research – in the UK partner universities. It has also attracted £23.3 million in capital investment from EPSRC and the Higher Education Funding Council for England for research facilities at Manchester. Meanwhile, Illinois has received an Industry/University Cooperative Research Centers award from the US National Science Foundation to set up a new centre looking at novel high-voltage/temperature materials.

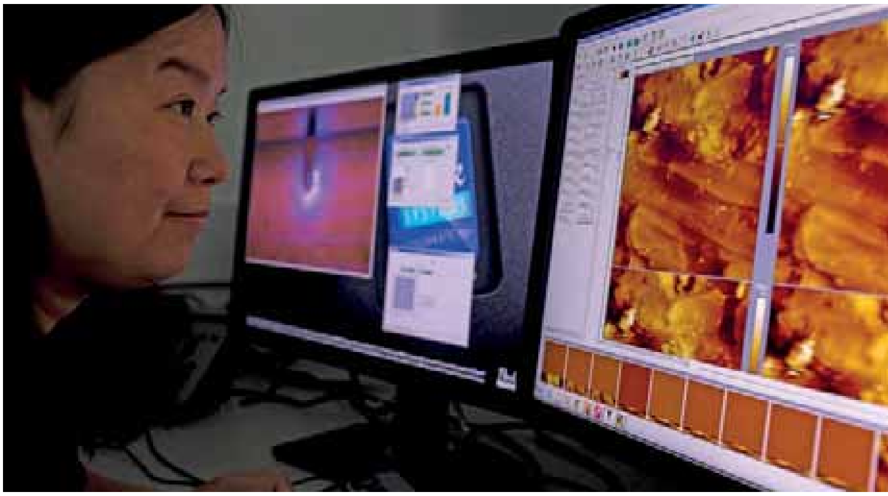
But, perhaps the most satisfying success so far has been the amount of genuine collaboration between the four universities and BP. More than 20% of BP-ICAM projects involve more than one university and the number of collaborations between universities is increasing. »

"The collaboration with four universities and BP is a unique model, certainly in the field of materials. It allows us to undertake advanced research, stay at the leading edge of science, and create a pool of expertise."

Bob Sorrell

Real-world challenges: (left) scientist at the University of Illinois at Urbana-Champaign; (below) and a PhD student carries out carbon dioxide testing at the corrosion and protection centre at the University of Manchester, part of the BP-ICAM programme.

Progress report: set up two years ago, BP-ICAM now has 70 researchers, including doctoral and post-doctoral students, working on 20 projects across four main research areas: structural materials, functional materials, smart coatings, and membranes.



The project investigating carbonaceous deposits is a case in point. All four universities in the partnership are involved, bringing together experts from across the globe to look at how these deposits are formed and what can be done to control them or reduce their impact.

Dr Durkan's team at Cambridge is using probe microscopy to observe the formation of carbonaceous deposits at the nanoscale, while Professor Muller's team at Imperial College is using computer models to determine how deposits grow over time in different scenarios, for example, on a variety of surfaces. This is complemented by efforts at Illinois to develop the modified surfaces, and work at Manchester to synthesise a range of oil samples for use by research groups attempting to model the behaviour of deposits.

"This a problem that has been looked at for 50 years in the oil industry, but this is the first time that it's been examined at this breadth and level of detail," says Dr Durkan. "One of the reasons that we've been able to get to this point is because the problem itself has been exceptionally well defined. BP went to a lot of trouble to speak to the right people in the business and get it clear, so that when the academics met up we could come up with the core research ideas in half a day. Strong support from BP management has been key from day one."

Project partnerships of this complexity don't come about by accident. So, as well as picking the right research talent to address a given problem, BP-ICAM funds a series of activities to promote collaboration. The annual research conference brings together BP staff and academics from all four universities, and the governance boards rotate their meeting location between the different universities. In addition, a programme of lectures and 'lunch and learn' sessions encourages university staff and students to share details of their research.

"The idea is to make links beyond the people we would normally connect with," says Sorrell. "But at the same time, there's no forced collaboration. We're here to facilitate linkages."

This facilitation played a key role in setting up the collaboration between Manchester and Illinois on a project investigating inorganic lubricant additives.

In simple terms, these additives are critical for the efficient running of engines, helping to produce thin lubricating films when the moving parts of an engine wear against each other. New formulations of these additives could help to increase the lifetime and efficiency of engines.

Complex chemistry

But, as Professor Shen Dillon from the University of Illinois explains, much of the research that has been carried out into new lubricant additives has been on a trial and error basis. "You can create a new chemistry, test it and produce some results showing that the lubricant performs a little better or a little worse, but it's very empirical," he says. "Films have very complex structures and the results that you get will be an overall response to a set of different mechanisms – sliding at the free surfaces or sliding at the film substrate interface, for example. So, if you create a new chemistry, it's difficult to tell how each of these mechanisms is contributing to your results."

"BP went to a lot of trouble to speak to the right people in the business and get it clear, so that when the academics met up we could come up with the core research ideas in half a day."

Dr Colm Durkan

Dillon's approach is to try to isolate the responses in different parts of the system, using a high-powered microscope to observe the lubricant films at the nano level. Results so far have been encouraging. "We've been really surprised by the complexity of the system at the nanoscale," Dillon says. "This provides lots of opportunities for further engineering."

However, without the collaboration with Manchester, it's unlikely that the project would have been able to produce results so quickly. While Dillon's team in Illinois has the expertise to carry out the experiments, it's Professor Paul O'Brien's team in Manchester that carries out the synthesis of the materials for analysis. "We wouldn't have been able to do these experiments without them, it would have taken a year for us just to make the materials," Dillon says.

Dillon and O'Brien decided to collaborate on the project during a BP-ICAM meeting in Illinois, where they realised that their areas of expertise were complementary. "We're interested in the making and he's interested in the testing," O'Brien says. "The kind of synergy we have with Shen's team is something we haven't experienced before, but the collaboration came about simply because of the connections BP-ICAM has helped to create."

Genuine change

O'Brien says that without BP-ICAM support, it's likely that the project wouldn't have happened. "I've been interested in this area of chemistry for what feels like 110 years, but no-one wanted to fund it," he says. "So, for BP to come forward and support the research was very welcome. We're doing real material science, taking it to the next level, and we feel that we can make genuine incremental changes. Later on, we will be looking at what materials we can use in the engines of the future, such as aluminium, for example."

The projects on inorganic lubricants and carbonaceous deposits are both at an early stage, with the focus primarily on getting a better understanding of the materials in question. But as Professor Muller says, the BP-ICAM scientists aren't afraid to aim high.

"Fully understanding the basics of how carbonaceous deposits are formed, that in itself would be a big step forward," he says. "But then again, I wouldn't be surprised if by putting so much effort and so many capable people together, we could understand deposition to the extent that it enables us to start to understand how to design molecules in such a way that we can prevent the aggregation of carbon deposits."

Muller's optimism is shared by his BP-ICAM colleagues, among whom there appears to be a contagious ambition to take their research to new levels. With the BP-ICAM partnership still in its infancy, and the number of collaborations steadily increasing, it appears likely that some of these projects might result in breakthroughs that revolutionise the way that the industry works.

Visit bp.com/bpicam to watch a film about another BP-ICAM project that is looking at ways of reducing corrosion in steel

"Working in science means that there's something different to work on every day. I have a lot of freedom to take an interesting idea and see if it might lead somewhere."

Interview> Sam Nuttall **Illustration>** Stuart Patience

FREEDOM TO EXPLORE

*PhD student **Aleksander Tedstone** is part of the BP-ICAM team at the University of Manchester investigating inorganic solid lubricants. He talks to* BP Magazine *about the freedom of scientific exploration and how the BP-ICAM partnership is helping to tackle real-world problems.*

Like many people, I wasn't sure what to study at university, but I decided to go with chemistry. Slightly unusually, **I studied philosophy alongside my science subjects**. It does give me a different perspective, an alternative way of looking at things. But, remember that natural science used to be called natural philosophy; in some ways, the disciplines aren't so different – they're both seeking the truth.

Working in science means that there's something different to work on every day. **I have a lot of freedom** to take an interesting idea and see if it might lead somewhere.

I'm currently working on the understanding and development of inorganic solid lubricants as part of the BP-ICAM partnership. **Doing fundamental research into something that has very pragmatic, real-world applications has always interested me.** We all rely on lubricant systems every day in transport, and almost every mechanical process at some point requires at least an understanding of frictional processes, so it's easy to see the relevance of the work.

There's lots of room for genuine improvement in lubricants. The use of a few additives has been entrenched for two decades or so and **there haven't been any breakthroughs for some time**.

There is some scepticism from people about working in collaboration with industry – I even get it from my own brother, who's also a scientist. They see industry support as something that limits the scope of research. But we haven't ever hit any red tape with BP.

In reality, **the BP-ICAM collaboration actively encourages us to publish our findings**. We're able to separate out and share the fundamental science, things that contribute to general knowledge, without disclosing any confidential information.

One of the real benefits of the BP-ICAM partnership is the opportunity to meet up with other researchers. **The collaboration between Manchester and Illinois universities** on the lubricants project came about as a direct result of a BP-ICAM conference. I've just returned from a month in Illinois. I got to see the results of experiments first hand, rather than just in write-ups.

It would be great to see some of the things that we're working on **break through to the public domain**, especially if we could develop new materials capable of outperforming those currently in use. On a personal level, publishing a couple of good papers would feel like success to me. Although I'm already rather proud of winning the crossword competition in the Royal Society of Chemistry's monthly magazine, *Chemistry World*!

2003

BP's partnership with the University of Manchester dates back to 2003. Over the years, it has grown into a strategic relationship that covers research and development, recruitment, and scholarship opportunities for students. In addition, the Projects and Engineering College is a key component of career development for BP leaders in engineering and project management.

$100m

In 2012, BP established the $100 million research centre, known as the BP International Centre for Advanced Materials, or BP-ICAM. For the next decade, the centre will lead research aimed at advancing the fundamental understanding and use of materials across a variety of energy and industrial applications.

REPORT> LISA DAVISON
PHOTOGRAPHY> RICHARD DAVIES

THE RIGHT FORMULA

BP's chief scientist, Angela Strank, joined the organisation more than 30 years ago as a young geologist. Rachel Fort is a graduate chemist, who has been with BP for just two years. They share their thoughts on a mutual passion for science and the challenge of encouraging young people to continue studying science, technology, engineering and maths (STEM) subjects.

Shared passion: Angela Strank (left) became BP's chief scientist in May 2014 after more than 30 years working in STEM roles in BP's Upstream and Downstream businesses. Rachel Fort is a graduate chemist, who joined BP two years ago following a summer internship before her final year at university.

BP Magazine: What attracted you both to science?
Rachel Fort: For me, it was finding out why. I was interested in why things happened in the way that they did, how they happened, and understanding the deeper reasons. Then, I went into chemistry because I liked bright colours and dramatic chemical reactions. Inventing new fireworks would have been a good career – but BP is pretty good, too.
Angela Strank: I was always interested in natural sciences and as a young girl was often out in the garden getting muddy, looking for insects and interesting things in the soil, looking up at the sky, wondering how the sun, clouds and rain formed. All of that intrigued me. That was the beginning of my interest in geology, although I did not know it at the time. Trying to understand how the world worked and how everything fitted together and operated – it was just fascinating.

BPM: How important was school and family life in encouraging that in both of you?
RF: My theory is that I never got discouraged by my parents for asking too many questions. My mum was a food scientist, which is a fascinating area. She used to make sweets for a living, which definitely helped! I don't remember being particularly engaged in science lessons in my first few years at school. The curriculum was a bit dry and didn't relate to the things I found interesting outside school, but there were some teachers that stood out because they did fun things in their classes.
AS: My father was an engineer and an architect – a wonderful combination of science with creativity. He would take us to see great buildings and explain how the domes and steeples stayed up from an engineering perspective. He was always inspiring and knowledgeable and supported me in whatever I wanted to do. He inspired me to ask questions and discover more.

BPM: Who were your scientific heroes growing up?
RF: For me, it was all about science in popular culture. I used to love reading the *Horrible Science* books. I think they are a really good way to get kids involved; talking about gruesome things definitely makes them interesting. I remember television programmes such as *The Really Wild Show* and *How2*. These sorts of programmes help make science seem cooler, which is one of the problems we always have. I don't get it myself, because I think science is incredibly cool.
AS: When I was younger, I watched a film about Marie Curie and asked a lot of questions afterwards. She made great sacrifices to make huge breakthroughs, from which we have all benefited. She had a big impact on me. Then, like Rachel, the television was an enormous influence. David Attenborough, for instance – a great palaeontologist and scientist, with breath-taking natural history programmes. I was also inspired by all the astronauts and cosmonauts involved in the pioneering space exploration programmes and the lunar landings – incredibly exciting frontiers exploration. I wanted to be part of this pioneering scientific world.

BPM: Why do you think your interest continued to grow when so many young people – particularly girls – switch off in their teens?
RF: For me, it was that at every stage of my education, I was reaching the next level of understanding and getting more profound answers to the questions that I had always been asking.
AS: In society, there is still a bit of stereotyping that goes on unconsciously. You do not pick up many women's magazines and see articles on engineering, nanoscience or biofuels. You'd probably be surprised how many people still say to me, "It's great that BP has a woman who is chief scientist." From a personal perspective, my interest in STEM subjects continued because I could see some exciting and different careers in science and engineering, especially in the expanding North Sea oil and gas industry at that time. All this, with an opportunity to travel the world, was something I really wanted to do during my career.

BPM: Are you both involved in encouraging young people in STEM activities?
RF: I have always been interested in getting more women into STEM and BP has given me the opportunity to do that through its support of the STEM Ambassador programme [a nationwide programme run by STEMnet, connecting schools with professionals in STEM careers]. I'm an ambassador and went into a school recently to talk to girls who are making their GCSE choices. We spent some time looking at stereotypes around packaging, 'girls' versus 'boys' toys, and the marketing reasoning behind these labels, and then did a form of speed-dating, where groups of girls talked to different ambassadors in turn to find out about our backgrounds and what we enjoyed. It was great to see how enthusiastic they were. But, you could see some of them had already turned away from science.
AS: I have always been involved in these activities externally at various STEM events and talked in schools, universities and at various societies on the subject. More recently, I have become involved with various government-related STEM initiatives, especially those encouraging more women to study and follow STEM careers.

BPM: Angela, what do you think has changed for women in STEM-driven careers since you joined BP?
AS: Things have changed a great deal. Our female graduates today are far more sophisticated about their aspirations and expectations of careers in BP – and there are »

"I used to love reading the *Horrible Science* books. I think they are a really good way to get kids involved; talking about gruesome things definitely makes them interesting."

Rachel Fort

many more female STEM graduates coming into our industry. Few women had STEM-driven careers in the oil and gas industry when I joined – especially in exploration. In fact, at that time, women were unable to go offshore in the UK North Sea due to lack of accommodation – but that changed quite quickly. Being the only female, in the early days of my career, I just wanted to fit in, work hard and do well, in what was a male-oriented industry at the time, with no senior female role models to aspire to. It was a completely different environment from the diverse and more balanced one we have in the industry today.

BPM: Rachel, what is your experience of BP's Challenge graduate programme?
RF: It's given me the chance to experience different areas of the business and understand how they interact. I think if you went straight into one discipline, you wouldn't necessarily see the links between them.
AS: Rachel raises an important point. It is good to have different work experiences early in your career, to see the big picture. In fuels and lubricants, where Rachel works, graduates generally have three placements in their first two years, usually two technical and one commercial across the two different businesses. It is important to understand how the application of science, technology and engineering adds value to BP's various businesses and helps to drive performance. Working in different areas and locations helps to build networks so you know who to approach for technical expertise and advice. Networking and sharing specialist resources across the company also helps to develop the 'one team' behaviours we expect as an organisation.
RF: There's also something about being part of a graduate intake. There were 200 of us that started in 2012. Around 70 of us spent the summer on secondment at the Olympics, so we already knew each other really well when we began at BP. It means that if I have a question about Upstream, I can go and talk to my friends who are working in Aberdeen and Sunbury.

BPM: How much time do you both get to spend in the laboratory?
RF: I would say it varies. At the moment, I am spending quite a lot of time in the lab because I'm organising a trial of a new piece of equipment. It is very 'science', with glowing lights and bubbling liquids. But, I do also work with other departments across the business. During my first placement, I spent a lot of time with sales and marketing, which is not something you would expect from a scientist's role.
AS: I used to work in a laboratory when I initially joined BP in exploration – preparing samples from rock cores and cuttings. Nowadays, I only spend time in labs when I visit BP's various businesses, operational sites and technology centres around the world. They are all different and there is great research and development taking place in these labs across all our businesses.

> "Being the only female, in the early days of my career, I just wanted to fit in, work hard and do well…It was a completely different environment from the diverse and more balanced one we have in the industry today."
>
> *Angela Strank*

BPM: Do you think multinational organisations such as BP have a role to play in encouraging children to consider STEM subjects?
AS: Yes I do, and I think BP does this very well, especially with our long-standing Schools Link programme, which now involves more than 190 schools in the UK. »

7%

Women account for only 7% of the professional engineering workforce in the UK

87,000

An extra 87,000 graduate-level engineers will be needed each year in the UK between now and 2020

16

Typically, women are lost to a potential career in engineering at the age of 16

"Every small child I have met has endless questions. It is just making sure that they continue to ask them."

Rachel Fort

BP has recently launched several further initiatives on this front, including the Ultimate STEM Challenge, STEMnet and the Science Museum Challenge – all designed to inspire children to study science and engineering. Science and technology underpin all of BP's businesses and we need the best talent available – men and women. Recent research shows that the UK needs 87,000 additional graduate engineers every year to 2020 to fulfil growing demand. Currently, we have only 46,000 graduating each year – it's a big gap to fill and it's a great career opportunity for schoolchildren today.

RF: I feel like it shouldn't be an issue, though. I have never experienced anyone being surprised that I am a woman doing science, but I do think it depends on the area you work in. I spent some time in our engine test department in fuels and lubricants, and that was more skewed towards the men. But then if you look at chemistry, it is around a 50/50 split.

AS: And biology is even better. Biology is a science that women have always done very well in, but I heard a statistic recently, stating that more than 50% of UK co-educational state schools had no females studying physics at A-level. But, if you want to be an engineer, physics or maths is important. Only around 5% of mechanical engineering graduates in the UK are female.

RF: I think that is the problem, though; people don't know what engineering is. When I talked to the schoolgirls, they equated engineers with mechanics, people who fix cars.

BPM: So, perhaps more needs to be done to help schoolchildren see the bigger picture?

AS: It's about showing schoolchildren all the opportunities open to STEM students, and bringing all kinds of engineering to life in a way that resonates with them – making it simple, relevant and compelling. Some children are more interested in how water comes out of a tap or how their lipstick winds up the tube, than building a refinery – it has to be interesting to them to make that initial engagement with science and engineering. Children are fascinated by how and why things work and we need to nurture those inquisitive and enquiring minds.

RF: It's the link between that interest and how you get to do it as a career that needs to be made.

BPM: What do you think is missing?

AS: Research shows that good advice from teachers, families and friends on various career pathways is influential at an early age – well before GSCE choices are made. Inspirational and informed teaching about the multitude of STEM career opportunities is key – being able to demonstrate the value that science and engineering bring to meet society's needs is also important to today's generation.

BPM: Do you think that women need particular qualities to achieve in STEM subjects that are somehow different from men?

RF: To be a scientist, you just need to be inquisitive, logical and thoughtful. I think those qualities are perhaps encouraged more in boys than they are in girls, but I don't think that is because they are innately different. Every small child I have met has endless questions. It is just making sure that they continue to ask them.

