Global Marine Technology Trends 2030

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Global Marine Technology Trends 2030

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Foreword

What's next? It's a simple question to ask, but it's not so simple to answer. Along with our stakeholders, we are constantly scanning the horizon to see what's coming, and what the future will hold for our world, our business and our lives. The answers are not immediately evident and, as we demonstrated in Global Marine Trends 2030 and Global Marine Fuel Trends 2030, there is never a single well-defined future.

The future poses many challenges but also opens many new opportunities. World trade is expanding. Shipping as its workhorse is undergoing a transformation and facing huge challenges in maintaining competitiveness. The shipping industry is constantly searching for cost-effective technology and business solutions to 'future-proof' their fleet and assets. The rule of the market economy – constant operational change to meet changing customer needs – is forever putting pressures on ship operators. Technologies can help in solving the environmental challenges and improving operational efficiency in the business world of the 21st century. With the explosion of consumption demanded by the growing middle classes from developing countries, the demand for raw materials, food and energy production will increase. With land-based resources depleting rapidly, attention will necessarily turn to ocean space for alternatives; efforts here will require sustainable technologies to protect the environment.

The emerging shift of geopolitical configurations and trade fragmentation has resulted in a competition between nations at sea. While this development will pose threats to peace and stability, new business opportunities are likely to open up for naval suppliers as a result of the increased demand for naval systems of all sorts. The search for new and cost-effective technologies to enhance many roles that the navy is required to play is forever pressing.

The speed of innovation is rapid and the introduction of new technologies is swift, which means that predicting which technologies will transform commercial shipping, ocean space exploitation and naval operations is always a challenge. A team from Lloyd's Register, QinetiQ and the University of Southampton, using publicly available information, proprietary data and horizon scanning methodology, has produced Global Marine Technology Trends 2030. This represents our look towards the future of technology and provides a glimpse of the future these evolving technologies may provide by 2030.

We hope that you will find Global Marine Technology Trends 2030 interesting and thought-provoking. We encourage you to take the time to read this important piece, reflect on what the future of technology means for you and your organisation, and then take all the steps necessary to deliver on technology's enormous potential to create value.

Richard Sadler
Chief Executive Officer
Lloyd's Register Group Limited

Executive Summary

Technology development is accelerating and will continue to do so. There is no indication that its rapid pace will slow in the next 15 years, nor will the trend toward the increasingly integrated nature of technology applications reverse. While the technology revolution is extensive, it will play out differently in commercial shipping, naval, and ocean space sectors. The Global Marine Technology Trends 2030 (GMTT2030) Report, developed by Lloyd's Register, QinetiQ and the University of Southampton, aims to help marine stakeholders understand the long-term challenges and opportunities that come with these technological changes. We hope it will also inform, energise and inspire young people and the wider public with respect to these exciting industries which play a vital role in job and wealth creation in an expanding world economy.

This report is a call to action for the worldwide shipping, naval, and ocean space industries. We believe that with far-sighted leadership, these three sectors can take advantage of these technologies for a prosperous, safe , sustainable and secure future. The report outlines the fundamental marine technology trends organisations can expect to see in the next 15 years, and their industry-wide impact in three interconnected sectors.

We examined more than 56 critical technologies that might possibly be developed and implemented around 2030 by the commercial shipping, naval, and ocean space sectors. Of these, we selected for further analysis 18 technologies that scored the highest in a net assessment combining technical feasibility on a commercial basis, potential marketability, and, most importantly, their transformational impact on the respective sectors. These 18 technologies are robotics, sensors, big data analytics, propulsion and powering, advanced materials, smart ship, autonomous systems, advanced manufacturing, sustainable energy generation, shipbuilding, carbon capture and storage, energy management, cyber and electronic warfare, marine biotechnology, human–computer interaction, deep ocean mining, human augmentation, and communication.

For each sector, we picked eight technologies for their transformational effects when used individually and in combinations. We analysed and assessed individual technology from four different perspectives:

- A concise explanation by a technology provider who wishes to sell to a potential buyer
- A concise business case by a buyer who wishes to raise capital from an investor
- An assessment by an investor on the risk and uncertainties
- An examination of the technology's wider transformational impact.

In the commercial shipping sector we evaluated robotics, sensors, big data analytics, propulsion and powering, advanced materials, smart ship, shipbuilding, and communication technologies. These technologies are transformational in nature when used individually and when combined.

We envisage that these eight technologies will be implemented differently from ship type to ship type. These ships will be called TechnoMax Ships as technology implementation will be at the optimal level in 2030. These ships will be smarter, data driven, greener, with flexible powering options, fully connected wirelessly onboard, digitally connected through global satellites.

TechnoMax Ships will require fundamental changes in terms of design, construction, operation and supply chain management. They will be designed by technologically-advanced shipbuilders, ordered and operated by owners to sharpen their competitiveness and boost their corporate social responsibility credentials.

The successful implementation of these technologies will depend on a favourable regulatory framework, technical standardisation on a worldwide scale and cooperation between marine stakeholders

In the naval sector, we concluded the big data analytics, advanced materials, autonomous systems, advanced manufacturing, energy management, cyber and electronic warfare, human–computer interaction and human augmentation technologies are transformational in nature when used individually and when combined.

Making use of these technologies will increase a navy's ability to project military power, which is directly dependent on gaining full-spectrum battle space access, including cyberspace, and on the capacity to coerce, deter and intervene in its warfighting role to protect national interests.

These technologies will also increase a navy's capacity to deliver humanitarian aid and disaster relief in times of crisis, to protect a nation's citizens, territory and trade from terrorism, crime, piracy, state-sponsored insurgency, and illegal restrictions on freedom of navigation.

In the ocean space sector, we found that big data analytics, advanced materials, autonomous systems, sensors and communication, sustainable energy generation, carbon capture and storage, marine biotechnology and deep ocean mining are transformational in nature when used individually and when combined.

These technologies will provide a deep understanding of the ocean space which may be used to help address the effects of climate change, the reduction of land-based resources, and the increasing population. Through the use of these technologies, we can better protect people living in coastal areas from extreme natural forces such as hurricanes and tsunamis. They can also be used to protect the ocean environment from excess exploitation and misuse as we gain a deeper understanding of the impact of human activity on the geology, meteorology and ecology of the ocean space.

Given the depletion of land-based resources, people will increasingly look to the ocean for food, materials, energy and medicines. In fact, the potential of the ocean to provide these resources is already being realised. It will become necessary to deploy advanced and sustainable technologies to harvest these ocean resources.

The marine technology of 2030 will integrate developments from multiple scientific disciplines in ways that could transform the design, construction and operation of commercial ships, naval assets, and ocean space equipment and systems. We envisage that a future marine world will be a connected and digital one, integrating people, software and hardware in a way that could transform how we operate and interact. A new operation paradigm will need to be created to meet these challenges across the shipping, naval and ocean space sectors.

We hope the eight technologies identified in each sector will generate debate and discussion as to their true significance, encouraging investment to make them resilient, affordable and implementable. We hope there will be parallel investment in infrastructure development, such as logistics support and regulatory framework development. We need to invest in capacity-building through the education and training of people working in these sectors. We have identified risks and uncertainties, and raised awareness and understanding within the marine communities of the complexities of these technologies and the profound changes they may bring.

The successful implementation of these technologies will depend on a favourable regulatory framework, technical standardisation on a worldwide scale and cooperation between marine stakeholders. We need to invest now and prepare ourselves for this new reality by working together to ensure a sustainable outcome.

Using Horizon Scanning

Any approach to map the future is, by its very nature, interdisciplinary, covering developments across fields with decades of research alongside ideas conceived just last year. Most people in management positions in organisations would say that they scan the environment, and indeed, nearly all of us are doing some form of scanning in our personal and professional lives every day—whether we realise it or not.

Almost all foresight work starts with or involves horizon scanning. The Global Marine Technology Trends 2030 project used a methodology that is primarily qualitative, but which also includes quantitative elements.

Horizon scanning involves systematically exploring the external environment to better understand the nature and pace of change. This understanding leads to identifying potential opportunities, challenges, and likely future developments relevant to our stakeholders. Horizon scanning explores new and sometimes weird ideas, as well as persistent challenges and trends today. It is the feedstock for strategic thinking, innovation, and risk and issues management.

The goal of horizon scanning is, therefore, to answer the question of how the future will be different. Important socio-economic, political, environmental, scientific and technological trends will influence this answer. This helps us to identify the potential opportunities and threats for the organisation implied by these trends, situations, and events.

There is also a need is to understand the characteristics of future challenges facing the commercial shipping, ocean space, and naval sectors. These then provide a basis for analysing future investments and opportunities to assist strategic planning and decision-making.

Horizon scanning is both an intelligence-led and evidence-based method for obtaining answers to key questions about the future. It is the best place to start when people desire more information on a particular upcoming trend, uncertainty, or wild card that may affect them or their domain. By collecting, analysing, and picturing what's likely or unlikely to happen within the global environment, mental models of possible and probable futures can be created. By choosing preferable futures, people and organisations can shape their and our tomorrows.

Our approach involved a systematic use of workshops, research, brainstorming sessions, and interviews of selected experts. The nature of our data sources is both quantitative, such as statistical data, and qualitative, such as expert opinions, experiences and personal perspectives. We also reviewed media articles, websites, conference event proceedings, and interviewed individuals within organisations.

Horizon scanning, for us, was not about being certain, but rather about being comfortable with uncertainty, ambiguity and complexity.

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Using Horizon Scanning

Step 1 – Scoping
Identify key stakeholders and key sectors

Step 2 – Environment
Identify competitive landscape

Step 3 – Content Generation
Identify critical technologies

Step 4 – Evaluation
Assess and identify transformational technologies

Step 5 – Recommendations
Outline future impact and actions

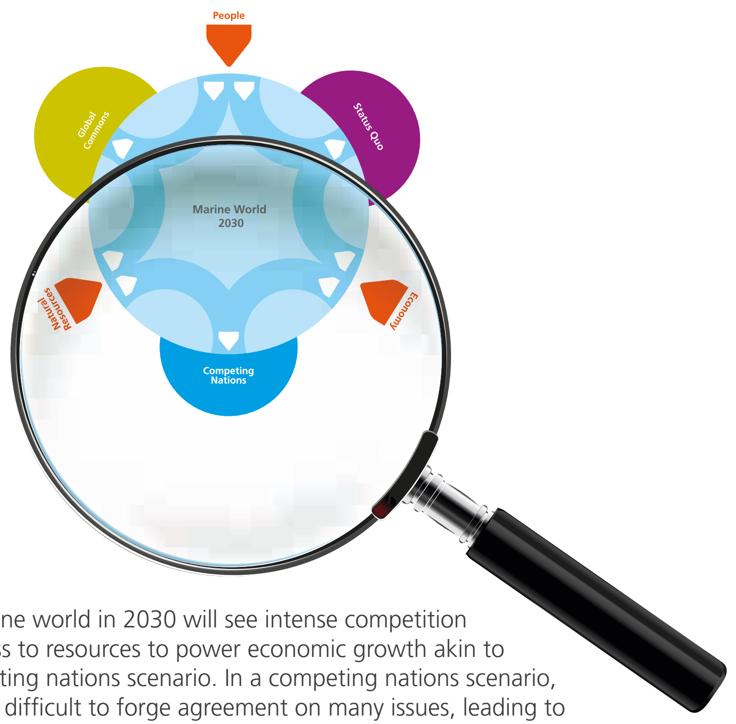
The Marine World 2030

Global Marine Trends 2030 (GMT2030) demonstrates that the shape of the marine world in 2030 will depend on the interactions between people, economies and natural resources. Using publicly available and proprietary information, and a scenario development methodology, GMT2030 envisions three possible scenarios, namely Status Quo, Global Commons, and Competing Nations.

These three scenarios were shown to have different impacts on individual marine sectors. The commercial sector is influenced by economy, people and natural resources, while the energy sector is influenced by economy and natural resources. In the naval sector, we find that the primary driver is economic power. In all cases, the marine industry will see growth, and will play expanding and positive roles in international seaborne trade and the global economy. We have decided to focus on three scenarios separated by degrees of global political cooperation. At global and local levels, the interaction between people is at the heart of business and the economy.

The GMT2030 Report led us to conduct the Global Marine Fuel Trends 2030 (GMFT2030) study which uses a similar scenario-planning methodology and similar principles. GMFT2030's central objective is to unravel the landscape of fuels used by commercial shipping over the next 16 years. The problem has many dimensions: a fuel needs to be available, cost-effective, compatible with existing and future technology, and compliant with current and future environmental requirements. The future of the marine industry itself is irrevocably linked with the global economic, social and political landscape of 2030, which in turn drives future marine fuel demands.

