A 7km pipeline bundle is towed from its fabrication site at Wick, Scotland. The bundle integrates the required oil and gas, water injection and gas lift flow lines with the control system for a subsea development, and assembles them within a steel outer carrier-pipe. Two powerful leading tugs will tow the bundle with a tug at the rear supporting the tail end. A guard boat will lead the convoy, accompanied by a survey vessel for checking the bundle en route to its subsea destination, typically 200-300 km away © Subsea 7

ACCESSING THE UK'S SUBSEA ASSETS

Far from being yesterday's industry, North Sea oil and gas remains an important part of the UK's economy. Allen Leatt FREng, Senior Vice President Engineering at Subsea 7, explains how new production technologies and underwater installation and maintenance techniques are reversing the decline in production, making it possible to recover reserves from previously uneconomic fields.

The UK became self-sufficient in oil production in 1980 and remained so for the next quarter of a century. Oil production from the UK continental shelf peaked in 1999 at 137 million tonnes, some 2.75 million barrels per day, and has been generally in decline ever since. By 2012, oil production had declined to 45 million tonnes, a third of its peak. Natural gas has exhibited a similar decline in production.

It is, however, far too soon to be writing obituaries for oil and gas production in the UK. The North Sea is enjoying record activity, with production set to rise again. This turnaround, fuelled in part by the rising price of oil and gas, owes much to the emergence of techniques for oil and gas recovery and new approaches to the maintenance of seabed production facilities.

Technological advances in the SURF market (subsea umbilicals, risers and flowlines) and the IRM market (inspection, repair and maintenance) have helped operators to exploit the smaller and more difficult reservoirs. These advances have also created export opportunities as offshore operators around the world adopt these engineering innovations. This new technology has been particularly relevant in deeper waters of up to 3km, such as those off West Africa, Brazil, and in the US Gulf of Mexico.

In 2013, total expenditure on the UK Continental Shelf was a record $40 billion (£25.8 billion). The industry also supports significant employment in the order of 450,000

A Subsea 7 fabrication site at Wick produces several flowline bundles a year weighing thousands of tonnes, which are then towed out to their subsea destinations. Welding pipelines together onshore reduces the need for heavy construction vessels offshore. Large prefabricated subsea manifold/tow-head structures at each end of the bundle enable the testing and commissioning of the complete system onshore, thereby reducing the time for bringing the oilfield on-stream offshore

ECONOMIC INCENTIVES

The rising price of oil has driven the interest in using new technologies to extend the life of existing fields and to develop new ones. For much of the 1980s and 1990s, an oil price of $20/barrel or less drove the pursuit of production efficiency. At that price, it was often uneconomic to develop all but the larger fields. Consequently, capital expenditure was often limited to large or very large reservoirs, not just in the North Sea but elsewhere in the world. That all changed in 2005, when crude prices trended quickly upwards and now stabilised at around $100/barrel. This changed the economics of North Sea oil and gas, and of fields that had been too small to be on the economic radar of large international oil companies.

The high oil price has maintained the industry's financial significance to the UK, not least because it is, as the trade association Oil & Gas UK has pointed out, the country's most highly taxed business activity. In 2013, total expenditure on the UK Continental Shelf was a record $40 billion (£25.8 billion). The industry also supports significant employment in the order of 450,000, so this is still a big business.

In the past 10-15 years, there has been a change in the complexion of the oil companies operating in the North Sea. The holdings of the traditional majors have declined while new companies, large and small, public and independent, foreign and domestic, have helped to create a vibrant and active marketplace. Some new players are specialists in late-life field production. Their approach is to use new technology to re-evaluate reservoirs and exploit their remaining potential to the full. Even old and abandoned reservoirs are being reassessed.

A major factor that has driven these changes is the use of subsea technology to connect satellite reservoirs to existing infrastructure. In this way, there is no need to invest in expensive new production platforms and transport systems to bring oil and gas ashore. Instead, these smaller reservoirs can feed their production into legacy systems, put in place at the peak of the North Sea's oil boom. The subsea industry that makes this possible brings together the SURF and IRM markets for engineering, installing and maintaining the production hardware that sits permanently and unseen on the seabed.

