Lloyd's Register Energy

Working together for a safer world

The Lloyd's Register Energy Oil And Gas Technology Radar

An assessment of the sector's innovation trends and drivers

2014

Foreword

Technology and innovation have a huge impact on shaping the development of any industry within the global economy. This is no less true of the oil and gas sector, which has been at the leading edge of technical innovation since the use of hydrocarbons as a major source of energy began in the 1800s.

Understanding the development and impact that key technological innovations can bring is fundamental for oil and gas organisations, who are operating in one of the most advanced sectors in the world.

The 2014 Oil and Gas Technology Radar takes an impartial viewpoint on the key technological developments touching the sector, how these developments are starting to address some key challenges, and the timeline to adoption.

Our research illustrates that the drive for access to new reserves must not lead to a compromised state on safety, the challenge of ageing infrastructure cannot be ignored, and the need to collaborate and share knowledge within the sector is intensifying.

Lloyd's Register Energy is committed to working with the sector to advance understanding of the challenges faced, and this report forms an integral part of the insight we are starting to share. Gaining a deeper knowledge of the implications of technology adoption and how we can assist in the application of new innovations is at the core of Lloyd's Register Energy's technology and innovation strategy.

I would like to thank all the participants who have contributed to this year's report, which provides a fascinating insight into how technology and innovation can advance the sector in which we operate.

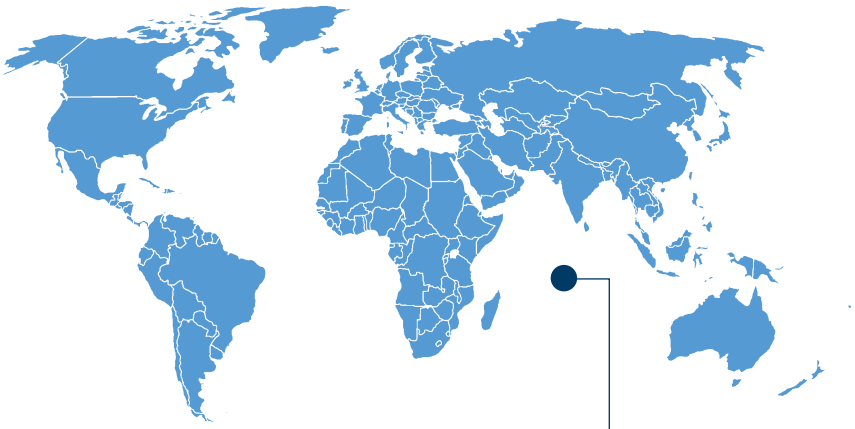
John Wishart
Lloyd's Register Energy

About the research

This Lloyd's Register Energy report, conducted in cooperation with Longitude Research, explores the state of innovation in the global upstream oil and gas sector, and provides an outlook on which technologies might have the biggest impact in the coming decade.

In particular, it seeks to address several key questions, such as which are the principal drivers of and barriers to innovation, how is the innovation process changing, and which organisations are leading the way on this.

To do so, the report draws upon two key inputs:



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The first is a wide-ranging survey of 257 oil and gas executives and professionals, conducted in April and May 2014 by Longitude Research. The respondents range in seniority from operational-level professionals through to board-level executives, representing private and public companies, as well as national oil companies. They come from a variety of roles across the sector, including operations, production, research and development (R&D), strategy and senior management.
The survey is global, with approximately one-third each from respondents based in Asia Pacific, Europe and North America. A full range of company sizes was represented, with just under one-half of respondents coming from companies whose annual revenues were below US$500m, 26% from companies with revenues between US$1bn and US$5bn, and 12% from major multinationals with over US$5bn in revenue.

257

Survey of more than 250 senior industry executives

2

The second research input was in-depth interviews with numerous experts and executives, listed below, who provided insight and context to the survey findings, based on their experience in the field. In addition, we conducted extensive desk research into the topic.

Our thanks are due to all survey respondents and in-depth interviewees (listed, alphabetically by surname) for their time and insights:

Jared Ciferno	**Director** *Strategic Center for Natural Gas and Oil* *National Energy Technology Laboratory (US)*
Ken Cronin	**CEO** *UK Onshore Operations Group*
Duco de Haan	**Senior Vice-President** *Energy Drilling Services* *Lloyd's Register Energy*
Neil Kavanagh	**Chief Science & Technology Manager** *Woodside Energy*
Mohammad Asad Khan	**Senior Investment Manager** *Enertech*
Gregers Kudsk	**Vice-President** *Maersk Drilling*
Tore Land	**CEO and President** *TouGas Oilfield Solutions*
Gal Luft	**Co-Director** *Institute for the Analysis of Global Security*
Claus Myllerup	**Senior Vice-President** *Technology* *Lloyd's Register Energy*
Greg Navarre	**President** *Horton Wison Deepwater*
Patrick O'Brien	**CEO** *Industry Technology Facilitator*
Joanna Pohorski	**Senior Vice-President** *Compliance Services* *Lloyd's Register Energy*
Gerald Schotman	**CTO** *Royal Dutch Shell*
Alberto Tesei	**Former General Manager** *Technology Commercialisation* *GE Oil & Gas*
Tim Walsh	**Senior Vice-President** *Asset Integrity Services* *Lloyd's Register Energy*
John Westwood	**Group Chairman** *Douglas-Westwood*

Executive summary

Hydraulic fracturing, or fracking – with its revolutionary impact on US energy production – may grab the headlines, but it is only a small part of a technological transformation underway within the global oil and gas sector.

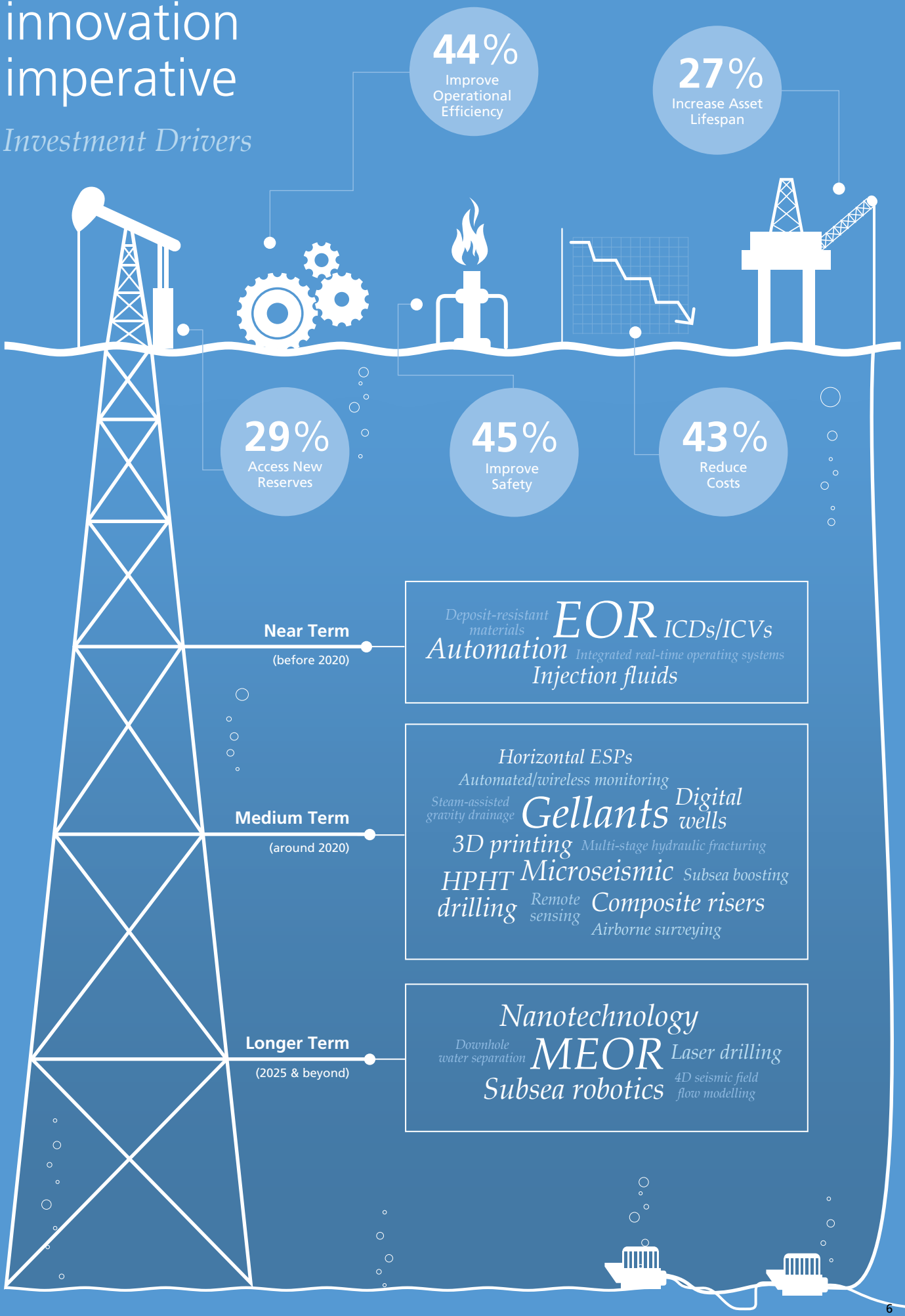
As easily accessible hydrocarbon accumulations become exhausted, innovative companies are increasingly looking to more challenging frontier areas to maintain proven reserves and grow output – all collectively pushing back the "peak oil" date. Bolstering this has been a sustained period of strong oil prices, which has also been a key driver of a broad wave of innovation that has propelled the sector to the forefront of global technological development.

This has been a reversal of a long-term decline, which, in turn, has driven advances in fields as diverse as robotics and automation, data analytics and nanotechnology. Added to this, technological solutions are required to tackle rising costs, ageing infrastructure, tougher regulatory demands, changing energy sources and skills shortages. Given this, today's companies are left with little choice but to innovate.

Any continuing technology-led transformation of a sector with such long-term investment decisions and high capital costs will be unpredictable and complex, and will always be, to a degree, conditional on expected future oil prices. This Lloyd's Register Energy report, drawing on a survey of more than 250 senior industry executives and in-depth interviews with numerous corporate leaders, considers the likely advances ahead, as well as potential changes in the sector's approach to innovation. Its key findings include the following points.

The innovation imperative

Investment Drivers



Innovation in the oil and gas sector is drawing on a critical mass of changes in a range of technologies, rather than any single breakthrough.

According to survey respondents, a variety of technologies looks set to have a high impact in the coming years, including several relating to extending the life of existing assets, such as enhanced oil and gas recovery (EOR). In terms of near-term impact, however, topping the list is automation, including remote and subsea operation, as firms seek to cope with challenging environments. High-pressure, high-temperature (HPHT) drilling and multi-stage fracking are also expected to have a major impact, but are only expected to become fully deployed around 2020, along with many other technologies. Just as important will be the more effective use of data and computing: 58% of those surveyed agree that many future breakthroughs will involve "bits and bytes, rather than physical hardware". Further out, from 2025 and beyond, the most eagerly anticipated innovations relate to subsea robotics.

As in other sectors, many technologies work best in combination, building on existing approaches or tools.

Interviewees note that it is often the innovations that use a variety of new or existing technologies in combination that bring the most dramatic change. With so much technology potentially coming on stream in the decade ahead, tomorrow's leading companies will likely be those that find the most effective ways of combining different technologies, to add to an expanding tool kit.

"58% of those surveyed agree that many future breakthroughs will involve bits and bytes, rather than physical hardware.

Innovation rates are accelerating, putting pressure on companies to keep up.

The vast majority of surveyed executives (73%) believe that the rate of innovation in the sector is increasing. This is not true across the board – slim-hole coiled-tubing drilling, for example, has been in the wings for 15 years and remains stuck there – but many technologies are clearly seeing advances. Accordingly, nobody is safe from the resultant competitive forces: over three-quarters of respondents say that the pressure to innovate has risen over the last two years.

59%
have increased their R&D spend in the past 2 years

68%
intend to increase their R&D budgets in the next 2 years

The sector is rapidly increasing the percentage of resources expended on innovation.

Investment in R&D, after decades of slow decline, began to rise in the middle of the last decade, driven in large part by high prices, as conventional production peaked against a background of strong global demand growth. Now it looks set to accelerate further: in the last two years, 59% of surveyed companies increased their average R&D spending, with almost one in four boosting this by more than 10%. Looking ahead, 68% intend to increase their R&D budgets, with about one-half of the total increasing this by at least 10%. Although part of that rise might be aimed at coping with higher costs, the bulk represents real growth in activity and interest. For example, management time spent on R&D and innovation has risen at 45% of companies in the last three years and 54% of respondents expect it to do so in the next three; only 6% foresee a decline.

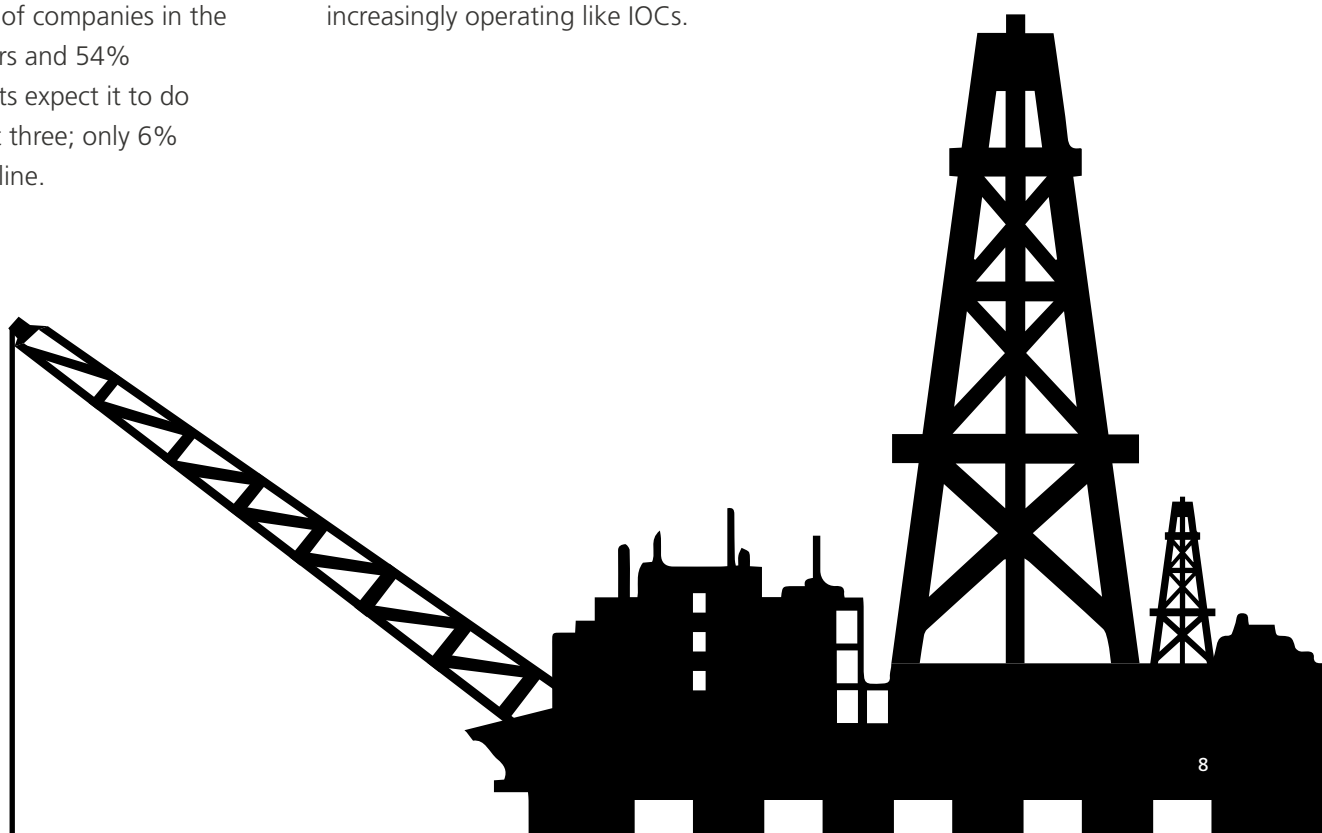
Respondents also expect the sources of innovation to spread, with national oil companies (NOCs) a rising force.