The marine world in 2030 will see intense competition for access to resources to power economic growth akin to a competing nations scenario



The marine world in 2030 will see intense competition for access to resources to power economic growth akin to a competing nations scenario. In a competing nations scenario, it will be difficult to forge agreement on many issues, leading to regulatory fragmentation, rise in protectionism and potential conflict. It will be difficult to provide a concerted international response to environmental and humanitarian disaster. Sophisticated and affordable technologies will help us to meet some of these challenges.

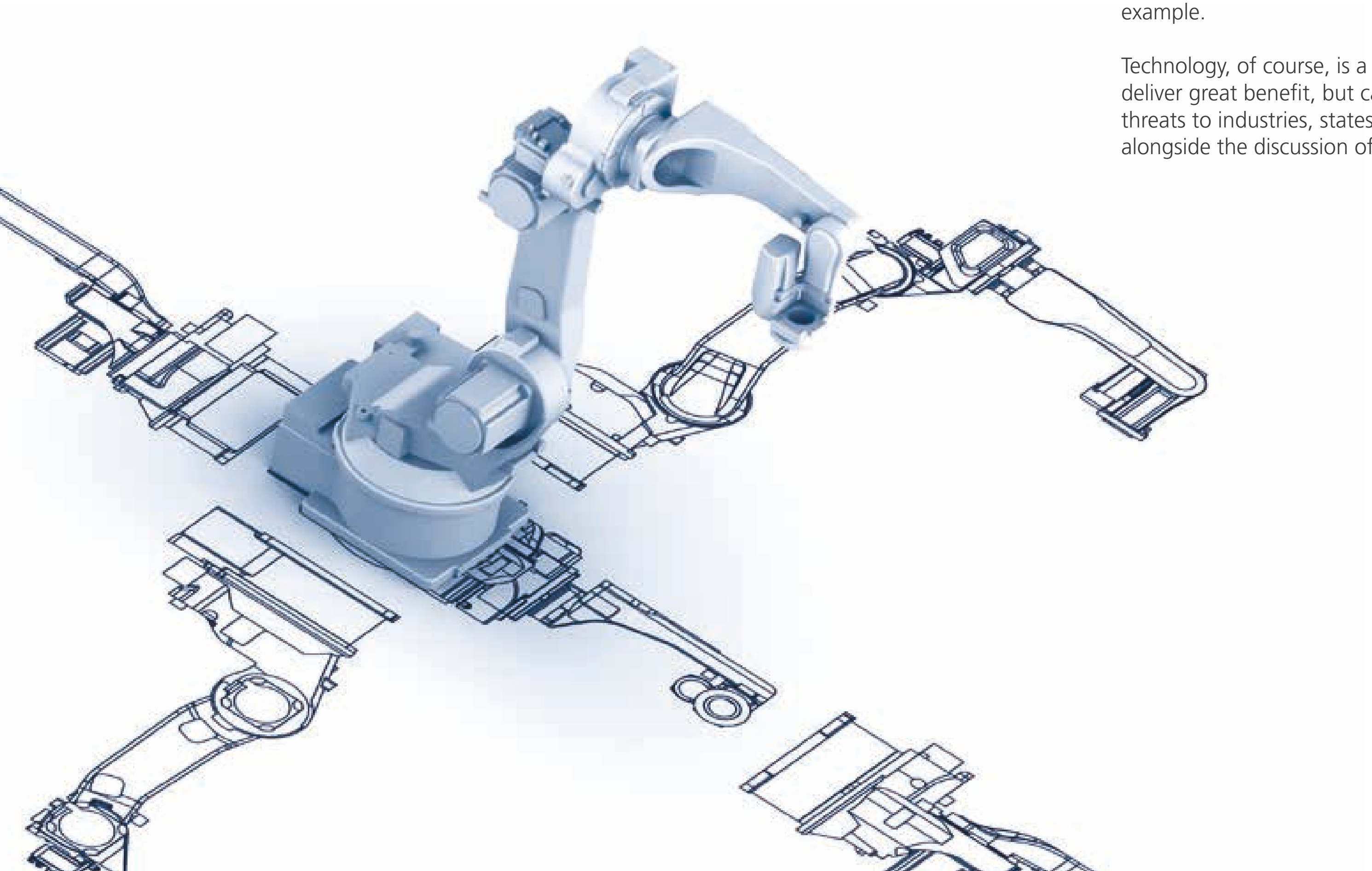
This Global Marine Technology Trends 2030 (GMTT2030) Report represents our look towards the future of technology. Technology trends are not isolated. They are intimately intertwined with societal trends, sustainable-resource exploitation, jobs, wealth, peace and war. Technology touches everyone in the modern world. It is at the heart of a nation's and company's competitiveness, driving business performance, and enriching people's lives like never before.

GMTT2030 examines a range of technologies with the potential to transform the marine domain in the next 15 years. Technology changes quickly and so do economic and political circumstances. In GMTT2030, we adopted a horizon scanning methodology which led to one being comfortable about a solution or path that is associated with three factors underpinning any future, namely uncertainty, ambiguity and complexity.

In GMTT2030, three important messages are apparent. Firstly, there are strong opportunities for growth in the commercial shipping, ocean space, and naval sectors in the future if businesses can harness the scientific and industrial capabilities required to take advantage of the technologies and innovation identified. Secondly, the commercial shipping, ocean space, and naval sectors will undergo a rapid transformation as competition intensifies and technologies mature in other sectors. Thirdly, there continues to be a critical need for a stable, coherent framework of regulation and support, so that the private sector has the confidence to invest.

Transformational Technologies

As the pace of technology development accelerates in the 21st century, the transition time between emerging and mature technologies continues to be shortened. In this new reality, the early identification of emerging technologies that will have significant value and impact on the commercial shipping, naval, and ocean space sectors will benefit policy- and decision-makers, helping them to make the right investment decision at the right time. It will also help to identify risks and opportunities.



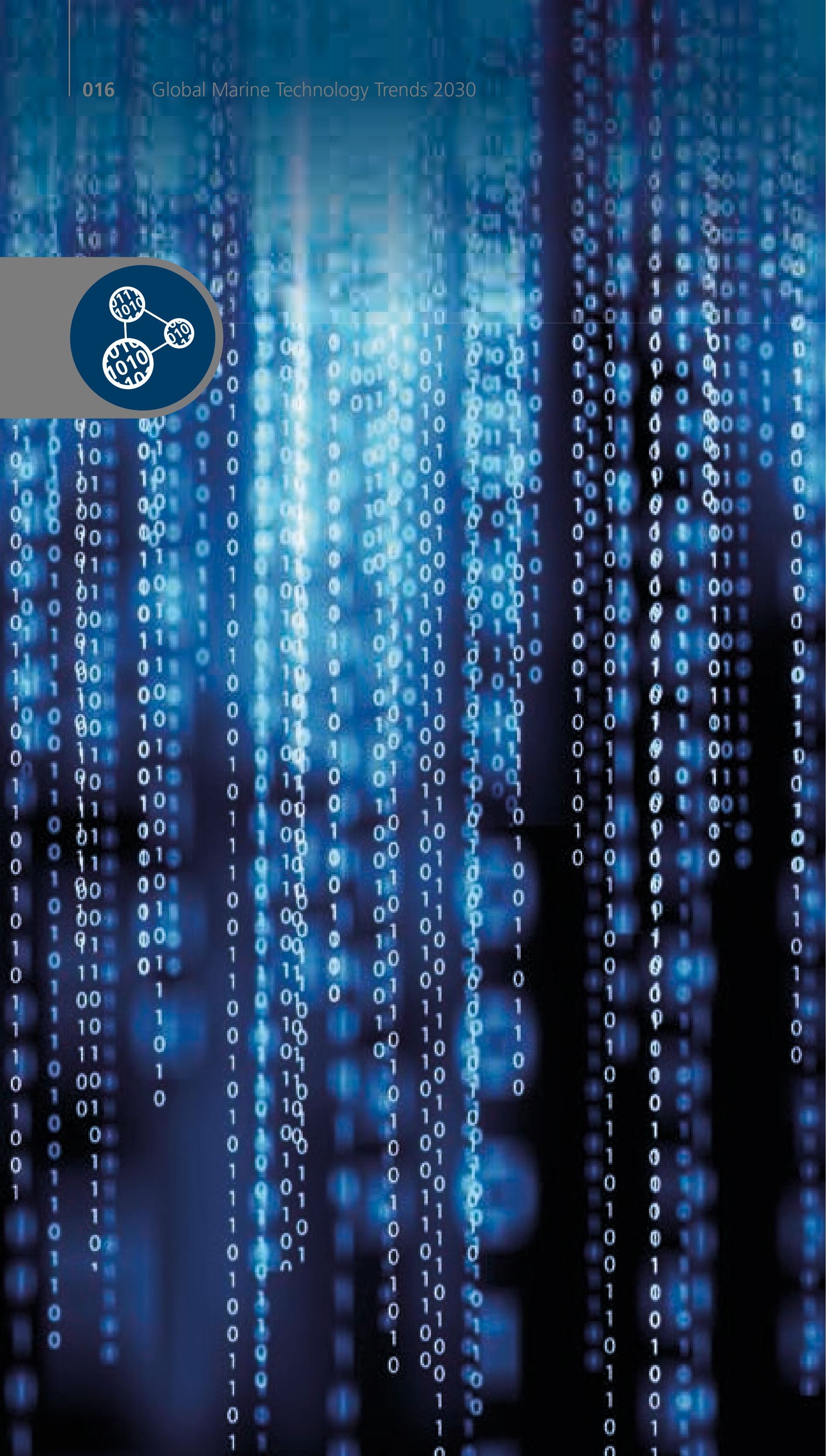
This report presents the results of a set of foresights into global marine technology trends and their implications for the marine world in the year 2030. The team surveyed more than 56 technologies and investigated their relevance to each sector. All these technologies carry substantial momentum and are the focus of continued research, development and debate. Marine applications require the integration of multiple technologies. New approaches to harnessing solar energy include the use of plastics, biological materials, and nanotechnology, for example.

Technology, of course, is a double-edged sword and has the power to deliver great benefit, but can also introduce both direct and indirect threats to industries, states and economies. This needs to be considered alongside the discussion of each technology.

The team identified 18 generic technologies with the greatest combined likelihood of being widely available and in demand in 2030. While some will affect only one sector, others will affect multiple sectors. However, the way they will be interpreted and implemented in each sector will be substantially different, as the drivers and outcome will vary. Each sector picked eight transformational technologies from the 18, and illustrated their investment attractiveness, highlighted their risks and uncertainties, and evaluated their sector-wide impacts. The implementation of these eight technologies on a specific application for each sector is presented based on the technology's feasibility.

These transformational technologies are often an integration of multiple technologies. The implementation of autonomous systems, for example, will require the application and successful integration of sensors, communications and robotics.

Interrelationship Between Technologies and Sectors
Due to the specific characteristics of every transformational technology, some of them will only apply to one specific sector (commercial shipping, naval, ocean space), whereas others will apply to two of them, or to all of them. By means of colour coding and technology icons, the interrelationship between technologies and sectors show how every technology applies to a certain sector, and shows those which overlap in different sectors. It also offers a holistic view as to how the transformational technologies will interact within the marine and maritime industries in 2030.



Big Data Analytics

Big data is data so large and/or complex that it is difficult to process using traditional data processing techniques and applications. The scale of the problem is well illustrated by the current estimate of a 4,300% increase in annual data generation by 2020. By 2030, that figure will have increased even further as this is an accelerating trend.

Most definitions of big data include the three Vs, data of high volume, velocity, and variety, or information assets that demand cost-effective and innovative forms of information processing for enhanced insight and decision-making. Some organisations have added a fourth V that represents veracity, which concerns the accuracy and reliability of data.

Big data analytics is a term used to describe the process of analysing this big data to uncover hidden patterns, unknown correlations, ambiguities, market trends, and other useful information.

The management and analysis of big data will become increasingly important, and we expect it to have a major impact on the marine world. It will be driven forward by the demand for information and the need to handle the variety of new data sources that are likely to appear. At the same time, big data will be subject to other factors that will threaten its adoption, such as the lack of the necessary data analysis skills required to exploit big data.

A greater volume of data won't always mean a better output. The quality of data is extremely important, and analysing poor-quality data can lead to ambiguous and misleading information, potentially resulting in poor decision-making. Big data techniques are not a substitute for information management.