Stern view of a new breed of heavy construction vessel that can house a crew of 400. This ship, shown undergoing sea trials, is equipped with a large crane for lowering a 1,000 tonne structure to the seabed up to 1,000m below sea level. It can also lay flowlines in ultra-deep water using both the S-lay and J-lay techniques. It is considered to be a $0.5 billion multipurpose solution for the global deep water SURF market

ACCESSING DEEPER WATERS

Today's seabed technologies came about as a result of the demanding economics of moving into ever-deeper water. In the 1960s, the industry imported certain early-stage technologies from the US Gulf of Mexico to develop gas fields in the shallow waters, typically 30-40m deep, in the southern North Sea. This technology was developed considerably in the UK during the 1970s and 1980s, as the industry moved north and into water depths of 150 to 200m – then considered to be very deep water. This fivefold increase in depth required significant increases in the size, weight and robustness of fixed platform design, together with the construction equipment needed to install it. In the mid-1990s, development commenced, and continues to this day, in much deeper water, at depths of 400 to 1,000m, in the West of Shetland basin – see *Underwater networks*.

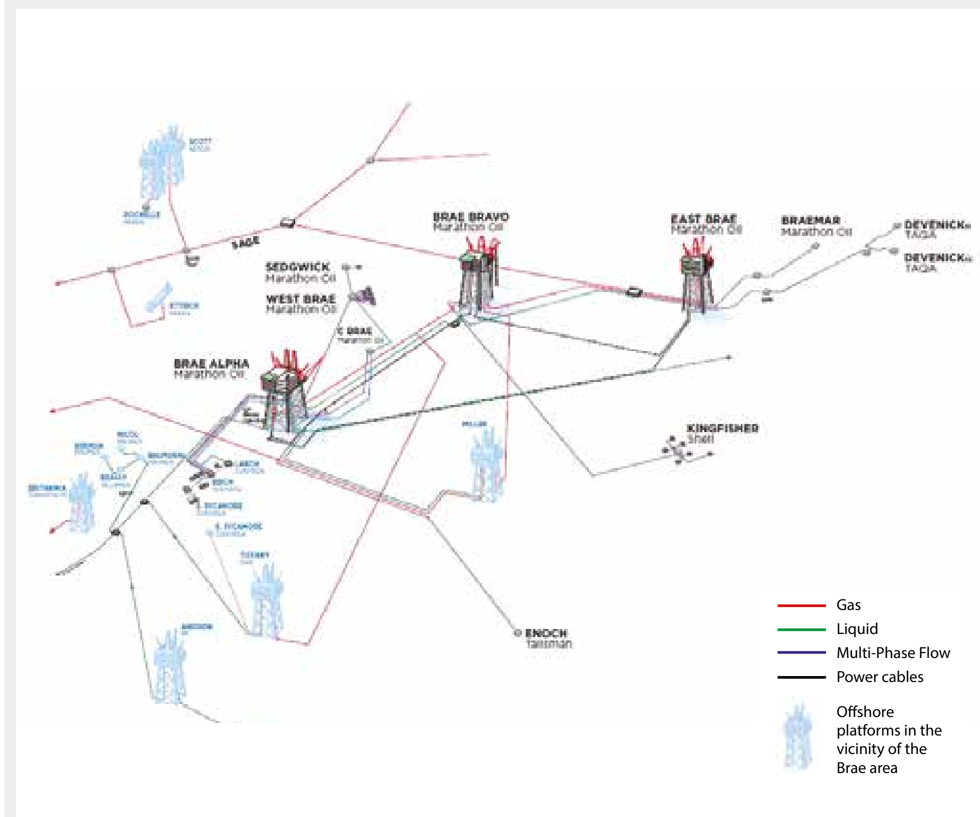
As a part of this move to deeper waters, in the 1980s and 1990s, the industry also adopted floating production facilities, such as the floating production, storage and offloading (FPSO) system. The FPSO is essentially a tanker-sized ship with built-in processing, oil storage and offloading systems.

The good news is that the development of these seabed technologies has created a new oilfield services industry, the SURF market. The bad news is that much of the existing infrastructure in the North Sea is more than 30 years old, and is at or beyond its initial design life. This can create volatility in production when operators need to upgrade the systems or conduct extended maintenance, or when operational mishaps result in wells being shut-in. This can have a

UNDERWATER NETWORKS

The UK has developed an extensive network of large fixed offshore production platforms and extensive pipeline systems for exporting oil and gas ashore. Acting effectively like a network of cities and highways, these facilities are, for the large part, still in operation today.

Since the 1990s, the industry, in the most part, has been filling in the 'suburbs' surrounding the 'cities', or central nodes in the network, with step-out and tie-back developments. These function in a hub-and-spoke arrangement to leverage the existing production and transportation infrastructure. The industry is now developing yesterday's stranded and economically marginal reservoirs with this infrastructure, together with the competitive cost of using existing facilities.