AS: I could not have put that better myself. I would add that recently published research in the UK shows that stereotypes, perceptions and unconscious bias still perceive STEM subjects to be more 'masculine' and for 'brainy boys'. This is just a long-standing perception, of course, but it does influence career choices of girls at school age, even though girls often tend to do better in science subjects than boys at GCSE level. Data also shows that the number of girls taking science at A-level drops off considerably.

> "It's about showing schoolchildren all the opportunities open to STEM students and bringing all kinds of engineering to life in a way that resonates with them – making it simple, relevant and compelling."
>
> *Angela Strank*

BPM: Have you experienced discrimination because of your career choices?

AS: When I was at school, I applied for a holiday job in a local plastics factory on a production line making plastic casings for radios – I went for an interview and there were three or four young men and myself, all about the same age. A couple of days later, I received a letter saying, "I have now had an opportunity of discussing the appointment and I regret that the chauvinists prevailed. It is felt that it would be better suited for a young man, and, therefore, I am unable to offer this position to you." I kept that letter and throughout my career it has reminded me that it is important to keep going and not worry about any discrimination you might encounter. It just made me more determined. In BP, though? Never. I've always been treated with great respect, and fairly. I have had some incredible roles, experiences and opportunities.

BPM: Why would you both encourage children, boys and girls, to consider STEM subjects and careers?

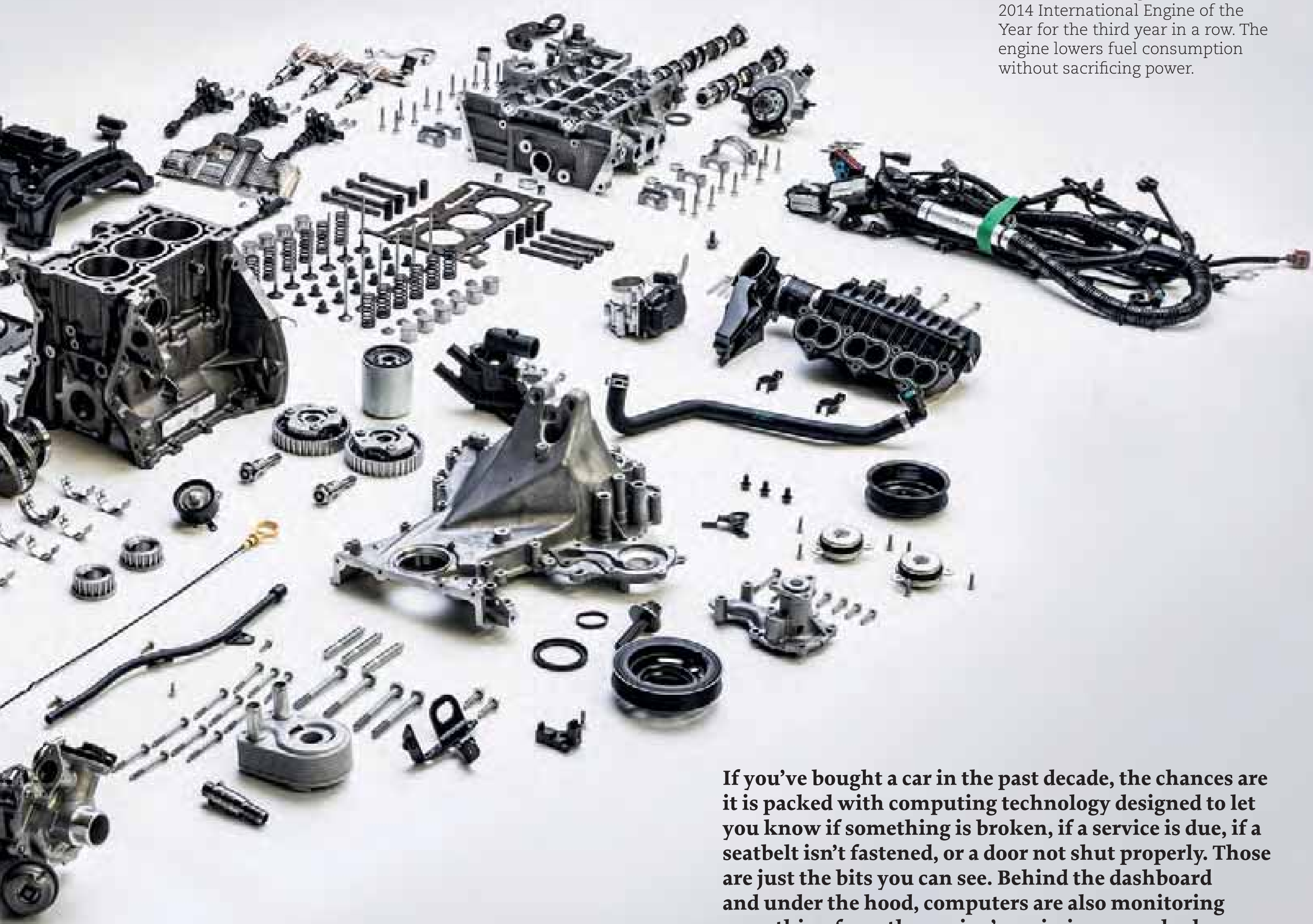
RF: There are so many different things you can go into through STEM. It is not all hard equations and sitting in the laboratory and scribbling notes. It is about getting involved in the world around you and affecting it.

AS: STEM subjects give you enormous scope and range to follow a variety of interesting careers. Technically-driven companies need STEM graduates, but so do management consultants, banks and other major organisations around the world – because they are smart, talented students. So, you have many well-remunerated career choices across multiple markets. You can go into business, move across sectors, or stay in science, engineering and technology. And it is great fun. I have never had a dull day in this company. Never. ●

Driving force

Ever since the invention of the internal combustion engine, the automotive and oil and gas industries have been interlinked – the product of one fuels the product of the other. Which is why, over the years, BP has developed a number of relationships with companies such as Ford to better understand each other's technical requirements and challenges. Ford's Andreas Schamel talks to **BP Magazine** *about the importance of technology in his industry and where the future of vehicle manufacture might take us.*

Report> Lisa Davison **Photography>** The Ford Motor Company



Award winner: parts for Ford's 1.0-liter EcoBoost engine laid out. The oil can respresents BP's work in lubricants. The engine was named 2014 International Engine of the Year for the third year in a row. The engine lowers fuel consumption without sacrificing power.

If you've bought a car in the past decade, the chances are it is packed with computing technology designed to let you know if something is broken, if a service is due, if a seatbelt isn't fastened, or a door not shut properly. Those are just the bits you can see. Behind the dashboard and under the hood, computers are also monitoring everything from the engine's emissions, spark plug and fuel injection rates, to brakes, air conditioning and air bags. In fact, there is far more computing power in today's average car than there was in the Apollo 11 space shuttle when it landed on the moon in 1969.

This technological revolution is transforming the design and manufacture of our everyday vehicles, keeping drivers safer than ever, while helping companies such as Ford to meet growing societal expectations on improved fuel efficiency – the distance a vehicle can travel on a single tank of fuel – and emissions reductions. One day, technology might even transform the very way in which we drive. The big challenge is to do all of that and still create a vehicle that the customer wants to buy. "It's about finding a balance between meeting our legislative commitments while remaining competitive," says Andreas Schamel, director »

global powertrain, Ford Research & Advanced Engineering (pictured left).

Since the early-20th century, the internal combustion engine (ICE) has dominated the car manufacturing industry. It's easy to see why, with the availability of large quantities of relatively cheap oil, combined with the simplicity of the chemical reaction inside an ICE – oxygen in the air reacts with the fuel to create power, while the waste heat, carbon dioxide, water vapour and other minor combustion products are released back into the atmosphere via the tailpipe.

But, what makes it cost effective also brings challenges. Much of the energy created in the chemical reaction between the fuel and the oxygen is lost as heat – indeed, only around 30% is turned into propulsion energy. Physics plays an important role here – heat metal for long enough and it will start to melt. Lubricants help by reducing friction and, therefore, heat. Meanwhile, on the car manufacturer side, improvements such as boosting and injection technologies, as well as in-air flow management, are in development and could improve the thermal efficiency of an engine to 45%. After that, says Schamel, "you break physics."

The environmental impact of the fuel is another key challenge and both the automotive and energy industries are subject to their own legislative requirements to reduce the amount of greenhouse gases a vehicle produces. In the oil and gas industry, decarbonisation of fuel is the main challenge and currently this is being met by the incorporation of biofuels.

Meanwhile, in vehicle manufacture, catalytic converters are now fitted as standard to reduce the amount of pollutants in the exhaust gas, while higher pressure injection systems deliver evermore precise amounts of fuel into the engine, thereby reducing the concentration of carbon dioxide emissions leaving the engine. Turbochargers are also having a significant impact, by forcing more air into the cylinder, which means more fuel can be added and combusted completely, giving the vehicle more power. As a consequence, engine size can be reduced – making the vehicle lighter – while producing the same power as a larger engine and using less fuel to travel the same distances.

Technological advances

Some of the technological advances that have been made in both fuel and vehicle have come about through closer working relationships. BP has a number of relationships with vehicle manufacturers and has worked in co-operation with Ford for more than a decade. Indeed, Ford's engineers and BP's oil formulators worked together on a joint engineering project: while Ford created a new engine – one member of its new direct injection petrol engine family called Ecoboost – that reduced carbon dioxide emissions without compromising on power, BP developed a specially-formulated engine oil – called Castrol Magnatec Professional 'E' – to support it. So successful was the venture that the oil was jointly branded. While BP worked with Ford to help it understand

Award-winning engine: (far left) workers at Ford's Louisville assembly plant in Kentucky, US, celebrate production of the 2 millionth EcoBoost engine; (left) Ford workers assemble the 1.0-litre EcoBoost engine at the Cologne engine plant in Germany.

how the oil was developed, Ford provided prototype engines on which BP could test the oil. "These relationships are very useful," says Schamel. "They help us to understand the nature of each other's challenges, which helps us to plan for the future."

Like BP, Ford plans for this future in a number of ways. "We conduct strategic analysis where we look out over the next 10 to 15 years to assess what new technologies might be coming through that could help us," Schamel says. "Once we identify something, we might work intensively for six or seven years before it is introduced into our vehicles at scale. We work closely with the academic world, we have strategic alliances with a handful of universities around the world and we have universities that we co-operate with on a project-by-project basis. We also work with consultant companies linked with universities. We fund research grants and are part of industry alliances such as USCAR in the US and EUCAR in Europe. Initially, we cast our net very wide, until we think we can see a unique selling proposition for Ford, at which point we bring the research and development and testing inhouse at one of our own technology centres."

So, where might the passenger car be headed in the next 15 years? Hybrids – which work by capturing and recycling some of the energy released during braking to power other parts of the car – look set to become more popular. There are already more than 3 million hybrids on US roads and the technology is improving and costs falling all the time.

"We expect to see a significant increase in hybrid technology," says Schamel. "The 'stop-start' applications in use now are basic levels of hybridisation and we can see opportunities to develop that further. Ultimately, to answer the challenges of increasing fuel economy requirements and environmental regulations, hybridisation is a must."

Vehicle future

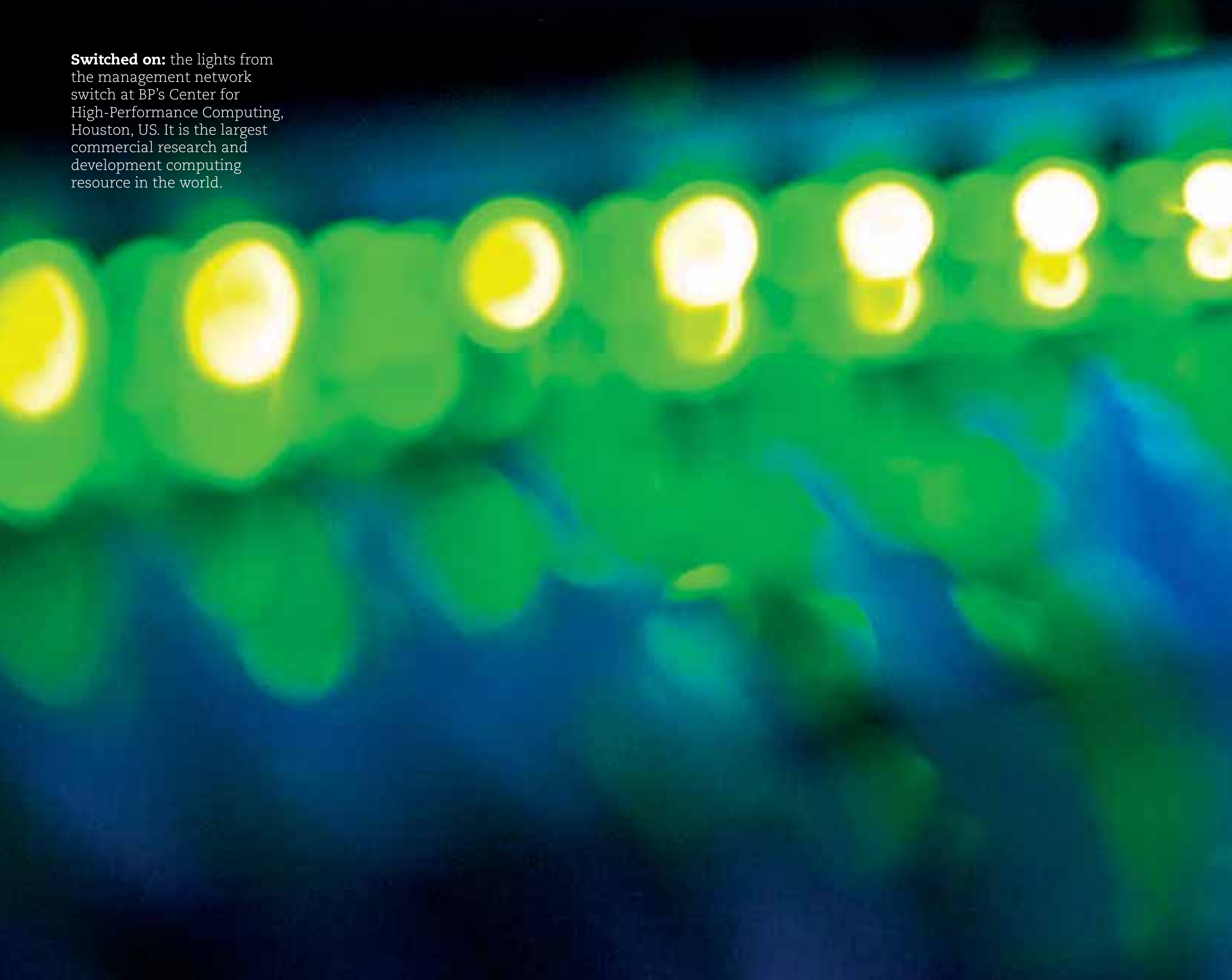
That said, hybrids still rely on efficient combustion engines. Pure electric and hydrogen fuel cells have long been seen as alternatives to the traditional engine, but both have their own challenges to overcome. "In pure electric, the fundamental challenge is in energy density," says Schamel. "Unlike a combustion engine, a battery must carry the fuel, the reactant and the waste product within it. And, so, there are limitations on a car's performance and travelling range. The other challenges are about fuel source – is the electricity produced from sustainable sources or from fossil fuels? – and battery charging speed. Even with what is known as fast charging, you're looking at 30 minutes of charging for 100 kilometres [60 miles] travelled, versus two minutes to fill a tank that might travel as much as 1,000 kilometres [620 miles].

"By comparison, we see hydrogen fuel cells reaching a point in the next five to 10 years where the cost can compete with the internal combustion engine and you can refuel it almost as fast as you refuel a gasoline tank. The challenge there is about infrastructure and, like pure electric, energy source – what fuel do you use to produce your hydrogen? Unlike fossil fuels, you don't extract and refine the hydrogen, you must produce it from another source, so the question is what source do you use? Do you use sustainable sources, such as solar, or create it as a byproduct from fossil fuels. In which case, in an environmental sense, you haven't gained anything."

To return to the digital revolution that's occurring under our car hoods, some of the next steps in technology could fundamentally change the way in which we drive. "The industry is starting to look at transport in a more holistic sense," says Schamel, "asking questions about buying patterns of future generations. Will the role of an individually-owned car change in the future? Will the transport system become more of a network and what are the business models connected with these questions?

"The industry is not far away from producing a car that handles traffic jams on motorways for the driver. Once the jam clears, the driver is back in charge. Obviously, this sort of technology wouldn't work on a rural road, where you might have animals jumping out or tree branches overhanging the road; the human brain is still better equipped to handle situations with multiple variations, but these automated systems can work in highly-controlled environments when the car knows exactly what it's doing."

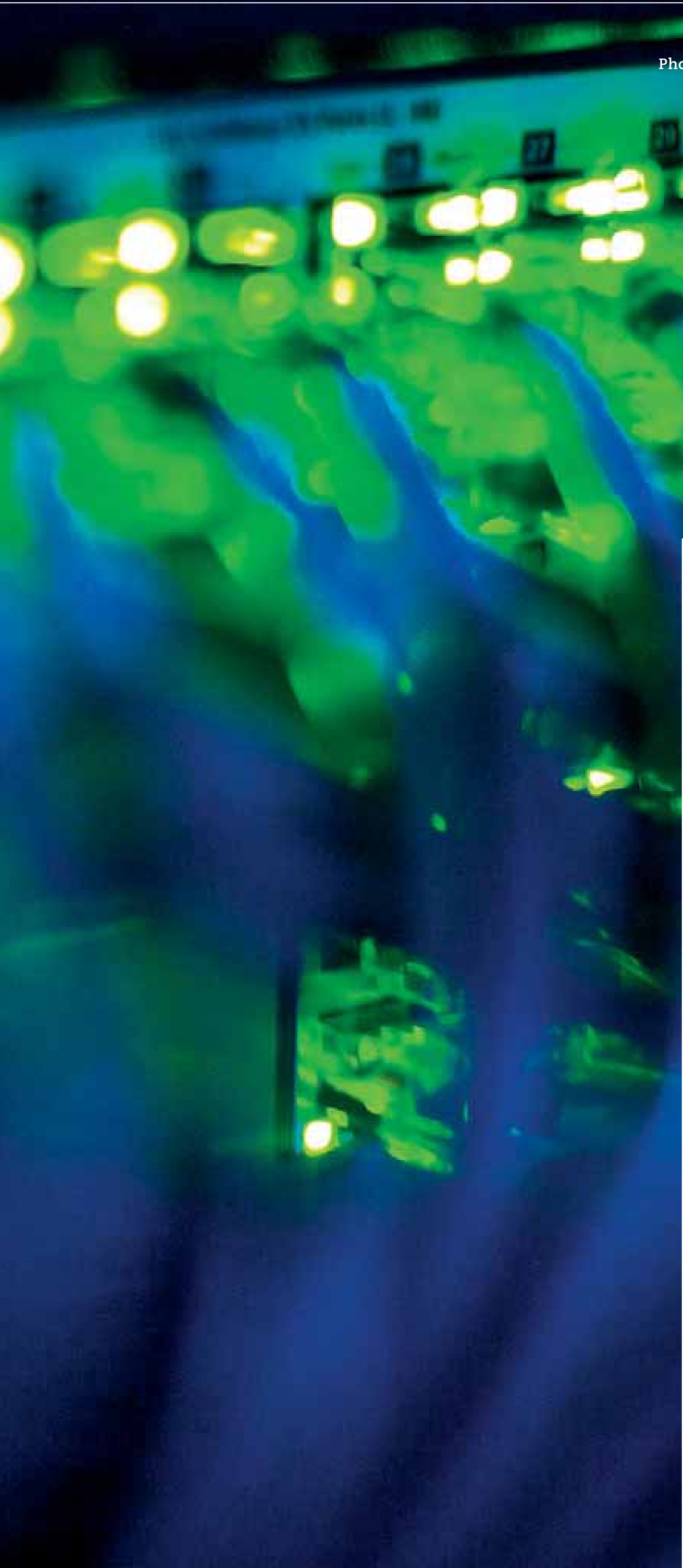
Fully-automated passenger cars that make every decision for you remain the stuff of science fiction, for now, but with the number of new passenger cars on roads rising every year – in 2012, the number globally exceeded 60 million for the first time – it's clear that we remain a species deeply attached to our vehicles. By pushing the limits of technology, companies such as Ford continue to find more efficient, more environmentally-friendly ways of keeping the world moving.