In the future, we expect new technologies to emerge that will improve big data analytics. Among these will be some of the so-called 'smart machine' technologies and computing systems that process data in a manner similar to the human brain.

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Sensors

The term 'sensor' covers the wide range of devices used to measure the physical environment in which a vessel may be operating (for example, ocean data), as well as the characteristics and state of the vessel itself, and the physiological and mental condition of the crew.

Sensor technologies are developing rapidly to meet the ever-growing demand for data and information that will enable consumer-driven needs. For example, The Internet of Things, which allows real-time monitoring and control of systems and processes, from home through to medical and industrial applications. These will also address the need for ever-increasing capabilities to measure the ocean (and near-ocean) environment, including biological, acoustic and electromagnetic characteristics.

The key trends reported by many commentators are: miniaturisation coupled with low-power, low-cost requirements to meet the demands of wearable technologies; closer integration of sensors, actuators and processing (moving the intelligence into the sensors); standardisation, in particular at the junction between device and architecture (system on a chip); the low-power transmission of data and energy harvesting; and the management and integration of sensor types such as semiconductors and Micro-Electrical-Mechanical-Systems (MEMS).

Sensors will be the enabler for infant technology developments like cognitive systems in which devices are able to use natural language processing and machine learning to improve the interaction between people and machines. Cognitive systems will not be programmed to anticipate every possible answer or action needed to perform a function or set of tasks, but by means of artificial intelligence (AI) and machine-learning algorithms, they will be able to feed the learning loop in an exponential manner.

We anticipate that the widespread use of sensors already being introduced in areas such as automotive and scientific applications will expand into the marine/maritime domain, enabling better situational awareness and vessel management.

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Autonomous Systems

Autonomous systems is a rapidly expanding and diversifying technology. The technology has attracted considerable interest from transport applications, particularly in air and automotive transport. The industry is maturing and cost, robustness, endurance and regulatory challenges are being addressed by a number of initiatives at an international level.

The focus in the marine industry at present is on improving safety by taking people out of dirty, dangerous and dull jobs. We expect to see a significant increase in the use of these systems in the marine domain in the future. Along side 'stand-alone systems', we will increasingly see the use of interconnected intelligent systems to the point that completely autonomous surface and underwater vessels become accepted. The development of new products and services required to support this scenario will provide vast opportunities for an array of small and medium-sized enterprises (SMEs) and large companies in multiple markets.

In the scientific sector, long-endurance sensing will enhance our understanding of the marine environment, supporting sustainable resource usage in areas such as carbon capture and habitat monitoring. For the global offshore energy market, the improved ability to gather data and intervene using autonomous systems will reduce risks and costs while opening up exciting new operating environments.

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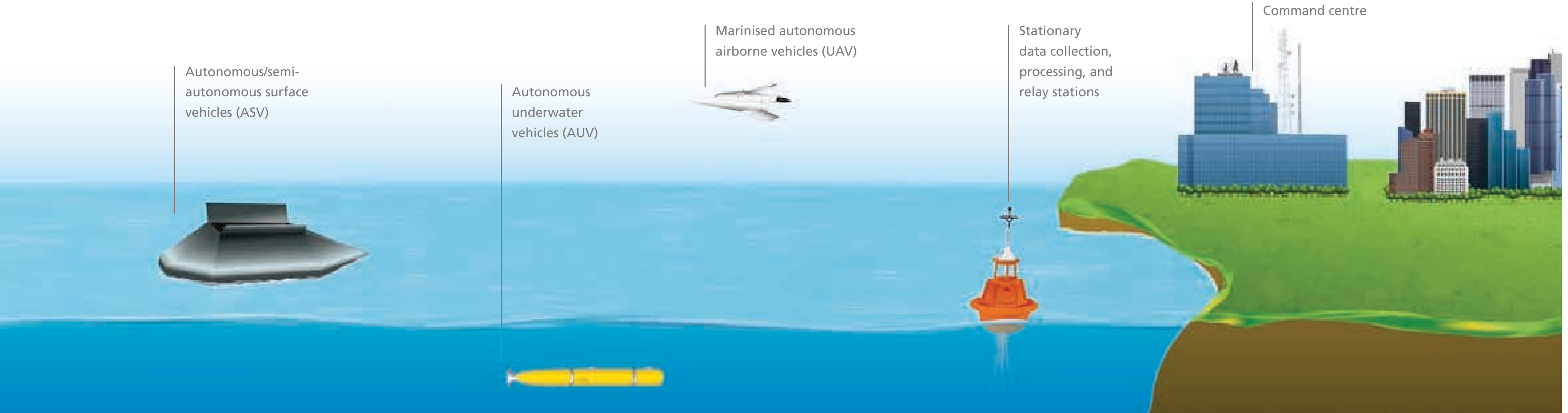

Robotics

A robot is capable of carrying out complex actions automatically. Assembly, collaboration with humans or machines, inspection, manipulation, and exploration are some examples of tasks that could be programmed into a robot. Robots can conduct different operations, from shipping to space missions.

Different levels of independent decision-making can be applied to robots. They can be remotely controlled, supervised, collaborative, or fully autonomous. Together with advances in motion control, cognition, sensing, miniaturisation, and robot-to-robot communication, enhanced robotic capabilities will stimulate market prevalence worldwide.

Driven by improving safety, security, and productivity, the widespread adoption of robotics has been observed across various sectors. Recently, industrial robots have been dominantly used by the automobile industry. Nearly half of professional service robots have been used by the defence sector. The construction and inspection business, even though small in total unit numbers, has seen some of the largest growth in the purchase of professional service robots in recent years.

Investment is likely to continue. The knowledge of technology will be expanded, revolutionising the future marine service and accelerating automation in the marine construction business. Robotics will become compulsory for tasks, especially those conducted in severe working environment, such as deep ocean mining and disaster relief.

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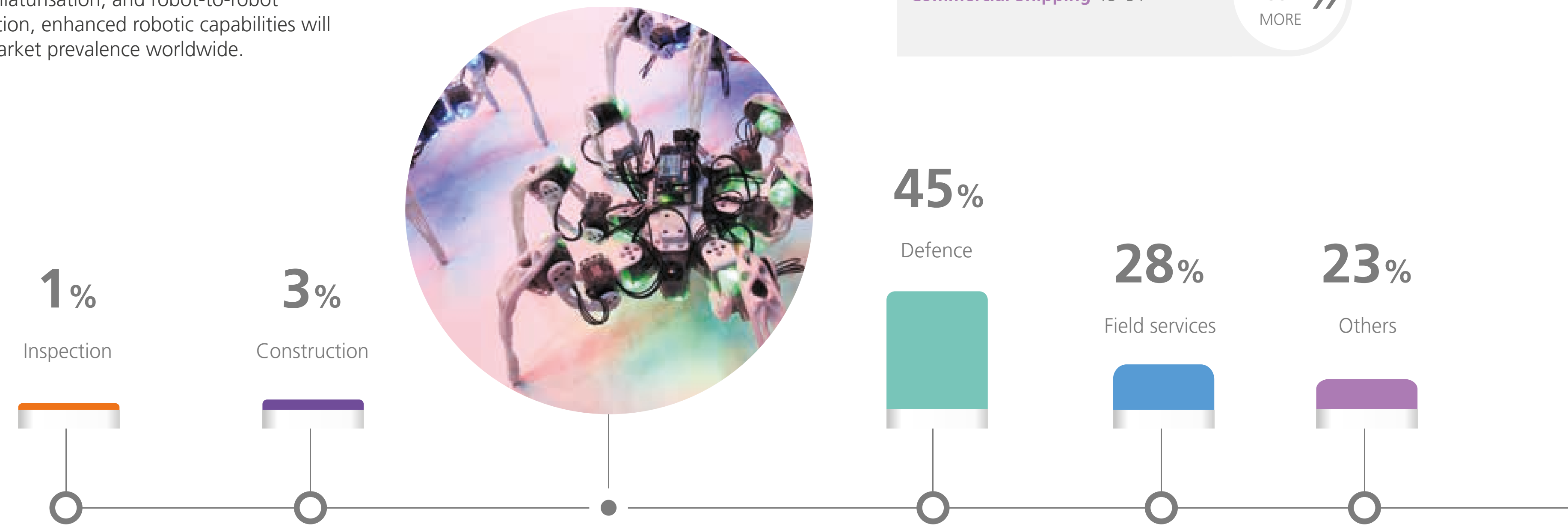

Percentage of service robot units sold for different uses in 2013. Source: International Federation of Robotics (IFR)

Smart Ship

Smart ships are being widely debated as the shipping industry's next technological revolution. In the manufacturing industry, the term 'fourth industrial revolution' describes how 'smart devices' will replace the role of humans for the management, optimisation and control of machinery. In consumer technology, this is referred to as The Internet of Things: using sensors and digital technology, our personal habits are mapped and translated to automation for the purpose of improving our daily lives.

In this context, smart ships are not a discreet technology, but a manifestation of the utilisation and exploitation of technology trends, many of which we elaborate on in this report (sensors, robotics, big data, advanced materials, communications and satellites). The application of these technologies will enable the transition into the smart ship era.

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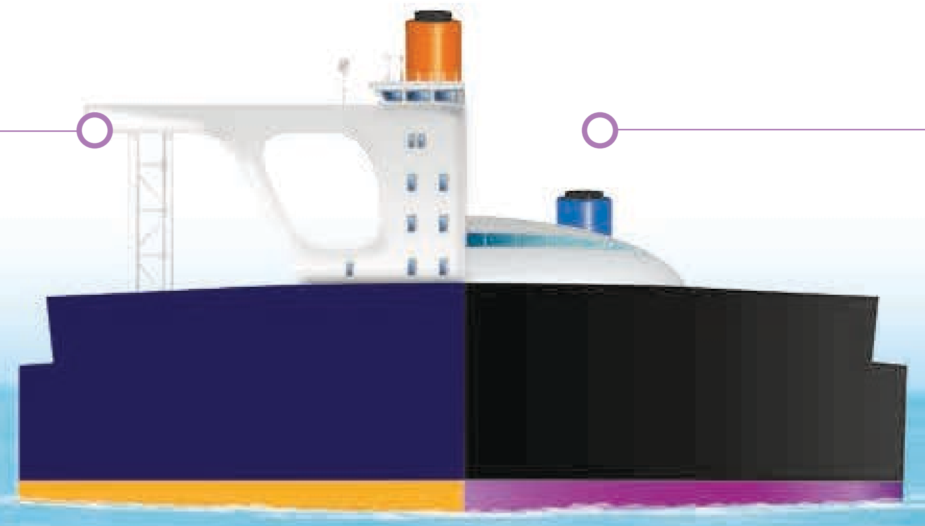
Short to Medium Term

From the Digital Ship to the Intelligent Ship:
The exploitation of big data acquisition, communications and analytics to introduce intelligent, real-time and proactive decision-making in the design, operation and maintenance of ships



Medium to Long Term

From the Intelligent Ship to the Autonomous Ship:
The exploitation of sensors and robotics technology to replace human operators, leading to semi-autonomous ships (e.g., engine-room crewless ships) or fully autonomous ships (remote controlled)

Communications

Remote operation is the norm in the marine industry. Communication technologies have therefore been crucial for situational awareness and exchanging information between different parties. The marine industry was an early adopter of some traditional communication technologies, such as radio. The capability to connect, communicate and interact with different parties and systems at sea is unfortunately much more difficult than on land. It also comes at a higher price.

Radiocommunications and satellites are examples of state-of-the-art technologies. As the technologies advance, we will begin to see fast market expansion and transition. For instance, maritime in-service units are expected to double in 15 years.

People onboard a vessel or on a platform rely on communication technologies to be socially connected to families and colleagues onshore. However, communication technologies are not just about supporting personal communication. They allow for emergency calls, geopositioning, marine-life tracking, and disaster warning. The increasing diversity and capability of communication technologies will enable the acquisition and connection of data from different sources, representing a key to open the big data door.