The UK has a large network of legacy offshore production facilities. The Brae field, operated by Marathon Oil, is located 220km off the Scottish coast. The field was discovered in the mid-1970s and three production centres have produced around 70 million tonnes of oil since the initial development in 1983. The main platforms currently produce from underlying reservoirs, with regular infill drilling undertaken to identify and exploit undrained pockets in the Brae stratigraphy. A number of subsea tieback fields in the area produce through-facilities on the platforms, extending their viability for years to come © Marathon Oil compounding effect when several fields are routed through a common hub. The need to reduce this volatility in production has created a strong market for the inspection, repair and maintenance (IRM) of subsea facilities, as part of an industry-wide asset integrity and assurance programme.

INCREASING RECOVERY RATES

Given the large scale of investments and inherent reservoir production uncertainties, the industry is naturally conservative in design decisions. New technology is welcomed in a controlled and incremental way, with an emphasis on continuous improvement that brings considerable efficiencies over time. The SURF business, worth approximately $24 billion (£15 billion) a year worldwide and $7 billion (£4 billion) annually in the UK, is competitive and focused on economic efficiency as a result of technical and operational performance.

This asset-intensive business requires sizeable manufacturing plants and yards to make production hardware and large specialist ships and equipment for installing it on the seabed. There are always dangers in oversimplifying the picture, but in essence the market addresses the need to connect subsea production wellheads, called wet trees, to production facilities on the surface of the ocean. The fixed or floating production platform typically stabilises and separates the oil, gas, water and sand deposits in the well stream before exporting the hydrocarbons to shore. There are often many wellheads in an oilfield and considerable design effort goes into the field architecture, for both short and long term production plans.

SUBSEA COMPONENTS

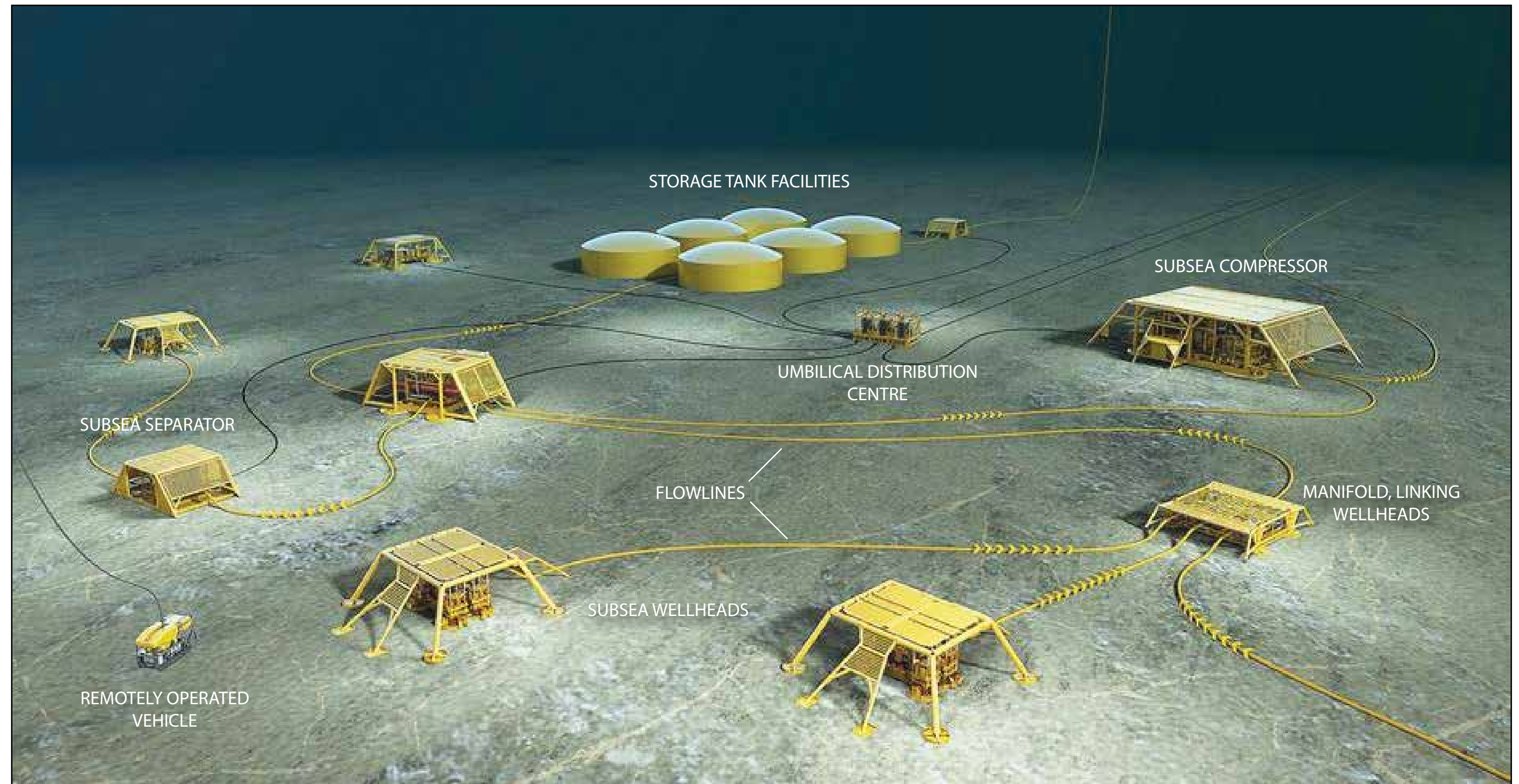
A subsea control umbilical being loaded into a large storage carousel located within the cargo hold of an offshore construction vessel. These specialist ships are able to automatically load umbilicals, many kilometres in length and several thousand tonnes in weight, at the quayside and accurately lay them on the seabed offshore. Remotely operated vehicles or divers then connect them to production hardware on the seabed