According to those surveyed, international oil companies (IOCs) have introduced by far the most breakthrough technologies in the last two years (cited by 46%), followed by exploration and production companies (31%). The need for IOCs and exploration companies to move into new areas and to exploit more difficult-to-access reserves explains their lead in innovation. In the coming two years, however, respondents expect the advantage of IOCs to diminish, as other companies bring in new technology. In particular, those surveyed see an increasing role for NOCs: two-thirds of those polled expect NOCs to increase their spending on R&D significantly, supporting their drive for greater international growth – and increasingly operating like IOCs.

Breakthrough technologies in last 2 years

International Oil Companies

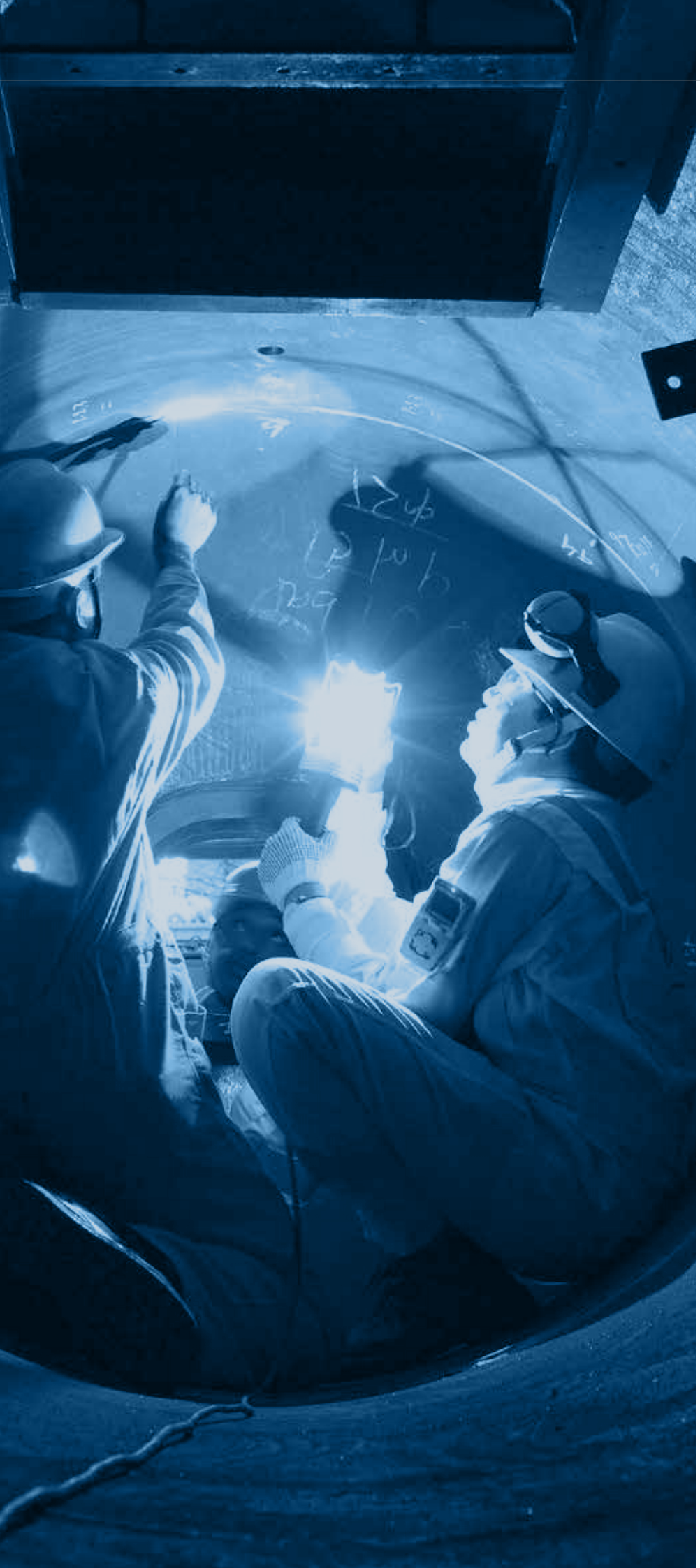
Exploration & Production Companies



Continued risk aversion in the sector, especially in respect of the deployment of new technologies, is a major brake on innovation.

The oil and gas sector, while becoming more eager to adopt change, remains highly conservative. In particular, the new skills required, combined with the risks that new technologies can bring, such as in operational disruption, make the majority of firms reluctant to be the first to adopt substantial innovations.

Instead, 56% of respondents describe themselves as "fast followers", who make changes once others have proved their worth; only one-quarter consider themselves to be "early adopters". Crucially, delayed deployment is a major barrier to progress, slowing the commercialisation of new ideas. In large part, this is due to the difficulties associated with testing in appropriate, real-world conditions. More than one in five (21%) cite this as their biggest headache in dealing with the quality-assurance requirements associated with deployment.



As it becomes more innovative, the sector is still searching for the most effective model to produce new ideas.

Given the link between innovation and competitive advantage, it is no surprise that those surveyed report that, in the past two years, in-house research has been the most widespread approach to developing innovation (cited by 59%). Although this will continue to be the most common model in the coming two years (51%), companies are looking to spread the costs and reduce the risks of development. In particular, specific joint ventures with external partners are set to become more common. This should lead to more rapid change. While firms that rate their innovation as "highly successful" rely on in-house R&D to a similar extent as their less successful peers, they are also far more likely to partner with others in their quest for success.

Part 1
The Energy Technology Radar

In summary >

Technologies that help extend the life of current assets, or improve uptime and efficiency, are getting the greatest prioritisation today.

In the near term, automation and EOR are expected to have the greatest impact on the sector; in the medium term, it is high-pressure, high-temperature drilling and multi-stage hydraulic fracturing; from 2025 and beyond, subsea robotics is seen as most promising.

When it comes to technology innovation, the oil and gas sector is brimming with activity. New technologies and processes are regularly emerging from the R&D labs of large and small players alike. Some technologies have been in development for many years and are likely to have a palpable impact on extraction and production in the relatively short term. Others are still being developed, but are expected to be hitting the mainstream by the end of this decade. Still others hold long-term promise and will only begin to have an impact a decade from now.

This Energy Technology Radar synthesises the oil and gas sector's view of which technologies harbour the greatest potential beneficial impact, and when that technology is likely to go mainstream (see methodology on next page). The time period it considers is split into three: the near term (before 2020); the medium term (around 2020); and the longer term (from 2025 and beyond).

Given the vast range of innovation underway, this study focuses on 25 specific technologies, highlighting five within each of five key categories of development: life extension, uptime and efficiency, supply chain, next resource and risk exposure.

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>
> Greg Navarre,
> President - Horton Wison Deepwater

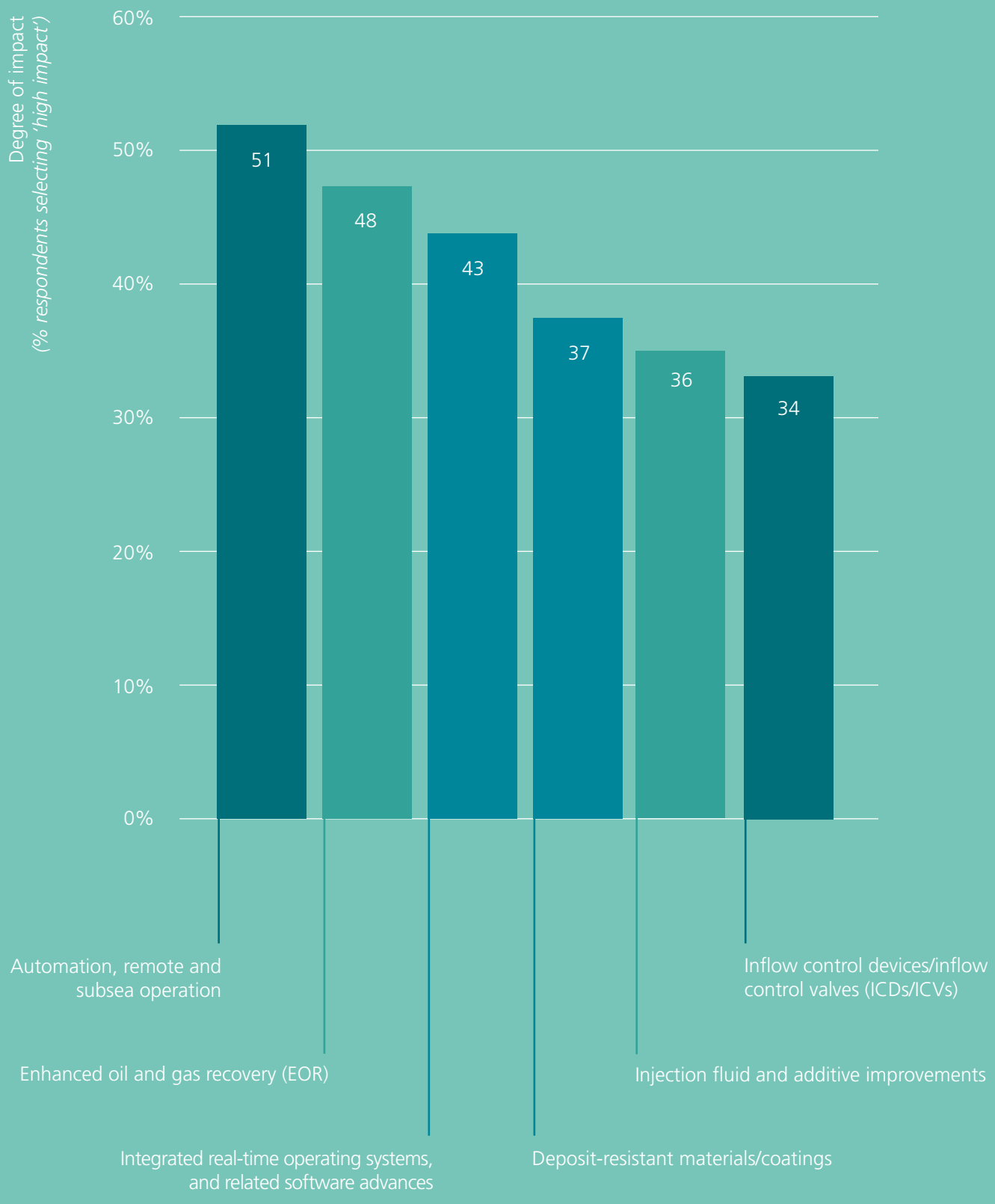
It is worth pointing out that the most influential advances may not be new technologies at all, but, rather, innovative combinations of existing technologies or processes. "The best inventions are often several other prior inventions or trade secrets that have been packaged and re-bolted together and re-purposed, including of technologies pioneered in other sectors," says Greg Navarre, President at Horton Wison Deepwater, a technology-development company. Other interviewees agree that it is often hard to pinpoint one particular technology or product as representing a breakthrough; doing so may require a combination of different elements. Even then, its introduction and adaptation to operating conditions is required before the advance becomes effective.

Furthermore, it is clear that the technology itself is only one part of the equation. For example, in the area of safety, technology developments are often secondary to the vital training and process changes needed here: "After Macondo, there has been an investment in technology around things like blowout preventers. But the primary investment has been in training and awareness of safe practice, and a review of safety management, rather than on the technology itself," explains Joanna Pohorski, SVP, Compliance Services at Lloyd's Register Energy.

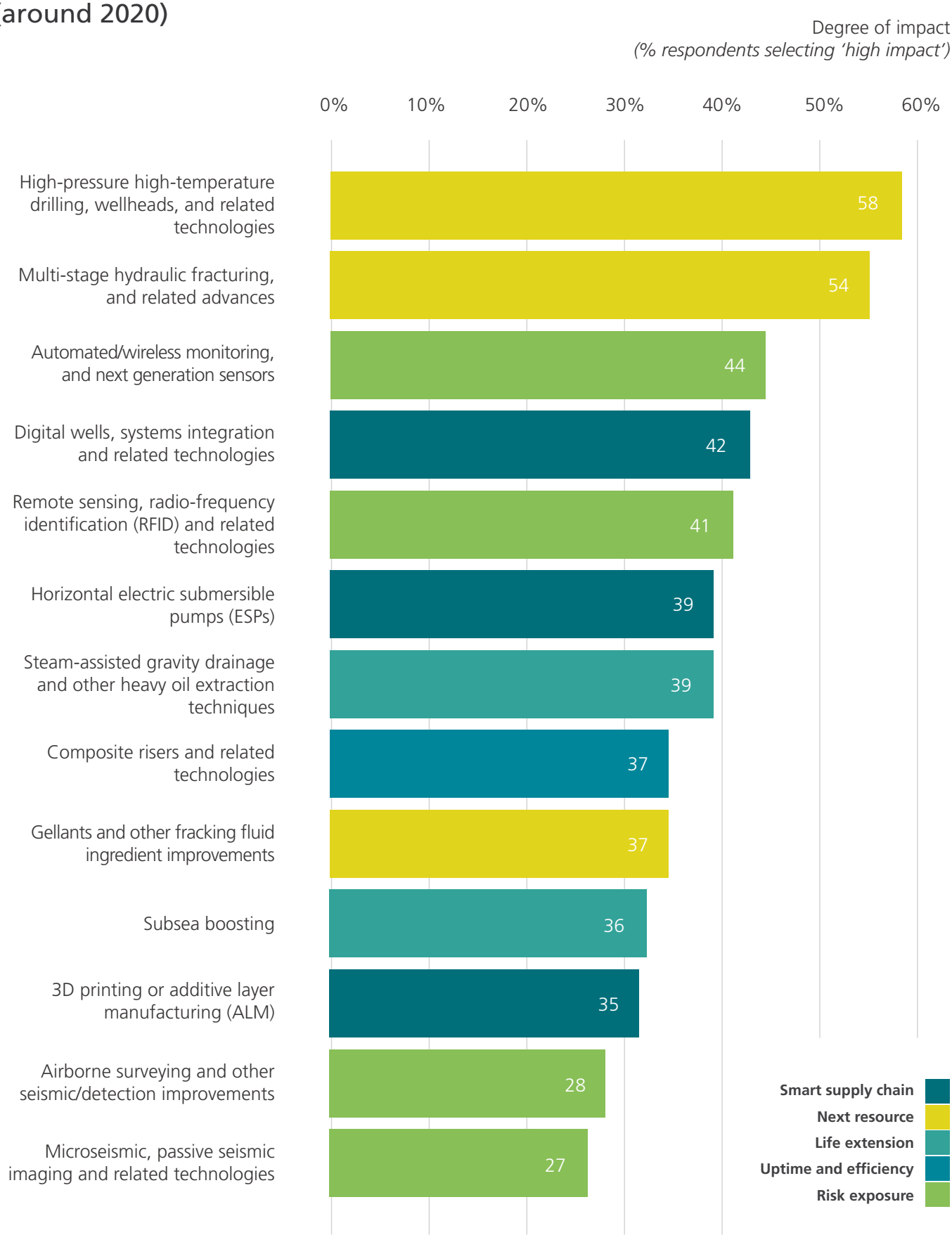
These caveats aside, our research pinpoints a handful of technology innovations that oil and gas firms will be putting to the test, with high hopes, in the coming years.