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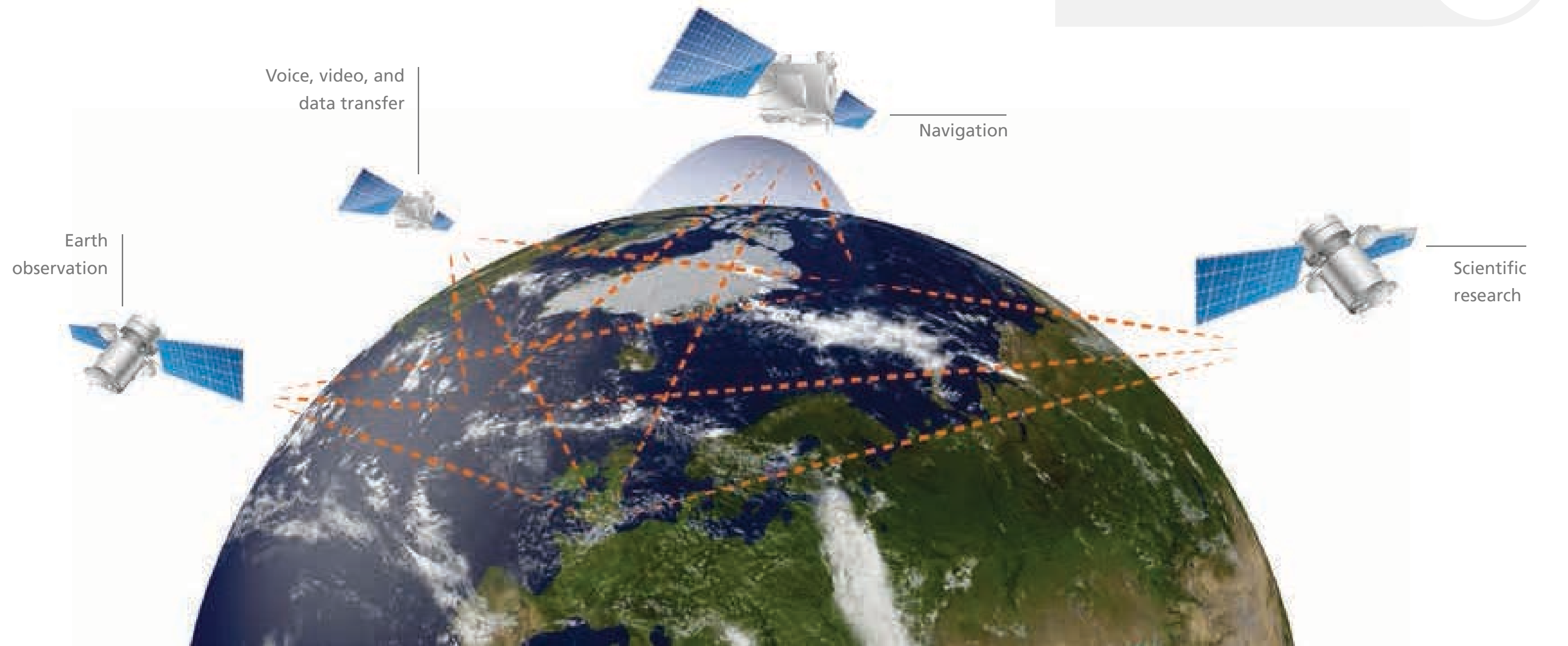

Advanced Materials

Advanced materials include all materials engineered to deliver specific physical and/or functional properties in their application.

The trend with all metallic, ceramic, polymeric and composite materials is to achieve improved capabilities such as strength, toughness, durability and other useful functionalities by designing it at the nano-scale and harnessing those properties in large structures.

The structure and properties of advanced materials at the nano-scale – i.e. one millionth of a millimetre – is now well understood, and this is leading to the challenge of manufacturing advanced materials to realise capabilities in bulk structures. This is termed nano-engineering and these materials are referred to as nano-materials.

The research and commercialisation of nano-materials will continue to accelerate and we expect large-scale structures with increasingly refined and reliable properties to be in use.

Desirable functionality, such as environmental sensing, self-cleaning, self-healing, enhanced electrical conductance and shape modification, is anticipated through the development of nano-materials, and, in turn, will deliver performance benefits in the commercial shipping, naval and ocean space industries.

Engineered Materials and Structures
Lightweight structures: Composites, adaptive, shape modification, multifunctional
Damage-tolerant systems: Self-healing, self-diagnostic materials
Coatings: Corrosion-resistant, self-cleaning, adhesives.

Energy Generation and Storage
Energy storage: Batteries, supercapacitors, hydrogen storage
Energy generation: Fuel cells, photovoltaics, piezoelectrics, energy harvesting.

Sensors and Electronics
Sensors and actuators: Chemical, biological, physical
Nano-electronics: Graphene, conductive polymers.

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Propulsion and Powering

As the demand for sea transportation increases, the global fleet is growing and ships are becoming larger in size. While efficiency has improved in relative terms (due to economies of scale), in absolute terms, the powering demands for the propulsion and power generation of ships have increased. Combined with concerns over future fossil-fuel dependency and our environmental footprint, propulsion and powering will become a key focus of technology development.

The scope of applicable technology is wide and innovation can take different forms like:

- Incremental improvement of an otherwise established technology, for example, an even more efficient slow-speed diesel engine for main propulsion
- Alternative or innovative machinery and propulsion configurations, for example, hybrid propulsion systems
- Commercialisation and deployment of novel solutions on a wider scale, such as hull air lubrication or sail-assisted propulsion.

In terms of technology application, it will vary depending on the ship type. This is due to two main reasons, the first of which is technical compatibility; for example, some energy-saving devices (ESDs) are not suitable for low design speeds, disqualifying the majority of the tanker/dry bulk fleet. The second reason is commercial compatibility; for example, high capital expenditure (CAPEX) technologies are more suitable to niche, high-value assets (e.g., cruise ships, passenger ships, offshore support vessels).

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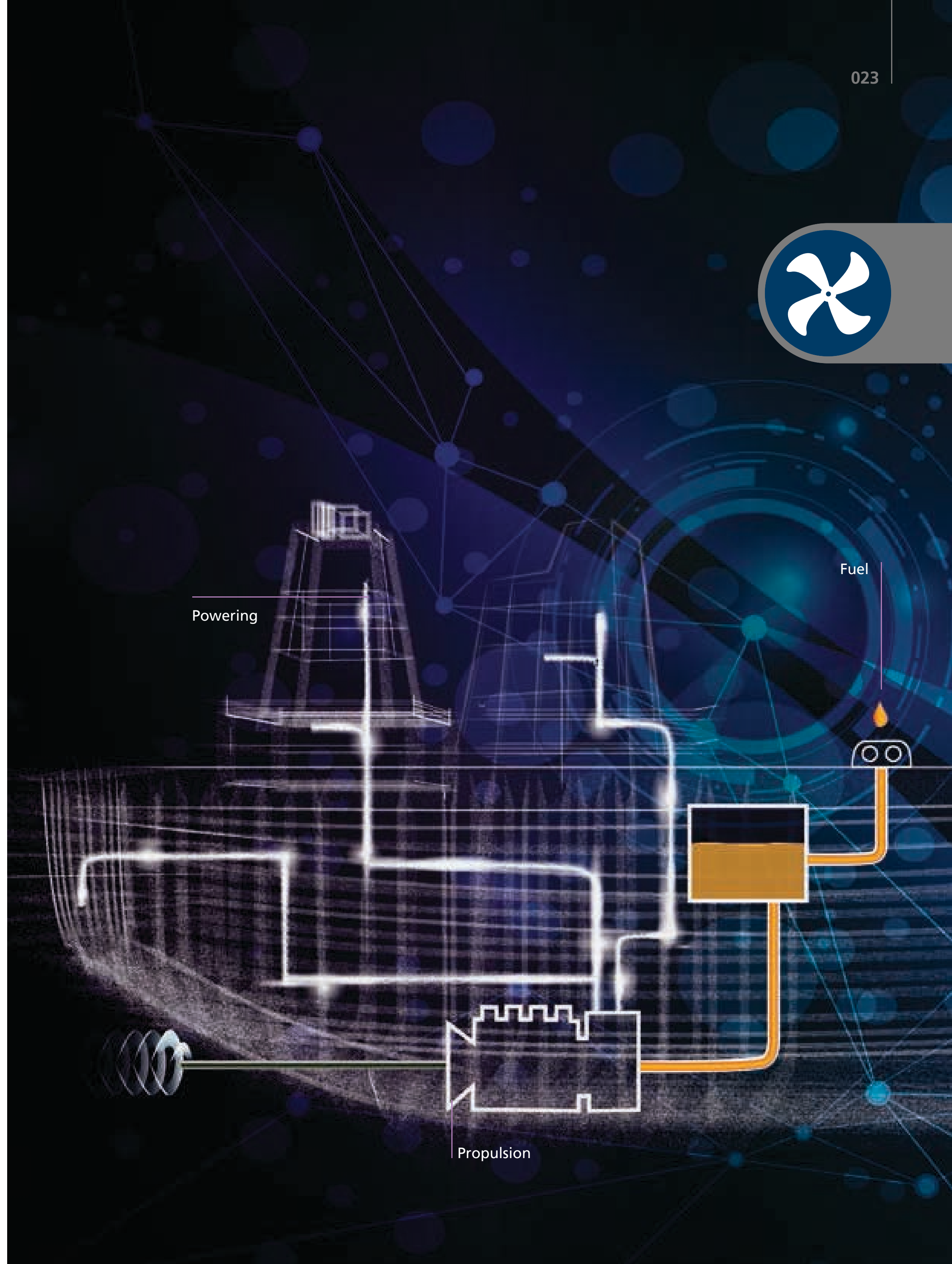

Shipbuilding

After receiving approval of new technologies, and negotiating and signing a new-build contract with a client, the shipbuilding activity, which involves ship design and construction, will begin. Various parties will be involved during this process, including shipping companies, shipyards, flag states, and classification societies.

Global competition in the shipbuilding industry will remain intense. Such competition will drive advances in the production technologies, which are often propelled by innovation in the production process and the creation of new designs.

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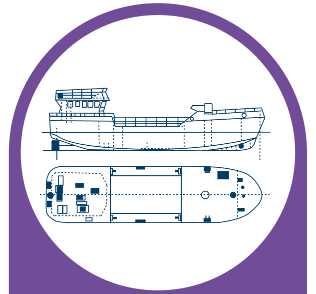
DESIGN — CONSTRUCTION



Customisation
Unlike aircrafts or cars, ships are usually built based on an individual client's request. With the help of ship model tests, virtual simulation, and 3D drawings, designers can optimise the vessel's specifications.

Shape Forming
Structural steel will be shaped by casting, forging, rolling, cutting, or welding. Technologies such as automation of the production line will be adopted to offer a competitive price and production efficiency.

Block Building and Block Assembly
Structural steel will be welded to form blocks at a weight that the shipyard cranes can support. Some smaller machinery will be fitted in at this stage.

Erection in Dock
Blocks will be placed on top of the keel in the dry dock. Engines, rudders, and propellers will be installed. The rest of the shipbuilding work will be completed here.

Launch, Sea Trial, and Delivery
In general, the construction of a commercial ship takes several months. It takes even longer to build a naval ship due to its sophisticated systems.

Advanced Manufacturing

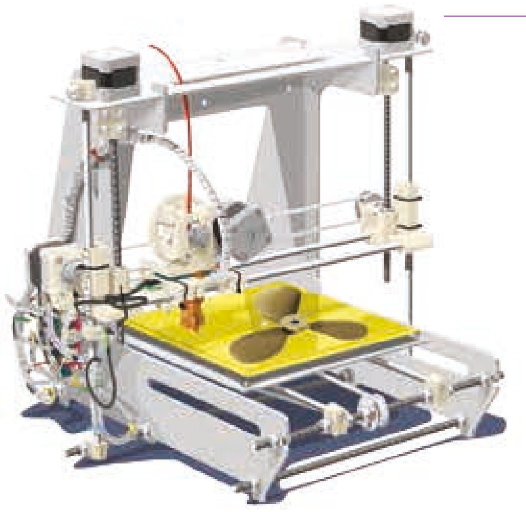
The development of innovative technologies and materials, coupled with the rise of consumer demand, has led to a transformation of manufacturing, its processes and, more importantly, its economics. Technologies such as additive manufacturing, coupled with the use of robotic systems for assembly, offer the opportunity to bring back manufacturing to high-value economies through increased productivity and competitiveness.

The key to this change is the ability to exploit and integrate adjacent technologies and business innovations, including: informatics which will apply information techniques to the manufacturing and logistics processes; automation and intelligent systems which will enable increased productivity, safety and quality; and simulation and visualisation techniques which will reduce the time from conceptualisation to production.

Manufacturing-technology developments are enabling high levels of innovation in all aspects of product development and support, reducing costs, weight and complexity. In the long term, these developments will enable the production of components and products on or near their point of use.