Umbilical - A wellhead comprises a series of high-pressure valves, sensors and instruments for controlling the flow of the oil and gas well stream. The subsea umbilical, which facilitates this control, consists of a number of tubes for hydraulic power to operate valves, electrical cables for powering equipment and optical fibres for data transfer. Other tubes can be added for chemical injection of the well and well stream. These components are often wound together to form a single helical cable or umbilical, typically 150-250 mm in diameter. In essence, it is the Ethernet cable of the subsea business.

Riser - Many types of riser system have been developed to transport oil and gas from flowlines on the seafloor to the surface production facility and to transport water from the surface to re-inject it back into the reservoir. Flexible and rigid steel pipe have been combined in ingenious ways for deep water use. All share the feature of being highly engineered solutions to cater for dynamic loading and the behaviour of the well stream on its journey to the surface. Risers vary in size and complexity and, importantly, with depth. In ultra-deep water, the riser needs to sustain its performance through the water column of several kilometres, spanning significant ranges in pressure and temperature.

Flowlines - The flowline is pivotal to the array of seafloor hardware for transporting oil, gas and water. Flowlines are usually relatively small diameter pipelines, no more than 30 centimetres or so. The pipe is normally rigid steel, manufactured in 12m sections or 'joints' of various material grades and mechanical characteristics. The design of the flowline must take into account the mechanical performance needed to sustain the pressure of the oil and gas, and the heat insulation and heat capacity needed to keep oil and gas flowing. There is a whole discipline of engineering in the business called flow assurance, which addresses the flowline insulation requirements to keep oil and gas flowing at the designed pressures and temperatures, without forming waxes or solids that could block the system. This is particularly relevant for heavier, thicker or low temperature oils.

Today's vessels use dynamic positioning rather than anchors to stay on location: propellers and thrusters keep the ship in position, controlled by computers connected to surveying systems such as GDPS, microwave, and acoustic positioning systems



The realisation of a vision for a 'subsea factory' is in sight. Today, the industry has fully commercialised, to great effect, the design and installation of subsea wells, flowlines and their associated hardware. Soon, more and more of the production processes, hitherto located on the topside facilities of fixed or floating platforms, will be relocated to the seabed. This will realise many opportunities for the industry for years to come in deeper, harsher and more remote environments around the world © Statoil

It is important to recognise that the recoverable reserves within an oil reservoir represent only a fraction of the actual oil in place. Recovery rates of 35-40% are typical today. As a consequence, there is a significant economic upside to improving recovery. The SURF market forms part of the picture of optimising production with an array of technologies, generally known as increased oil recovery (IOR) strategies.

The SURF market consists essentially of three generic hardware components: subsea umbilicals that control the systems, risers that carry oil and gas from the seabed to surface production facilities and flowlines that carry hydrocarbons across the seabed – see *Subsea components*.

The new model of North Sea operations, with smaller fields connecting to an extended infrastructure, also calls for new approaches to installing and maintaining systems. There are similarities between the vessels and equipment used to install flexible products such as umbilicals and flexible risers and flowlines, and vessels used to install rigid risers and flowlines.