Switched on: the lights from the management network switch at BP's Center for High-Performance Computing, Houston, US. It is the largest commercial research and development computing resource in the world.

Dynamic data

The volume of data in the world is growing at an unprecedented rate, but, if we are to get anything useful out of it, there is a hierarchy to appreciate. Raw data alone does not tell us much, but put that data into some sort of meaningful structure and turn it into information from which we can extract knowledge, and data becomes one of our largest and most valuable 'natural' resources.



Report> Helen Campbell
Photography> Marc Morrison/Mehmet Binay/Richard Davies/Frank Horn

Data is everywhere, bombarding us every minute, every day, in every kind of environment, from business and government to education and social media. Just two decades ago, we worked in megabytes (10^6). Then, just as we got used to terabytes (10^{12}), petabytes (10^{15}) emerged.

These giant leaps represent a huge opportunity for companies to enhance their strategic thinking and commercial advantage, but the trick is in mining this vast resource effectively. As it has been said: "A GPS coordinate is data, a contour is information, a map is knowledge, and someone who knows how to read it is wise..."

When data becomes too difficult to manage by conventional means, either because of the volume, the speed, or the variety, it becomes what is known as Big Data, not necessarily 'big numbers' – although many certainly are – but numbers that, as well as being present in huge Volumes, also come at high Velocity. The Variety of data compounds the problem. The fourth 'V' of Big Data is Veracity, because data may not be of consistent quality, yet may still be useful. Managing all four 'V's and applying algorithms and data analytics – the mathematical treatment of data – can help companies to make faster, better and more focused business choices.

Retailers, airlines and banks are doing this already, tracking customer behaviour to target services and resources more effectively. And, there is a growing recognition in BP of the immense opportunity that Big Data could offer to help it better understand reservoir activity, increase refinery efficiency, improve biofuels yields, and make better trading choices. In 2012, the organisation established a decision analytics network – now 200-strong among its professionals – to examine ways to advance use of data and to help BP's businesses harness these opportunities.

"As an organisation, as an industry, we are increasingly putting more sensors into our facilities, on rigs, wells and pipelines, for example, to measure temperature, pressure, chemicals and equipment vibrations," says Paul Stone, »

Super performance: part of BP's Center for High-Performance Computing. The supercomputer's vast data-crunching capability – 2.2 petaflops of computing power and 23.5 petabytes of disk space, equivalent to more than 40,000 laptops – is available for use by the whole organisation.

"Since 1999, BP's computing needs have grown by a factor of 22,000, with computer power doubling almost every year."
Keith Gray

decision analytics network leader. "The variety of sensors available is increasing all the time and we are getting more data back, in real-time, with ever-shorter cycles. This is data in motion, not data just sitting on a disk drive, and it is telling us about operational conditions that can be used by our businesses in order to further strengthen safety and improve performance. So, we need to make sense of it as it is acquired, not after the fact."

The rapid growth in BP's data volumes is a direct result of its greater ability to acquire it in the first place. Data is acquired for a range of reasons, including reliability and performance. For instance, by installing fibre optic 'distributed acoustic sensing' in its wells, BP will be able to receive data from deep underground that lets production teams know where and how effectively the well is producing hydrocarbons. Such a system can easily deliver many terabytes of data each day from just one well.

"Real-time monitoring enables us to see if the relationships between physical properties while drilling a well, for example, are changing unfavourably, because understanding the various patterns that are formed by these relationships is important when it comes to diagnosing problems," says Stone. "The biggest benefit of analytics, though, is that it provides the opportunity to predict what will happen, instead of recording what has happened or is happening. All these different data points allow people to spot patterns as they form, patterns that point to future conditions before they occur and, with all this extra data, we can take the right action ahead of time."

BP strengthened its commitment to computing and advanced information technology in October 2013, with the opening of its new Center for High-Performance Computing (CHPC), the largest commercial research and development computing resource in the world. Replacing a previous facility, this 'supercomputer' was established primarily to help with seismic imaging, but its vast data-crunching capability – 2.2 petaflops of computing power and 23.5 petabytes of disk space, equivalent to more than 40,000 laptops – is available for use by the whole organisation. The site's location in Houston, near institutions such as Rice University and the University of Texas, means that the CHPC can attract some of the best mathematicians and computer scientists, aligning itself with the likes of technology giants Google, Amazon and Microsoft, themselves avid consumers of data.

"Since 1999, BP's computing needs have grown by a factor of 22,000, with computing power doubling almost every year," says Keith Gray, manager of the CHPC. "To illustrate that, in 2004, a new group of computers that we put in popped the main circuit breaker for Westlake [BP's Houston headquarters], putting it in the dark. It soon became clear that a new computing facility was appropriate to support the organisation and its businesses."

In BP's Upstream business, the CHPC facility helps the seismic imaging teams to simulate, process and predict what will happen in a reservoir. It does this by processing and managing huge volumes of geological data from across BP's global portfolio, helping teams to see more clearly below the Earth's surface. It helps reduce the amount of time needed to analyse large amounts of seismic data and can also enable more detailed in-house modelling of rock formations before drilling begins. With field developments costing billions, this knowledge is invaluable and its pursuit puts BP at the forefront of seismic advances.

"Data volumes 25 years ago were measured in megabytes," says John Etgen, distinguished adviser, seismic imaging. "Individual data sets are now approaching petabytes in size, with volumes having grown by a factor of a billion, just in my career. But, this is not only about volume, because the way sound waves propagate in the earth is very, very complicated and the science we use is never complete. Sound waves react to things down to the scale of grains of sand. Even at very high resolution, the images we can make today still have gaps bigger than the size of a conference room."

Etgen continues: "Computing power has always been a limiting factor for this industry and increased computing power certainly enables us to do things much faster than we could before, but what is important for the business is image resolution, not just timescales. With faster computers, like the »

CHPC, we do not necessarily use them just to go faster, but we let the computer run to its limits and give us the highest resolution we can get. These higher resolutions allow us to 'see the future' and to find out what kind of value a reservoir is going to deliver, earlier than before."

The data-processing and knowledge-generating power of the CHPC has had a global impact, with BP's businesses in the Caspian, Trinidad & Tobago, the North Sea, Gulf of Mexico and Indonesia all benefitting.

"The CHPC allows us to investigate the most modern seismic processing methods ever known, and, even better, to create some new ones," says Etgen. "And, this is at the highest possible resolution that we can drive out of the data. It can't do everything we want to be able to do, not yet, but we are in a good place, keeping our key resources of people, ideas and the fundamental data itself all aligned and appropriately invested."

The CHPC might be the world's largest commercial facility of its type, but computing needs are changing exponentially. The CHPC has been built to be 'future-proof', and is looking to potentially double its computing power

"The CHPC allows us to investigate the most modern seismic processing methods ever known, and, even better, to create some new ones."

John Etgen

between now and the end of 2014 and to triple by early-2016.

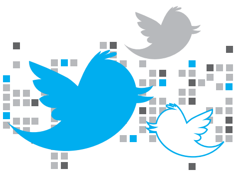
While the supercomputer primarily supports the seismic teams, BP IT&S's Innovation Lab, housed in the same building, has been created as a 'hot zone' for testing bold new ideas and proofs of concept for any part of BP's global business.

"We wanted to take some of the things that make the CHPC so successful – its agility and its ability to solve problems quickly – and use them to test ideas," says Stefan Garrard, the Lab's manager. "This is a separate set of resources, available to any part of BP's global business that wants to come in and try out proofs of concept, in a very quick and very agile environment, before things are done in a production situation, with time and money at stake."

BP's biofuels business regularly uses the CHPC's resources to aid its development of organisms, such as yeasts that can produce products such as ethanol. Using this data, BP's scientists can improve yields and reduce costs in its biofuel conversion processes. This has been particularly valuable to the group's biomass-to-ethanol projects in Brazil. In addition, the team is investigating the use of this technology to improve BP's understanding of a type of corrosion that is caused by microbes and forms in its equipment around the world.

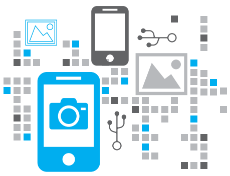
"The technology that we use generates millions of short DNA sequences, which are then assembled to produce the genome sequence for a given organism," explains Tom Goldman, a senior scientist on the computational biology team at BP Biofuels' Global Technology Center (GTC) in San Diego, US. "A typical assembly would have in the region of 15 million data reads, or 15 gigabytes, and the process is computationally

Data stats



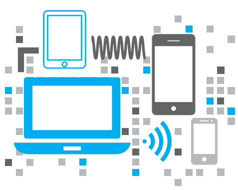
+12 terabytes

Amount of data Twitter processes every day



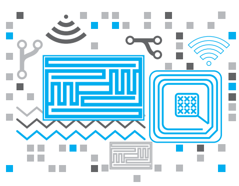
4.6 billion

Number of camera phones worldwide



1 trillion

Number of devices connected to the internet



30 billion

Number of radio-frequency identification tags today. In 2005, the number was 1.3 billion

intensive, like putting together a linear puzzle with tens of millions of pieces.

"It requires large amounts of computing memory, fast hard drive access, and multiple processors. In the past, our own machines and those of third parties crashed. Since we first started accessing the CHPC's resources in 2011, we have been able to run dozens of genome assemblies and to complete them, on average, 10 times faster, using the resources onsite. As a result, we have already produced better-performing yeast strains that have been transferred to our demonstration plant in Jennings, Louisiana, US and is then planned to be commercialised in Brazil."

Refining activities

In its Downstream business, BP's refining activities have a long history in data collection, with refineries needing to take thousands of different process measurements just to run and monitor their 'everyday', yet complex, operations. Refineries are dealing not so much with overwhelming masses of data, but with many, many different sources of real-time data across multiple frequencies – the challenge is how to get that into useful formats to aid decision making.

"We have process measurements taken every second, and analytical instruments that provide data perhaps every 25 to 45 minutes," says Sean Goodhart, principal control engineer, BP refining and logistics technology. "We also have daily laboratory data, with analysis results for samples taken early in the morning often delivered the same afternoon, along with additional sensing from corrosion and equipment monitoring. We even have smart instruments that tell us about the health of their own sensors and valves."

Now, what is known as advanced process control (APC) sits at the heart of all of BP's refineries. APC uses mathematical models derived from a site's data to find the optimal operation parameters within the process constraints and then set the right 'compass heading', not unlike a plane running on autopilot. While simultaneously monitoring all the key variables in the refining process, the software calculates and controls the right level for many valves, to allow the refinery to prioritise operating within safe operating constraints, while pushing units to their optimal economic performance. One refinery really seeing the »

Broad usage: (left) an employee conducts seismic interpretation – the Center for High-Performance Computing was established primarily to help with seismic imaging; (above) setting up ultrasonic wireless corrosion sensors at Cherry Point refinery, Washington, US. Data from smart instruments like these can tell BP a lot about the health of a plant; (right) and an oil trader at work at BP's Canary Wharf offices in London. Data analytics is being applied to help IST work to monetise the organisation's assets, optimise its hydrocarbon chain, and manage price risk.

benefits is Cherry Point in Washington, US. The plant had a new APC system installed in 2013 and has since achieved record production rates and significant economic benefits in just the first year.

"Our crude unit APC manipulates around 40 process variables and monitors and controls some 70 constraints, while pushing the unit operation to maximise efficiency," says Jason Yuryevich, senior process control engineer, Cherry Point. "Pushing the limits continuously and simultaneously requires a lot of attention and is a task well suited to a computer. A well-installed APC application is like having your best operator running the process, day in, day out; it constantly adapts to changing operating targets and feed conditions, and it never gets tired."

Trading environment

Refineries constantly need to match crude intake and products output to market demands. In the fast-moving trading environment, things are tighter still. BP's Integrated Supply and Trading (IST) team trades oil, gas, electricity and currency, both physical and on paper, out of its four main trading hubs in London, Chicago, Houston and Singapore. Data analytics is being applied to help IST work to monetise the organisation's assets, optimise its hydrocarbon chain, and manage price risk.

"Physical trading markets are influenced by lots of variables that come into play when you are trying to make a commercial choice," says David Rae, chief information officer, global oil trading. "These variables could be the global variations in the price of a commodity, global government and political events, or weather patterns and underlying seasonal variations that affect the markets. IST teams are constantly ingesting and analysing these vast reams of data to be able to make the best and quickest commercial decisions they can. The consolidation and interpretation of all these different types of data becomes an opportunity." Oil markets move fast and the most successful traders need to move as fast.

"Ours is not really a volume challenge, like that of Upstream," Rae says. "Our challenges are speed, accuracy and variability of the data, and making sure that we can react at the right speed. For us, Big Data is about improving our intelligence, and how quickly we can turn the data into information and intelligence, and, then, turn that intelligence into better commercial decisions and trading activities."

With computers doing so much of the thinking, it might seem as if a human's place in Big Data is limited. But it's more about adaptation, and about letting computers do what they can, so we can do more with what they tell us. Computers do not programme themselves, and BP has a great need for data scientists and is growing its inhouse capability for data analytics.

"The organisation will have a growing need for 'hybrid' individuals who can help to bridge the gap between the businesses and the IT capability," says Stone. "In fact, there is potential for every one of us to become a data analyst."

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>
> Paul Stone

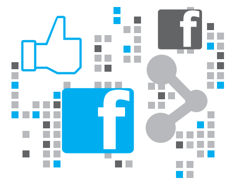
Digital centre

To support this, BP is establishing a new Digital Centre of Expertise (DCoE), under the accountability of Fereidoun Abbassian, BP's vice president of wells and production in Upstream technology. "We have taken this step in order to bolster our skills in Big Data and data analytics," says Abbassian. "The DCoE will build on our past successes in these areas and will allow BP to scale up and accelerate the pace of digitisation throughout the business."

The centre will be hosted by BP's Upstream business, with a focus on the segment's analytics programmes. However, it is also intended as a resource for the whole of BP. "The combination of these specialised skills, along with domain expertise, will unlock the true value of Big Data, helping us to improve decision making and overall performance across the group," says Abbassian.

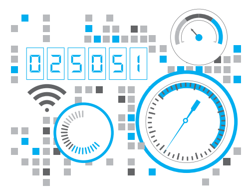
The message from BP's experts is loud and clear: the opportunity to harness data is as huge as some of the numbers themselves. We just need to be more prepared to trust computers to do the heavy lifting.

Data stats



25+ terabytes

Amount of log data on Facebook every day



200 million

Number of smart meters by 2014. In 2009, the number was 76 million

80%

Amount of world's information that is unstructured content

11 hours

Speed at which the world's information base doubles

To watch a film on real-time data in BP visit: bp.com/realtimedata

Stats courtesy of IBM

Production boost: (below) trading desks on the IST gas trading floor at the office in Houston, US; (bottom) and staff scientists discuss one of BP Biofuels' proprietary enzymes in a filamentous fungal host strain at BP's biofuels facility in San Diego, US. Big Data could help to improve biofuels yields.

"For us, Big Data is about improving our intelligence, and how quickly we can turn the data into information and intelligence, and then turn that intelligence into better commercial decisions."

David Rae

THE OUTSIDE VIEW: IBM

Experts at IBM, the global technology consultancy, are helping BP to explore its potential to access and analyse the huge amounts of data present throughout its global business and to harness opportunities.

"Petroleum is a big focus area for IBM, and analytics presents a great opportunity for oil companies that have significant dollars at risk in their operations and back office functions to get more predictable," says John Joyce, IBM's global lead consulting partner for BP. "We try to bring together a business and IT team to achieve specific business outcomes, linking data that can have a big impact and look to provide answers to questions that the businesses have not previously been able to ask."

Pierre Haren, IBM's vice president and worldwide leader for advanced analytics, reiterates the size of the opportunity, but also the size of the challenge to make sense of the data.

"Every two years, the volume of data in the world doubles and there is a very strong incentive financially for companies to make the best use of it," Haren says. "The challenge is to extract from this mountain of data something that makes sense and discard the useless 'ramble'. Of course, humans have to decide initially what will be important and what will not be important, but once the software is set up, machines do the rest."

Some companies store all sorts of data way beyond regulatory requirements, simply because they don't know what to do with it. But, storage costs are not going down and there has to be good governance of the lifecycle of data.

"An oil company never knows if it is going to find another identical geological formation that would benefit from the same treatment as a previous project," says Haren. "A lot of data about geology should be kept forever, because geological data is not going to change in our lifetime!"

For now, it is about recognising the analytics 'goldmine' in almost every company. "Nobody has reached the ultimate level of analytics leverage and most companies could reap incredible improvements in their bottom line and service to their customers," says Haren. "The big question right now is how quickly decision makers can deploy the existing technology to reap the benefits achievable today."

Catalyst for change: (main) senior chemist Dave Law observes laboratory machinery gauges at the Hull Research and Technology Centre in Saltend, Hull, UK; (opposite) and he holds up a model of a catalyst molecule.

Report> Roger Lakin **Photography>** Stuart Conway

Modern day alchemists

As conversion processes in the oil and petrochemicals industries become ever-more proficient, are we now approaching a point exceeding even the dreams of medieval alchemists: the ability to conjure almost anything we choose out of something else? For an expert perspective, **BP Magazine** *talks to the vice president of BP's Conversion Technology Centre, Mark Howard.*

Without conversion technology, today's refining and petrochemicals industries would not exist. Crude oil produced upstream is now efficiently converted downstream into high-quality fuel components, oils and petrochemicals – the fractions of the whole from which energy and a range of hugely versatile molecules can be readily released.

BP's strength in producing high-quality downstream products is backed up by a programme of investment in research and development, focused on maintaining a competitive edge in key specialisms, including high-performance fuels, premium lubricants and advanced petrochemical processes.

As with any mature industry, many of the improvements in the major conversion technologies deployed in refineries and petrochemicals plants are incremental rather than fundamental. But, there is always the potential for a breakthrough innovation that opens up new possibilities. This is where Mark Howard and BP's Conversion Technology Centre come in. »

"Conversion is the basis of the modern oil and petrochemicals downstream sector," says Howard, acknowledging the huge experience and expertise that exists in the industry. "My role with the Conversion Technology Centre is to explore the gaps and crossovers between the traditional refining and petrochemicals value chains and identify specific areas where BP can create value by applying its strengths. We're charged with looking for new conversions, or conversions that have perhaps only started to make economic sense in today's environment."

Hummingbird® and SaaBre™

Recent developments suggest that the gaps and crossovers being scrutinised by Howard's team, and by technology colleagues elsewhere in BP, are proving fertile territory: in particular, in November 2013, BP announced the commercial readiness of two new proprietary conversion technologies.

The Hummingbird ethanol dehydration process upgrades a long-established method of catalytically converting ethanol to produce ethylene. Its advantages include low set-up and running costs, greater energy efficiency and a higher purity product. The conversion to ethylene is achieved at lower temperatures and with less waste compared to conventional processes, and results in the conversion of more than 99% of the ethanol feedstock into ethylene – a few percent above the conventional approach.

The other technology, the SaaBre process, is a completely new chemical route for the production of acetic acid from a relatively low-cost feedstock called synthesis gas (a mixture of carbon monoxide and hydrogen), also known as syngas.