Methodology: The Technology Radar charts in this chapter show a set of technologies expected to hit the mainstream in a defined time period. In each, the size of the bar of each technology represents the share of respondents from the total sample who believe that the selected technology development will have a "high impact" on the oil and gas sector. The expected time period for when these technologies will hit the mainstream is based on a weighted average calculation. For this, we multiplied the percentage of respondents in each time band against the mid-point of that band, while respondents selecting "Don't know" were excluded. From this, all responses were divided into three groups: the near term, in the next two to three years; the medium term, in the years around 2020; and the longer term, 2025 and beyond.

High-impact technologies going mainstream in the near term (before 2020)



High-impact technologies going mainstream in the medium term (around 2020)

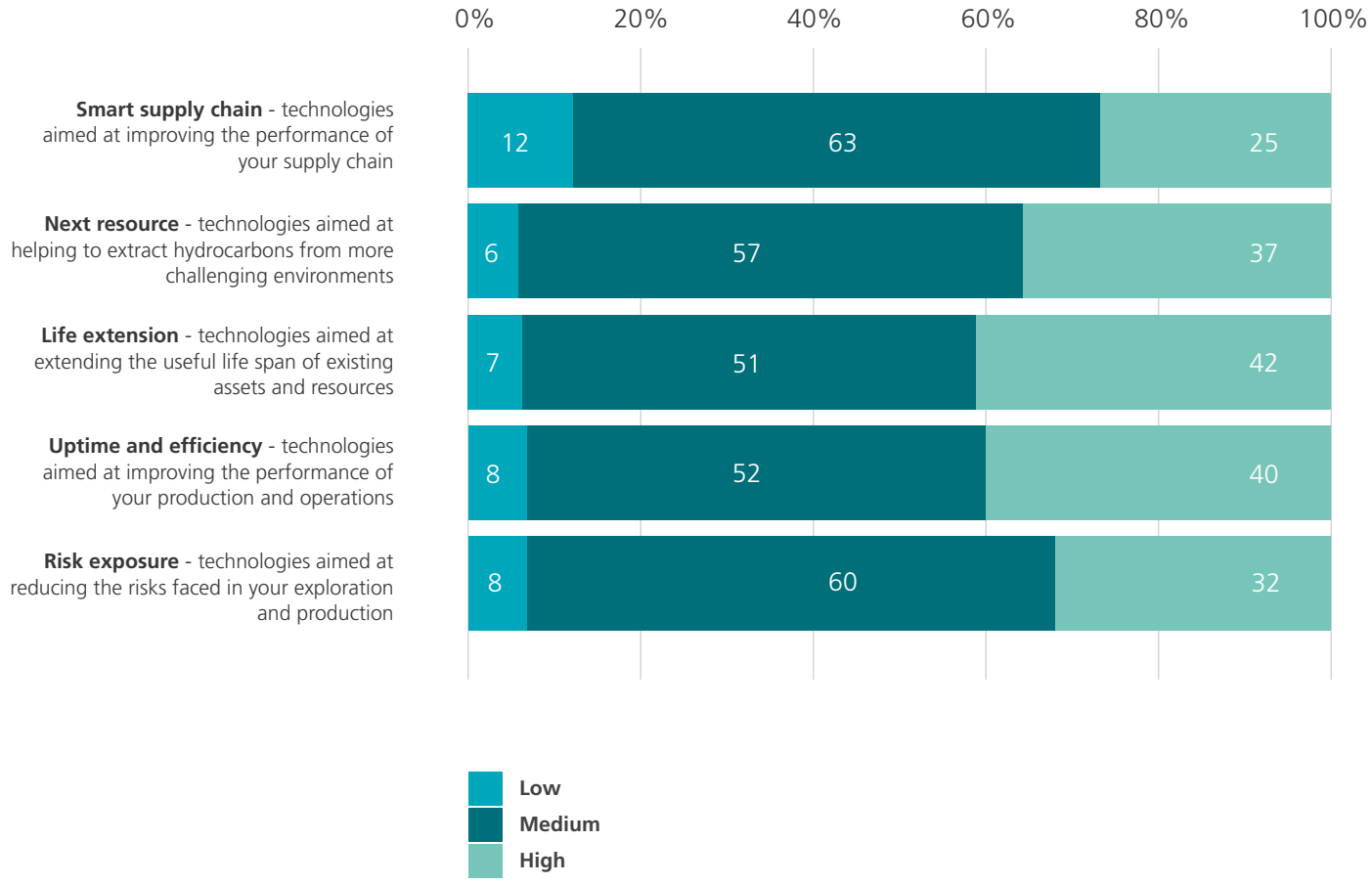


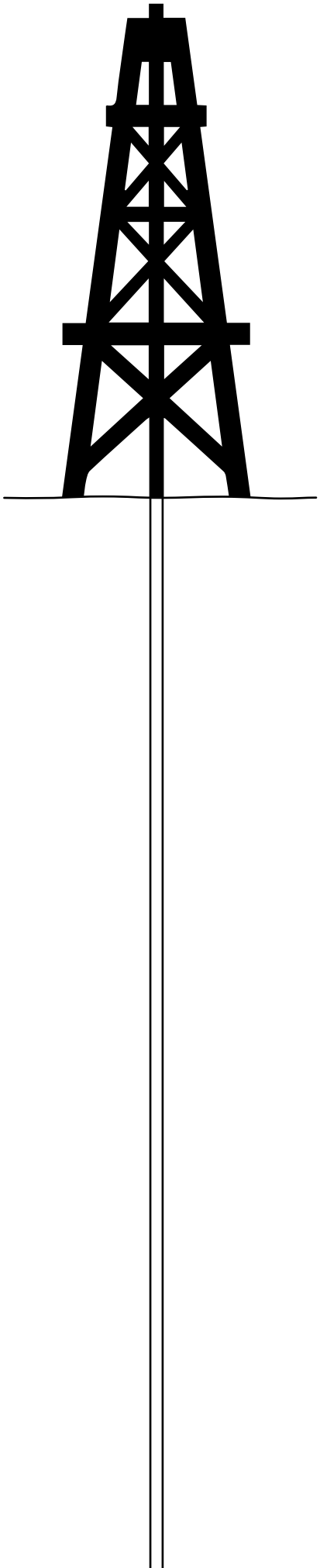
The outlook to 2020

Generally speaking, industry executives believe that the most important technology advances taking place today fall into the categories of "life extension" – extending the life of assets and resources – and "uptime and efficiency". "Next-resource" technologies that help extract hydrocarbons in challenging environments are another current focus of innovative activity. When it comes to technologies in the near term, survey respondents expect the biggest impact to come from automation, including subsea and remote operation, and EOR. "Automating can take people away from hazardous drilling and help with drilling direction. Computers are better drillers than humans," argues Shell Chief Technology Officer Gerald Schotman.

> *"Automating can take people away from hazardous drilling and help with drilling direction. Computers are better drillers than humans.*
>
> Gerald Schotman, —
> Chief Technology Officer - Shell

In your view, what is the rate of technological innovation within the oil and gas sector in each of the following categories right now?





Drilling and extraction

Looking ahead to the medium term, the sector expects much from HPHT, underpinned by new materials technology, including advanced alloys to tackle more demanding reservoirs. Gregers Kudsk, VP of Maersk Drilling, says his company expects great improvements from down-hole measurements, which would ultimately be used to control the drilling process itself: "We are looking towards increased use of information and communication from below to the surface, to allow much better and safer use of our existing drilling machinery."

Nevertheless, several interviewees suggest there will be a slight move away from technologies aimed at the very harshest of environments. Claus Myllerup, SVP for Technology at Lloyd's Register Energy, believes some more extreme areas are "no longer viable in the way it appeared 10 years ago – given shale and other changes, some may need to wait longer before going to that extreme." Neil Kavanagh, Chief Science & Technology Manager at Woodside Energy, adds that low-cost, slim-bore exploration wells for deep water are "progressing slowly post Macondo disaster".

Nevertheless, such technologies still harbour enormous potential, and "safety technology and cost pressures should revive them," he says.

Survey respondents also put a lot of faith into multi-stage hydraulic fracturing over the medium term, with 55% anticipating a great impact. Of course, this is highly geographic, reflecting the technology's limited progress to date outside the US. Within the US, the technology is far further ahead, highlighting how local conditions affect the development and deployment of any innovation. However, as incrementally harsher environments are tackled, and existing equipment gets older, there is a major push to produce more robust equipment that can be maintained more effectively, with an extended design life. This is leading to the development of another whole range of technologies, including automated equipment monitoring, which survey respondents expect to have an impact in the medium term, and deposit-resistant materials, which are likely to go mainstream in the near term. "Ageing assets are a real driver of technology innovation. They're increasingly prevalent. Operators may be looking to extend their lifespan, or innovate something to replace the asset," says Tim Walsh, SVP for Asset Integrity Services at Lloyd's Register Energy.

Enhanced oil recovery

Judging from the survey, EOR-related technologies are a focal point for many firms, and one that could have a major impact. Executives interviewed for the report agree on the importance of life extension overall. Tore Land, CEO and President of TouGas Oilfield Solutions, prioritises EOR to simply "get more production out of existing known reservoirs". According to Mr Navarre, the technology having the greatest impact will be that which "exploits a higher percentage of the reservoir, enabling companies to increase their value through an increase in the monetisation of their reserves."

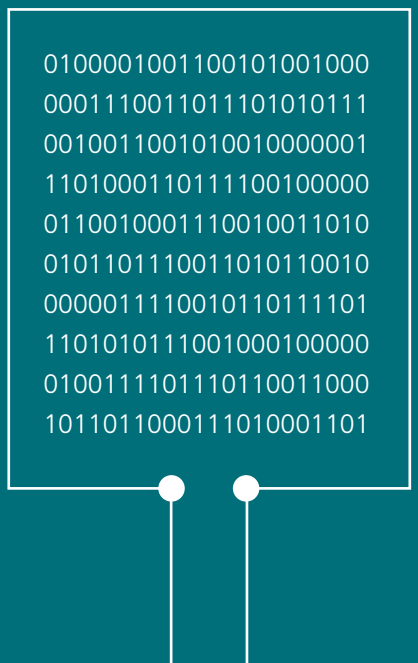
For Jared Ciferno, Director of the Strategic Center for Natural Gas and Oil at the US National Energy Technology Laboratory (NETL), increased hydrocarbon recovery factors, aimed at lifting global average recovery rates "for combined primary and secondary recovery above the current average of 35 to 45%", will have a substantial impact.

He expects developments in chemistry, biotechnology, computing and nanotechnology will raise these recovery rates while minimising operational costs and environmental footprint.

The ability to view and control field dynamics, and to manage declining fields better, will add substantial value for the entire sector. Developments in several fields will contribute to this, including improved seismic and other field data, better analytics and modelling, and drilling and completions technologies, as well as EOR techniques such as advanced fluid injection. Combined, they should enable a more clinical approach to field development, with each production well carefully targeted and a holistic view of flow within the field.

Data crunching

Massive growth in computing power is helping the process. Companies are transforming operations through digital connectivity, making strategic investments in digital infrastructure, real-time communication, modelling and other technologies, vastly improving their ability to operate fields safely and reliably. According to Duco De Haan, SVP for Energy Drilling Services at Lloyd's Register Energy, many drilling contractors and operators are investing heavily in technology that collects data. "We can now obtain so much data from either drilling assets or the well itself, or the subsea equipment, that the trick is interpreting the data, and deciding how to act on it."
In Norway, for instance, improved seismic analysis of huge volumes of data covering the Norwegian continental shelf – one of the most heavily surveyed areas in the world – has helped drive up discovery rates. Exploratory drilling success on the shelf is up over recent years due to technological advances, even though average discovery sizes are down[1].



Woodside's Mr Kavanagh also ascribes importance to wireless monitoring – 45% of survey respondents expect this to have a substantial impact on the sector in the medium term – including the use of seabed-based measurement of seismic response, and gravity and electro-magnetic detection.
Mr Ciferno notes that the critical areas of innovation prioritised for the upstream sector by the Society of Petroleum Engineers (SPE) include higher-resolution subsurface imaging, or "advances in seismic and gravity data acquisition, electromagnetics, signal processing and modelling."

This is not only relevant for the wells themselves, but also the site infrastructure overall: "When assessing the condition of ageing assets, we still rely on individuals physically examining them. There should be more options these days. You should be able to continuously monitor your equipment's condition, and there should be greater visualisation through technology," explains Mr Walsh.

Another technique given importance by both the NETL and SPE – relating to the "next resource" category – is in-situ molecular manipulation. This includes ways to extract energy from unconventional hydrocarbon resources through, for example, "in-situ upgrading of heavy oil or sweetening of sour gas, including through biological mechanisms," explains Mr Ciferno. This also has major applications in EOR. According to Mohammad Asad Khan, Senior Investment Manager with Enertech, a strategic energy technology investor and part of Kuwait's sovereign wealth fund, anything in this area that reduces water use is a high priority, and particularly relevant when fracking technologies are applied to EOR in the dry Middle East.

> *"45% of those surveyed expect wireless monitoring to have a substantial impact on the industry in the medium term.*

[1] "Petroleum resources on the Norwegian continental shelf: 2013 Exploration", Norwegian Petroleum Directorate, 2013

Safety first

The survey results show safety and environmental improvements to be a major objective of innovation, especially related to remote operation. Our interviewees agree. According to Alberto Tesei, the former General Manager for technology commercialisation at GE Oil & Gas, "Safety is extremely important. Customers want automated operations for remote or dangerous sites so they can reduce personnel and risk as much as possible. Whatever the technical innovations are, reduced manning will be attractive to operators."

Mr Kavanagh sees innovations to reduce offshore manning, for example through technologies that make possible subsea long tiebacks, making progress - and nearly four in ten (37%) survey respondents believe that related technologies, such as composite risers, will have a noticeable impact around 2020. These tiebacks to the shore or to existing hubs, "will involve a combination of subsea processing, electrical power, distribution and subsea compression," says Mr Kavangah.

There is also greater openness to collaboration when it comes to both health and safety and environmental concerns, argues Patrick O'Brien, CEO of the Industry Technology Facilitator (ITF), an industry body. He cites the example of reducing the costs of well abandonment, which he says account for about 43% of the costs of decommissioning: "There's a significant technology 'win' there if we can find better solutions to safely abandon those wells."

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Alberto Tesei,
Former General Manager
for technology commercialisation
- GE Oil & Gas

Future game-changers: 2020 and beyond

In the longer term, subsea robotics, autonomous underwater vehicles and other ultra-deep-water advances are seen as key areas of advancement, along with laser and rigless drilling, and other forms of directional drilling improvements. "Robotics, which we have yet to see the start of in our industry, will be a big game-changer," believes Shell's Mr Schotman. Another key area relates to downhole water separation and related advances, which nearly half of respondents cite as having a great impact.

Beyond these, digital technologies are also expected to continue developing during this time frame, from 4D seismic flow modelling through to digital wells. One Russian oil and gas operator already has a team of 600 people engaged in modelling and simulation of future wells, but is constrained to resolutions of just 100m x 100m; in a decade from now, it hopes to advance this to a molecular level, a challenge several orders of magnitude more complex than today's computing allows.