As the technologies develop, the size and complexity of components are expected to increase. Trials are already underway to conduct 3D printing onboard ships. Future developments such as 4D printing, coupled with nanotechnologies and robotics, are expected to lead to the printing of autonomous vehicles that can suit specific mission needs in-situ.

Naval 108–111 FIND OUT MORE



3D printing of propeller

Robotic assembly of propulsion system

Human–Computer Interaction

Human–computer interaction (HCI) refers to the study and design of the interface between people and computers. For any system where people are 'in the loop' with computers, HCI plays a crucial role in ensuring that the system serves its purpose effectively. HCI as a discipline is challenging; there are fundamental differences between how the human brain and computer processors work—HCI seeks to bridge this gap. HCI is necessarily multi-disciplinary, encompassing aspects of computer science, psychology, cognitive science, design, and visualisation.

Over the last decade, the technology enabling HCI has developed most rapidly on consumer devices, such as smartphones and tablets, which use multi-touch displays. In contrast, the majority of traditional fixed workstations and personal computers still use the ubiquitous interfaces of mouse, keyboard and display. This is set to change and by 2030 we can expect a number of new HCI technologies to replace or augment those we currently use, both in fixed locations and when on the move. These technologies will enable us to interact with computer systems in new ways and will be smart enough to recognise our requirements and our personal preferences. Many of these technologies are familiar to us now and include gesture control, speech recognition, and eye tracking. When combined, these technologies promise to dramatically improve our experience working with computers. Other technologies likely to make an impact over the next decade include brain–computer interfaces and intelligent personal assistants. The latter are software entities that are designed to act like personal secretaries, observing our behaviour and learning about our needs, so as to support us in our everyday lives.

Naval 104–107

FIND OUT MORE »

Human Augmentation

Human augmentation has made considerable advances in terms of enhancing both physical and cognitive human capabilities. Human augmentation technologies include power-assisted suits or exoskeletons that enable paraplegics to stand and walk; ocular sensory substitution devices to enable improved vision; and cochlear implants to enhance hearing.

Current developments have mainly focused on enabling individuals to reclaim functions lost due to illness or injury, yet the technology also promises to raise the performance of fit and healthy humans well beyond the normal level. The field of human augmentation extends beyond the use of prosthetics and exoskeletons to include bionic implants (referred to as 'bions') and the development of drugs and administrations that can enhance human biological functions.

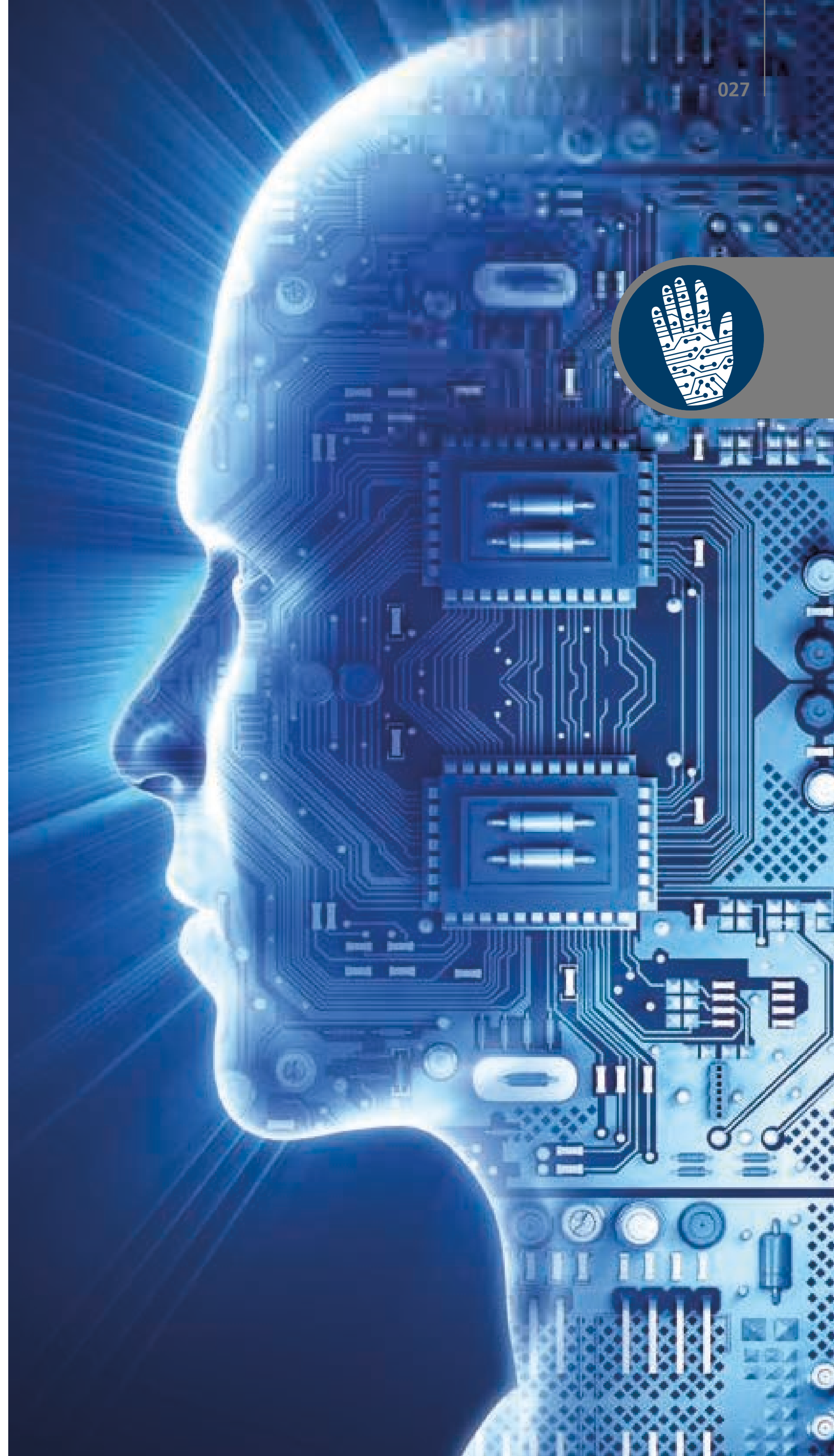
In the future, human augmentation technology will eventually merge the human body with the machine. Research is currently looking at device architectures that resemble the body's own musculoskeletal design, actuator technologies that behave like muscle, and control methodologies that exploit the principles of biological movement. Alongside these developments, work is also focusing on 'neuro-enhancements' to enable superior memory recall or speed of thought.

As research and development continues to increase exponentially and interest in the technology extends more widely, it is likely that by 2030 healthy non-disabled people will be implanting 'bions' inside their bodies. Over the next quarter century, the human augmentation market is expected to become a multi-billion-dollar market. It is easy to be sceptical about the use of bionic implants, but when one considers the vast number of people who have already gone ahead with cosmetic surgery, it is not difficult to envisage a world in the non-too-distant future where human augmentation is commonplace.

Human augmentation's promise of improved human performance and the need for future navies to operate more effectively with fewer crew members will drive the technology's adoption. We can expect exoskeleton technology to be at the forefront of this adoption, but intrusive bions and neuro-enhancements will appear much later.

Naval 120–123

FIND OUT MORE »



Cyber and Electronic Warfare

Cyber warfare and electronic warfare are grouped together in this document in the naval section, although threats to systems in commercial shipping and the ocean space also exist. The term ‘cyber warfare’ refers to the intentional attack of software systems to intercept, steal, deceive and disrupt data/information to inhibit a target’s ability and freedom to act.

With the proliferation of software-based systems and an exponential expansion in the volume of data collected in military and non-military activities, the importance of cyber-security-related technologies in 2030 will remain high.

Malicious software, or ‘malware’, will continue to increase in sophistication, and developments in sensing and encryption technologies can be expected.

In parallel with the ever-present cyber threat, the electronic systems associated with sensing, positioning and communication will remain vulnerable to attack. Electronic warfare refers to the manipulation of the electromagnetic spectrum to deceive sensors and disrupt communications.

The dependence of many activities on global navigation satellite systems (GNSS) for precision navigation and timing will drive the development of alternative precision positioning systems, such as combinatorial chip-scale clocks; cold-atom technology on the microscale; chip-scale nuclear magnetic resonance (NMR) gyroscopes; and inertial measurement units based on cold-atom interferometry.

An escalation in cyber and electronic warfare can be expected, and continued development of a suite of technologies will be needed to support electromagnetic stealth and resilience to electromagnetic attack. National cyber forces will deploy increasingly sophisticated cyber risk mitigation strategies to defend against the persistent attack from individuals, groups and states with malicious intent.

Naval 116–119 FIND OUT MORE ››

Energy Management

Energy management refers to the efficient production, storage, delivery and re-use of energy onboard vessels at sea. The technologies associated with the whole energy management system are particularly important in naval vessels where the demand for ‘high-capacity surges’ from energy-intensive systems will continue to grow between now and 2030.

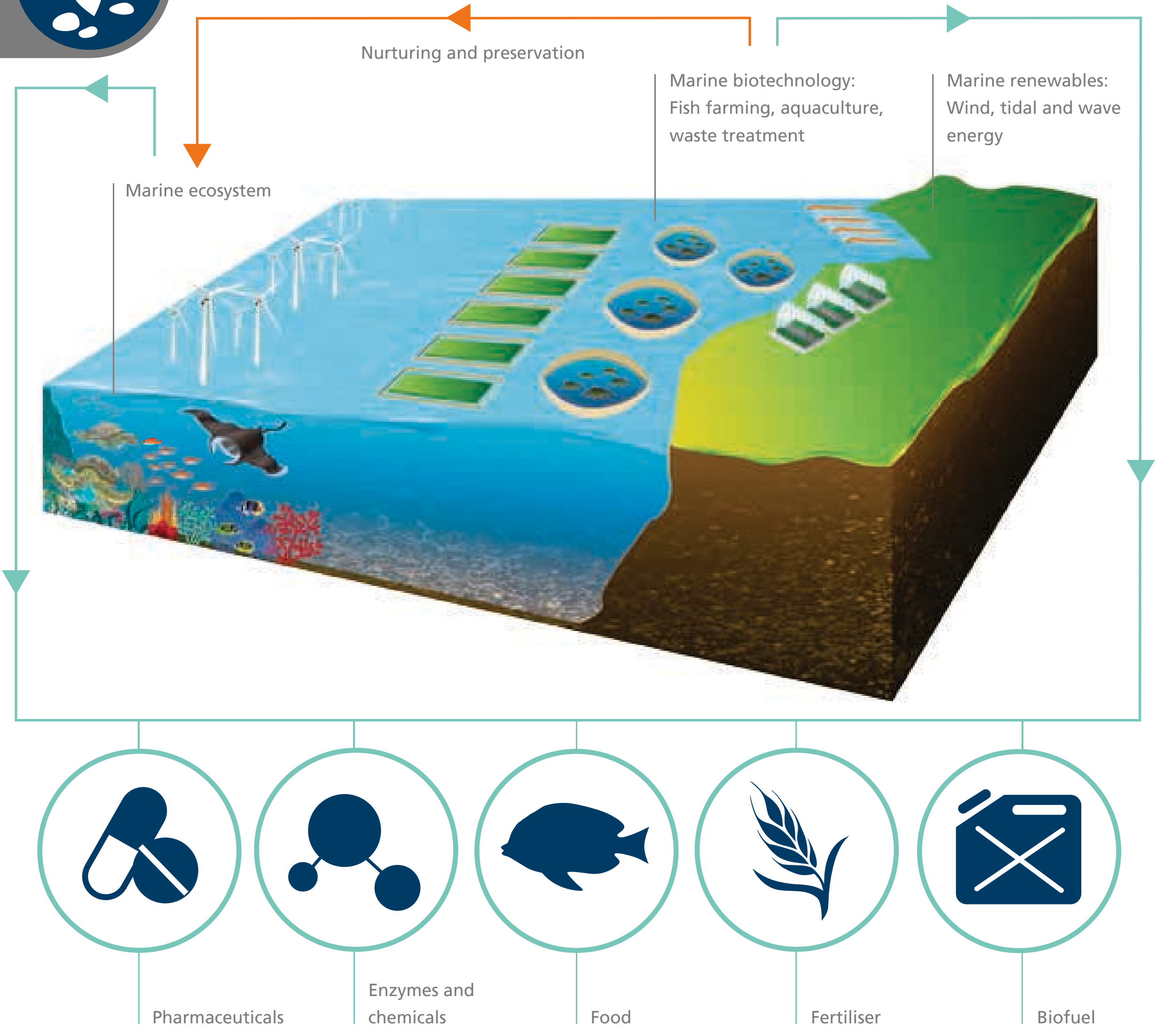
In energy production, the technology will be driven by environmental legislation and the need for lower predictable operating costs. This will increase the attractiveness of flexible hybrid-power solutions in which adaptable power architectures can manage electricity generated from both renewable and non-renewable sources. In the timescale, economically viable small-scale nuclear fusion reactors may also be possible.