Both processes have performance and cost advantages for the production of these two staples of the chemicals and manufacturing sectors – and demand for ethylene and acetic acid continues to soar globally. What's more, with bioethanol feedstock, the Hummingbird process can enable the production of many 'renewable' derivatives from the basic ethylene building block.

Howard is quick to point out that neither of these new processes is the product of intellectual curiosity alone: "New conversions come about in response to the many different moving parts that affect the oil and gas industry: price, availability, access, taxes, stability of supply and so on. Go back 10 to 15 years, when oil prices were much lower, and had been lower for sustained periods, then many of the technologies we are working on today would not have made economic sense."

In simple terms, crude oil is such a good source of gasoline, diesel and petrochemicals feedstock, that when the oil price is relatively low other conversion routes from other feedstocks cannot compete. It is a different story when oil prices are relatively high.

Veba Combi-Cracking™ and Fischer-Tropsch

The production of diesel offers two current examples. One is a technology called Veba Combi-Cracking (VCC™), which – by adding hydrogen derived from natural gas to carbon – can convert both coal and oil residues into diesel. This opens up possibilities for accessing the

New developments: (left to right) trainee technician Dan Graves takes a sample for analysis while researching SaaBre technology at the Hull Research and Technology Centre in Saltend; research technician Michelle Gray puts together a catalyst sample in the synthesis laboratory; and operations technician Eric Frankland takes a sample on a pilot plant during researching Hummingbird technology.

vast alternative resource of coal and for generating greater value from the carbon-dense, low-value, heavy oil residue left over after traditional refining.

The other example is a conversion technology originally dating back to the 1920s called Fischer-Tropsch (FT), which can produce diesel from feedstocks other than crude oil, such as natural gas, coal and even biomass. Over the years, the conditions have never been quite right for either technology – being both complex and expensive to carry out – to have competed widely for any length of time with the traditional crude oil-to-diesel value chain. But, both have come a long way in recent years.

Howard points out that FT remains an attractive technology for certain niche volumes of gas and coal conversion and considers VCC well on its way to becoming an important process. Five VCC licences have been granted, with three plants currently in construction around the world – two in China and one in Russia.

"We see other potential opportunities as well for VCC, such as the conversion of bituminous coal and, in principle, the conversion of heavy oil in the field rather than at the refinery."

Shifting conversion landscape

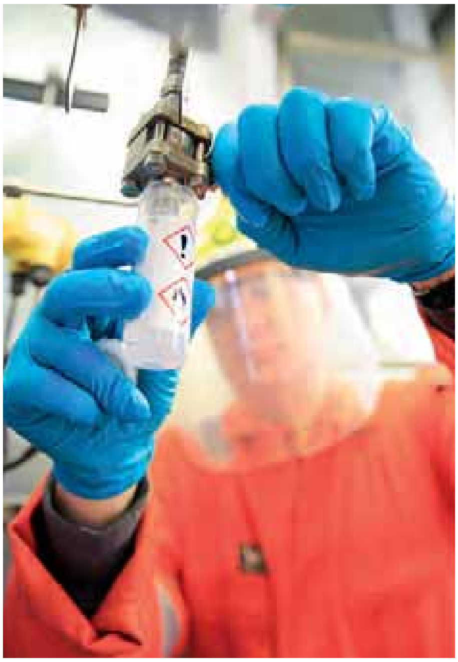
Asked to speculate in general about what the next big breakthrough may be in energy conversion, Howard points to the generation of chemical feedstocks and fuel oils from municipal solid waste. "Most people looking at the woody, cellulosic matter in municipal waste are doing so in terms of its potential as feedstock for generating power, which is probably sensible at the moment. But, there are also small-scale projects that are trying to make methanol from it, and some trying to make diesel, which makes this an interesting area to watch at the moment.

"This is a really expensive, capital-intensive area," Howard continues, "but people get paid to take away waste, so the feedstock can be a revenue source, not a cost. Couple that with conversion to a product that can go into the fuels market and command a premium and the potential might be there for someone in the fullness of time. Some of our own BP technologies, such as SaaBre and FT, can make chemicals and fuels from syngas derived from lignocellulosic feedstocks like grass, straw or trees, but it will require time, and further cost reductions, to commercialise – as well as the right economic conditions."

Recognising BP's focus on oil and gas, Howard points out that not all businesses will want to participate in all areas of conversions, but, he says, "There is value in having expertise in how the different bits all fit together, because that gives you options. The energy world changes in surprising ways." To illustrate this point, Howard says that companies have had to adapt to the US switching from a potential importer of natural gas to a prospective exporter as a result of the shale gas boom of the past few years.

"It's important to an integrated oil company's future that it's able to react to dislocations, such as the US shale revolution. An understanding of the conversion landscape is an important contributor to the ability to react quickly."

In terms of how that conversion landscape is shifting, Howard sees a growing merger between biological and thermochemical processes – a trend BP recognised early when setting up the Energy Biosciences Institute in 2007. "Petrochemicals has always been a multi-disciplinary environment, but now it's more important than ever for anyone considering a career in conversion technology to recognise the multidisciplinary nature of new technology developments. If you have depth in one area of expertise, say on the chemistry side or process engineering, you may also benefit from an understanding of bugs and fermenters. For example, industrial plants that perform biological processes have to be hygienic, which is not something that has been thought about a great deal in traditional petrochemicals or refining."



Anything into anything?

With all these skills coalescing, does Howard foresee a time when the potential of conversion technology will become almost limitless? "Broadly speaking, if you want to make a product that is derived from the refining or petrochemicals industry, like a plastic bag, for example, you can make it from trees, oil, sugar, or any other carbon-based feedstock. But, of course, these are only economic under the right conditions.

"At BP, we have a growing position in bioethanol and we know there is a good pull from potential customers for ethylene produced from renewable resources – in other words, for ethylene from bioethanol produced from sugar." It's an example that neatly encapsulates Howard's focus on new conversions that create new value chains, and BP's interests in both the production of bioethanol and the provision of licences for the Hummingbird process that can convert bioethanol into bioethylene.

"Actually, there is nothing we currently make that can't be made from all sorts of different resources. It's all about the price that markets are willing to pay, the environmental consequences of doing it in that way, and competing with the alternatives. Societal changes can have an impact on the feedstocks that we employ," Howard says.

He summarises some of the forces at play in that world – including geopolitical turmoil, environmentally-driven regulation, and the many factors that influence the price of oil and gas – before concluding that, "while the economic environment may be hard to predict and plan for, conversion technology has an important role to play." One certainty is that BP's modern-day alchemists are brimming with ideas for when the economic forces align.

HUMMINGBIRD and SaaBre are trademarks of BP p.l.c.

Veba Combi-Cracking and VCC are trademarks of BP Europa SE.

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→ talking point

Illustration> Brett Ryder

INDUSTRY CONNECTIONS

The 17th century poet John Donne famously declared that 'no man is an island'. The same could be said of today's oil and gas industry, where relationships are crucial in helping to solve the world's energy challenges. BP's head of Upstream technology, Ahmed Hashmi, discusses the importance of collaboration.

Technology is the lifeblood of our business. It helps us to overcome the challenges we face, such as finding and producing resources safely, accessing new frontiers, driving efficiency through our operations, or delivering lower-carbon fuels. All operators share these challenges. So, while this is a competitive business, it often makes sense to collaborate and it's not uncommon to find several operators working alongside each other in the same region and on the same issues.

Collaboration takes several forms and depends on where you are in the technology development cycle. In the earliest stages, it is about understanding the science and advancing knowledge to create new and better technologies. Once the scientific mechanisms are understood, we move into applied research, involving prototypes and testing. Then, it's about integrating different technologies and know-how into engineered solutions and digital tools. This occurs at a larger scale and may require approval from regulatory authorities. Only then, are you ready to deploy a technology into a project. The cycle tends to start with inhouse research or research with universities and research institutes, before moving into small engineering design companies and then on to larger engineering and manufacturing companies.

At BP, it starts with business strategy – we only hold proprietary technology rights where doing so adds differential value to the business. Our work in enhanced oil recovery is a good example of this. It gives us an opportunity to clearly differentiate our offer and bring unique value to resource owners who are interested in working with us on new and existing resource development.

There are several research projects that we are involved in where the majority of the work is not proprietary; for example, Project 20K, where the challenges of the next generation of high-pressure, high-temperature deepwater development face the entire industry. Initially created by BP, Project 20K will help us to develop technologies to unlock these resources and we're now working alongside FMC Technologies, Maersk Drilling, GE Oil & Gas, Anadarko, ConocoPhillips, and Shell.

BP also has a strong track record of collaborating with other industries. For instance, we're using technology from the medical world to help us to understand rock formations. Analysing types of rock that can hold hydrocarbons requires specialised studies that can take months. However, by using CT scanners to study small pieces of rock at high resolutions, we can create a mathematical model that allows us to understand its properties more quickly. At our new Center for High-Performance Computing (CHPC) in Houston, US, we're working with Intel to process and analyse seismic data more quickly and effectively than ever before and we continue to collaborate with them to help develop the next generation of digital technologies (for more on data analysis in BP, see page 34).

We also work, via our venturing business, with smaller, start-up technology companies, providing investment and testing opportunities to help develop novel technologies, such as specialist acoustic telemetry – technology placed inside wells to collect and transmit real-time data – developed by a company called XACT. These technologies might one day enter our mainstream business. Again, strategic alignment is key and we only invest in areas with a strong business linkage and value potential.

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For more on BP's major technology programmes visit: bp.com/techprogrammes

HI-TECH OPERATIONS

From equipment that boosts the aerodynamic efficiency of wind turbine blades to the use of global positioning systems to improve sugarcane cultivation, technology is transforming the way in which BP's Alternative Energy business operates.

Blade runner: an engineer, pictured with his climb bag (containing all his tools) hanging below him, installs vortex generators (VGs) on the blades of a turbine at BP's Silver Star 1 wind farm in Texas, US. The VGs can improve aerodynamic efficiency and increase the amount of energy that a blade can extract at a given wind speed.

Report> Helen Campbell
Photography> Art Giraldo/Content Co-Op/Marc Morrison

According to BP's *Energy Outlook 2035*, global demand for energy is set to rise by 41%, with renewable energy sources expected to continue to be the fastest-growing class of energy. If you include biofuels, renewables are expected to have a higher share of primary energy than nuclear by 2025. Technology is playing an enormous role in this rapid development and in BP, where the focus is on wind and biofuels, it's having a revolutionary effect on the way in which its turbines operate and its feedstocks are harvested and efficiently converted into biofuels.

In 2005, BP made a commitment to invest $8 billion in Alternative Energy (AE) and achieved this two years ahead of schedule in 2013. In the US, BP's wind business has interests in 16 wind farms, generating almost 2,600 megawatts of renewable power – enough to power 780,000 average US homes, or a city the size of Houston, Texas. BP is also a leading player in the production of bioethanol, with three mills in Brazil and the Vivergo facility in Hull, UK (a joint venture with AB Sugar and DuPont). Between them, the mills produce around 11,000 barrels of oil equivalent per day. In addition, BP is using its assets to develop and commercialise innovative proprietary biofuels technologies.

"In AE, technology is at the core of what we do," says Tom Campbell, technology vice president for biofuels. "For example, our biofuels business is deploying advanced control technologies that are helping to automate the planting process at our three sugarcane mills in Brazil, which, in turn, allows us to reduce risks and increase yields. Through our proprietary cellulosic ethanol technology, Cellulex™, we are also using BP's bioscience skills to develop feedstock and conversion technologies that unlock the production of lignocellulosic [second-generation] ethanol.

"In wind, we are installing new technology on some of our turbines to increase the production of renewable electricity, and we are using technology to monitor our operating turbines from a dedicated operations centre to enable us to enhance performance."

Technology potential

Technology is also helping BP's wind business to address key challenges of productivity, cost and sustainability. The 'vortex generator' (VG), for example, is a relatively simple piece of technology that fits into the palm of the hand and yet when several hundred are installed on wind turbine blades, they can improve aerodynamic efficiency and increase the amount of energy that a blade can extract at a given wind speed. In fact, VGs have the potential to increase the power generated by BP's owned and operated US wind assets by up to 3% annually, equivalent to the energy consumption of 250,000 15-watt compact fluorescent light bulbs being turned on continuously for a year.

A VG's optimal position on a blade is determined by mathematical calculations and onsite visualisations of the wind flow. Each one is installed using a high-performance industrial adhesive that can cope with extreme conditions, including rain, ice, snow, and, of course, high winds. They work by keeping the air flow attached to the blade longer, which generates more rotational force or lift. This causes the blades to spin faster and generate more energy than a non-VG-equipped turbine in the same wind conditions. Air flow separation occurs when the air flowing along the surface of the blade detaches,

Advanced harvest: (opposite) a harvester tips sugarcane into the back of a tractor for producing biofuels in Brazil. The business is using several technologies, such as GPS and onboard computers, to improve sugarcane cultivation; (below) BP's Ituiutaba mill, Brazil; (bottom) and wind operators discuss data displays in BP Wind Energy's remote operations centre, Houston, US.

reducing the force available to move the blade. Similar to how an aeroplane stays in the air by using lift, wind turbine blades are designed by balancing structural stability with aerodynamic efficiency and the VGs help to improve this efficiency.

Enhanced performance

In 2013, as part of its focus to enhance performance across its wind business and through an investment set up by BP's venturing team, BP joined forces with UpWind Solutions, a San Diego-headquartered turbine service provider that is now installing VGs on turbines at six of BP's wholly-owned US wind farms: Titan 1, in South Dakota; Edom Hills in California; Flat Ridge 1 in Kansas; and Trinity Hills, Silver Star 1 and Sherbino 2 in Texas.

"This has been a tremendous opportunity for us to become a technology partner with BP at six of its sites," says Peter Wells, UpWind chief executive officer. "It has enabled us to further expand our footprint in the US, and to work with a company so focused and appreciative of the value that technology delivers to a business."

James Madson, director of performance services for BP Wind Energy, says: "Wind speeds vary substantially, even across one wind farm. This relatively simple technology helps us to generate additional energy across the operational range of wind speeds and helps to keep each turbine operating as close to its full power as it can, as often as it can. In a trial of VG technology on five turbines at the Trinity Hills wind farm in Texas, earlier in 2014, we achieved a greater than 2% improvement in energy production.

"Working on our behalf, UpWind is installing 69 VGs on each of the three blades of these turbine rotors. We plan to install VGs on 212 of our Clipper turbines by the end of 2014. We are also pursuing discussions with partners and other VG vendors about the potential to install this technology on the assets we co-own."

Meanwhile, BP's biofuels business is using several technologies, such as global positioning system (GPS) and geographic information system (GIS), auto-pilot and onboard computers in its Brazil operations to improve the way in which sugarcane is cultivated across its 130,000 hectares – an area almost the size of London. Together with advances in the industrial conversion process – such as the use of near-infrared (NIR) for process monitoring and other applications of process intensification – these developments in 'agricultural intelligence' are contributing to growth of up to 45% in BP's sugarcane value chain. Not bad for a crop with a 500-year history in Brazil.

"Using GPS technology to map the farms and to plan and monitor our sugarcane planting and harvesting, we are maximising our use of the land and increasing our production with the same area," says Wesley Ambrosio, technology director for BP Biofuels in Brazil. "Our machines are spread out across several thousand hectares, and we are using GPS and onboard computers in the fields as a tracking tool to monitor the progress of automated planting and harvesting vehicles and to enable greater efficiency at scale.

"We are also using GIS technology to integrate our soil maps and varietal portfolio, so that we can optimise and improve the way we plant, irrigate and fertilise the crops, so we get the best out of the land and resources. Biofuels in Brazil was perceived as an agricultural business, but these approaches are changing the mindset and it is becoming much more of an energy business. We are increasing yields and efficiency as a result."

Ambrosio adds: "On the industrial side, the application of process-intensification technologies, such as fermenting sugar juice to generate ethanol in a continuous process, instead of fermenting it in batches, as is the industry standard, allowed us to increase productivity almost threefold. The use of the process-intensification approach has also allowed BP in Brazil to double its anhydrous ethanol production capacity using the same distillation columns. This approach of efficiency through technology is well used in other BP businesses and is improving the profitability of BP's existing sugarcane mills in Brazil."

As BP's AE businesses mature, technologies like these will be essential in maximising the energy that can be produced from wind and sugarcane. ●

"Our biofuels business is deploying advanced control technologies that are helping to automate the planting process… in wind, we are installing new technology on some of our turbines to increase the production of renewable electricity."

Tom Campbell

Report> Nick Reed
Illustration> Mike Stones

Eye in the sky

The use of unmanned aerial vehicles (also known as drones) is on the rise, with the military to Hollywood finding practical applications. BP, too, was an early adopter, conducting its first tests eight years ago. And now that the Federal Aviation Administration has given the organisation approval for the first commercial operation in the US, this technology looks set to change the way in which BP carries out some of its most challenging tasks.

Keeping road grader vehicles or drill rigs on course in a harsh Alaskan winter can be a slow, difficult business. So, too, can inspecting a flare stack on a refinery cooling tower. But, the growing use of unmanned aerial vehicles (UAVs) is helping organisations such as BP to change the way in which these necessary tasks are managed.

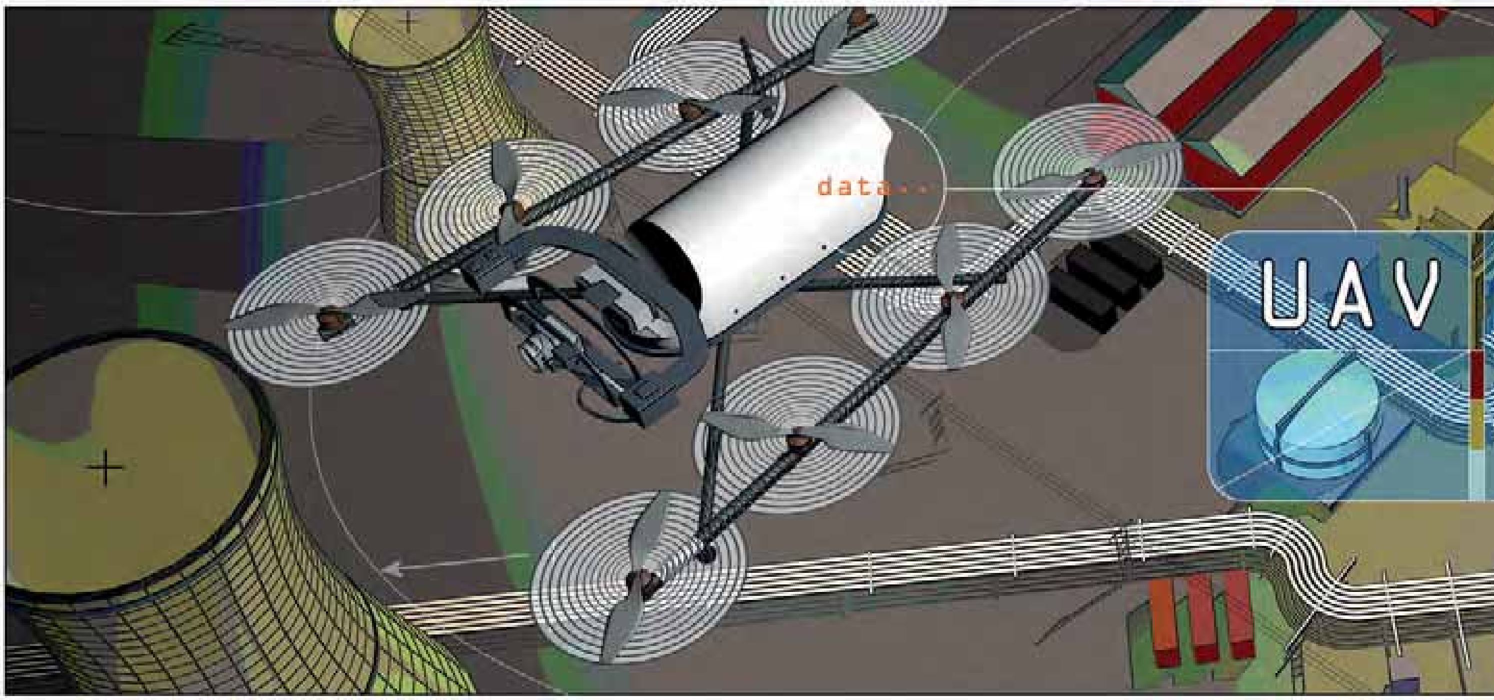
BP has been testing UAVs for its own purposes since 2006, although widespread commercial use was previously limited by cost, regulation and privacy issues. That all changed earlier this year, though, when the Federal Aviation Administration (FAA) approved BP and California-based manufacturer AeroVironment's request to fly the Puma AE UAV at BP's Prudhoe Bay oilfield on Alaska's North Slope. It's the first time the FAA has authorised the commercial operation of a UAV over land in the US.