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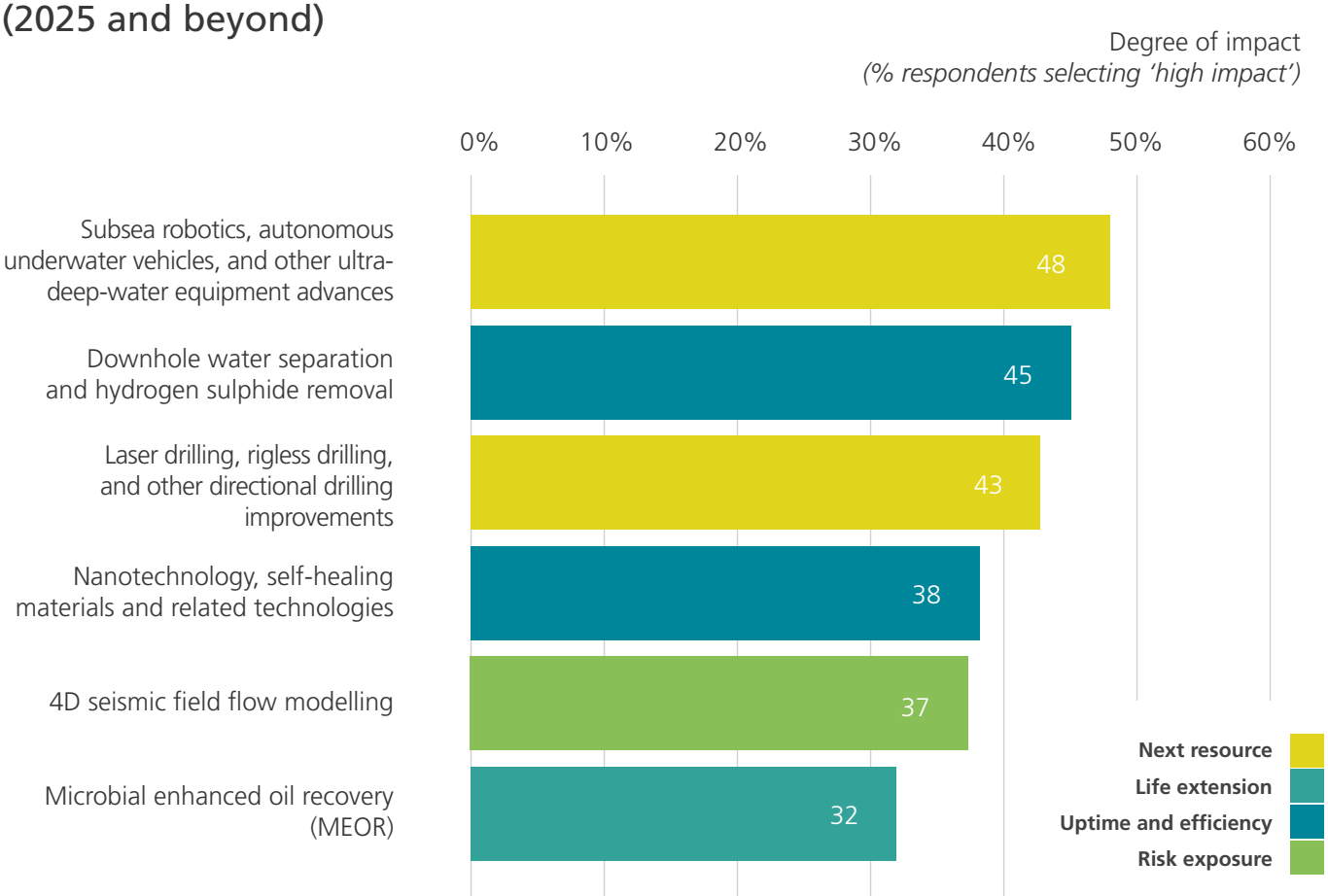
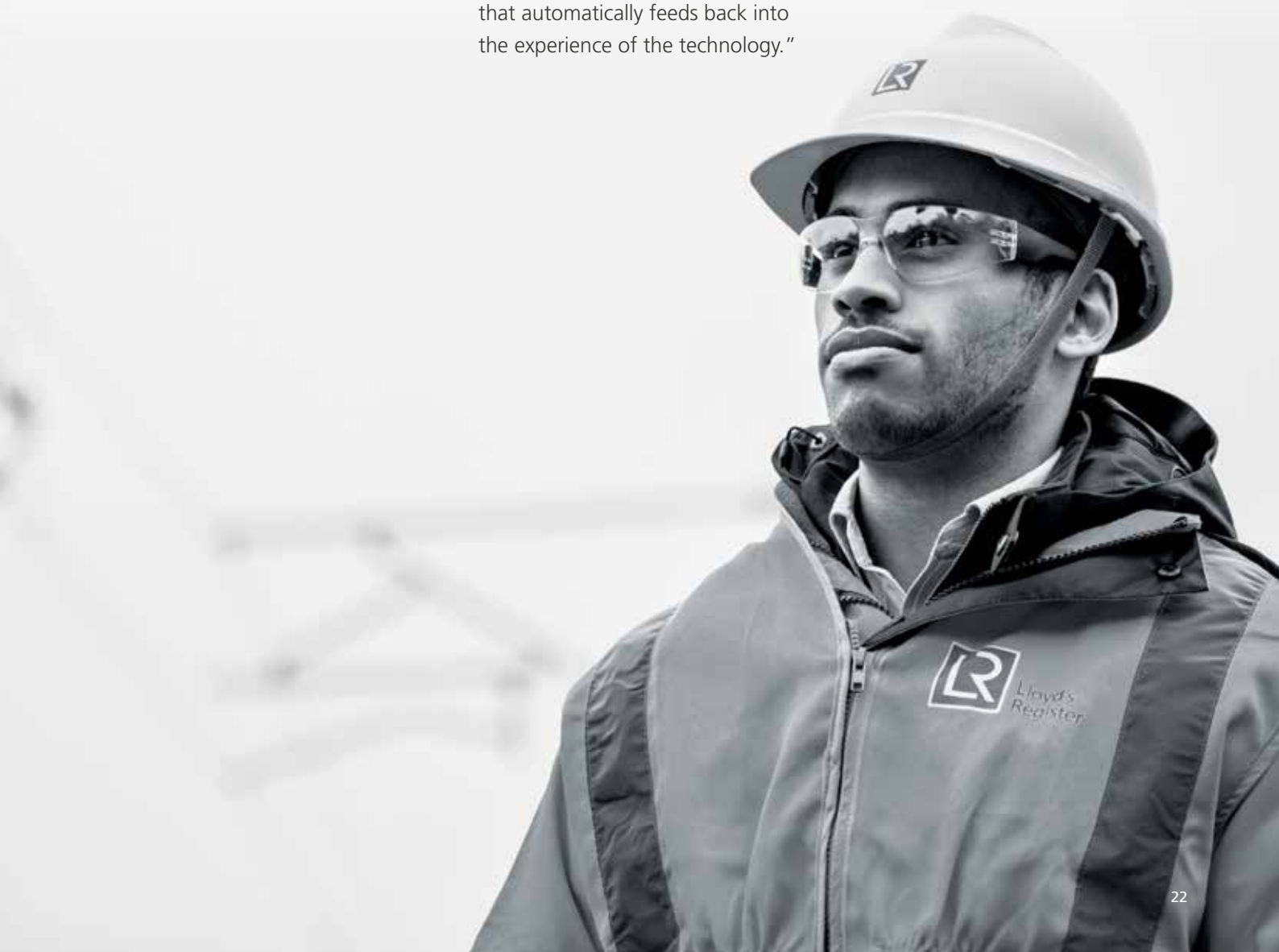
High-impact technologies going mainstream in the longer term (2025 and beyond)



Clearly, many other developments will emerge too, some already forecast and others not yet imagined. The NETL and the SPE ascribe great long-term importance to technologies related to carbon capture and sequestration (CCS), notes Mr Ciferno. "These will help us to sustain many of the benefits of using hydrocarbons to generate energy as we move into a carbon-constrained world," he says.

A more important factor is how some of these technologies might combine to open up new possibilities. "We have learned from the shale evolution that one thing builds on another," explains Gal Luft, Co-Director of the Institute for the Analysis of Global Security (IAGS). Others agree: Ken Cronin, CEO of UK Onshore Operations Group, explains that various developments are now building on top of the breakthroughs that have already come in areas such as horizontal drilling. "Technologies are coming along at a time when you can retrospectively look at wells that didn't work out properly and go back in and look again, using that technology, and find out the reasons why it didn't work and that automatically feeds back into the experience of the technology."



Part 2
The drivers of and barriers to innovation

In summary >

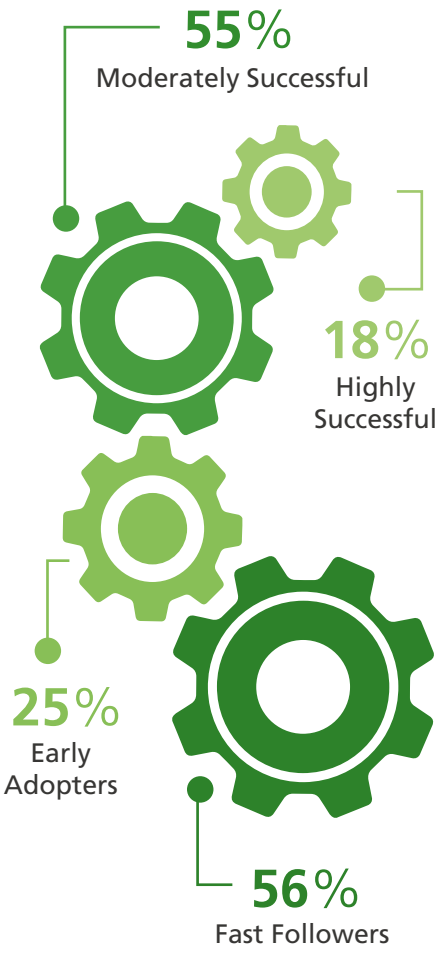
The pressure to innovate within the oil and gas sector is intensifying for most players, but only a minority of 25% consider themselves to be early adopters of new technology.

A wide range of challenges continues to inhibit innovation, including cost, uncertainty over energy prices, skills shortages, regulatory and other risks, and the challenges of scaling up any innovation.

For many companies, both investment and management time devoted to innovation are being increased.

The mantra "innovate or die" today applies to businesses in all sectors. Oil and gas firms are no exception. Three-quarters (75%) of survey respondents say pressure to innovate has intensified over the last two years. A majority maintain that they have responded well: 63% are of the opinion that they are better innovators than their rivals, for example. Most also feel their company has been moderately or very successful in the development of new technology.

Digging deeper to examine these claims, however, reveals a greater dose of modesty. For example, prompted to characterise their ability to meet its innovation objectives over the past two years, some 55% describe their firms as "moderately successful", with just 18% believing they are "highly successful". Likewise, just one-quarter (25%) of executives describe their firms as "early adopters", who aggressively trial new and emerging technologies; the majority (56%) say they are "fast followers": quick to adopt new technologies as soon as they see proven implementations.

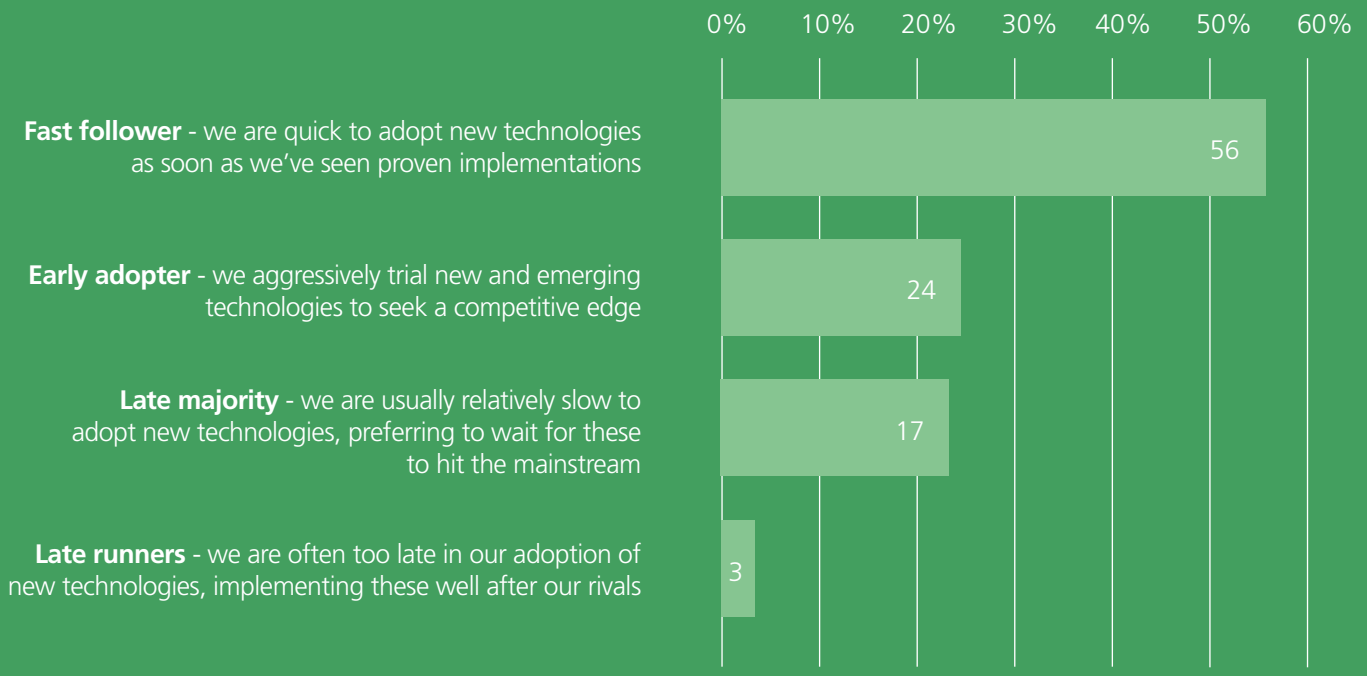


> *The sector can be conservative and it will stick with proven technologies, rather than innovating.*
>
> Joanna Pohorski, SVP, Compliance Services - Lloyd's Register Energy

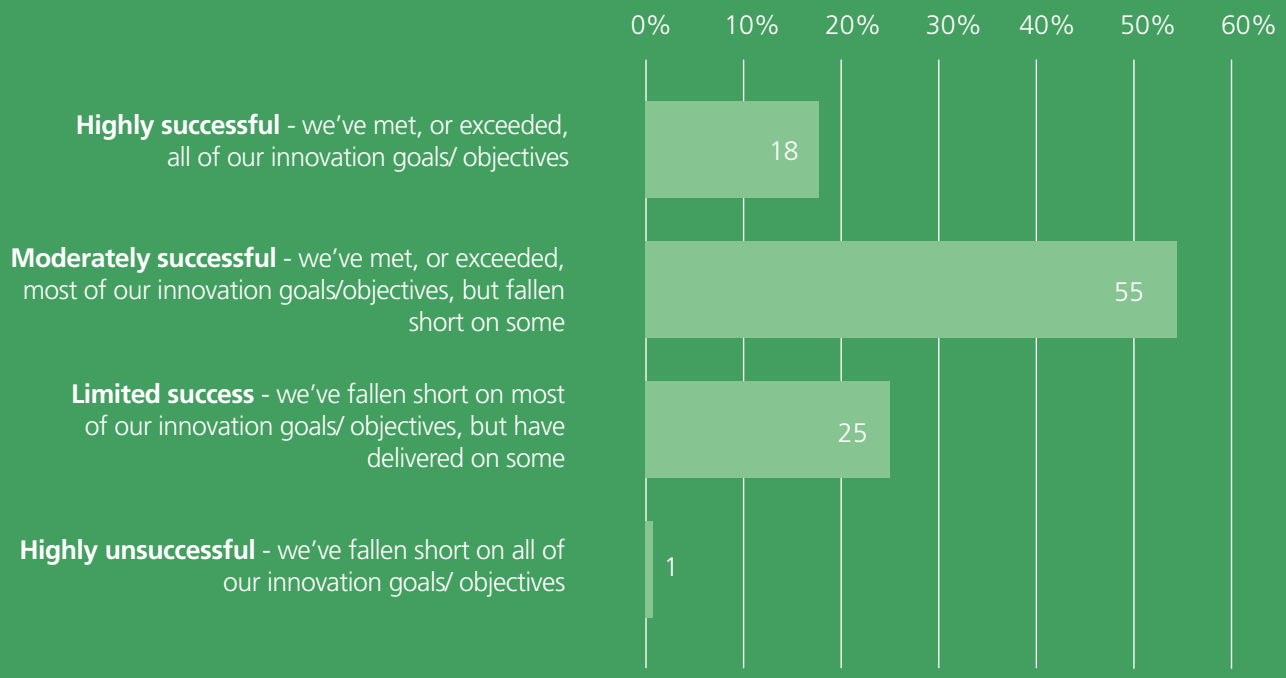
All this reflects the inherent conservatism of the sector, a point noted by numerous interviewees. "Some operators are very clear about it, aiming to be second," says Mr O'Brien. "There's definitely a race to be second, no doubt about it, as they don't want to be first in introducing technology. But, of course, there's a mix of cultures, with both leaders and followers," he says.