In energy storage, the development of lightweight, high energy density fuel cells which convert hydrogen (produced via a variety of methods) into usable electrical energy, will continue.

The delivery and re-use of energy is equally important, and the combination of improved system architectures and the application of more advanced materials for electrical transmission will reduce energy losses and consequently reduce heat onboard.

Increasingly flexible and adaptable power-system architectures will enable improved power availability to allow the rapid allocation of power according to the dynamically changing operational roles and mission dependencies of naval vessels.

Naval 112–115 FIND OUT MORE ››



Marine Biotechnology

Oceans are vast reservoirs of food, energy, and other resources, representing a unique opportunity for innovations in pharmaceuticals, development of industries, and sustainable solutions. Marine biotechnology seeks to harness this potential through the application of technological tools, in order to deliver products, services, and knowledge. Due to its interdependence on the fragile maritime environment, this technology must be used with particular consideration for preserving and nurturing the marine ecosystems.

Traditionally, it is processes such as fishing or drug development that have been associated with marine biotechnology. More recently, applications focusing on aquaculture, biodegradation, or the use of biological sensors have also become increasingly popular. This sector of the ocean space industry is expected to grow by about 10% per annum in the coming years.

One of the most promising of the possible future advances in this area is the large-scale use of algae. These marine organisms, representing a vast variety of species, may be used to treat waste water, obtain biomatter usable for food, livestock feed and fertilisers, produce biodiesel, and release oxygen. Such potential, combined with the availability of space and renewable energy offered by the oceans, will allow for a whole new industry to be developed and interlinked with already existing processes, such as fish farming or waste processing.

Ocean Space 168–171 FIND OUT MORE

Deep Ocean Mining

Deep ocean mining addresses the recovery of resources from the ocean floor for commercial purposes. Offshore operations will involve the extraction of minerals such as nickel, cobalt, zinc, copper, silver, gold, and manganese nodules using specialised subsea equipment. The potential mining sites are situated around large areas of subsea geological sites, such as plains, mounts and vents.

Advances in technologies deployable in deep oceans, as well as growing concerns about the supply of minerals from existing onshore mines, will drive the investment required to establish deep sea mining as a viable market. The global turnover of deep ocean mining is expected to grow from almost nothing to €10 billion, where 10% of the world's minerals will be sourced from the ocean floors. The emergence of this new technology will lead to a progressive growth in markets that are already evolving to support deep ocean mining operations.

Ocean Space 164–167 FIND OUT MORE

Sustainable Energy Generation

Most power stations combust fossil fuels to generate electricity. Some use nuclear power, but there is an increasing use of sustainable energy obtained from non-exhaustible resources. The provision of sustainable energy serves the needs of the present without compromising the ability of future generations to meet their needs. These energy sources, including solar, wind, wave and hydroelectric energy generate intermittent power.

Sometimes excess energy is generated, owing to existing environmental conditions. Ideally, this excess energy should be stored. The energy storage systems in use can be broadly categorised as mechanical, electrical, chemical, biological and thermal. For example, excess electrical energy can be captured by electrical grids during off-peak hours and stored in other forms. At a later time, the energy can be converted back to electrical form and returned to the grid as needed.

Marine energy carried by ocean waves, tides, salinity, and ocean temperature differences can be harnessed to generate electricity to power homes, transport and industries. A novel form of sustainable energy is the use of hydrogen as a fuel. Using the abundance of the oceans, it is possible to split seawater and harvest hydrogen for use on land.

Ocean Space 160–163 FIND OUT MORE

Carbon Capture and Storage

Carbon capture and storage (CCS) involves capturing carbon dioxide (CO_2) emissions, caused by human activities, ideally before they enter the Earth's atmosphere, then transporting and storing them securely in geological sites. Fossil fuels provide over 85% of the total energy supply, and are projected to continue at that rate through to 2030. In 2004, CO_2 emissions from developed nations (OECD member countries) and developing countries were about equal. The projection is that, by 2030, developed country emissions will increase by 30%, while that of developing countries will double.

The Earth's atmosphere has approximately 800 gigatonnes of elemental carbon: mostly carbon dioxide but also methane. Without such gases, the Earth would be frozen, with temperatures of about -18°C. With too many greenhouse gases, Earth would be like Venus, where the greenhouse atmosphere keeps temperatures around 400°C. Therefore, for maintaining a good climate on Earth, we need to ensure that the atmosphere has the right amount of such gases.

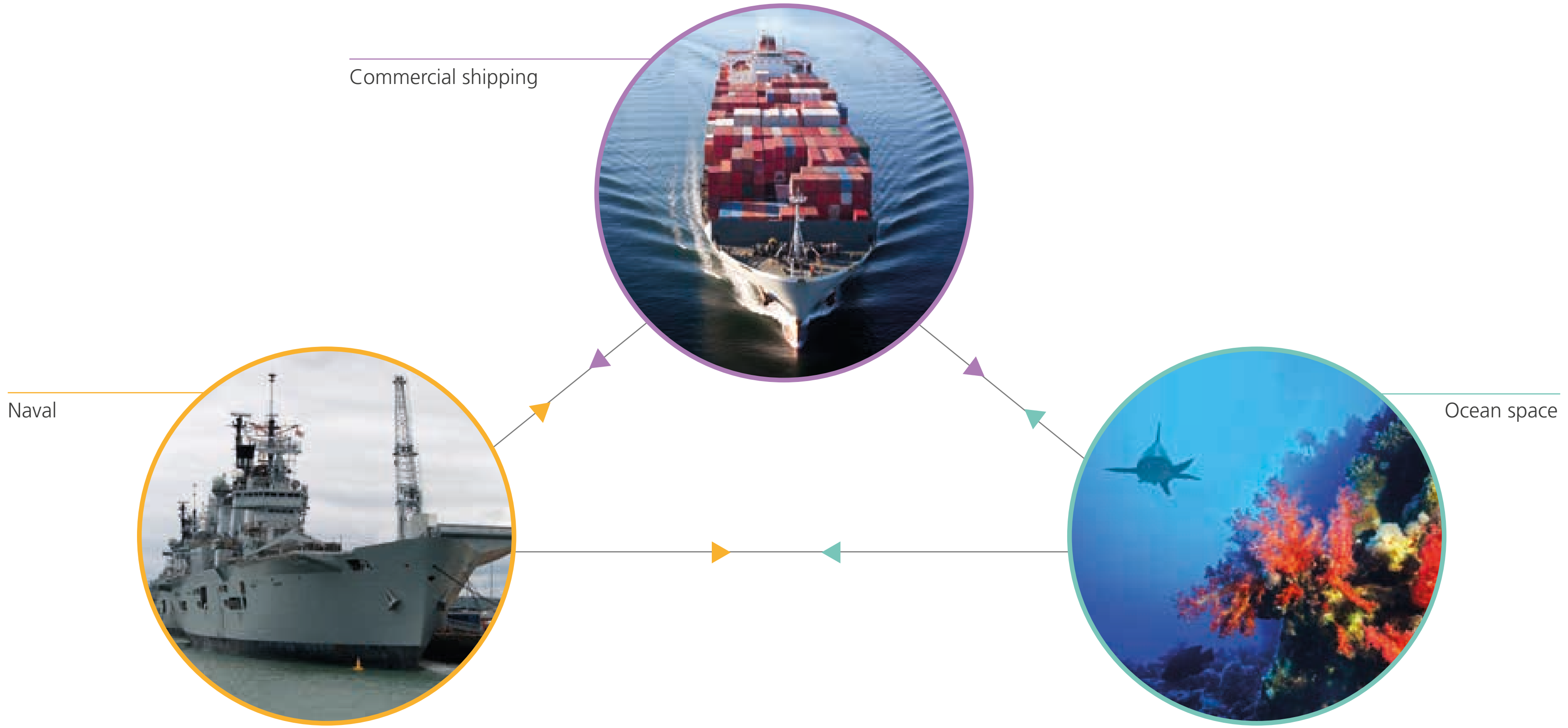
A growing body of scientific research indicates that, if global average temperatures are allowed to increase by more than 2°C from today's levels, we face extreme dangers to human health, economic wellbeing, and the ecosystems on which we depend. We have good prospects of staying below this temperature increase if atmospheric concentrations of carbon dioxides and other greenhouse gases are kept within certain limits and emissions reduced. This requires curtailment of atmospheric carbon dioxide. Hence, CCS is critically important as a key technology.

Ocean Space 156–159 FIND OUT MORE

Interconnection of Different Sectors

The three sectors of commercial shipping, naval, and ocean space are closely related and interconnected. The global trends and drivers of population growth, climate change, increasingly wider economic prosperity, increased migration, and rapid technological change create new opportunities and challenges in each sector.

Of the 18 technology areas described in this report, not all might be relevant and important to every sector. Each sector has its own perspective on which eight technologies have the most impact and importance to its operations. These will depend on the specific functional needs of businesses and stakeholders in the three sectors. Some of these stakeholder needs will converge with common technologies among the three sectors, some will overlap with technologies in two of the three sectors, and some will be single-sector specific.



Four generic features overarch the potentially divergent sectoral pulls, and these are outlined below.

Firstly, it is clear that scientific and technological development is speeding up tremendously, with new discoveries emerging at increasing rates. This requires organisations to react much more quickly in adopting new technologies to the needs of their stakeholders.

Secondly, many of the technologies have interdependencies and overlap with one another. This implies the need to integrate developments of concepts in related and parallel fields in a more timely and efficient manner.

Thirdly, the linkages between technological systems and the human element will become increasingly more complex to deliver an improved performance at the system level. The management of the complexity will require better understanding at the design, manufacturing and operational phases of product and system development.

Finally, the increasing complexity of the technologies will impose demands on the skills and competencies of the people designing, manufacturing and operating systems and equipment.

These four features interconnect the 18 technologies in the three sectors, the success of which will require good coordination and increased collaboration among the concerned stakeholders for a particular sector, with lessons to be shared across the sectors on an appropriate basis.

Commercial Shipping

Tom Boardley
Marine Director
Lloyd's Register Group Limited

Future technology trends are not just a matter for technology companies: they're a matter for all of us in the marine domain. Around the world, there is a lively and important conversation taking place among stakeholders on how the accelerated pace of technology development will affect us all – as individuals, consumers, mining companies, manufacturers, cargo owners, ship owners and operators, port operators, regulators, policy-makers at a government and corporate level, investors, and the public at large.

The Global Marine Trends 2030 (GMT2030) report published a couple of years ago led us to believe that 2030 could well usher in an era during which the prevailing trends and themes would be opportunity and growth, despite the volatile nature of commercial shipping. We published a follow-up report last year on Global Marine Fuel Trends 2030 (GMFT2030) which used a similar scenario-planning methodology and principles to explore the driving forces and conditions influencing the future marine fuel mix.

Global Marine Technology Trends 2030 (GMTT2030) is the third study that focuses on technologies with the potential to transform the marine future. GMTT2030 gives a fascinating insight into technologies with the potential to transform shipping, naval and ocean space operations.

In the commercial shipping sector, we have identified eight technologies, and illustrate their potential, their practical implementation, the associated technical and investment risks, and their long-term impact on ship operations, logistics and supply chains.

Our future is driven by technology and we need to make the best use of it if we are to remain competitive and prosper.

Eight Technologies: Commercial Shipping

Two technology arenas will shape commercial shipping in 2030 with a significant impact on ship system design and ship operation: the first technology arena originates from within the industry, as intense competition encourages technology sophistication and operational efficiency in order to gain commercial advantages. The second technology area comes from other sectors, as maturing technology is ripe for transfer to ship system design and operation to enhance safety, as well as financial and commercial performance.

The first arena includes propulsion and powering, ship building and smart ship. The second arena includes sensors, robotics, big data analytics, advanced materials, and communications.

These eight technologies were selected on the basis of their transformational effects, likelihood of implementation, investment attractiveness, and their expected overall impact on the shipping business in 2030.

These eight technologies are not isolated, but are connected to each other. For example, smart ship technology is the integration of sensors, big data analytics, communications, and advanced materials. It also includes propulsion and powering, as efficiency and emissions reduction are linked with future smart ship design and operation.