Today's vessels use dynamic positioning rather than anchors to stay on location: propellers and thrusters keep the ship in position, controlled by computers connected to surveying systems such as GDPS, microwave, and acoustic positioning systems. These specialist ships have large power generation systems (15-30MW) for station-keeping in bad weather. The complement of crew for a flexible lay vessel is typically 100-150, and 150-500 for a rigid 'pipelay' ship.

None of the principal pipelay methods are particularly new, but they have been refined extensively over time and are highly optimised for operational efficiency.

PIPELAYING METHODS

A reelship laying a flowline at sea. When loaded onshore, the flowline is plastically strained as it is spooled on the reel. When offshore, the process is reversed and the flowline passes through a three-point straightener before being laid via tensioners positioned on a variable-angle ramp. The technology is extremely efficient for the relatively short flowlines used in the hub-and-spoke architecture in the North Sea SURF market © Subsea 7

The pipelaying vessel lowers the pipelines onto the seafloor in a continuous process through a series of tensioners that grip and squeeze the outside of the pipes, holding the full weight of the line in the water column as it is laid. The scale of equipment for this efficient process is large for ultra-deep water, with top-tension capacities of 500 tonnes or more. There are several competing techniques for installing rigid steel flowlines.

The early development of the North Sea required large-diameter (about a metre) 'trunklines' for transporting oil and gas several hundred kilometres ashore. The overwhelming need today is for infield and intrafield flowlines. Two methods involve welding pipe joints together onshore (reel-lay and bundles) and then taking them offshore. Two other processes (S-lay and J-lay) involve welding the pipe joints together offshore.

The reel-lay method uses large purpose-built ships to spool pre-welded pipe onto a large reel, typically 3,000 tonnes, and fitted mid-ships. The vessel then travels offshore and reverses the technique to unspool the flowline onto the seabed. The reeling process plastically deforms the pipe, within predetermined limits, and the pipe is straightened again as part of the laying process. This fast technique reduces the need to wait for a favourable weather-window offshore. Onshore welding also helps take the weather out of the picture and reduces the operating cost of laying pipe offshore.

The bundle method is another land-based fabrication method. Multiple flowlines are preassembled inside a large outer carrier pipe, typically 1m to 1.5 m in diameter. The whole assembly, often 5 km - 7 km long, is then towed off the beach to the North Sea location using what is called the controlled depth tow method (CDTM). The technology has been developed to a high degree over many years and the process has established a strong niche in the market.

MAINTAINING OIL AND GAS FIELDS

The high-end inspection, repair and maintenance (IRM) business in the UK is worth around $1 billion (£600 million) annually and $5 billion (£3 billion) worldwide. The requirements are extensive and range from simple visual inspections of production hardware, as part of regular underwater surveys, to sophisticated structural repairs and modifications to platforms. The practice extends throughout the whole life of the field and encompasses many disciplines, such as: structural, welding, corrosion, and geotechnical engineering.

While much of the recent progress in the North Sea has been in the use of new technologies that automate the installation and maintenance of new and existing infrastructure, there is still a need for divers for a good deal of intervention work on the seabed – see *Intervention alternatives*.

In many ways, the North Sea has been a laboratory for many of the processes, hardware and techniques in use globally today. The North Sea oil and gas industry has been instrumental in the development of new technologies for the domestic market that went on to be exported to other parts of the world.

The remotely operated vehicle (ROV) is the system of choice for subsea intervention in deep water. ROVs are deployed to the required working depth from specialist construction vessels and remotely controlled by a team of pilots and technicians onboard the ship. An umbilical cable provides necessary electrical power and control telemetry for 'flying' the vehicle and operating the manipulator arms and tooling systems. Like the airline industry, ROVs are today in constant operation around the clock worldwide