Not all UAVs are the same. The Puma, for example, is a radio-controlled, fixed-wing vehicle around 1.8 metres (six feet) long with a two-metre (seven-foot) wingspan. Made of ultra-light Kevlar, it weighs less than seven kilograms (15 pounds).

Other fixed-wing UAVs are 'autonomous', which means their route, speed and height are all preprogrammed ahead of flight. Both versions can fly for around three-and-a-half hours and remain stable in winds of up to 50 kilometres (30 miles) an hour. This makes them ideal for checking pipelines and mapping land outcrops for exploration purposes.

There are also radio-controlled multirotor UAVs – effectively mini-helicopters – that are smaller and have a shorter range. These are perfect for checking vertical structures, such as flare stacks and cooling towers, as well as flat roofs and electrical lines. BP is also investigating their potential use inside vessels and tanks. The beauty of a multirotor UAV is that it can collect accurate data from a structure at a distance of seven to nine metres (25-30 feet), without having to shut it down.

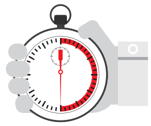
UAVs are controlled by mobile ground stations crewed by one person flying the



machine and someone else operating the onboard cameras, usually accompanied by subject experts onsite to analyse the pictures and data as they come in.

The machinery is highly sophisticated technology, which is one reason why UAVs are classified as aircraft. But, the real innovation is in the kit they carry. As well as high-resolution photography and video cameras, the fixed-wing versions carry the latest light detection and ranging (LiDAR) equipment, which incorporates remote sensors that use laser pulses to collect 3D images. The laser scanner transmits up to 400,000 pulses of light per second, recording the time delay between transmission and reception to calculate elevation values. Those values are then integrated with information from the UAV's global positioning system (GPS) and orientation measurements to produce a 'point cloud' – a set of data points – showing the location of crops, forests, roads, railways, airports, bare earth, mountains, valleys, lakes, rivers, glaciers, buildings and other urban developments. Since LiDAR can be reflected from any object the laser pulse strikes, up to five returns are collected per pulse. The multiple returns are recorded and each point is assigned a classification to identify landscape features. The intensity of the reflected energy is also captured and

In numbers



30 minutes

Amount of time it takes a Puma AE UAV to check a three-kilometre section of pipeline. This would take a human up to seven days

1,930 kilometres

Length of pipeline at BP's Prudhoe Bay field in Alaska

400,000

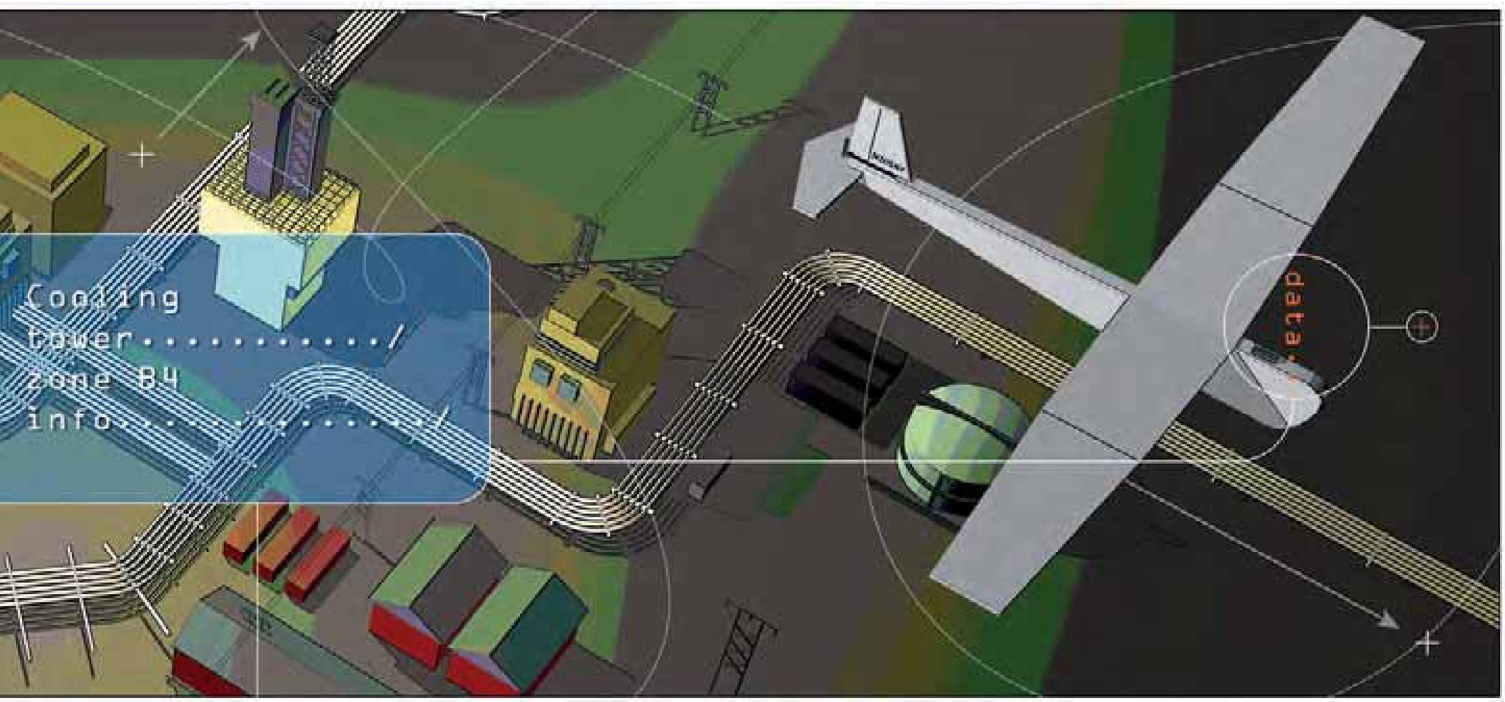
Number of pulses of light per second that LiDAR equipment transmits in order to collect 3D images

analysed: all of which makes it very useful for high-resolution topographical mapping and 3D surface modelling.

For BP in Alaska, this technology is proving invaluable at its Prudhoe Bay site, where floods, ice break-ups and ice floes constantly alter the topography, making other monitoring methods difficult, costly and time-consuming. Using UAVs and LiDAR technology, the team is able to create highly accurate, real-time models that help to keep drivers on course along gravel roads, even in low-visibility conditions. The UAVs also help to scan BP's pipeline network to identify areas that need repair from frost damage.

Elsewhere, UAVs are helping BP's exploration team to produce cost-effective 3D models of onshore outcrops in Azerbaijan. At its site in Hull, UK, the unmanned Cyberhawk 'octocopter' has helped to assess the integrity of a 100-metre (330-foot) cooling tower, removing the need for scaffolding and people working at height.

The regulatory environment for using UAVs differs from country to country, determining how and where this technology can be used. But, with costs falling and increasingly sophisticated technology – of both the machines themselves and the sensors and cameras they carry – the future looks very promising for UAV use across BP.



A DIVERSE OPPORTUNITY

With interests in three oil sands projects in the province of Alberta and exploration work taking place in the Beaufort Sea and Nova Scotia, it's a busy time for BP's Canadian business.

REPORT> ERIC HANSON **PHOTOGRAPHY>** JOSHUA DRAKE/AARON TAIT

Line out: (main image) pipelines running from the Sunrise oil sands project through the northeastern Alberta forests. Sunrise Energy Project is a 50-50 partnership between BP and operator Husky Energy; (below) and construction manager Clarence Letendre ascends a furnace tower for inspection.

Fossils are big business in the Canadian province of Alberta. Forty-nine different dinosaur species from the Late Cretaceous epoch – around 5% of all the known species in the world – have been found at the UNESCO World Heritage site Dinosaur Provincial Park. Meanwhile, the region's Royal Tyrrell Museum houses one of the world's largest displays of dinosaurs. The province even has its own species – the Albertosaurus sarcophagus – discovered in 1884 by Joseph Burr Tyrrell.

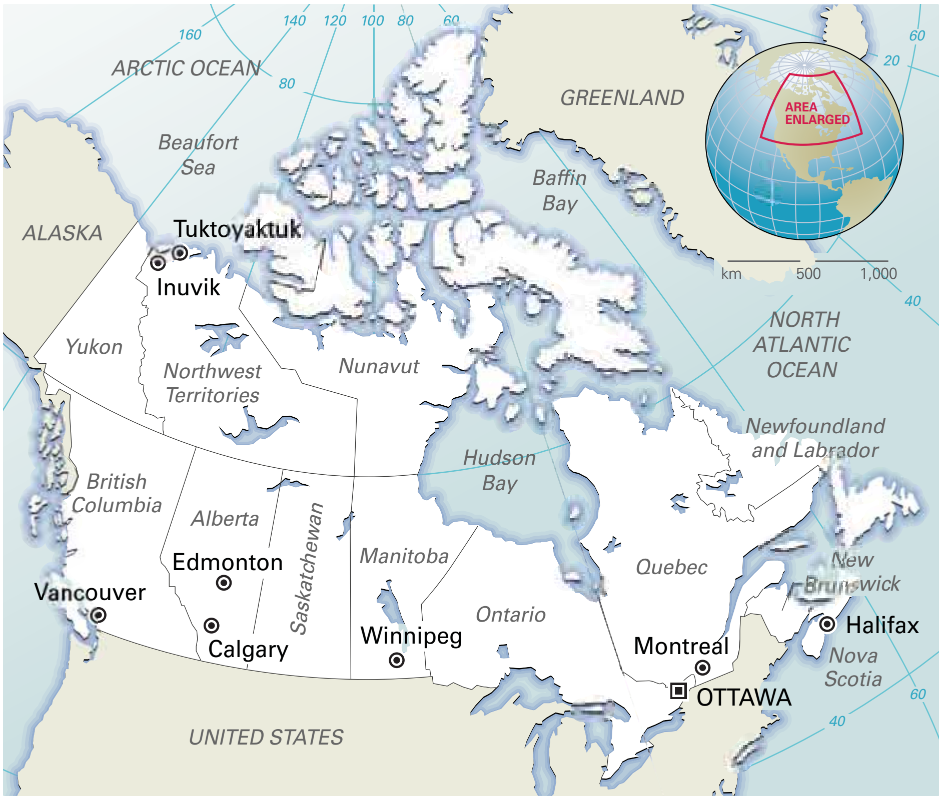
But, these days, dinosaurs are not the only Albertan fossils attracting attention. With significant oil sands reserves, the province is also playing an increasingly important role in Canada's diverse energy industry. From conventional oil and gas formations to shale, and from deepwater basins to huge oil sands deposits, Canada has it all, says BP Canada president Stephen Willis: "If you name a type of oil and gas resource, Canada has it, and all those resource types are available and are being evaluated, progressed, developed and produced."

Not surprising, perhaps, when you remember that Canada is the world's second largest country after Russia and has more oil reserves than any other nation except Saudi Arabia and Venezuela.

BP's role in the Canadian energy industry is just as diverse. In the north and east, it is exploring deepwater basins in the Atlantic and Beaufort Sea (see page 59), while in Alberta, it has interests in three oil sands projects – Pike, Terre de Grace and Sunrise.

Located in northeastern Alberta, the Sunrise Energy Project is a 50-50 partnership with operator Husky Energy to develop an oil sands reservoir containing 3.7 billion barrels of proved, probable and possible ››

New plant: (below) newly-constructed once-through steam generators (OTSGs) stand ready to operate at the Sunrise project; (right top) Eric Mofford (right) and Clarence Letendre walk the project site to gauge progress; (bottom right) and a view of Lake Moraine, in Banff National Park, Alberta.



"If you name a type of oil and gas resource, Canada has it, and all those resource types are available and are being evaluated, progressed, developed and produced."

Stephen Willis

resources. The estimated recoverable resources for the first two phases are thought to be around 1 billion barrels. Regulatory approvals are in place to produce 200,000 barrels per day and the first $2.5 billion-plus investment stage is expected to produce up to 60,000 barrels per day. Start-up is due to begin by the end of 2014.

The bitumen in oil sands deposits is thick and hard like a hockey puck, until it is heated. Some of it lies at or close to the surface and is extracted by open-pit mining.

However, Husky and BP are targeting bitumen in deeper-lying deposits, such as Sunrise, where the reservoir lies at depths between 140 and 275 metres (460 and 900 feet). Instead of mining, the projects in which BP participates will use a process called steam assisted gravity drainage (SAGD), which involves injecting steam into the reservoir via a long horizontal well. The steam, which is generated using natural gas, heats the bitumen into a fluid that can then flow down into a second and lower horizontal well, which collects the oil.

SAGD offers a benefit over mining in that it has a smaller surface footprint, which means reduced land usage and easier site reclamation. And, only around 10% of the lease acreage is actually used in the operations, the rest is left relatively undisturbed.

While SAGD is less disruptive than mining, it still has its critics, who argue that the process can still cause some damage to the environment because of higher carbon emissions, higher water usage and pollution, some land disturbance, and some wildlife disruptions.

BP and its partners have a strategic plan in place that is designed to meet strict government regulations, address environmental concerns, and minimise the impact on wildlife and the local Aboriginal communities who live in the region (see page 61).

Gary Mackay, a BP senior advisor on climate change and carbon for oil sands, says BP and Husky are very focused on delivering an effective carbon management plan.

The first step in the plan is to improve energy efficiency. "Be more efficient, reduce the amount of steam you need," says Mackay.

To do that, efforts are under way to increase thermal efficiency. For example, insulating the SAGD wellbores with specialised piping is being evaluated to reduce the amount of heat that is lost on the way to and from the well and the plant. In turn, this cuts the amount of energy required. Trials are also under way that use solvents or additives to reduce or eliminate steam requirements. It's possible, as regulations evolve, to capture the greenhouse gas emissions before they even enter the atmosphere and store them in underground reservoirs.

The Sunrise team is also looking at energy offset initiatives – in which a company producing high emissions can buy credits from another that is low in emissions – as a way to reduce the overall total.

"There are many well-developed initiatives in Alberta to allow for this and it is carefully managed," says Mackay. "A tonne of carbon dioxide is a tonne of carbon dioxide, whether it's produced in an oil sands facility or whether it is reduced by building a wind farm."

BP is also working with Canada's Oil Sands Innovation Alliance (COSIA) to develop industry-wide solutions. Made up of 14 organisations, COSIA is focused on accelerating the pace of improvement in environmental performance in Canada's oil sands and, to date, the alliance companies have shared 560 distinct technologies and innovations worth more than $900 million. Furthermore, future technology may provide »

Seismic survey: a view of a navigation screen display showing the position of seismic streamers on a monitor. In the summer of 2014, BP conducted a large seismic survey off the coast of Nova Scotia. Operated from Halifax, the survey vessels acquired data from more than 7,120 square kilometres (2,750 square miles) of ocean.

"The geology of Nova Scotia looks very analogous to other places in the world where BP has been successful. We are hopeful of what we will find."

Bob Ball

NEW EXPLORATION

In other parts of Canada, BP is investigating two other sources of hydrocarbons, with offshore exploration off the Atlantic coast of Nova Scotia and further opportunities in the Canadian Arctic's Beaufort Sea.

In the summer of 2014, some 3,700 kilometres (2,300 miles) to the east of Alberta, BP conducted a large seismic survey off the coast of Nova Scotia in water depths ranging from 90-2,740 metres (300-9,000 feet). Operated from Halifax, the survey vessels acquired data from more than 7,120 square kilometres (2,750 square miles) of ocean. Bob Ball, BP Canada's exploration coordinator, says now the team will need to analyse the vast amounts of data from the programme before making a decision in 2015 about whether to proceed with an exploration well.

The region's geology makes it of particular interest to the industry. Located on the Atlantic Margin, it is part of a much larger geologic trend associated with the opening of the Atlantic Ocean that includes Argentina, Uruguay, Brazil, Newfoundland and, on the other side of the ocean, Morocco and Angola.

"Based on our understanding of the Atlantic Margin and the Gulf of Mexico, we would expect to find the existence of a similar deepwater subsalt geologic play," Ball says. "Our geologic evaluation has indicated that all the components of a petroleum system should be there."

It's early days yet and many of these assumptions will need to be tested, but, says Ball, "the geology of Nova Scotia looks very analogous to other places in the world where BP has been successful. We are hopeful of what we will find."

In the Arctic, the Canadian Beaufort Sea has been of interest to the industry since the late-1960s and oil and gas companies have drilled more than 150 wells, many successful, yet none has been developed commercially.

Exploration and drilling is a challenge in this remote, harsh environment, where winter is long and the ice sheet extensive. BP is investing in research and working with industry partners to improve the industry's overall Arctic skills to tackle these particular challenges. At best, an organisation can expect to be operationally active on a wellsite for between 90 and 100 days each year during the open-water season. "In that time, you have to drill that well and then pack up and get out very quickly," says Ball.

With water depths of 270-460 metres (885-1,500 feet), the new potential Beaufort wells will be in deeper water, up to three times as deep as previous wells in the area, and drilling to deeper targets, and so could take two or three operating seasons to complete.

Before any drilling could happen, however, much work needs to be done on the regulatory front. "The Beaufort Sea has not seen an offshore well drilled in about 25 years, so this is a new kind of arena, both for the operators and the regulators," says Ball. BP and its operating partner, Imperial Oil, expect to obtain clarity of those regulations by 2016, so any new exploration well is still some way off.

In partnership: workers (above) at the Sunrise project, Alberta; Susan Casey, safety advisor (middle), is part of a safety team that has promoted a strong safety culture onsite; and an onsite fire and rescue squad (far right) trains rigorously in order to stay prepared.

another way of addressing carbon emissions. Husky also has plans to address greenhouse gas emissions and other environmental concerns, including the use of technologies to reduce sulphur and nitrogen oxide emissions and recover gas vapours from tanks and vessels so that they can be used as fuel. To help minimise the impact on wildlife, the pipelines that lead from the wells to the various units have crossings for moose, deer and other animals incorporated into their design. Remote-controlled imagery confirms these crossings are being used.

The first introduction of steam – known as 'first steam' in the business – into the Sunrise wells will mark the culmination of a project that began for BP seven years ago and has involved thousands of workers creating a network of pipes, storage tanks, pumps, wells, living quarters and other buildings in remote areas of Alberta.

"Sunrise is essentially a big water treatment centre," says Eddie Rollinson, Sunrise project general manager.

The facility uses natural gas to turn water into steam, which is then injected into the reservoir underground. "First, non-potable water is purified, then fed into steam generators and the steam is then injected into the reservoir. The oil and water is recovered and separated, at which point the water recycling loop starts all over again," says Rollinson.