Lloyd's Register Energy's Joanna Pohorski agrees: "The sector can be conservative and it will stick with proven technologies, rather than innovating. But, when there is pressure from the external market, and when there are funds, there is the determination and effort to generate new technology."

Which of these best describes your company's speed at adopting new technologies and innovation?



How successful has your organisation been at meeting its innovation goals and objectives over the last two years?

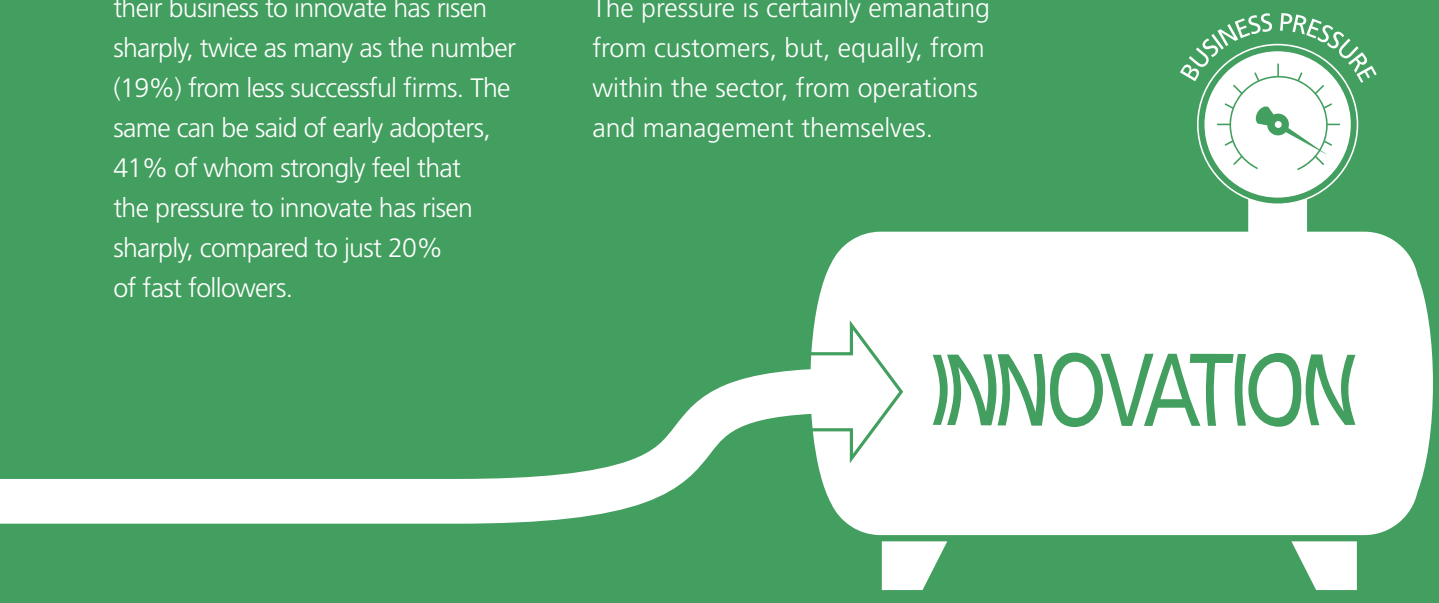


How do oil and gas companies in these categories compare on various aspects of innovation? Those executives describing their firms as "highly successful" certainly appear to be feeling the heat: 37% of respondents from these companies strongly agree that the pressure on their business to innovate has risen sharply, twice as many as the number (19%) from less successful firms. The same can be said of early adopters, 41% of whom strongly feel that the pressure to innovate has risen sharply, compared to just 20% of fast followers.

TouGas Oilfield Solutions' Mr Land argues that, "Ultimately, technology leadership is absolutely critical for success in the oil and gas sector. Nowadays, access to capital is relatively straightforward; it's all about technology."

The pressure is certainly emanating from customers, but, equally, from within the sector, from operations and management themselves.

Mr Tesei, formerly of GE Oil & Gas, affirms that innovation today is "largely driven by top management of the company, with feedback from operators or maintenance people".



Investing to accelerate?

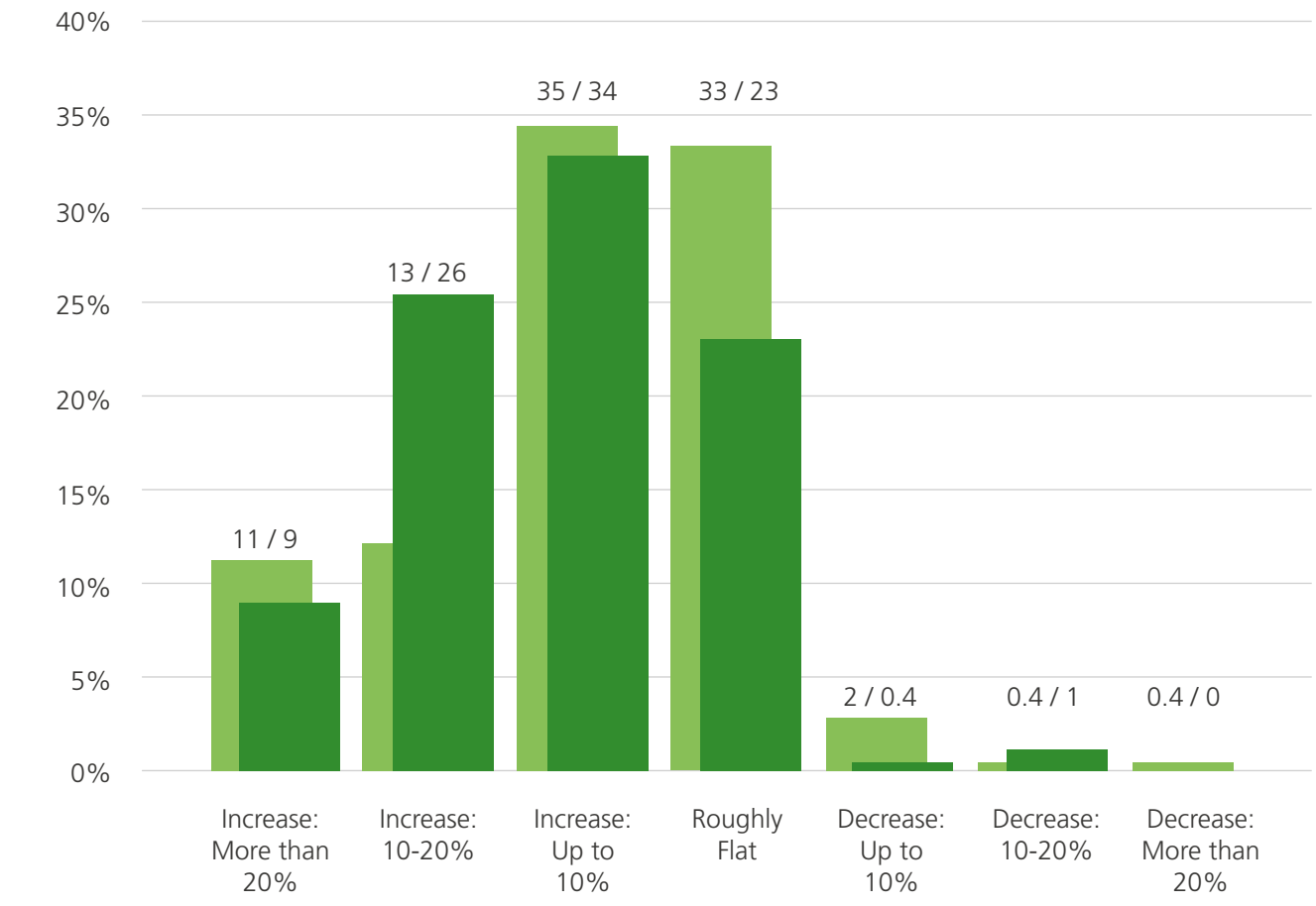
This pressure to innovate has resulted in higher spending in real terms, which is expected to continue rising over the next two years. Nearly 60% of surveyed executives have seen R&D and innovation spending in their firms rise in the last two years, and almost 70% expect that to continue.

This is especially likely among highly successful firms, where 15% plan to increase spending over the next two years, compared to just 5% of less successful ones. The situation is similar for early adopters, 23% of whom expect to boost innovation spending by more than one-fifth, compared with just 5% of fast followers.

"If you look at the innovation cycle in marine systems today, compared to its early days, there's an order-of-magnitude difference.

Claus Myllerup,
Senior Vice-President -
Lloyd's Register Energy

How has your firm's spending on R&D and innovation changed over the past two years? And how do you expect it to change over the next two years?



Highly successful firms are also patient: 39% say the average time it takes to develop a technology from concept to deployment has increased, compared to 24% of less successful firms. Patience is certainly required as complexity and risk levels increase. This has driven cost, effort and time to develop and deploy new innovation upwards. A majority of survey respondents expect these trends to continue.

Does this mean the rate of innovation is slowing down? Even if it takes longer to introduce some new technologies, the vast majority of executives (73%) believe the overall rate of innovation is actually accelerating. "Innovation has increased and we are trying to innovate faster. The time of easy oil and gas is gone, and so technology will need to develop in response to that challenge," explains Shell CTO, Gerald Schotman.

Of course, speeds vary. "Some things move really fast, and there are things that move almost at a snail's pace," says Lloyd's Register Energy's Mr Myllerup, who adds that, as a sector matures and there is a bigger body of science to draw on, the pace of development can pick up. "If you look at the innovation cycle in marine systems today, compared to its early days, there's an order-of-magnitude difference."

Woodside's Mr Kavanagh doubts that innovation is unequivocally accelerating, citing the example of slim-hole coiled-tubing drilling, which has been in the wings for the last 15 years, but gives another rationale for this. "It's partly because the international drilling community has been growing fast in deep-water". In his view, the more the sector can recreate the circumstances of shale gas, the more likely that the pace of innovation will pick up. "The difference between shale and deep-water drilling," he explains, "is that people are not able to experiment on deep-water exploration wells, where there isn't the same ecosystem of many small players trying different things".

What's holding innovation back?

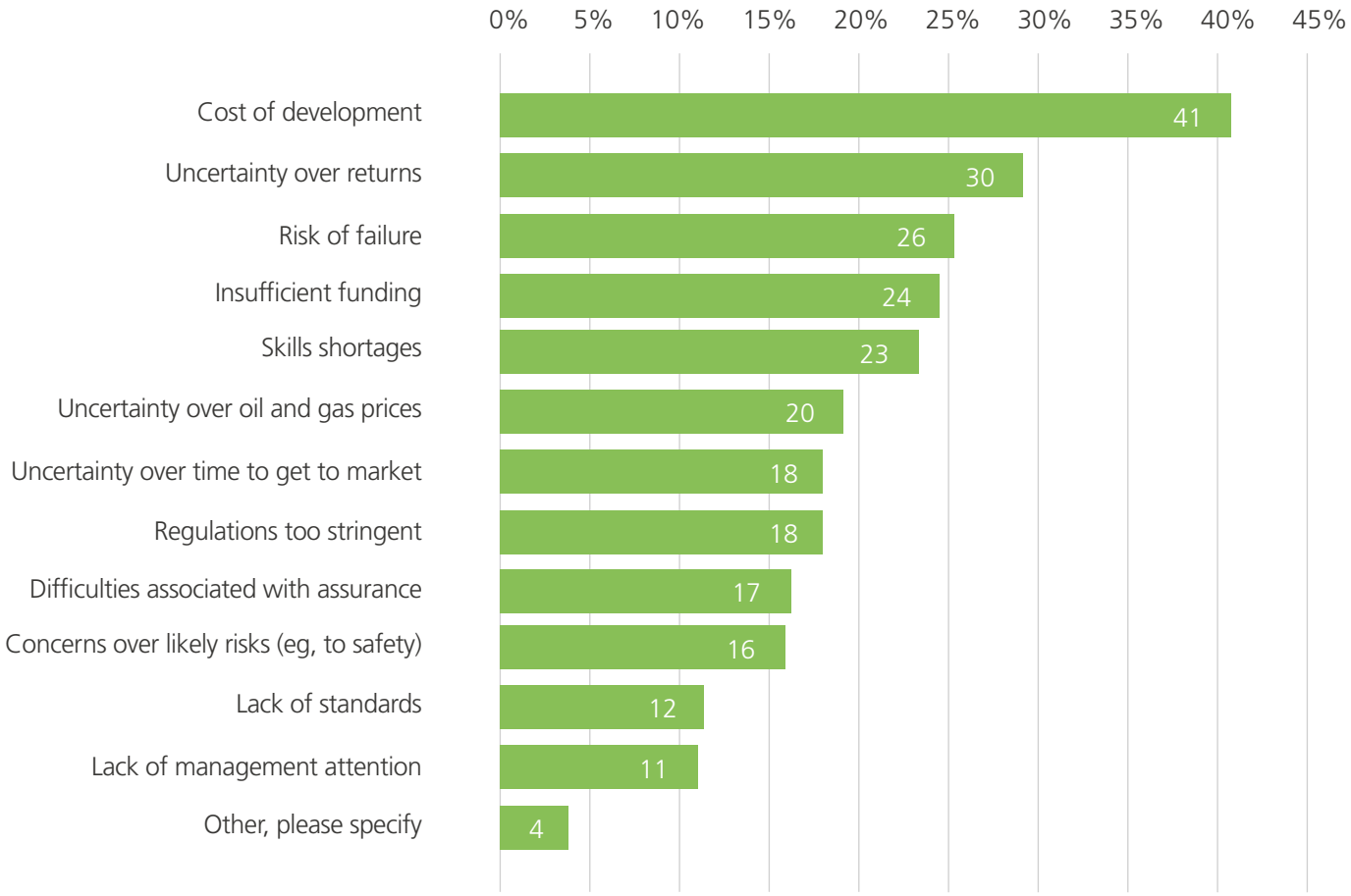
Rising costs

Far and away the largest barrier to developing and deploying new technology in the sector is cost. "Costs are constantly rising, and are keeping a lid on the pace of innovation," confirms Maersk Drilling's Mr Kudsk. "Much innovation is directed at improving the efficiency of operation in order to reduce the well construction cost. If you cannot demonstrate savings to compensate for a higher capital cost, then you don't have a chance to promote new technology."

According to John Westwood, Group Chairman of consultants Douglas-Westwood, between 2000 and 2013 capital expenditure of oil and gas firms increased 374%, while oil prices rose just 24%, and gas prices 43% on average.