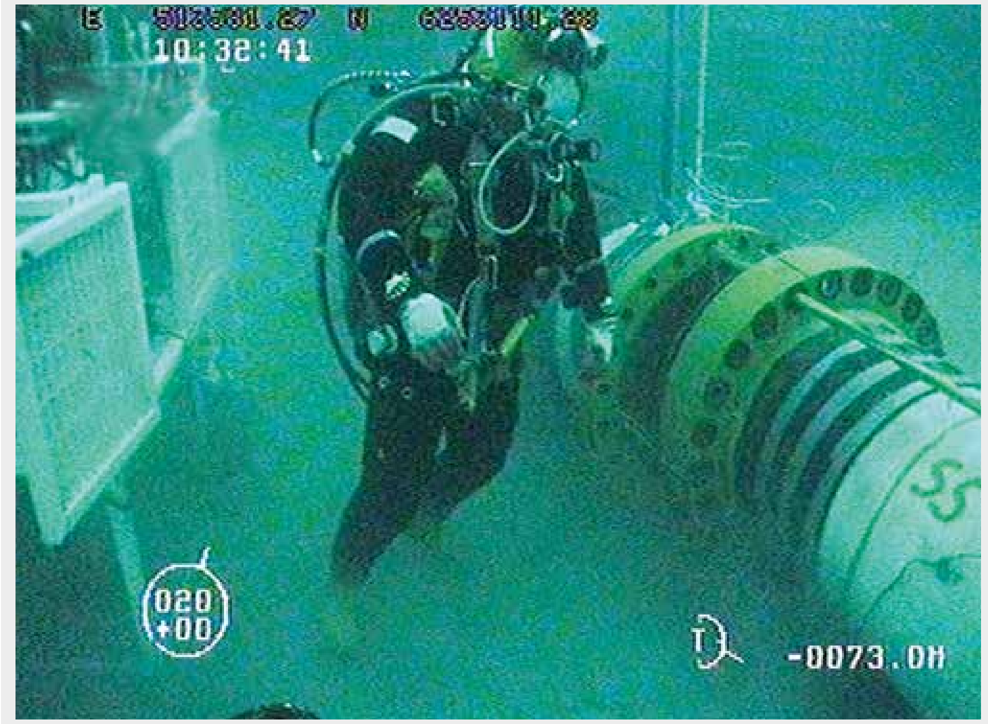
For example, North Sea operators developed and commercialised much of the modern subsea production hardware, together with the installation ships, equipment and techniques, as well as the maintenance and operating regimes for keeping production flowing every day, year-in and year-out.

SUBSEA FUTURE

Today, the UK plays a significant role internationally, as a centre for technology and business, with strong exports of products and services. Despite the oilfield maturity of 50 years of exploration and production, the prospects for the North Sea are still very good.

The accelerated depletion in production in recent years has been well recognised, and steps are now in place by the government to implement the recommendations of the influential Wood Report for maximising the economic recovery of the UK continental shelf.

This strategy will create a new industry regulator to drive collaboration across industry, together with pursuing multiple objectives around asset stewardship, new technologies, exploration, and infrastructure development. This is no small job, given that today the UK has over 300 offshore fields to manage. Since the 1960s, the North Sea and wider UK continental shelf has produced some 42 billion barrels of oil and gas equivalent to oil (BOE). The prize of this new strategy will be to recover another 12-24 billion BOE over the next 20 years and maximise the economic benefit to the United Kingdom. There is no doubt that the subsea industry will play an important role in this endeavour.



A diver at work on the seabed connecting two sections of pipeline with hydraulically operated bolting equipment. Divers live in a large saturation diving complex onboard a diving support vessel for 14-28 days at significantly elevated pressures to simulate the working depth of the mission. The divers breathe heliox, a managed mixture of the partial pressures of helium and oxygen, which saturates their body tissues. This technique avoids the risks associated with repeated short-term compression and decompression

INTERVENTION ALTERNATIVES

The UK was a pioneer in the commercialisation of deep-water saturation diving techniques, as well as in the evolution and development of equipment to make it safe and efficient. There is still strong demand for deep diving in the UK, and an active market for state-of-the-art diving support vessels (DSV). A DSV today will be dynamically positioned with two diving bells for round-the-clock diving. The diving bell will usually hold three divers, two of whom will 'lock-out' and go to work, while the third stays in the bell as a safety stand-by diver. The processes today are highly optimised, with large saturation diving chambers and life support systems.

In deeper water, beyond, say, 250m, remotely operated vehicles (ROVs) are the sole commercially viable intervention technology on a large scale. The work-class ROV is an electro-hydraulically powered (100-200kW) underwater flying vehicle, approximately the size of a small car, equipped with an array of cameras and remotely controlled manipulators and tooling systems for conducting construction and intervention tasks. An umbilical links the vehicle-to-surface power and control facilities on the vessel, where pilots and technicians drive and manoeuvre the vehicle remotely.

BIOGRAPHY

Allen Leatt FREng is Senior Vice President Engineering at Subsea 7, based in London. He was closely involved in early formation of what is now known as the subsea industry, and has held senior management positions with industry-leading organisations. He has worked internationally in both the construction and manufacturing sectors of the industry.