Horizontal wells ranging from 730-975 metres (2,400-3,200 feet) in length are drilled in pairs, one above the other, through the deposit, which is sometimes as thick as 36 metres (120 feet). "The top well carries the steam, which heats the oil sands until the oil begins to flow down into the collector well," Rollinson says.

It can take a few weeks or months for the steam to warm the reservoir enough for the oil to begin to flow and once the process starts, it continues until the well is closed. It is economically intensive work and the project must have large enough economies of scale, coupled with big reserves.

"The seismic results we've acquired are changing where our operator decides to drill and that leads to higher success and saves money."

Chris Natenstedt

"You probably need to have in the range of 400-500 million barrels of recoverable oil to really make this attractive."

Tony Deakin, partnerships and regulatory affairs manager for Global Oil Canada, adds: "Once the oil is pumped from the ground, it has to be moved to refineries. Fortunately, the oil sands have an established export pipeline infrastructure, as well as rail-loading infrastructure, as an alternative while current capacity constraints persist to transport oil to customers."

"When we see our first crude from Sunrise, our role will be to make sure that it physically flows from the project to the markets," he says. "We want to maximise the value and that can mean placing it internally at one of our own refineries or selling it to a third party if we believe that is the best BP value for the crude."

Although not the operator on the project, BP's role is one of experience and expertise, says Chris Natenstedt, BP vice president of reservoir development. "We have a track record of being able to identify where we can help work with the operator on the subsurface side, as well as on the project side, to improve business decisions."

As SAGD is a relatively new recovery process, even experienced oil sands operators are still on a learning curve. So, BP puts a lot of effort into studying what other industry SAGD operators have done, learning what has and hasn't worked. At the same time, the organisation has been able to use its extensive expertise in seismic acquisition and analysis across all three of the oil sands projects it is involved in.

"We have done 3D seismic over these properties and that is turning out to be more and more important," says Natenstedt. "We shot high-density seismic at Pike and processed it with BP's state-of-the-art techniques, which is making a big difference. In many cases, we are now able to see the probable presence of sand in the reservoir before we drill. The seismic results we've acquired are changing where our operator decides to drill and that leads to higher success and saves money," he says.

The development of the Pike SAGD opportunity is a BP joint venture with Devon, which is currently producing crude from its nearby Jackfish project. Devon operates the Pike lease as well and was selected, largely due to its technical knowledge and track record. "Devon is quite experienced with Jackfish as a SAGD operator," says Natenstedt. "That is one of the reasons we decided to partner with them."

BP operates the Terre de Grace lease, meanwhile, with ViBrant Petroleum as a 25% partner. The lease is currently in the appraisal stage to see what might be commercially viable.

"BP's oil sands properties provide access to world-class volumes of recoverable oil with a development lifespan that will last for decades to come," says Natenstedt. "SAGD is a young, unconventional extraction technology. The industry has learned an enormous amount since it was first commercially applied around 15 years ago and it is exciting to think about how we can improve and what we will accomplish over the next 50 years."

BP IN THE COMMUNITY

As well as its rich fossil life, Alberta is home to local Aboriginal communities who have lived and worked on its land for centuries.

BP has a long history of working with Canada's First Nation and Métis communities in the region, along with local Inuvialuit people in the Arctic. Before moving forward with any project, the BP team puts a tremendous amount of effort into strengthening these relationships.

Early consultation is crucial when developing a new project and BP works with Aboriginal communities to get their feedback on project design, environmental and socioeconomic impact assessments, land access and traditional knowledge studies. The organisation also seeks to help create and support new opportunities for employment, education and training and business development. Through The Banff Centre, located in the Albertan town of Banff, BP Canada offers scholarships to attend Aboriginal leadership and management programmes, designed to help Aboriginal leaders and community decision-makers from the communities in which BP operates to develop their skills in areas such as strategic planning, financial management, conflict resolution and economic policy creation. Since 2005, the organisation has provided scholarships to more than 100 people.

According to Eric Mofford, project general manager for project execution on assignment at Husky, a collaborative environment means people will often make an additional effort to solve a problem or accomplish a goal. "When you do run into a tight area or you need something quickly delivered and you have a long-term relationship, people go the extra mile," he says. "Projects are people. You get safety right, you get the project right and you get the people right, then the rest is just getting the job done."

One of the members of BP Canada's community relations team who spends much of his time visiting Aboriginal communities in northeastern Alberta is Jacob Handel, community relations advisor for BP. "There are several Aboriginal communities in the area around our interests in the oil sands region, with around 500 people living nearby. They are right in the heartland of oil and gas development," he says.

"There has to be an understanding of the options available in order to set the criteria that meets the ability of the operator to work and the interests of the community to minimise the impact," he adds.

Traditional activities, such as hunting, fishing and trapping, are a key part of daily life in Aboriginal communities, which means the land they inhabit is of great importance. "There are quite a few trappers from the First Nations and they have areas they actively trap," says Handel. "They have an interest in how that land is being used, so Husky, as the operator, has engaged them in meetings and had active conversations to address their concerns."

Meanwhile, some First Nation groups have formed businesses that are providing services to the energy industry. "A lot of the communities have taken an active role in resource development by setting up First Nation-owned companies, as well as private entrepreneurship and there is also a significant amount of joint ventures," he says. "Many of these companies and joint ventures are putting their profits back into the community, while private entrepreneurs have been very active in giving back to the communities through employment of members or supporting social, cultural and athletic activities."

AZERBAIJAN: TWO DECADES OF DEVELOPMENT

Twenty years since Azerbaijan signed a landmark agreement with BP and 10 other international oil companies to develop three major oil fields – Azeri, Chirag and deepwater Gunashli (ACG) – in the Caspian Sea, the country has seen immense change. Dubbed the 'contract of the century', the deal proved a turning point for the nation's economy, as it emerged from the post-Soviet era. Here, Ilham Shaban, director of the Baku-based Center for Oil Studies, explains why 20 September 1994 was so significant.

Promising landscape: view of the Deepwater Gunashli platform with the *Neftegas* supply boat in the foreground, Caspian Sea, Azerbaijan.

Interview> Amanda Breen **Photography>** Stuart Conway/Corbis

Looking back 20 years, I'd say the difference between Azerbaijan then and now is striking indeed. During the first years of independent statehood, the country was shouldering the impact of a recently agreed ceasefire over Nagorno-Karabakh with up to one million internally-displaced people, against a back-drop of high unemployment and a shrinking economy, following the collapse of the Soviet system. These scenes are still vivid in my memory. Back in those days, the dollar exchange rate was not determined by the Central Bank of Azerbaijan, rather by the black market that dominated our capital city.

President Heydar Aliyev laid the foundations of a new oil strategy for the country, giving rise to the rebirth of a modern Azerbaijan. At the ACG signing ceremony in 1994, BP's John Browne said: "The investments will open new possibilities for Azerbaijan." There was scepticism among many people at that time, but those words turned out to be prophetic. The country saw favourable changes almost immediately – the 'contract of the century' brought foreign investment, new job creation and oil played its part, for the first time, in the development of the service sector.

Macro-economic indicators show consistent growth in Azerbaijan's gross domestic product (GDP) since 1995. According to the State Statistical Committee, between 1995 and 2003, the average annual increase in GDP was 9% and the average salary grew more than five times. Foreign investment increased tenfold and domestic investment, five times. The state budget deficit fell to its lowest level. In the past 10 years, since 2004, »

Old and new: (left) view looking over the walls of Baku's old town towards the very modern Flame Towers, the tallest buildings in the capital city of Azerbaijan. Construction was completed in 2012; (below left) on the walkway of the Deepwater Gunashli platform, part of the ACG field; (below) and Ilham Shaban.

Azerbaijan's GDP has grown by an average of 14%, with the private sector share making up almost 82%.

Oil has been produced here for more than a century and a half; Azerbaijan has long been open to co-operation with foreign companies. At the dawn of the first oil boom in the late-19th century, the likes of the Nobel brothers and the Rothschild family invested in Baku, and many Western oil companies had their offices here. But, many later turned their backs due to the nationalization of the industry. In 1978, the USSR cabinet of ministers allocated $700 million for the construction of the Deepwater Jacket Factory on the shore of the Caspian Sea and its operations began within two years, with hydrocarbon exploration increasing in the area, as a result. The industry had kept regular ties with Western companies, but prior to the ACG agreement, Azerbaijan had never been involved in joint projects with foreign partners on such a large scale. Twenty years later, the country has signed 32 oil and gas production sharing contracts with international companies.

Today, the Azerbaiijani economy as a whole shows good momentum – and GDP is likely to continue to grow with the full-field development of the Shah Deniz gas field and additional gas export pipelines. However, we cannot reduce the country's dependence on oil revenues yet. Statistics show that during the first half of this year, crude oil amounted to 86% of total exports – it was almost the same situation five years ago. However, the government spends millions of dollars annually to support other sectors, such as tourism and private entrepreneurs. There are results – the share of the non-oil sector gradually grows – but it takes time to strengthen other sectors.

Established in 1999 by presidential decree, the State Oil Fund of the Republic of Azerbaijan aims to preserve the nation's oil and gas revenues for future generations. As of September 2014, more than $105 billion has been received from the ACG development, and revenues from these oilfields account for around 95% of total income for the fund.

And, so, looking to the future, let us imagine Azerbaijan in 2034. By then, the existing ACG reserves will probably have been recovered. However, the industry is looking beyond this point. The state oil company, SOCAR, is now building a sixth-generation semisubmersible drilling rig that will conduct exploration and appraisal drilling in more difficult geological conditions. Who knows, maybe in the sunset of ACG, a new era will begin with the development of even deeper deposits in this block?

To read Vugar Bayramov's – founder and chairman of the Center for Economic and Social Development – thoughts on how Azerbaijan has changed visit: bp.com/azerbaijananniversary

AZERBAIJAN

Gross domestic product (GDP)
1994 $3.31 billion
2013 $73.56 billion

GDP per capita (current US$)
1994 = $436
2013 = $7,812

Exports of goods and services as a % of GDP
1994 – 25%
2013 – 49%

Energy production (million tonnes of oil equivalent)
1994 – 14.95
2011 – 59.95

1,768km

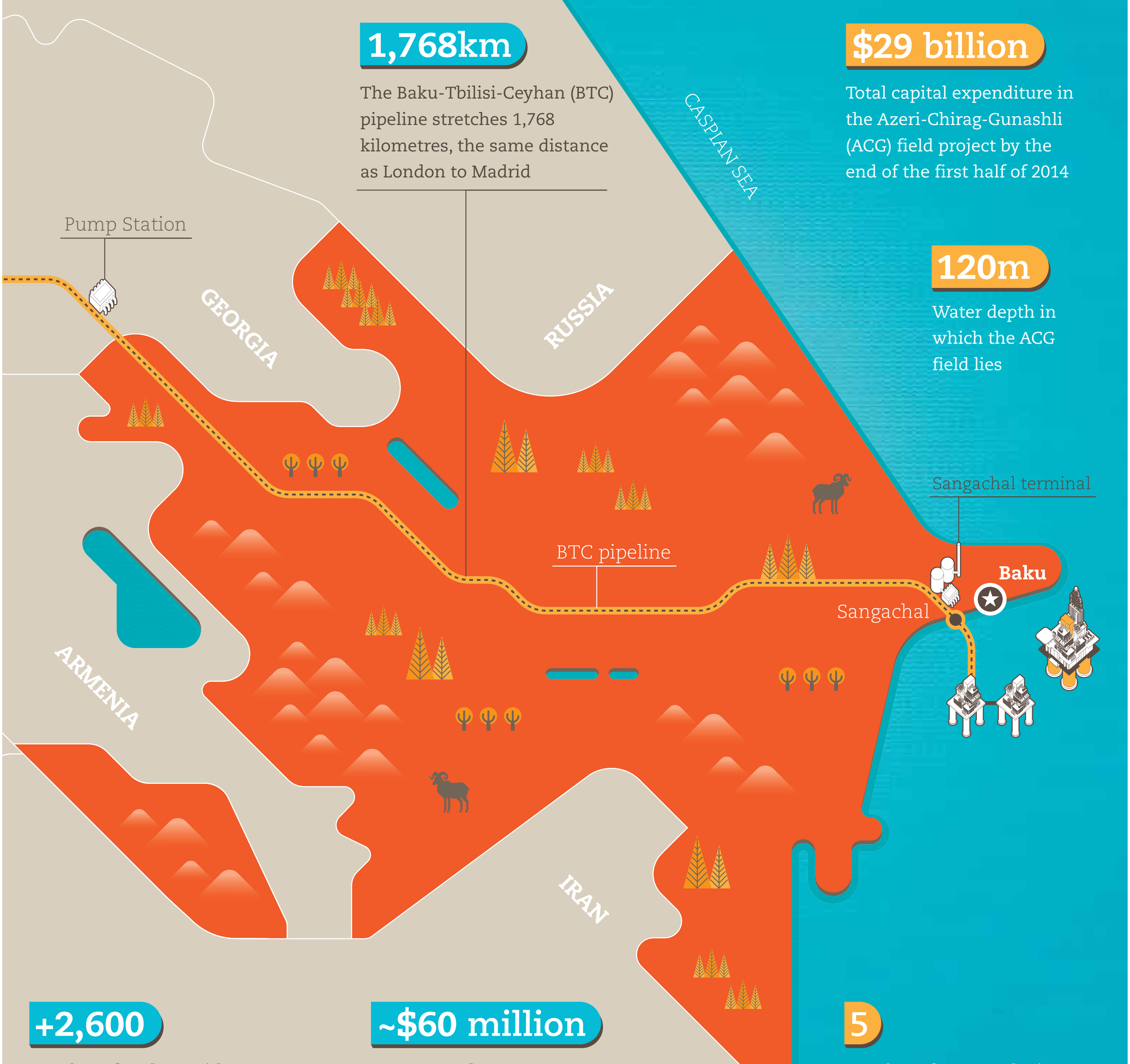
The Baku-Tbilisi-Ceyhan (BTC) pipeline stretches 1,768 kilometres, the same distance as London to Madrid

$29 billion

Total capital expenditure in the Azeri-Chirag-Gunashli (ACG) field project by the end of the first half of 2014

120m

Water depth in which the ACG field lies



+2,600

Number of tankers with ACG crude that have been loaded from Ceyhan terminal in Turkey

~$60 million

Amount BP has spent on sustainable development projects in Azerbaijan since the start of the ACG project in 1994

5

Number of new producing platforms built as part of the ACG project. One platform – Chirag 1 – was also renovated


BP
SEA QUEST
BP

GOLDEN YEARS

In September 1964, BP was awarded the first UK North Sea licences. A year later, it discovered the West Sole gas field, triggering a revolution that would change the energy landscape of northern Europe.

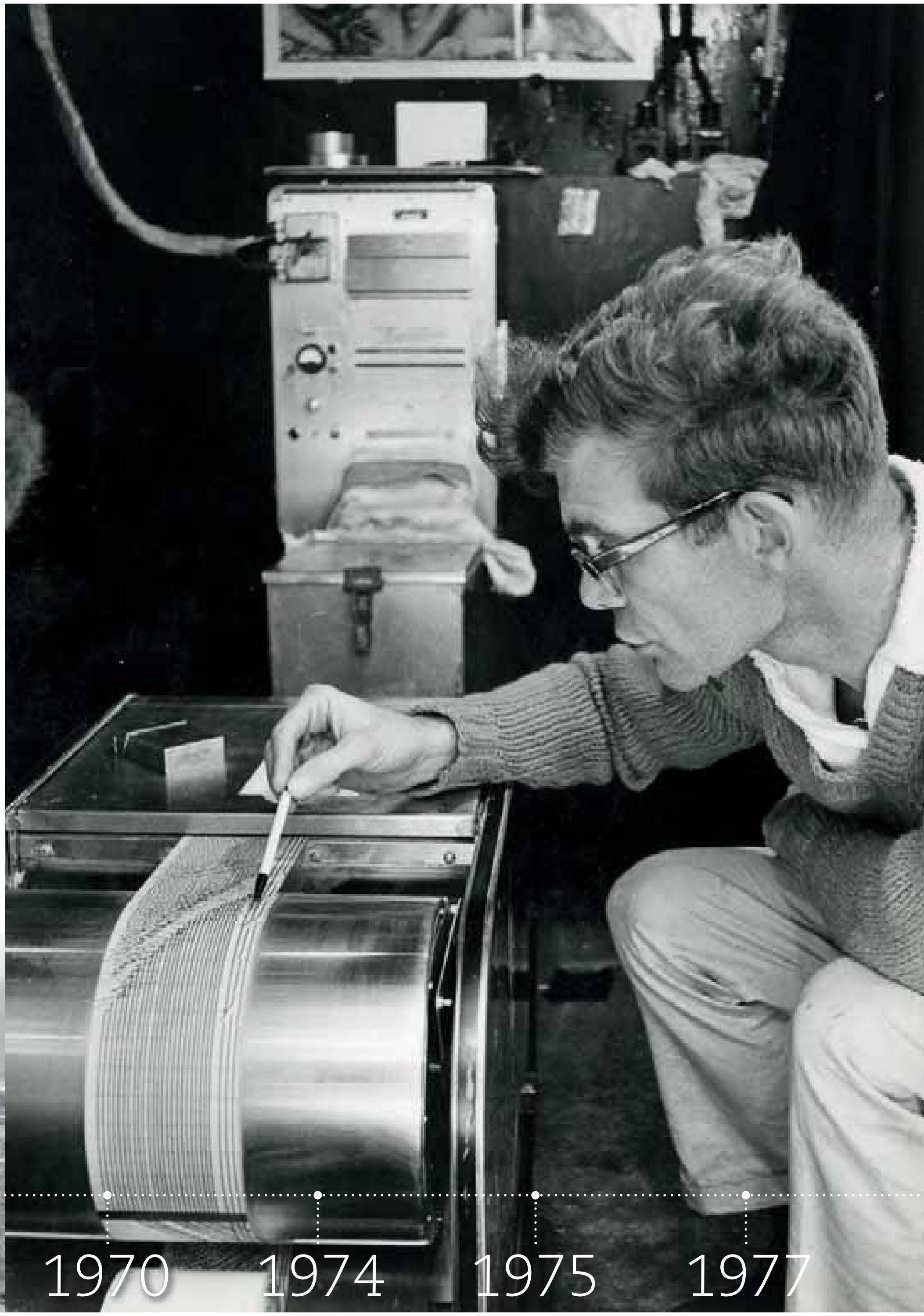
Other discoveries – gas and, later, oil – followed and in 1970, BP discovered what would become one of the jewels in its crown: the Forties field. With its 2.5 billion barrels of recoverable oil reserves, Forties would go on to supply one-fifth of all of the UK's oil demand at its peak. First oil was delivered via the new Forties Pipeline System (FPS). Still operated by BP today, the FPS now carries around 40% of the UK's oil and gas.

BP and its heritage companies would go on to start up more than 15 fields throughout the 1970s and 1980s, eventually becoming responsible for more than a quarter of all the oil produced in the UK North Sea. BP also has a significant presence in the Norwegian North Sea.

Fifty years since those first licences was awarded, BP has produced more than 5 billion barrels of oil and gas equivalent from both the UK and Norwegian North Sea and today employs almost 4,000 people in the region. Over the next five years, BP and its partners will invest more than £7 billion in the region as it continues to discover new sources of oil and gas while developing new fields and extending the life of its existing fields. *BP Magazine* looks at some of BP's North Sea milestones.

TECHNICAL FRONTIER

Technology has played a key role in the North Sea since the very early days. Indeed, in the 1960s, BP was one of the first to use two-dimensional seismic imaging to map the region's relatively shallow reservoirs. Today, four-dimensional seismic allows geologists to see how a reservoir reacts over time. BP also operates one of only two enhanced oil recovery (EOR) programmes in the UK waters at its Magnus field. In Norway, the Ula field relies entirely on EOR technologies to continue producing. BP is currently incorporating EOR technologies into the new Clair Ridge and Quad204 developments. Clair Ridge will be the site of the world's first offshore full-field deployment of *LoSal®* EOR.