This provides an idea of the extent to which the sector's cost base has ballooned. In the survey, 39% of highly successful firms report that the total cost involved in getting a new technology from development to deployment had risen in the last two years, compared to 34% of less successful firms. "We have a general challenge in this sector, in that we could spend more on R&D, but there's the question of the spiralling costs of development,"

What are the biggest barriers your business faces in bringing a new technology or innovation to market?



says ITF's Mr O'Brien. "There has to be a role for technology in terms of finding solutions that can reduce costs." Lloyd's Register Energy's Mr De Haan stresses that cost is a particular issue in frontier sectors: "The IOCs have great difficulty replacing their hydrocarbons reserves, which drives them to go into the most challenging and expensive environments.

As a result, costs have exploded in the last four to five years. Major oil companies and drilling contractors are now putting pressure on their suppliers throughout the whole supply chain to reduce costs, which is related to concerns over oil prices."

> *"374% capital expenditure increase of oil and gas firms between 2000 and 2013.*
>
> John Westwood, Group Chairman - Douglas-Westwood

Price uncertainty

Oil and gas prices have a major impact on which technologies are being developed; this is the view of over 70% of survey respondents. Several interviewees note that the prospect of steady prices of over US$100/barrel in forward oil markets for many years to come is underpinning recent R&D spending growth. Mr Luft of IAGC suggests that innovation is only strong when there is a price signal. "Sustained high prices have made the sector the most innovative in the world," he says, "but the overall trajectory of innovations always needs to follow some sort of price signal." Lloyd's Register Energy's Ms Pohorski agrees: "Everything is determined in the end by the forward price of oil and gas. Take the offshore processing of liquefied natural gas as a floating LNG platform. This is a very expensive way of developing gas reserves, but, of course, when the gas price is high, then it is a viable option."

Nevertheless, despite a sustained period of high prices, there have been recent signs of price uncertainty, in particular related to a possible release of low-cost OPEC oil. According to Mr De Haan, "Uncertainty in the longer-term price of oil is causing some to hesitate over heavy investment in frontier innovation, slowing the explosive growth we have had over the last two years. There is currently a high degree of political uncertainty – Iran and Libya coming on line, and possibly Iraq – all cheap oil to extract, and that could impact the oil price."

This prospect could well be causing some executives to hold back on new projects and technologies, although strong forward markets mean the risk can be hedged to some extent.

Low prices do not mean that innovation will go away. In the US, low gas prices mean independent fracking companies are innovating primarily to cut costs. Mr Tesei recalls that, when gas prices were high in the US, all the innovation was on shale extraction; when they sank, innovation "switched to cost reduction per well". In Mr Luft's view, the divergence of oil and gas prices that is starting in the US could precipitate "a wave of mergers and acquisitions", which could have either positive or negative impacts on innovation. "On the one hand, there are synergies, but, on the other hand, M&A can stall or delay projects."

Skills shortages

Skills shortages are another concern, cited by 23% of respondents. Although overshadowed by cost and uncertainty on our survey respondents' list of innovation barriers, over 30% say that addressing skills shortages will be a major boon to their ability to innovate and bring technologies to market (second only to higher oil and gas prices). "Ultimately, innovation-developing, driving, executing it – is about people," says Mr Land. "We would love to hire more people if we could only find the right talent, but that is a problem I'm sharing with everybody in the oil and gas sector." Mr Myllerup sees additional spending going on higher salaries, rather than hiring more people, with the result that employees are "too busy solving day-to-day problems or just delivering on promises".

Adding to this problem is the fact that many of the people who originally set up much of the sector's infrastructure and assets are retiring and moving on, taking their knowledge with them. "As assets last longer, there will be fewer people familiar with them, so knowledge transfer is key. A lot of knowledge we have today is either in the heads or notebooks of a few individuals," explains Mr Walsh. "If an installation has been in place for 20-30 years, it will have had plenty of modifications – bits taken off, bits added on. The records aren't always that good. Many operators are struggling with this, but it's fundamental to understanding how long something can last before it needs replacing, or what is needed to keep it to minimum standard."

Challenges of scale

At corporate level, some companies are driven to innovate primarily to improve return on capital and expand their reserves base, and others to ensure a competitive advantage. Mr Land says efforts to improve the return on capital employed could easily lead to "cuts or a halting of investment completely." He notes, for example, that the US shale boom was initially driven by independents, in part because the types of operations involved did not suit the scale-driven culture of the majors, which have been far less active in the sector. (A related driver was the handling of mineral rights in the US, which incentivised land owners to allow drilling and fracking on their properties in the first place.) However, outside the US (and Western Europe, where small companies are taking a lead due to perceived public opposition), NOCs and IOCs are expected to drive fracking, and the innovative focus has switched to adaptation of existing technology to local conditions.

John Westwood puts it a different way: "Big oil and gas companies need big projects; the majors are not commercially structured to deal with a multiplicity of different small projects. They would need to set up overseas operations structured to drill thousands of wells, which is fundamentally an industrialised well-drilling process – a different set of innovative drivers from what they're used to."

There are also issues of scale involved in deployment of innovation, with the significance of the improvement offset against the risk of disruption. Minor changes can be unpopular among operators due to their potential to disrupt major projects and introduce unforeseen risk. Mr Tesei, formerly of GE Oil & Gas, says that, unless there is considerable added value, there is often insufficient incentive to take on the additional risk. "The oil and gas sector tends to be conservative, because investments are very high, and daily production often cannot be interrupted."

NETL's Mr Ciferno agrees, noting that the risks do not stop at corporate level: "In addition to safety, financial and environmental risks, in some major E&P companies there can be more risks than potential benefits for an individual employee who champions a technological innovation."

Mr Navarre says it's essential to find individuals who will get behind an innovative product: "This is the human factor—it's about finding the individuals within a company who are prepared to champion the technology."

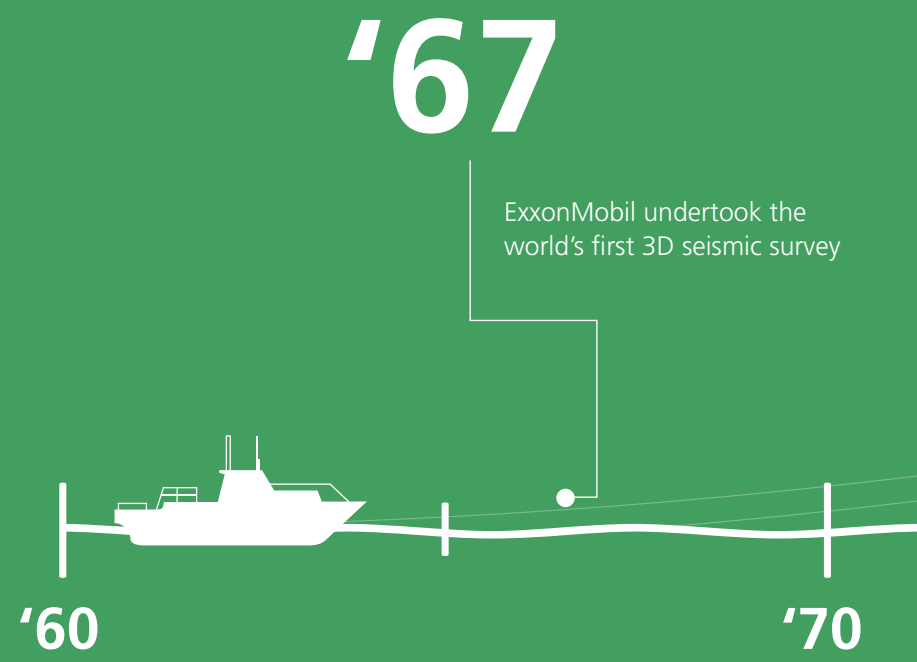
Taking it to the field: Deployment difficulties

Beyond any challenges relating to the actual discovery and development of new technologies, deployment is another major concern in the oil and gas sector, given its unique pressures. "Technology is worth nothing if you cannot implement it. Deployment is crucial," argues Mr Schotman.

However, the commercialisation of new upstream technologies often takes longer than in other sectors, due to scale and risk, and also to the long lead times between discovery and production. Many changes are incremental, and it may take decades for their cumulative effects to have a major impact. In the case of shale, which, to many, appeared an almost overnight sensation in the US, the evolution of lower-cost, practical technologies for both horizontal drilling and large-volume, multiple-stage hydraulic fracturing actually took 30 years. ExxonMobil undertook the world's first 3D seismic survey in 1967, but it was not until the mid-1980s that the technology went mainstream. One key reason for this was the time it took for unrelated technologies to develop that would prove crucial in the uptake of 3D seismic surveys, such as the ability to start directly transferring data via satellite to a processing centre on shore, rather than for a ship to physically have to return to harbour.

"The sector is conservative when it comes to managing innovation, meaning the adoption of new technology can take years," explains Mr Land. "Deployment is a very technical function, because every site is different, and you need people to work in the field with customers on specific reservoir challenges."

This research also highlights the fact that firms have differing degrees of adeptness at deploying new technology. Leading firms, which some interviewees term "tier-one" companies, are best at this, and, unsurprisingly, are, as a consequence, often correlated with early adopters. By contrast, second- and third-tier companies are typically less well equipped or trained to deal with major deployment risks, which makes their projects inherently more risky.



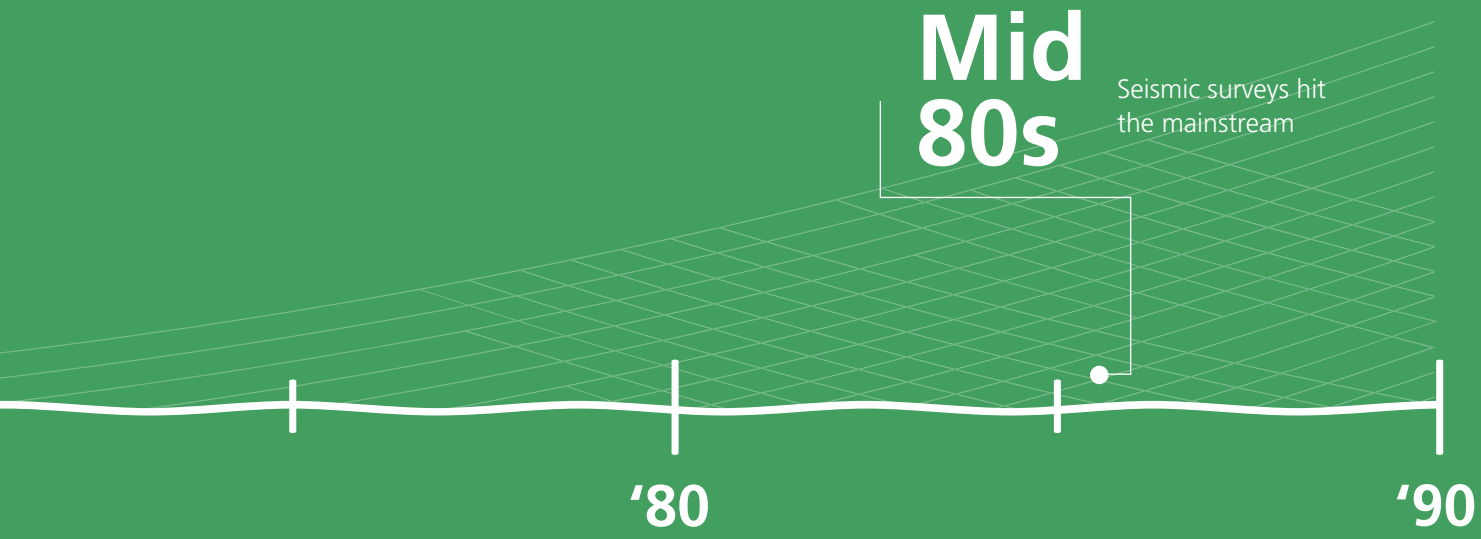
In part, this is due to rising levels of complexity of equipment being used, while experience is often lacking, not least due to the skills shortage in the sector.

Mr Navarre of Horton Wison Deepwater says that, although they had a group of major companies supporting them, it was normally left to an independent to partner and deploy technology the first time around. "The independents, driven by lack of options, a unique location, or a logistics hurdle, seem to adopt our new technology first and then majors follow on very strongly… hats off to the independents who jump right in with both boots," he says. This is a common story: only just over one-quarter of respondents believe their company would be willing to introduce a new technology for the first time. "A big issue for us is to facilitate technology deployment, not just development. It's how you get it into the field," says ITF's Patrick O'Brien. "Take offshore test sites, for example. Making available a real live well for testing is a tricky process, but there's a need there."

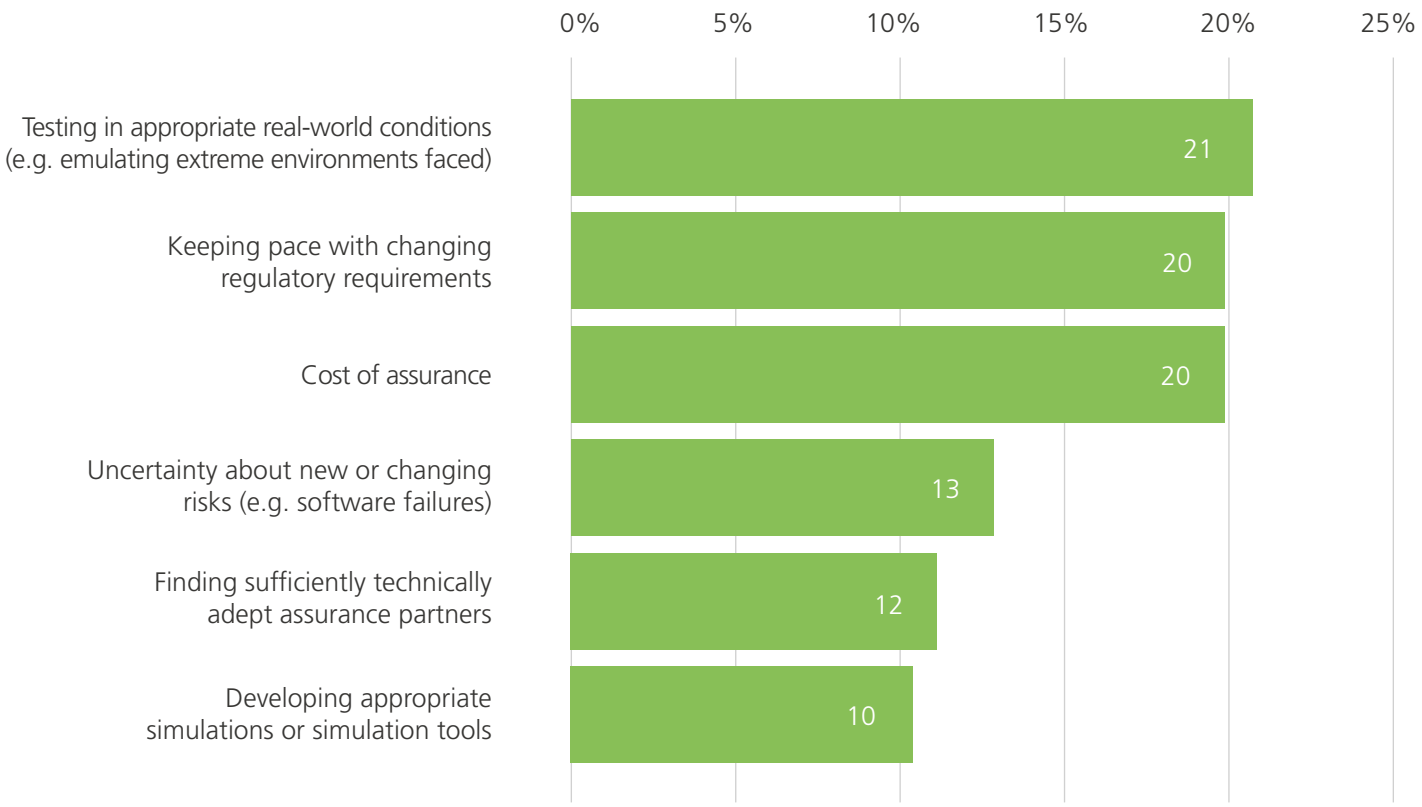
Even deep-pocketed IOCs can be wary of deployment. Shell recently postponed a long-awaited subsea compressor project at a deep-water field in the Norwegian Sea. The project was visionary in scope, but was set back by both complexity and uncertainty over returns. "Ultimately, it's not [just] whether you can technically do something or not, it's also about whether it's affordable, and deployable, and how it compares with alternatives," says Mr Schotman. "You can make a small tool, but the trick is ensuring that it can be used worldwide. You must think globally, but act locally. You must educate and train the best people, build relationships and work to your business model."