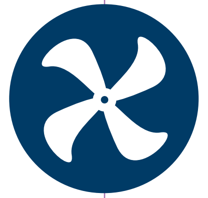
Robotics technology will include sensors that give robots better sensory and mechanical capabilities than humans, making them ideal for routine tasks. Robots' cognitive abilities will be highly dependent on big data analytics technology, and many of the building blocks for futuristic and highly disruptive robotic systems will be in place by 2030.

The wide application of sensors and communication technologies on ship components, systems and ships will generate extremely large volumes of data in nano-seconds. Data analytics technology is necessary for ubiquitous infrastructures to make use of these data for enhanced ship operational efficiency and to generate new business opportunities.

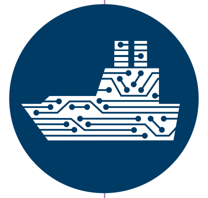
Together, these eight technologies will help the shipping industry to meet demands from customers who want shipping to use the latest technologies in order to give them a competitive edge and to be socially responsible.

First arena: internal development

Shipbuilding

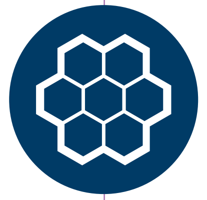


Propulsion and powering

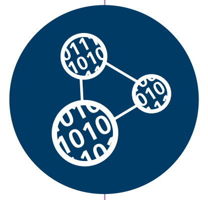


Smart ship

Second arena: external development



Advanced materials



Big data analytics

Robotics

Sensors

Communications

Advanced Materials

Developing advanced materials for ship applications will be a critical component of improving future ship performance. New features will be introduced, and multi-functional materials can be created.

Materials Fine-Tuned at Microscale or Nano-scale

The characteristics of metals will be enhanced by adjusting their structures at microscale or nano-scale. The exceptional combination of strength and toughness of metals can be achieved by nano-precipitation, such as doping nano sized carbide or copper precipitates. A new class of alloys can be created to offer high malleability and corrosion resistance. Introducing magnesium or calcium nano-particles will strengthen welds. A new anti-corrosion coating doped with graphene will potentially offer premium formability and corrosion protection to low-alloy steel in comparison to the traditional zinc-based coatings that are less ductile than the substrate steel.

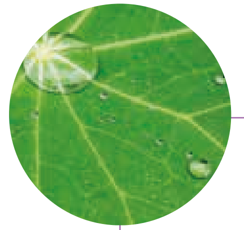
Thriving Composite Materials

Metals will still be the dominant bulk material used in ship structures, but there will be an increasing appetite for composites to replace steel in selected applications. The use of polymer matrix composites, from the traditional glass fibre and epoxy resin to the more recent carbon-fibre-reinforced plastics, can offer lightweight, stronger, and tougher materials that do not corrode. Next-generation resilient mount materials will be explored to actively reduce the noise and vibration released from machinery.

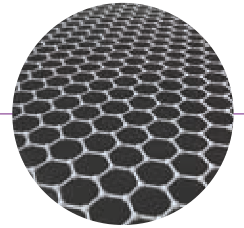
Bio-Inspired and Bio-Based Materials

Organisms in nature have evolved to adjust to the changing and tough environment. Bio-inspired materials will exhibit chemical or physical attributes to protect the surface from external challenges such as abrasion, fouling or icing. Instead of being sourced from petrochemical production, the future biocomposites and bio-derived adhesives can be made from natural and sustainable resources. Such materials will explore opportunities in selected marine markets that can rival their conventional counterparts.

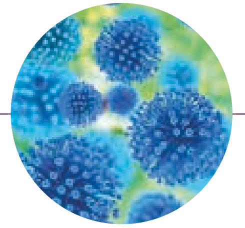
High strength, toughness, malleability, corrosion resistance and self-healing structural material



Self-cleaning and self-repairing finishes



Graphene-doped anti-corrosion coating

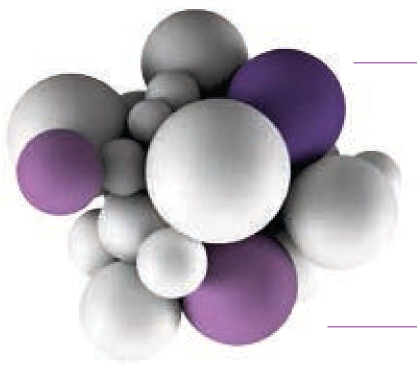


Bio-based materials made from sustainable resources such as bacteria, waste plants, or fast-growing and non-food feedstock

Going Light, Versatile and Sustainable

With the ever-tighter competition, shipping companies are driven to invest in new materials that offer better mechanical properties or versatile functionality, leading to improved operational efficiency and reduced operating expenditure (OPEX). Better fuel economy or more cargo-handling capacity can be achieved by introducing high strength-to-weight structural materials, such as advanced high-strength steel, aluminium, glass fibre, or carbon fibre composites. Self-repairing materials can reduce the need for maintenance. Meanwhile, material suppliers will continue to seek for sustainable sourcing.

Drivers of advanced materials include:

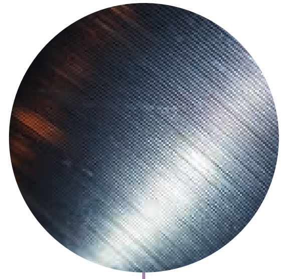


Protection of People, Assets, and the Environment
- Higher structural and fire protection performance to safeguard people and assets
- Improved ship stability by lowering the centre of gravity
- Ergonomics and comfort
- Sustainable sourcing
- Design for end-of-life

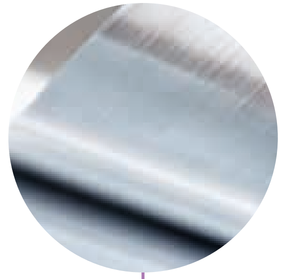
Energy Consumption
- Reduce lightship weight
- Reduce energy consumption of heating, ventilating, and air conditioning (HVAC) system
- Offer a surface that improves hydrodynamic efficiency

Improve Operational and Maintenance Efficiency
- Higher cargo-handling capacity
- Reduced maintenance costs

400–1800+
Carbon fibre composites

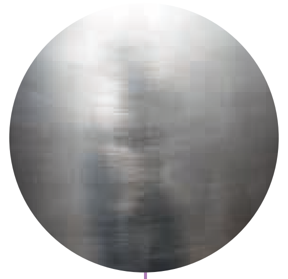


48–600+
Glass fibre composites



27–220+
Aluminium and Al matrix composites

52–200+
High strength steel



<31
Mild steel

Strength-to-weight ratio of materials (kN·m/kg)

The cost of purchasing new types of advanced materials and their price volatility will always be the first hurdle. As such materials will be new to the marine environment, their life expectancy and material performance are unknown. Materials should be marinised, for instance, delaying the degradation caused by seawater. When nano-particles are embedded, potential releasing routes should be analysed. Workers in the shipbuilding, repair, and recycling yard should subsequently be given instruction for health and safety protection.

When combustible materials are proposed, the strict fire-protection requirements exclusively made for the marine industry can be a showstopper if regulators are not convinced by the suitability of their fire-safety design. If different materials are applied, the bonding method should be carefully designed to avoid failures.

RISKS AND UNCERTAINTIES

Economy	Material properties	Safety	Manufacturing	End-of-life
CAPEX	Material durability and degradation	Regulatory requirements	Machinery customisation	
Insurance costs	Repairability	Health and safety	Connection between different materials	
Availability	Predictability of catastrophic failure	Fire safety	Formability	
Price volatility	Fouling		Low-energy production	

Even though we will not see a drastic steel replacement in commercial ships on the same scale as the aviation or the automobile industries over the next 15 years, a revolution in advanced materials will quietly come into full play, from ship structure to machinery.

A new generation of machinery will emerge with enhanced performance. Inherent smart features can be designed for corresponding applications; these may include self-repairing materials developed for bearings or for the exposed surface of ice-class vessels. Materials will become more dependable and more reliable. However, new materials' behaviour-monitoring strategies should be developed to accommodate materials' new characteristics.

Regulators and classification societies should develop requirements in surveying and testing these new technologies. The use of more versatile materials could lead to some parts of vessels being less recyclable. End-of-life strategies should be considered during the product development stage.

Superstructure and Hatch Cover
can be made of lightweight composites which enable modular construction. Some of such composites can be made of bio-based materials. The superstructure will also be fitted with thermochromic or electrochromic windows

Cargo Hold
will be fitted with self-regulating thermal insulators that adapt to changing operating conditions where temperature control is vital

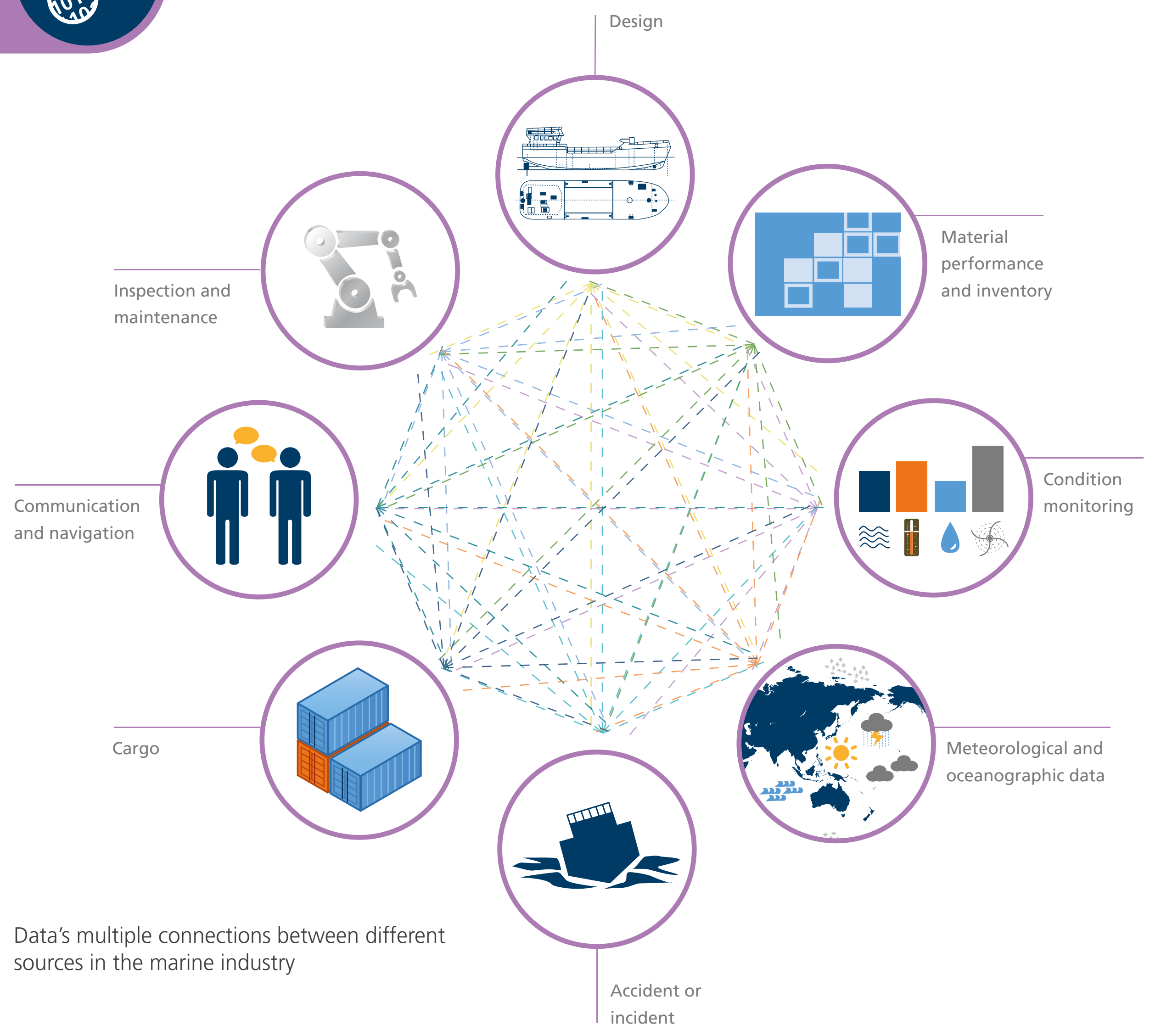
Ship Structure
will be built with high strength and toughness structural materials

Propellers and Rudders
can be made of composite materials. Self-repairing materials will be developed for bearings

Engine and Other Machinery
will be made of ceramic or metal composites. New noise and vibration damping materials will be introduced to the system

Hull
will be built using self-healing materials. The surface of a ship's hull will be protected by advanced anti-corrosion and anti-fouling coatings that are effective and more environmentally friendly

Big Data Analytics



Data's multiple connections between different sources in the marine industry

An unprecedented amount of data associated with shipping has already been produced by different sources and in different formats, such as the world meteorological and oceanographic data, traffic data, material and machinery performance data, data on cargo flows across the world, maritime accident data, and even passengers' and seafarers' personal data. The traditional analysis does not allow for full use of so much data, nor can it translate complex connections between different datasets stored in different formats. The main difference between traditional data analysis and big data analytics is that the former requires a person to define what questions to ask. A keyword search is implemented for troubleshooting, even though the solutions may or may not be found. Big data analytics involves deploying a large number of algorithms designed to identify the correlation between data. When the correlation is spotted, new algorithms will be established and applied to the dataset automatically. This is how the 'dynamic-learning' feature comes into play. Intuitive conversions will offer a confidence-ranked response. Researchers will no longer need to predefine sampling or structure the data before they can analyse it, offering instant knowledge to realise fact-based management. The same dataset can also serve different purposes for different organisations.