1965
BP discovers first commercial gas field – West Sole. It is still producing today

1969
BP opens its first office in Aberdeen, employing around 15 people

1970
BP discovers the Forties field. At its peak, the field meets a fifth of UK oil demand

1974
BP opens an exploration office in Stavanger, Norway

1975
BP brings first oil from Forties ashore to the UK

Amoco discovers the Valhall field in the Norwegian North Sea

1977
BP discovers the Clair field. However, technical challenges prevent development until 2001

BP discovers the Rhum gas field

CHALLENGING ENVIRONMENT

The conditions in the North Sea remain some of the most challenging the organisation faces, with winter storms capable of generating winds of more than 250 kilometres (155 miles) per hour and 25-metre-high (80 feet) waves.

1978

Oil reaches BP's new Sullom Voe terminal in Shetland

1982

Production starts at the Valhall field

1983

The UK's largest, deepest and most northerly platform – Magnus – begins production

1986

Production starts at the Ula field in the Norwegian North Sea. Today, it has tie-backs to three subsea fields (Blane, Oselvar and Tambar)

1990

BP expands the Forties Pipeline System to increase its capacity for providing transportation to other companies

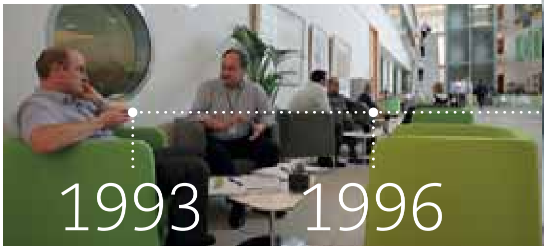
The Hod field in the Norwegian North Sea starts production

EARLY TRAGEDY

Sea Gem was BP's first offshore drilling platform and its crew was the first to discover natural gas in the UK North Sea – enough to supply the fuel needs for around 300,000 people. However, on 27 December 1965, part of the structure collapsed while being transported to another site three kilometres (1.8 miles) away, with the deaths of 13 of the 32 men onboard. New safety regulations were brought in as a consequence of the accident, including the provision for a standby boat and legal requirement of an offshore installation manager for every platform.

FUTURE PROSPECTS

BP is hard at work on a number of new developments in the North Sea, such as Kinnoull – discovered in 2008 and due onstream in 2014 – and Clair Ridge, a £4.5 billion investment in the second phase of the Clair field, expected to begin production in 2016. It is also working on projects designed to extend the life of existing fields, such the redevelopment of the Schiehallion and Loyal fields. Known as Quad204, the £3 billion project is expected onstream in late-2016 and includes a brand new floating production, storage and offloading (FPSO) vessel and a major upgrade of the subsea infrastructure. To date, BP has awarded contracts with a value of more than £1 billion UK-based companies as part of this project.



1993

Gas production begins from the Bruce field

1996

Tony Blair – future UK Prime Minister – inaugurates the Andrew field

1997

The Foinaven field starts up, the first production from the West of Shetland region

1998

Production begins at the ETAP development, which sees the joint development of nine fields that could not stand alone economically

Production from the Schiehallion field begins, via the world's largest purpose-built FPSO

2002

Enhanced oil recovery begins at Magnus

2003

BP sells a number of North Sea assets, including Forties, Montrose, Arbroath, Bacton terminal and a number of associated southern North Sea fields

IN NUMBERS

+40%

The amount of UK oil and gas that is transported by BP's Forties Pipeline System today

46%

The amount of reserves at the Ula field that have been produced in 25 years of operations. The goal is to reach 70%

8 billion

Estimated barrels of oil in place at the Clair field, making it one of the largest fields in Europe

10 billion

Number of cubic feet of gas that have been re-injected into the Magnus field, resulting in the production of approximately 8,000 additional barrels of oil

£35 billion

Amount BP had invested in the North Sea by 2012

BP IN NORWAY

BP has had a presence in Norway for almost a century, establishing a downstream business in 1920. However, it wasn't until 1974 that it opened up an exploration office in the coastal town of Stavanger and bought a share of what was to become the Ula field. That same year, Amoco – a BP heritage company – discovered the Hod field. BP made several discoveries, including the Tambar and Gyda fields. In 1998, the same year as its merger with BP, Amoco discovered the Skarv field, located farther north in the Norwegian Sea. Skarv was successfully brought onstream by BP in December 2012.

2005

Oil production from Clair begins

Gas production from Rhum begins

2008

BP discovers two new fields – southwest Foinaven and Kinnoull

BP begins decommissioning work on Northwest Hutton

2011

BP gives the go-ahead to develop Kinnoull and Clair Ridge, and redevelop the Schiehallion and Loyal fields (the Quad204 redevelopment)

BP discovers oil in the southwest area of the Clair reservoir

2013

Valhall's new production and hotel platform starts up in January, extending the life of the field by a further 40 years. The redevelopment project includes a pioneering power-from-shore system

2014

The Kinnoull reservoir, developed as part of a wider rejuvenation of the Andrew area, is tied back to BP's Andrew platform, enabling production there to be extended by a further decade

Illustration> Stuart Patience

LEARNING CURVE

Question: What's the one thing you would change about the way in which STEM subjects are taught in school?

IAN BLATCHFORD

DIRECTOR OF SCIENCE MUSEUM GROUP, LONDON

"More students (and teachers) conducting their own research. Too many young people fail to see the relevance between what is learned in school and the world around them, particularly in mathematics. They struggle to apply what the workbook says to new situations, and subjects are often taught in silos, without cross-curricular reference. So, it's not surprising that research shows that, while many students enjoy science, they do not see themselves as scientists. It is maddening. Investigative work driven from students' questions would help them to build connections to the real world and their interests, provide opportunities to transfer knowledge and procedures to new situations, integrate mathematics into science, and help young people to see themselves as scientists. This is something that the Science Museum's 'Citizen Mathematics' project (launching in 2016) aims to achieve. We know that there's a need for imaginative thinkers in the field of science, engineering and mathematics. Supporting young people to form meaningful questions and identify effective ways to answer these now will help us to build the next generation of thinkers."

PROFESSOR LOUISE ARCHER

PROFESSOR OF SOCIOLOGY OF EDUCATION, KING'S COLLEGE LONDON

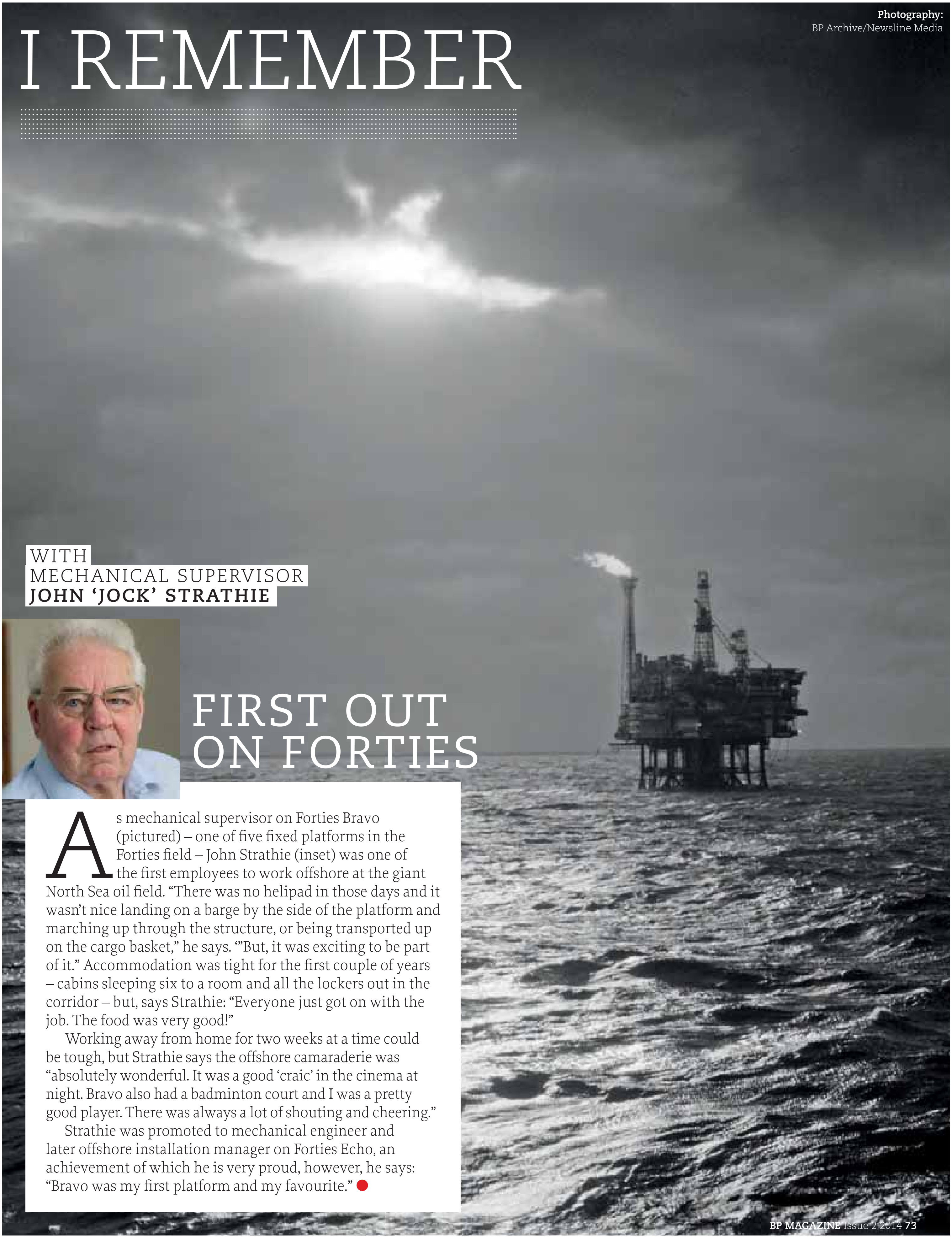
"It is hard to choose just one thing! But based on our ASPIRES research study findings [www.kcl.ac.uk/aspires], which included surveys conducted with more than 18,000 young people aged 10-14, the one thing I would change would be to make STEM subjects less 'special'. To do this, I would stop the different organisation of science at GCSE-level into 'double' and 'triple' award routes – we don't do this for any other subjects, so why science? I would also replace A-levels with a Baccalaureate-style system. England is out of step with much of the rest of the world in this respect, and our current set-up helps to perpetuate a myth that the arts and sciences are separate and different. Why would I do all this? Because I believe it would help to both increase and broaden participation in STEM. Currently, only a small minority of young people see post-16 science as 'for me' – to substantively change this, we need to rethink the system."

RACHEL FORT

GRADUATE CHEMIST, BP

"Making STEM subjects more relevant and applicable to the real world through field trips and experiments on everyday items, instead of just being lectured at in classrooms. I think that would be the main thing. You need to learn the theories, equations and background behind the subjects, but seeing them applied in the world around you is what really brings them to life and makes them interesting. We did do experiments at school, but they were always to prove a single point from the curriculum and were detached from life outside the classroom. I remember setting fire to magnesium in chemistry, which was great fun, but it was missing that link to how it can be applied in the real world – going to a fireworks display would definitely have brought it home! The STEM subjects affect everything in the world around us and we interact with them all on a daily basis, but you're not always aware of that from what you're taught at school."

To see Professor Louise Archer talk more about inspiring STEM students visit bp.com/stem



Photography: BP Archive/Newsline Media

I REMEMBER

WITH
MECHANICAL SUPERVISOR
JOHN 'JOCK' STRATHIE

FIRST OUT ON FORTIES

As mechanical supervisor on Forties Bravo (pictured) – one of five fixed platforms in the Forties field – John Strathie (inset) was one of the first employees to work offshore at the giant North Sea oil field. "There was no helipad in those days and it wasn't nice landing on a barge by the side of the platform and marching up through the structure, or being transported up on the cargo basket," he says. '"But, it was exciting to be part of it." Accommodation was tight for the first couple of years – cabins sleeping six to a room and all the lockers out in the corridor – but, says Strathie: "Everyone just got on with the job. The food was very good!"

Working away from home for two weeks at a time could be tough, but Strathie says the offshore camaraderie was "absolutely wonderful. It was a good 'craic' in the cinema at night. Bravo also had a badminton court and I was a pretty good player. There was always a lot of shouting and cheering."

Strathie was promoted to mechanical engineer and later offshore installation manager on Forties Echo, an achievement of which he is very proud, however, he says: "Bravo was my first platform and my favourite."

Ming dynasty shines again

A new BP-supported exhibition has opened at the British Museum, shedding new light on one of China's greatest empires and featuring many artefacts that, until now, have never left the country.

Report> Lisa Davison **Photography>** Jon Challicom/Giles Barnard/British Museum

Precious objects: set of paintings from a monastery in Shigatse. Anoymous. Gouache on cotton. circa 1403-35, probably circa 1425. Tashi Lhunpo Monastery (the main seat of the Panchen Lamas of Gelugpa Sect), Shigatse (Xigazê) in Tsang, Tibet (Xizang). Trustees of the British Museum. Standing Bodhisattva, gilded bronze, Yongle mark and period, 1403-1424. Musée Cernaschi, Paris. Śākyamuni, the historical Buddha. Gilded bronze, Yongle mark and period, 1403-1424, which Qianlong (1736-1795) mandorla and stand. Nanjing or Beijing. Trustees of the British Museum.

If you're thinking of establishing a new ruling dynasty, it's worth taking some time to consider the name. Chinese peasant-turned-army-general Zhu Yuanzhang must have known this better than anyone. Having ousted China's Mongol rulers and taken the capital city of Nanjing, he declared himself the Hongwu emperor – meaning 'vast military might'. A statement of intent if ever there was one. But, it is the dynastic name he chose that has stood the test of time: Ming – meaning brightness. It was a glow that its emperors would bask in for 300 years.

After years of war, flooding, famine and disease, the prospect of a little brightness must have appealed to the 85-million-strong Chinese population, and the early days of the dynasty were to become something of a golden age: its fleet travelled to India, Japan, southeast Asia, the Middle East and the east coast of Africa, trading silk for ostriches (among other things); its second emperor built a vast palace in the new capital of Beijing that remains a tourist attraction today; and its artists produced some of the most beautiful porcelain ever made.

Staggering collection

And yet, typical Western understanding of this Chinese empire tends to have been formed by our knowledge of the Qing dynasty, which followed the Ming era, largely because it was during this time that Europe and China first encountered each other.

A new exhibition at the British Museum is hoping to change all that. Five years in the making, the BP exhibition *Ming: 50 years that changed China* has brought together a staggering collection of porcelain, jewellery, calligraphy, painting, sculpture, books, costume and furniture from the period 1400-50, during the reign of four Ming emperors. Ten Chinese institutions and 21 international lenders have provided artefacts that would once have adorned the imperial court in Beijing or were found in three regional princely tombs in Sichuan, Shandong and Hubei. Some of the pieces were only excavated in the past decade. Many of them have never left China. Most are unlikely to ever again.

"This really is a one-off show," says Jessica Harrison-Hall, the British Museum's curator of Chinese ceramics and one of the exhibition's three curators.

Sophisticated society

The decision to focus on a 50-year period in China's history is something of a departure – in the past, Western museums have tended to try and take on its vastness. "Most histories of China are written from a 'China awakes with the arrival of Europeans in the 16th century', but that's a nonsense," says Harrison-Hall. "China at this point is incredibly sophisticated, it is one of the most literate societies on the planet, producing some of the most beautiful objects we've ever seen. We wanted to do something different, to look in detail at what China was like long before the vast majority of Europeans turned up."

Like England's Elizabethan era 150 years later, the Ming golden age was one of relative stability, trade and contact. It was also a period of great social and cultural change: Beijing became the permanent capital, foreign diplomats were a regular sight, and the Yongle (meaning perpetual happiness) emperor built one of »

THE BP CONNECTION

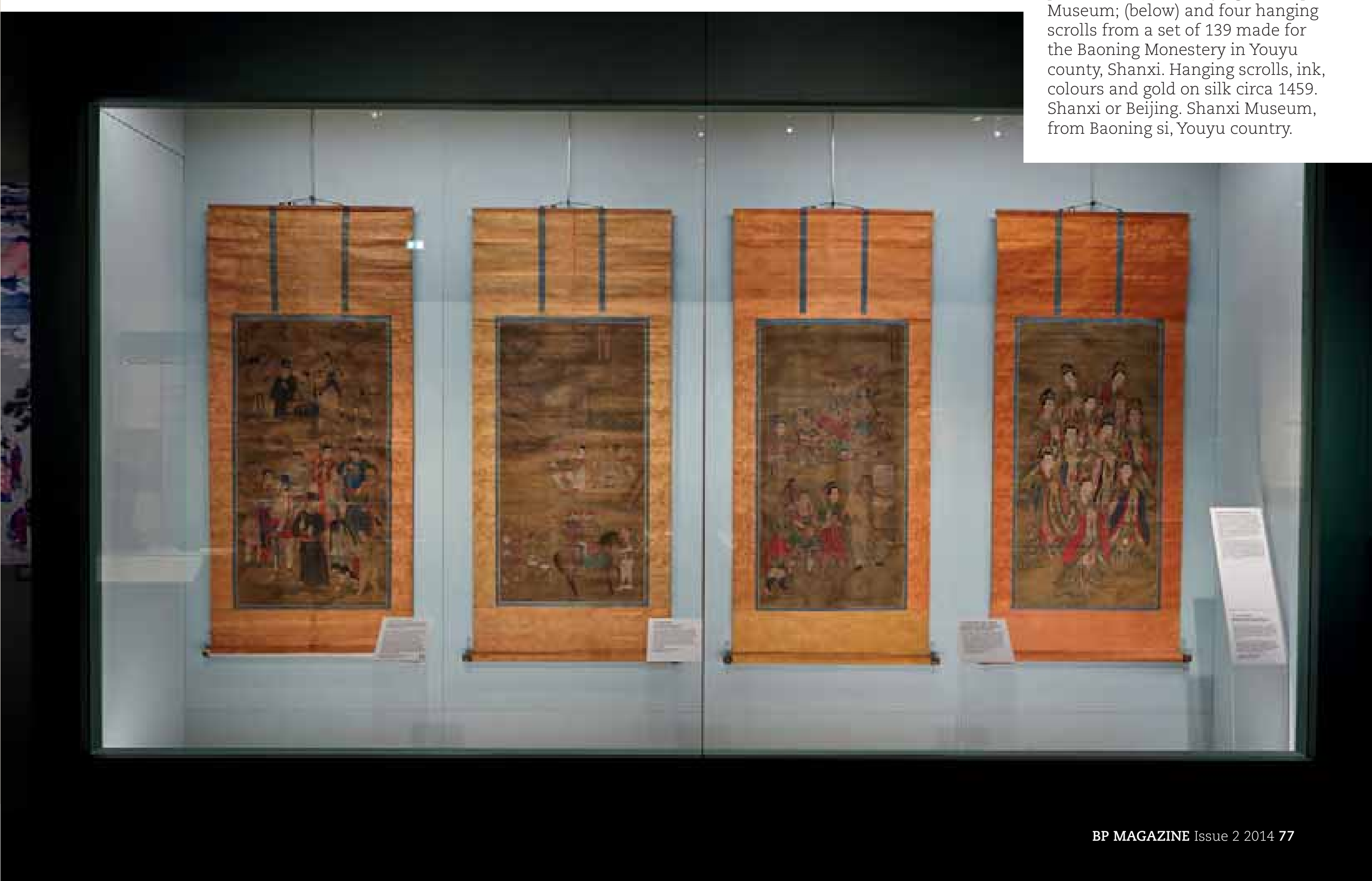
The BP exhibition *Ming: 50 years that changed China* is the second major exhibition that BP has supported at the British Museum this year. The first – *Vikings: life and legend* – was a runaway hit, with almost 300,000 visitors during its four-month run.