As our survey shows, most companies prefer to wait until advances have been tested, and then seek to adopt them quickly, if successful. Among early adopters, 68% spend more time on R&D and innovation, compared to 43% for fast followers, although this gap is expected to narrow in the next two years, to 61% for early adopters, and 52% for fast followers.

For one in five upstream participants, there is a clear preference to simply wait until technologies are well established. These companies instead work to gain competitive advantage in other ways, notably in terms of low cost or providing generic services, or else in the specialisation of existing niche roles, according to experts interviewed for this report.



What is the primary challenge in managing quality-assurance requirements as you implement new technologies/innovation?



Another key issue for deployment lies with quality assurance. Respondents flagged up a range of concerns here, with the challenges of testing in real-world conditions, difficulties in keeping pace with regulatory change, and related costs all prominent. One issue is that technologies are sometimes introduced too early, pushing up operations and maintenance costs, as well as inspection costs, says Mr Kudsk. "Quality assurance is complicated by real-world conditions, cost and regulatory requirement changes," he says. Ms Pohorski agrees, citing the example of a mega-project like Shell's Prelude FLNG platform. "Assurance in the supply chain is the big challenge for projects of this scale and complexity, because you are bringing components and equipment from a number of different manufacturers around the world to one of the largest floating installations ever developed."

In Mr Land's view, assurance companies, regulators, governments and commercial participants in the oil and gas sector need to collaborate more closely to make it less risky to deploy innovative products. This is a recurring theme noted by executives interviewed for this research, and may well be a more fundamental characteristic of how the sector seeks to operate in future.

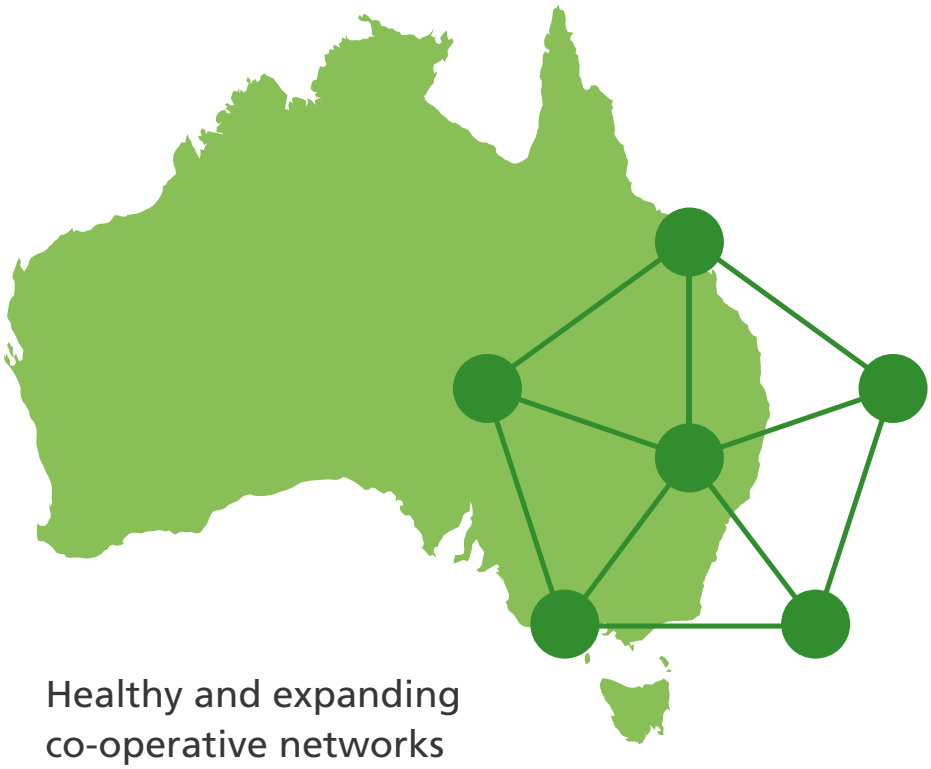
Opening up to mitigate the risks

In several respects, the conservative nature of the sector may be giving way to a more open approach that allows for a more objective assessment of various options to mitigate risk and cost, whether in technology development or deployment. One avenue favoured by survey respondents is partnership, ensuring developers are able to introduce products with support from operators. "Our suppliers work with us to solve the problems," says Mr Kudsk. "This provides the opportunity to closely tailor some of the solutions."

In Mr Tesei's opinion, a good approach is to obtain some sponsorship from a potential customer at concept stage, and to involve that customer in the development and prototype stage, as long as the intellectual property remains well defined. However, Horton Wison's Mr Navarre cautions that, although smaller players seek to partner up more, "The larger guys are very resistant to going beyond a certain stage."

Woodside's Mr Kavanagh notes that there are already healthy co-operative networks in Australia, and these are expanding. He points, for example, to ITF, a not-for-profit organisation owned by the major operators; it was originally set up in the North Sea, but is now international. "We post challenges to suppliers and they come back with suggestions and innovative solutions," he explains. "They are then given an invitation to bid for a research work programme, and the member companies decide if they want to take part or not."

Major incidents can actually spur co-operative innovation, according to Mr De Haan. Since Macondo, BP and others "have increased emphasis on collaborative work and information sharing. The IOCs may have moved away from deep water after Macondo, but they cannot afford to give up on it," he says.



Healthy and expanding co-operative networks in Australia

Part 3
Shifting approaches and innovation leaders

In summary >

IOCs have dominated technology development to date, but a wider ecosystem of players is now growing in importance – including start-ups, corporate spin-offs and public bodies.

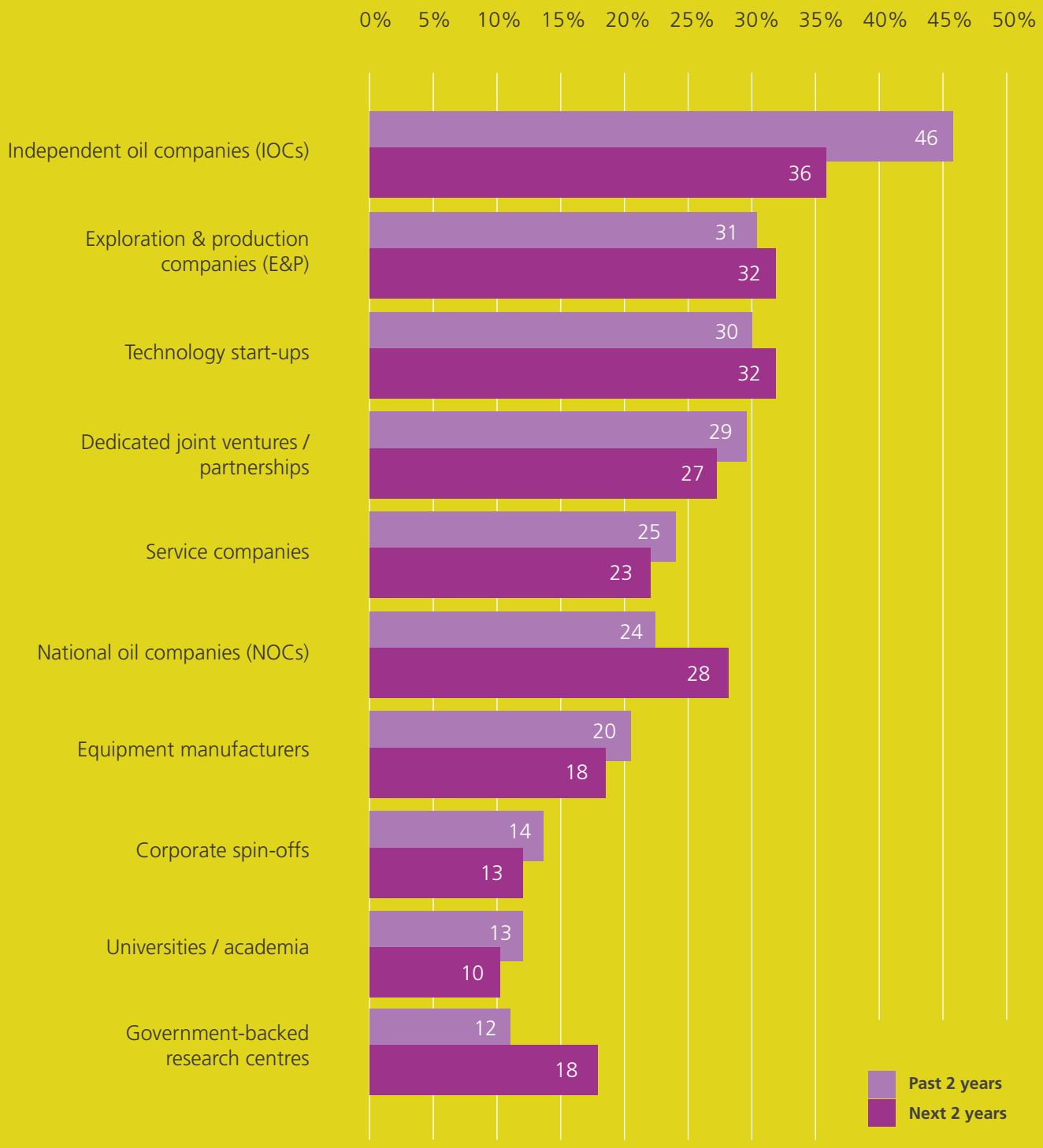
Many in the sector see NOCs as a rising force in innovation, with 63% agreeing that state-backed players are rapidly increasing spending on R&D.

Successful innovators are more willing to partner or collaborate with third parties, compared with their less successful peers.

Oil majors have been behind most of the technology innovation in oil and gas to date, but shifts are underway in the sector. While nearly half (46%) of survey respondents point to IOCs as the source of most innovation over the past two years, they see others – including exploration and production (E&P) players, dedicated technology start-ups and NOCs – becoming more active in the year ahead. For IOCs, this is a risk, given the importance of innovation in helping replenish reserves, argues Lloyd's Register Energy's Mr Myllerup: "They're forever extending the reach of their search for new fields and ways to better exploit ones they already know. That requires constant innovation."

> *"They're forever extending the reach of their search for new fields and ways to better exploit ones they already know. That requires constant innovation.*
>
> Claus Myllerup, Senior Vice-President - Lloyd's Register Energy

Which of the following actors within the global oil and gas industry do you believe have been most responsible for introducing breakthrough new technologies over the past two years? And which do you believe will be most responsible in the next two years?



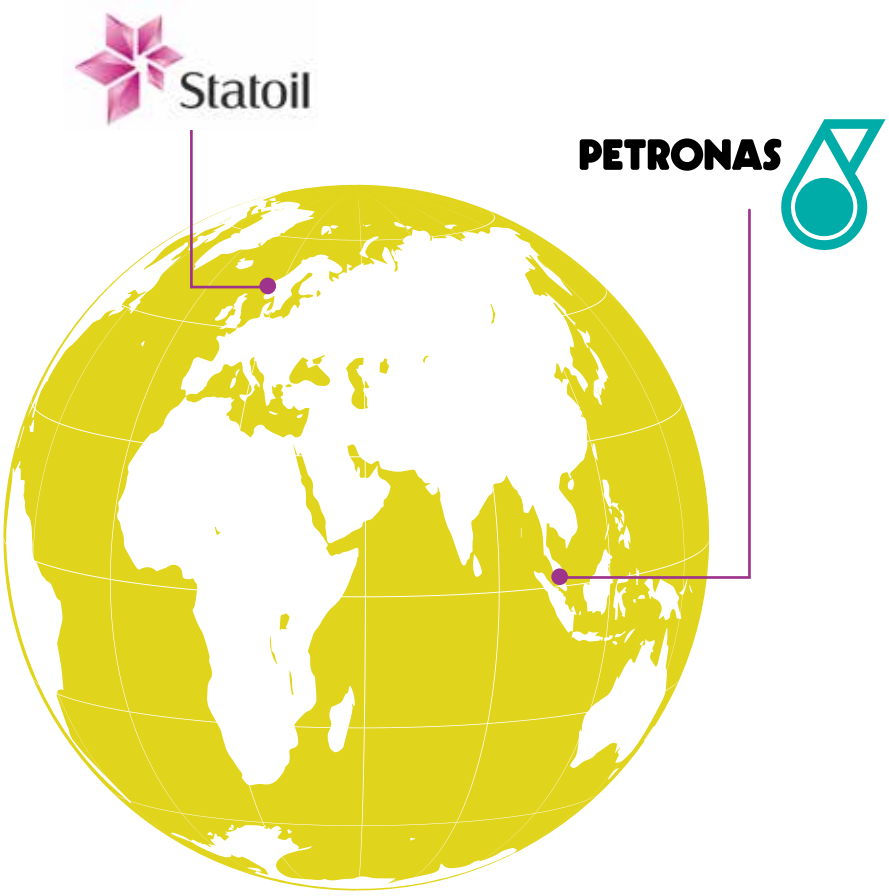
Woodside's Mr Kavanagh echoes this sentiment, warning that IOCs that are "lazy" on innovation will face tightening constraints ahead: "If IOCs and other private upstream companies don't actively seek growth through exploration and innovation, they will expire. Easy-to-access oil is now controlled by NOCs, and so we have to work hard in order to stand still and really sprint in order to grow." He points to Woodside's four deep-water blocks in Myanmar, and BP's exploration acreage in the Great Australian Bight, as examples of places that only those with the best technology could hope to tackle.

Underneath this all, there is a clear sense in the sector that NOCs are rapidly increasing their spending on innovation: 63% agree that NOCs and state-backed operators are rapidly expanding investment into R&D as they expand. They have no choice, believes Mr Kavanagh: "NOCs with maturing assets need to grow. While they have an advantage nationally, for any international success they have to fight for it with innovation and with hard-core exploration." Two leading examples he cites are Norway's Statoil, with its innovative shale gas activity in the US, and Malaysia's Petronas, which is exploring in regions like Sudan and Iraq, and is also active in coal-bed methane LNG in Australia.

NOCs hold one vital advantage here: they are often able to think longer-term than more commercially-driven companies, enabling a more strategic approach to innovation. They are also often given a freer hand in their home territory to push ahead with new initiatives.

Nevertheless, while a longer-term perspective is important, the reality remains that many NOCs still struggle to generate innovation internally, relying heavily on co-operation with private-sector partners. Enertech's Mr Khan observes that some Asian NOCs have huge R&D centres and research budgets to match, but generate relatively little output for the amount of money being spent. "They need help from giants like Halliburton or Baker Hughes to support their R&D," he argues.

Furthermore, the fact that some NOCs operate within home markets that are less competitive than, say, the US, also means that local private-sector technology development is not always as fast or responsive to changes in demand. "Historically, we viewed NOCs as innovating for the long haul and taking an asset from the cradle to the grave, rather than disposing of it," explains Lloyd's Register Energy's Mr Walsh. "Now we're seeing NOCs moving on some of their assets to smaller independents that specialise in late-life operations. It's becoming more nuanced; there's no longer standard NOC and IOC models."



Case Study:
Opening up Shell's innovation ambitions

Royal Dutch Shell, the Anglo-Dutch multinational, is a behemoth in the oil and gas sector, generating revenue of US$451bn in 2013. It's also responsible for some of the sector's biggest technological developments, quite literally –its Prelude floating liquefied natural gas (FLNG) project is due to be the biggest floating production facility in the world, with a deck longer than four football fields.