"We are extremely grateful for BP's support," says Jessica Harrison-Hall, the British Museum's curator of Chinese ceramics. "These vast projects just couldn't happen without it. You could have the intellectual understanding and perhaps a book, but you couldn't physically bring all these objects together."

But, it's not just the objects that BP's support helps to bring over. The British Museum puts a lot of work into offering visitors additional events, such as films and lectures, to help place the exhibition in greater context. During this exhibition's run, the British Museum is hosting a group of musicians who are the 27th generation from a temple in Beijing, along with displays from Chinese acrobats, opportunities to learn about food, and debates on Ming versus the European Renaissance.

Including the British Museum, BP has four long-standing arts and culture partnerships in the UK with Tate Britain, the National Portrait Gallery and the Royal Opera House. In 2012, it began a new partnership with the Royal Shakespeare Company.

"BP's support for the arts is part of the organisation's wider contribution to UK society, helping to connect audiences with world-class art, inspire creativity and to make a difference in people's lives," says Des Violaris, BP's UK arts and culture director. "Over the past 35 years, some 50 million people have experienced BP's arts and culture programme."



Royal connections: (opposite) crown of leather, woven bamboo, lacquer and semiprecious stones, circa 1380. Excavated from the tomb of Zhu Tan (1370–1389), Prince Huang of Lu at Yanzhou, Shandong province. Image courtesy of Shandong Museum; (above) three tiles from the Great Monastery of Filial Gratitude. Earthenware, moulded and sculpted with lead-fluxed glazes. Yongle to Xuande periods, 1412-31. Nanjing Municiple Museum; (below) and four hanging scrolls from a set of 139 made for the Baoning Monestery in Youyu county, Shanxi. Hanging scrolls, ink, colours and gold on silk circa 1459. Shanxi or Beijing. Shanxi Museum, from Baoning si, Youyu country.

Princely robes: (left) Ming prince's 'dragon robe'. Silk, circa 1389. Excavated from the tomb of Zhu Tan (1370-1389), Prince Huang of Lu at Yanzhou, Shandong province. © Shandong Museum; (below) and set of saddle plates. Iron, gold foil, lapis lazuli, blue and green turquoise. circa 1400, Nanjing, Beijing or Tibet. Metropolitan Museum of Art, New York.

China's most enduring emblems – the Forbidden City.

"It is a wonderful moment in China's history, sandwiched between two quite violent episodes – civil war and the temporary kidnapping in 1449 of the Zhengtong [right governance] emperor by the Mongols," says Harrison-Hall, whose fascination with China from an early age led her to study Chinese and fine art at university.

It was also a moment of unprecedented contact with the wider world. While Hongwu had imposed restrictions on foreign trade, his successor, the Yongle emperor, sent court-eunuch-turned-admiral Zheng He out on a series of seven expeditionary voyages, some 90 years before Christopher Columbus discovered America and almost two centuries before Sir Francis Drake circumnavigated the globe. In exchange for gold, silk and blue and white porcelain – arguably the world's first global brand – Zheng He brought back ivory from Africa, the folding fan from Korea and Japan, and ceramic techniques from the Middle East. He also brought ostriches, zebras, camels and giraffe – particularly prized in China because they were thought to be 'qilin' – a mythical hooved chimerical creature and proof of favour from heaven upon the Ming emperors.

"We wanted to look at not just what China put out into the world, but what happened as a result of its engagement with other communities, what changes there were within China," says Harrison-Hall. "It's a time when great imperial encyclopaedias are being written, you have remarkable religious tolerance – one of the pieces we're showing is a Koran from 1401."

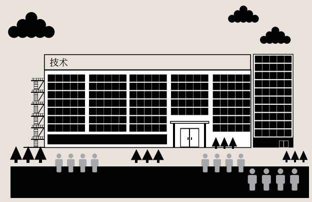
Military culture was particularly prized at this time – not surprising given that the Mongol threat was never very far away. "In this early Ming period, you have this swaggering, macho culture, where the men wear lots of lead robes to look beefy," says Harrison-Hall. "It's quite different from the willowy silhouette of the Chinese scholar that we are more familiar with in later Chinese paintings."

But, when you're ruling an area roughly the size of modern Europe, you need a little more than a good-looking lead waistcoat. So, the emperor positioned 24 of his 26 sons all across China, acting like a fence along its borders and rivers. These princes were given palaces and costumes that echoed those of the emperor, albeit a little more modestly. "There was extraordinary continuity with the imperial court back in Beijing," says Harrison-Hall. "The princes had their own smaller armies and carriages but to the people, they would have looked like the presence of an emperor. We have a silk robe embroidered with dragons that belonged to one of these princes. It's faded yellow now, but would have been bright at the time. It's one of the most evocative pieces in the exhibition." »

BP IN CHINA

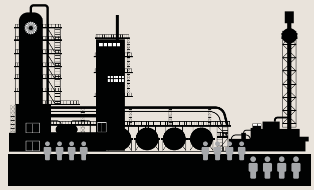
BP has operated in China since the 1970s and today is one of the leading foreign investors in the country's oil and gas industry. Its activities include petrochemicals manufacturing, aviation fuel supply, oil product and lubricant sales, a gas terminal, pipelines and chemicals technology licensing. It has established partnerships with all three national oil companies, both in China and abroad, and is the only foreign partner in China's first liquefied natural gas terminal. Technology plays an important role in BP's relationship with China. It has collaborated for more than 10 years with Tsinghua University and the Chinese Academy of Sciences on research and development and has a long history of supporting education and environmental initiatives in the region. The BP Foundation has provided financial support following health crises, such as the SARS outbreak in 2003, and natural disasters, such as the 2005 tsunami and several catastrophic earthquakes.

BP China in numbers



3

Number of technology centres in China

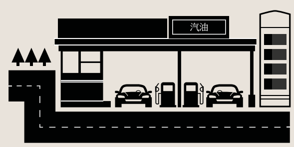


1,400

Number of direct employees

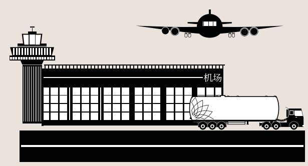
$4.4 billion

BP's investment in China up to first quarter 2014



~850

Approximate number of dual-branded retail stations



18

Number of airports supplied by Air BP

No Ming exhibition would be complete without blue and white porcelain (see opposite page). "The funny thing about porcelain is that it's so fragile and yet it's almost impossible to destroy it utterly, so you end up with shards of it washing up on beaches all over the world, from India to England," says Harrison-Hall.

But, while porcelain features heavily, the exhibition aims to tell a broader story. As well as trade and diplomacy, the artefacts shine a light on life inside the imperial court, the military, culture, and beliefs in the early years of one of China's most famous dynasties. Scroll paintings that once hung in palaces and temples depict both courtly and everyday life. Some are as long as 11 metres (36 feet) and are so delicate that they can only be shown under lights for three months every 10 years. Costume features heavily, with intricately decorated crowns and robes. A cloisonné (an ancient technique for decorating metalwork objects) jar has become the poster child for the exhibition and is an example of how other ceramic techniques were brought back into China.

The way in which China's art blends both native and foreign techniques in this period is fascinating, says Harrison-Hall. "It's a mixture of their own techniques and appropriation. For example, red carved lacquer is a Chinese-developed art that is not affected by contact with other places, although other countries, such as Japan, do create their own in response to contact with China. The original idea for blue and white porcelain would have been brought from the Middle East, but by the time of Ming it is intrinsically a Chinese technique."

The exhibition is underpinned by a three-year research project supported by the Arts and Humanities Research Council, which has enabled Harrison-Hall and her colleagues to immerse themselves in this period of history. It's also thrown up a few surprises. "When we started the project," she says, "we always thought that the Beijing-based Mandarin dialect was widely used in this period, but as we have got to know more linguistic scholars, we've discovered quite a debate. Some believe that Mandarin was picked up later and, in fact, the Nanjing-based Wu dialect was the main language. The great thing is that this exhibition is right in the middle of the research project, so we have another year to deepen our knowledge still further."

Any major exhibition takes years to come together and relies heavily on support from museums and private collectors alike. But *Ming: 50 years that changed China* is particularly special, given how unlikely it is that many of the objects now on display will ever be seen outside China again. Harrison-Hall is in no doubt of the responsibility that the British Museum holds. "The Chinese museum directors have been incredibly generous, partly because they hope this exhibition will inspire people to visit China. It is our responsibility to make sure that as many people visit this exhibition as possible."

To learn about Jessica Harrison-Hall's favourite pieces in the exhibition, visit: bp.com/ming
The BP exhibition Ming: 50 years that changed China *is on at the British Museum until 5 January 2015*

Court life: (below left) detail from 'Amusements in the Xuande emperor's palace' showing the emperor playing an arrow-throwing game. Handscroll, ink and colours on silk. Xuande period, 1426–1435. Anonymous. The Palace Museum, Beijing. © The Palace Museum; (left) sword and scabbard with inscription. Iron, gold, silver, wood and leather. Yongle era about 1420, Beijing. © Royal Armouries; (right) and large porcelain flask painted with underglaze blue decoration. Made in Jingdezhen, China. Ming dynasty, Xuande mark and period, 1426–1435. © The Trustees of the British Museum.

THE POWER OF PORCELAIN

The phrase 'priceless Ming vase' is ubiquitous for good reason. Although less ornate than those produced during the Qing dynasty, its manufacture was strictly controlled, to meet the highest standards. Today, vases and cups are some of the most sought-after items at auction. In July 2014, Chinese art collector Liu Yiqian was lambasted for drinking out of a rare 'chicken' cup from the later 1465-1487 Ming period. He bought the cup – one of only 17 in the world and described as the 'Holy Grail' of Chinese art – for an eye-watering $36 million.

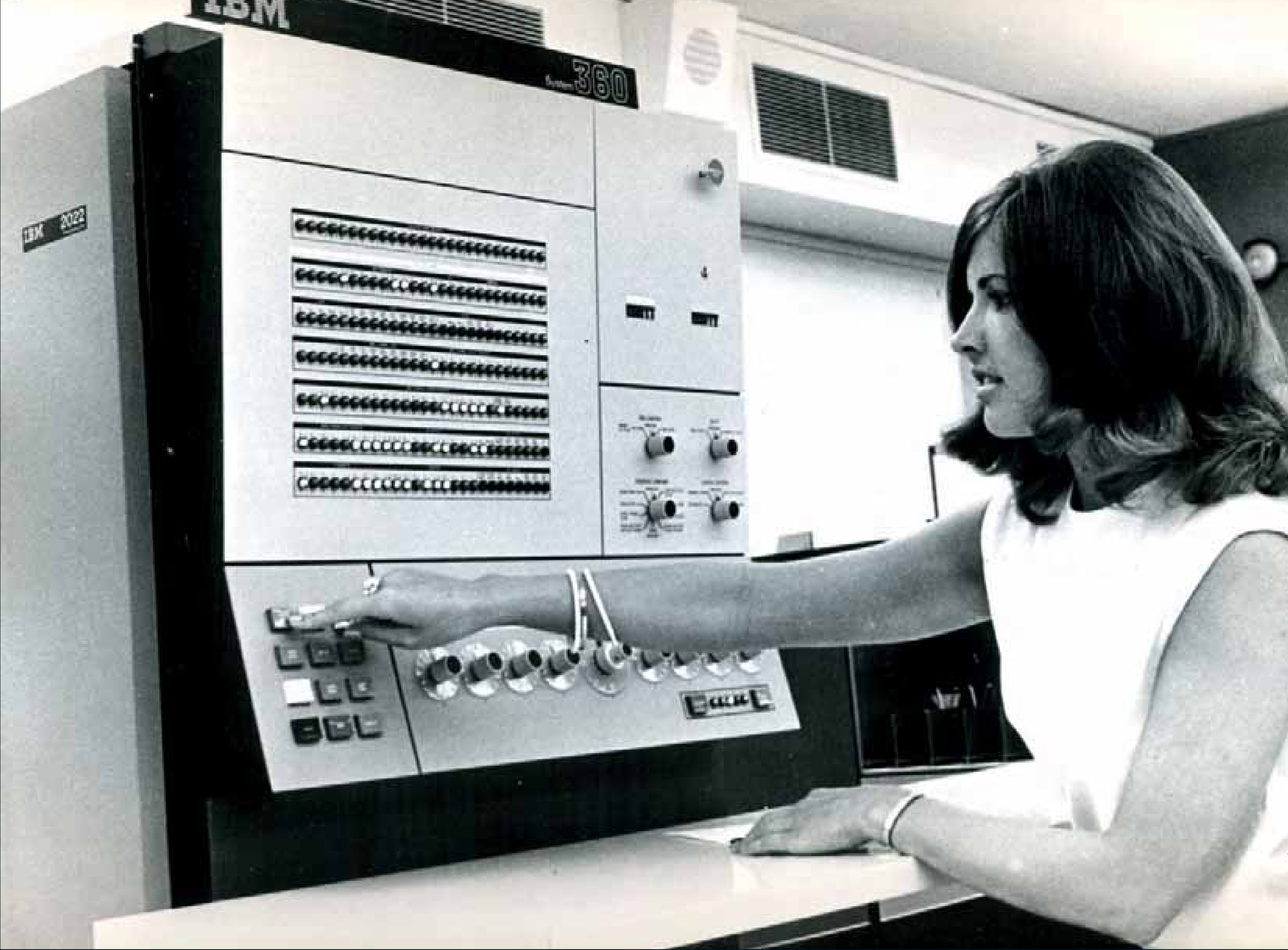
Europe's love affair with porcelain was almost immediate. One of the paintings in the BP exhibition *Ming: 50 years that changed China* demonstrates this beautifully. Created in 1462, Andrea Mantegna's *The Adoration of the Magi* features a small blue and white porcelain cup filled with gold coins right at its centre. "This is still 30 years before Columbus," says Jessica Harrison-Hall, the British Museum's Chinese ceramics curator.

And, it is a piece of porcelain (left) that is helping the British Museum to spread the Ming message across the UK. With BP's support, this early Ming vase is currently halfway through a tour of four venues in Glasgow, Sheffield, Bristol and Basingstoke, giving local communities an opportunity that they might not ordinarily have to connect with art. Each local museum is also using the vase to highlight their own Chinese collections. Decorated with a lotus scroll in cobalt blue and featuring the reign mark of the Xuande emperor (1426-35), the 50-centimetre-high (20-inch) Ming vase – the largest in the British Museum's collection – is typical of the skill and quality of imperial production during the early 15th century.

Photography> BP Archive

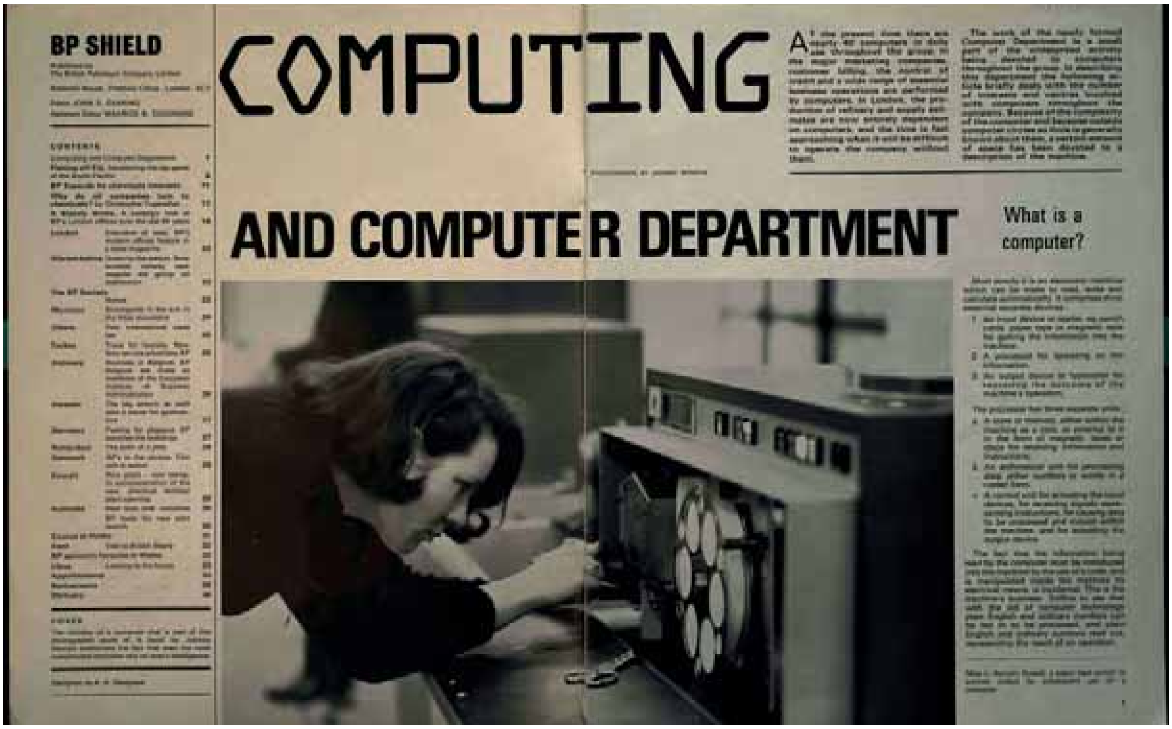
BYTE-SIZED HISTORY

Back in 1967, *BP Shield* magazine ran an article proudly announcing that there were almost 40 computers in use across the organisation. It added, rather prophetically: "The time is fast approaching when it will be difficult to operate the company without them." Since then, computer size, speed and power have changed beyond recognition, as these archive images show.



Above: computers in use at BP Oil. This model is an IBM 360 and the photograph is dated between 1967-69. **Left:** a computer at BP's former London headquarters in Britannic House, 1960-66. It was policy for small- and medium-sized machines to use British-made equipment in the UK, so this model is either the ICT 1301 or the ICT 1905. **Below:** historical image of computers used in BP Oil. This model is the IBM 1440, dated sometime between 1967-69.

Left: programming with computers. Mr Fletcher and Mr Ackland of S&D, with Mr Wheatley, of production control branch, refineries department, and Miss A Taylor, a computer operator. **Below:** another example of the computers used in BP Oil, this time the model is an IBM 705 electronic data processing machine. Electronic data processing was one of the key uses of computers at this time. It was used for collection and storing of accounts data, including payrolls and invoices, and also processing information on stocks, stores, staff and sales.



BP SHIELD

COMPUTING

AND COMPUTER DEPARTMENT

What is a computer?

Top and middle: article from *BP Shield* magazine in April 1967. The piece dedicated a number of pages to computers because “so little is generally known about them.” The article included sections on ‘what is a computer?’, a who’s who of the programming department, ‘special features of a computer’ and ‘what can computers be used for?’ **Left:** historical images of computers used in BP Oil. This model is the IBM 370 and the photograph is dated between 1967-69.

Photography> BP Archive

A century at sea

Next year marks the centenary of BP Shipping and the next edition of *BP Magazine* will feature a special report on the 100-year-old business. Pictured here is BP's 16,000-ton tanker, *British Vigilance* in the frozen Baltic at Gavle, 190 kilometres (120 miles) north of Stockholm, Sweden. An ice-breaker had to clear a path into the port for the tanker before she could unload her cargo of gas oil, in a temperature of -36º Centigrade (-4º Fahrenheit).

The next edition of *BP Magazine* will be out in April 2015.

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