Its £1.3bn R&D budget dwarfs those of many of the firms it works with, and this spending represents just one element of its innovation efforts. "Innovation is about clever technologies, but it's also about human capital, finding alternative business models and working processes. These extra expenditures aren't included in R&D spend estimates," says Chief Technology Officer Gerald Schotman. And while the company still develops most of its technology in-house, he is increasingly pushing the firm to open up. "We believe that technology is a key differentiator," he says – and he is clear that the firm needs to work with a wider range of stakeholders to deliver on this.

Its efforts here are wide-ranging. When developing ideas, it now invites people from both inside and outside the business to join creative panels.

It has also set up a corporate venture-capital fund to invest in promising technologies, and has established a technology centre – dubbed the 'Shell Tech-Works' – in Boston's hi-tech start-up community. "Our lab is staffed by specialists, trained to recognise technologies from other sectors that may have applications in oil and gas," says Mr Schotman. This approach is expanding, with similar labs planned for the Far East and Europe. The business has also undertaken some technology-led acquisitions, such as a stake in a solar-panel manufacturer, which will be used as a low-cost power source for an EOR project in the Middle East.

Furthermore, some of the most exciting innovation opportunities, including what Mr Schotman dubs "tricks with big data," are at the interface between the oil and gas sector and other sectors. Examples range from using drones for remote inspection and flare management, through to gaming technology from Silicon Valley being used in its geological and field-modelling packages. "I think robotics and automation will be important, taking people away from hazardous areas, and directional drilling will become increasingly computerised," adds Mr Schotman. Part of this aims to try and restrict the surging cost pressures that the sector has faced in recent years: "If you simply stick with existing technologies then our industry becomes very labour intensive and unaffordable".

Gerald Schotman,
Chief Technology Officer -
Royal Dutch Shell

> *"If you simply stick with existing technologies then our industry becomes very labour intensive and unaffordable.*

Of course, Shell's scale and global reach are also a vital part of the mix: "We recognise the leverage we get from having a global agenda and being able to bring technologies from one place in the world to another, as well as ensuring that both locations are learning," says Mr Schotman. For example, the company is adapting technologies from the US to now tap shale deposits in China. "We are able to think globally, but then act locally. That is one of the tricks that a big company can bring."

Opening up? How innovation is being unlocked

Today, in-house spending dominates the innovation process for most firms, making it a key focus for 60% of companies polled. But this, too, is changing. Over the next two years, just 51% expect to do it all in-house, while firms explore other approaches in pursuit of new technology. The ITF's Patrick O'Brien points to Brazil's Petrobras as one example: "It was very smart in engaging with the sector 20 years ago via collaborative means, joining collaborative projects to understand what was going on. It built up its own capability such that, today, in areas like deep-water technology, it is leading the world."

"It was very smart in engaging with the industry 20 years ago via collaborative means, joining collaborative projects to understand what was going on.

Patrick O'Brien, CEO - Industry Technology Facilitator

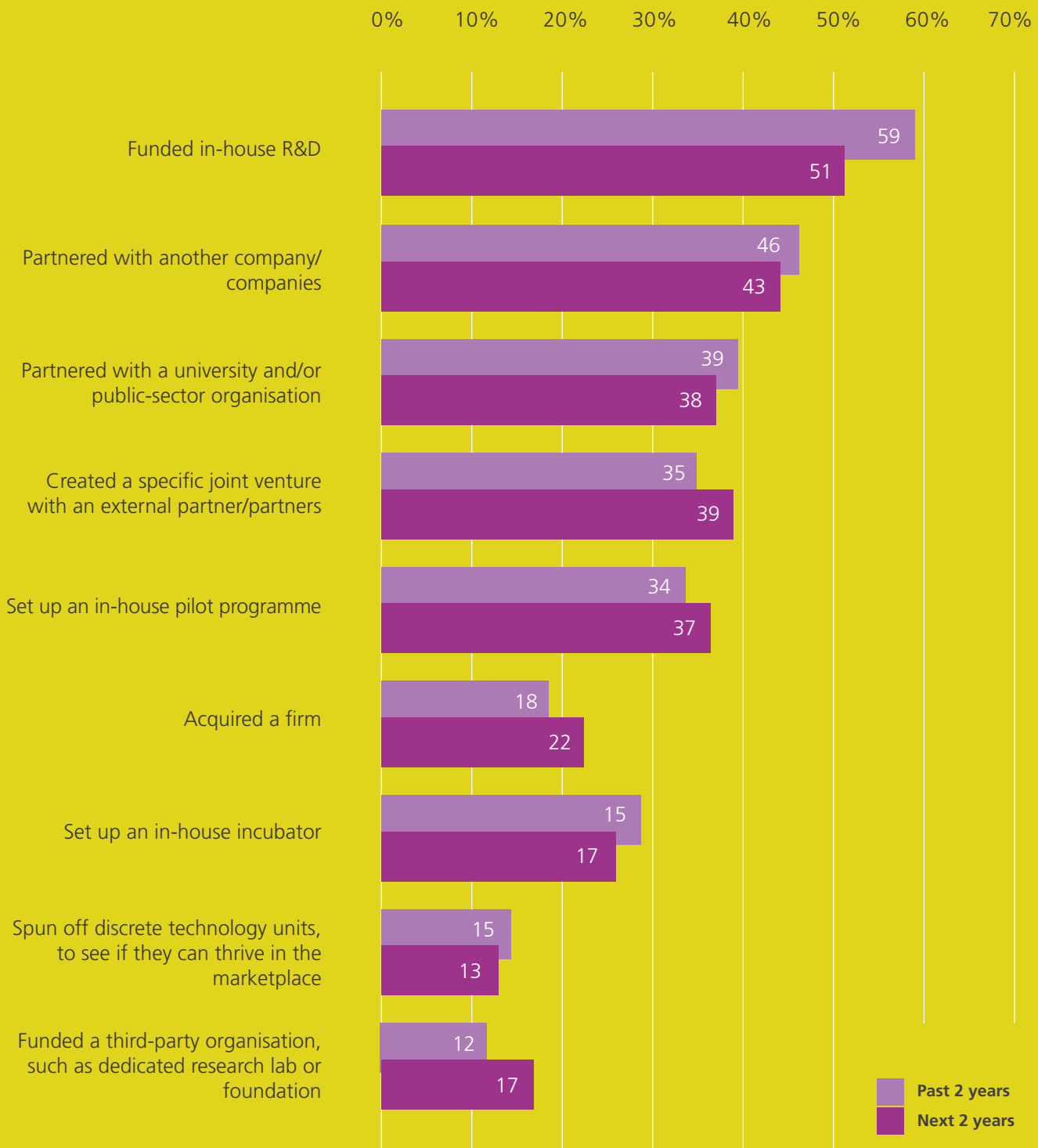
This highlights a greater interest among some players in taking a more collaborative approach, a recurring theme among interviewees – but also more often the approach taken within successful innovators. While highly successful and less successful firms both rely on in-house R&D to a similar extent, the former group are far more likely to partner with other companies (51% versus 42%), or with a university or other public body (42% versus 27%).

Shell's Mr Schotman gives one example of why sector leaders are seeking to open up: "We're keen to look outside the traditional oil and gas industry for technology developments, because some of our current requirements can only be sourced externally. For example, the defence industry is using fibre-optics in a way that can help us measure on-shore seismic signals in a cheaper and faster way."

Nevertheless, in the near term, most firms remain most comfortable with approaches where they retain control. For example, while joint ventures are on the rise, other growth areas to support innovation include in-house pilot programmes, acquisitions of firms with promising technologies, and the setting up of in-house incubators.

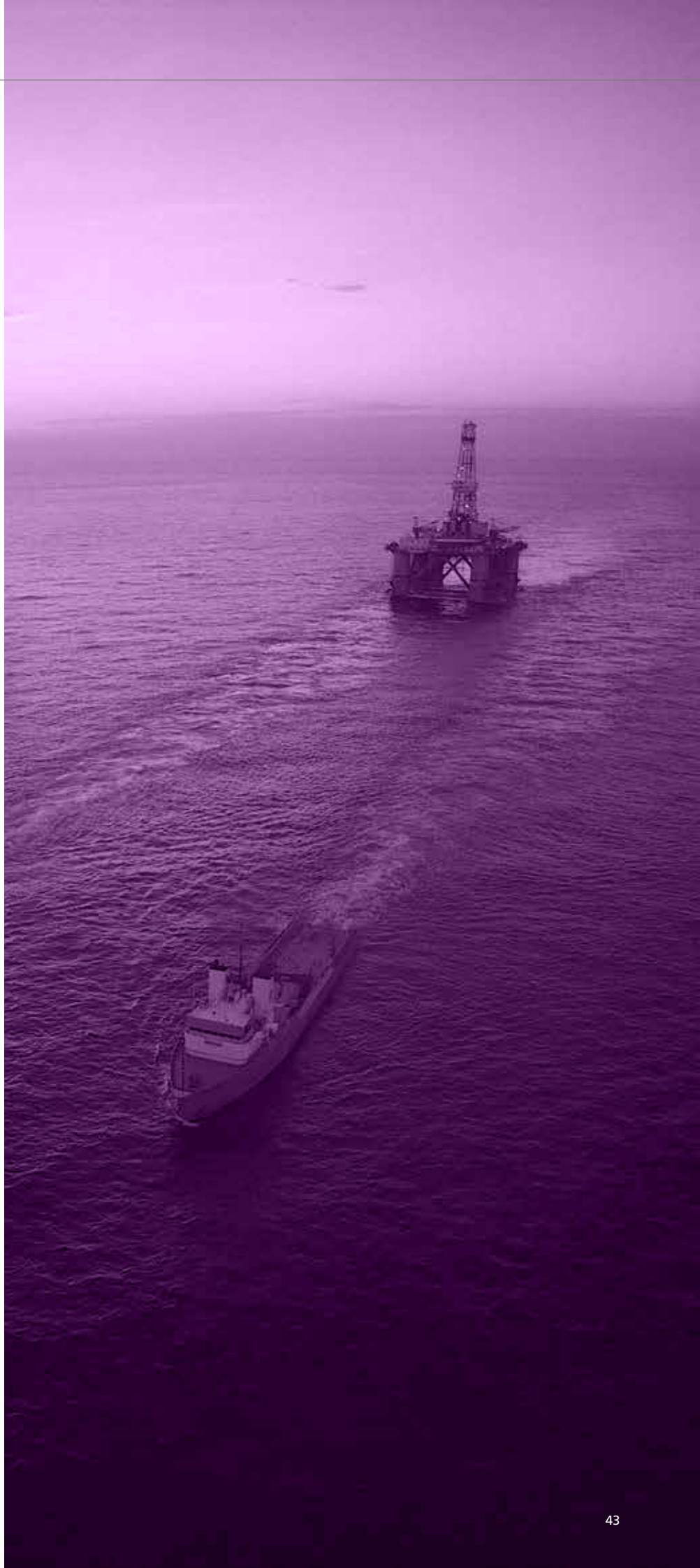
According to NETL's Mr Ciferno, companies such as Schlumberger are now developing new technologies both internally, and through the acquisition of smaller technology start-ups or corporate spin-offs. Over a third of survey respondents said the value of their firms' technology-led acquisitions had increased over the last two years, and this was expected to continue in the next two years, while just 10% expect a fall. More than half also agree there is a move to more of a "buy it", rather than "make it" environment in the sector, a sentiment that only a single-digit minority disagreed with.

Which of the following approaches to innovation has your company undertaken in the past two years? Which do you expect it to pursue in the next two years?



If your cost is only a dollar or so a barrel, it doesn't matter if you pay a bit more to expand recovery, it's still way below the costs that IOCs incur in going offshore or into the Arctic.

Mohammad Asad Khan,
Senior Investment Manager
- Enertech



Start-ups and public bodies

All this makes it an interesting time for technology start-ups in the sector, although these players face specific challenges. While they are expected to remain on the periphery, there is clear agreement among many interviewees that start-ups and corporate spin-offs do help offload risk while fostering a more dynamic, innovative small-business environment. "I'm amazed at the number of SMEs working on innovative solutions, working at ground level and at the earliest possible stage," says UKOOG's Ken Cronin. "When an operator has an issue or problem, the SME group tends to be able to work quite quickly to get those solutions put into place."

Of course, these smaller players face their own challenges, not least in terms of how long it might take to get a new technology actually deployed in the field. "Success for entrepreneurs and investors depends on the deployment of their technology and products in a timely fashion," says TouGas' Mr Land, who feels the sector needs to find more ways to pilot new technology. Another factor that shapes the success of start-ups is that of strategic investors, including among the major operators. In Kuwait, Enertech's Mr Khan says his organisation's strategy is to invest in technology that is appropriate to Kuwait and the wider GCC region – and that means into EOR or water-treatment issues. "If your cost is only a dollar or so a barrel, it doesn't matter if you pay a bit more to expand recovery, it's still way below the costs that IOCs incur in going offshore or into the Arctic."

There is also a clear role for public bodies, not least in partnering with the sector. Survey respondents indicate that the role of academic and government entities will likely become more significant, which many agree with: "I definitely see the involvement of universities becoming a more important aspect, especially in technological areas such as nanotechnology for shale-gas development," says Mr De Haan. Woodside's Mr Kavanagh notes that relationships between oil companies and academia are already strong in Australia. And UKOOG's Ken Cronin adds that universities are also keen to do more: "We are seeing a growing interest from academia across the country in R&D, in terms of universities wanting to get involved. That base of research is beginning to develop quite quickly."

This matters, not least as universities and publicly funded research have an increasingly vital role to play. About two-thirds (64%) of those polled consider public investment into early-stage science and research to be critical for the future health of the sector. Often, this work bolsters developments in areas that the private sector deems insufficiently profitable, including more fundamental research that may not have clear applications as yet. One explanation for the anticipated rise in public research involvement is that as the oil and gas sector moves towards the forefront of technical advances, it relies more on fundamental research. Another is the increased role of NOCs, which tend to have close links with national research institutions.

In addition, public research often highlights the potential risks to human health and the environment, encouraging the development and deployment of new technologies that mitigate such risks. It also develops technologies that address getting the most out of resources, while minimising environmental impacts, including technologies to reduce carbon footprints, emissions, water use and gas hydrates. In east and south Asia such research is not only driven by high oil and gas prices, but most of all by pressing concerns over the security of energy supplies. Areas of research include shale, coal-bed methane, and gas-hydrate-production technologies, which are being tested in Japan and India, and now also China.

All of this highlights the fact that the oil and gas sector is slowly opening its doors to greater collaboration with third parties, not least as it gears up to tackle tomorrow's challenges.

Conclusion

The importance of technological innovation is rising as the search for new oil and gas reserves moves beyond the conventional and easily accessible. The days of sticking a drill in the ground and hoping for the best have long gone; in future, it will be increasingly important for oil and gas companies to be able to identify, adopt and integrate critical technologies, even if they are not the primary developers.

Helped by increased computer power and communication, combined with a recent expansion in global reach and investment of companies from rapid-growth markets – especially NOCs – the sector continues to push back the date of "peak oil", meeting the growth in global energy demand even as older fields mature and dwindle. All this is aided by ever more ingenious methods of extracting oil and gas from tough new formations and locations. Indeed, despite rising demand, over one-third of respondents expect recoverable oil reserves to grow over the next two years, while just 8% expect a fall.

Nevertheless, ongoing technological development is not guaranteed. While a can-do attitude pervades successful innovators, who demonstrate much greater willingness to explore new partnerships and approaches, much of the sector remains cautious. However, as both complexity and risks mount, along with rising competition, tomorrow's leaders will show a greater willingness to explore new routes to innovate – or risk failure.

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