IT infrastructure will be upgraded to retrieve, store, and process data in real time. Archived data can be stored either onboard a ship or onshore, thanks to the support of communication technologies. Furthermore, cognitive systems will act as data interpreters for humankind. These systems will combine machine learning and natural language processing to offer an intuitive interface between a person and a machine.

The shipping industry will therefore move from a decision-tree-driven approach to the adoption of a probabilistic approach. Real-time performance monitoring, alert systems and/or visualising situational awareness can all be achieved wherever you are and whenever you want.

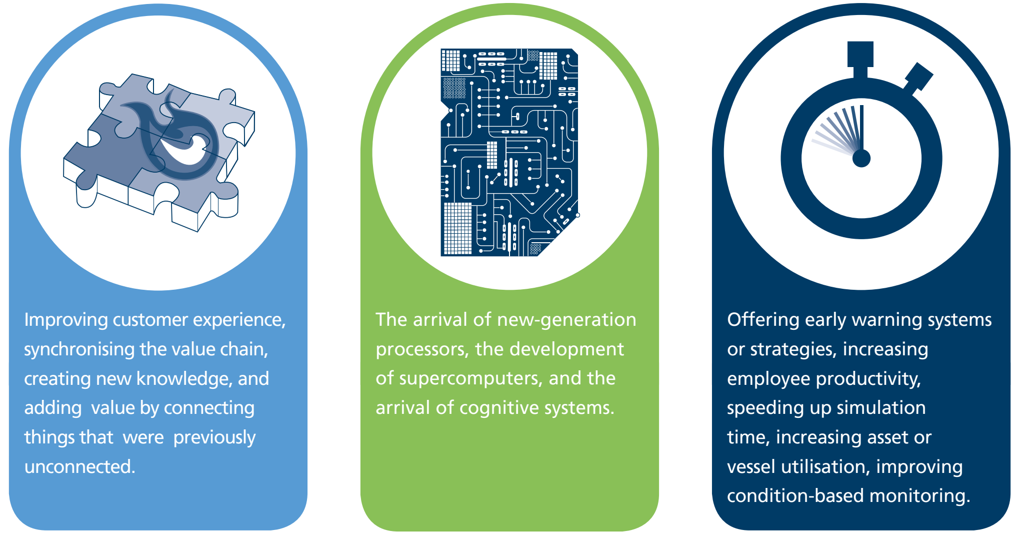
Drivers

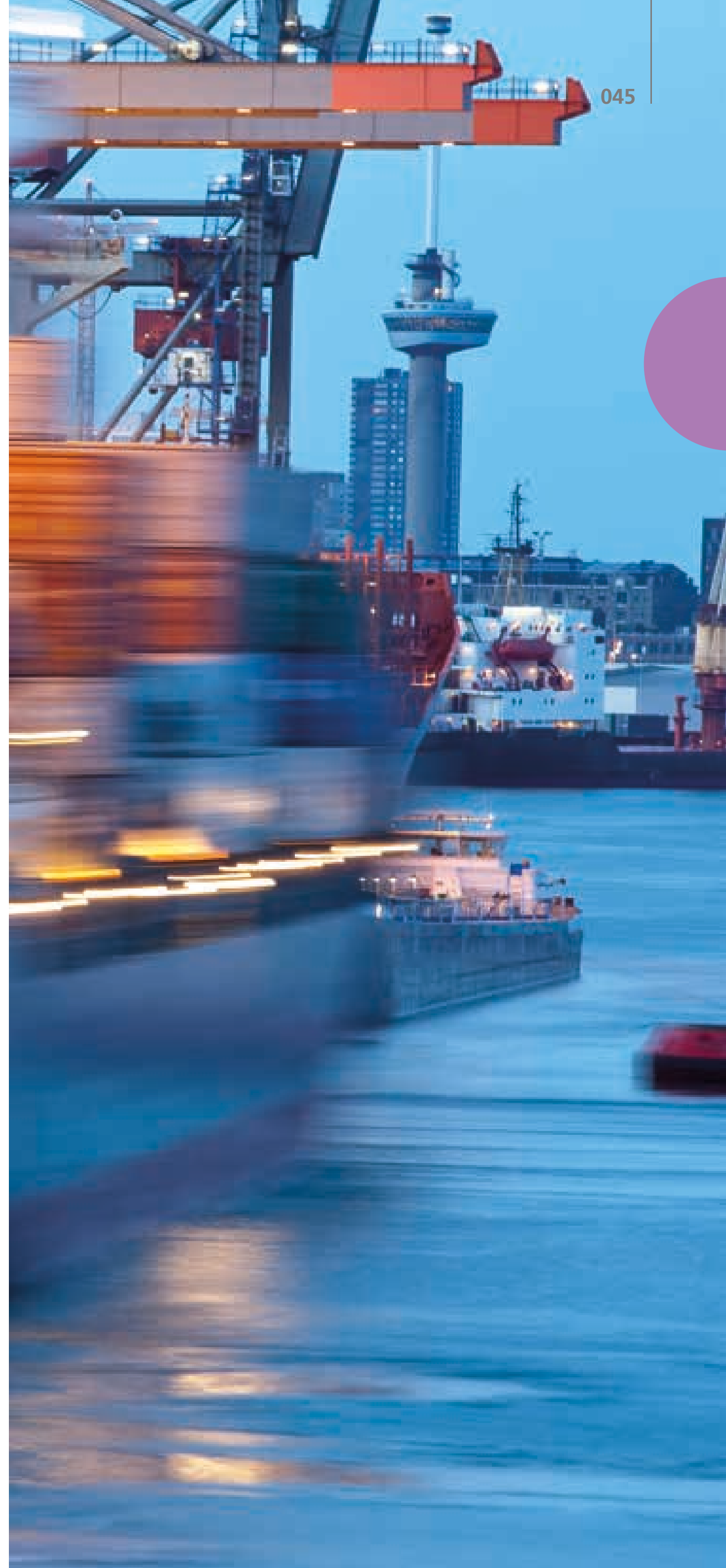
Mining data in the shipping industry will offer new knowledge and added values that we've never known before. A well-informed decision-making process based on high-quality data and analytics can achieve a lower life cycle cost.

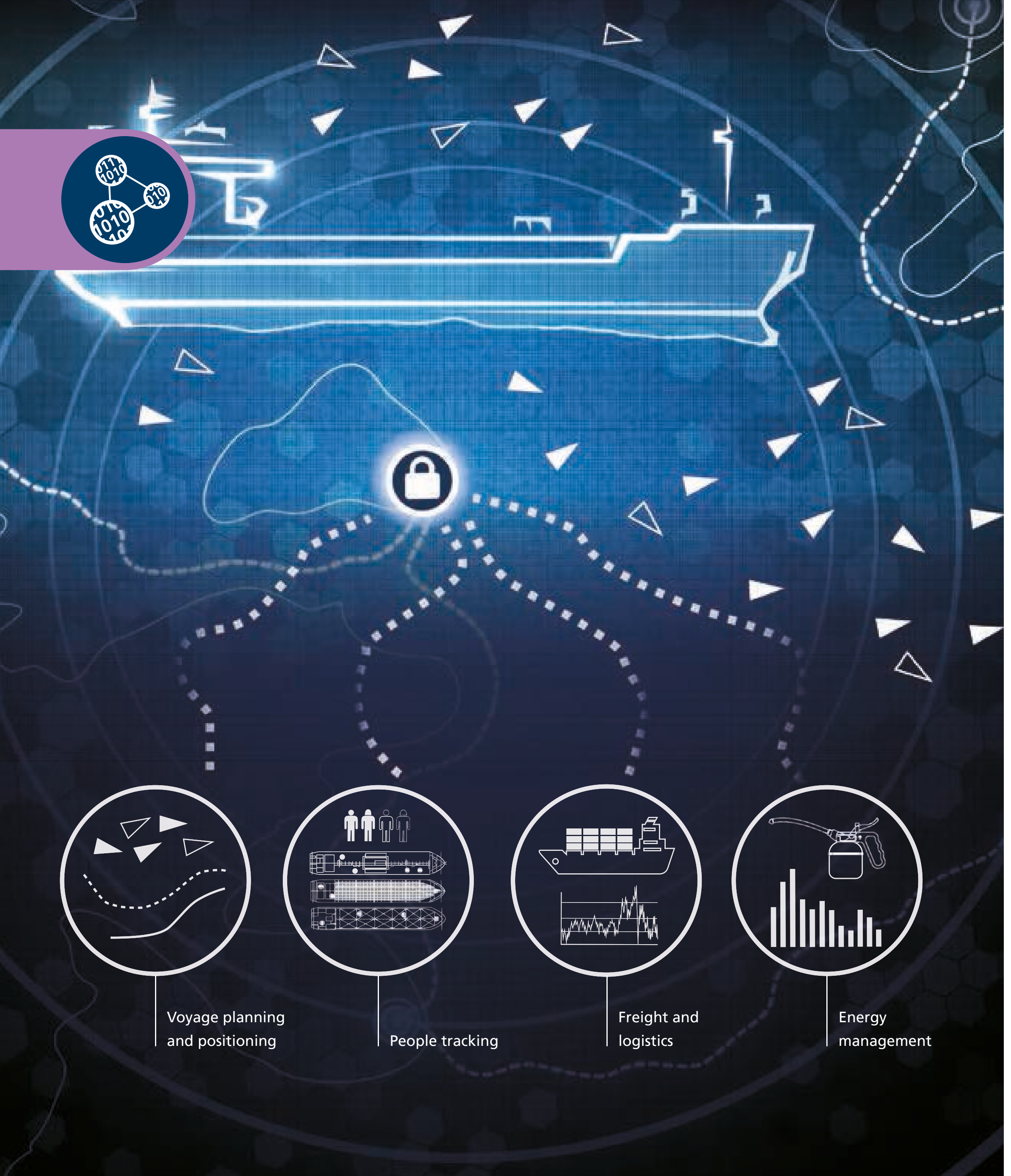
Data analytics can help us better understand our customers. Business strategies will be amended to offer more competitive pricing and services. Together with new customer support services, this will lead to higher customer satisfaction and will increase the chance of winning new business.

Faster and more capable processors will handle data of high complexity and volume. The data transfer speed will be accelerated with the help of the increasing bandwidth of affordable satellite services provided for commercial shipping applications.

An early recognition of problems can be achieved. Speeding up the simulation time will allow the industry to take faster actions. Asset utilisation, employee productivity, customer experience, and supply chain logistics will be improved. Big data analytics will optimise operational efficiency, ease traffic congestion, maximise vessel or fleet utilisation and prioritise resource allocation, by improving the understanding the patterns of trends. This will then help to increase business competitiveness and will assist the shipping industry stakeholders to take proactive actions.







Cybersecurity
As data networks and management will become vital to shipping, the system will need to be able to shield itself from external interferences, such as viruses, piracy and terrorist attacks. The system will need to be kept safe from manipulation which can compromise its credibility.

Data Protection
Acquiring data from other stakeholders can be a challenge. Companies will not allow their proprietary data, which may contain commercial secrets and intellectual property, to be extracted from their gateways. Privacy and identity protection for passengers or crew members by international agencies or governments will allow individuals to disable data sharing. Alternatively, sensitive data will be shared externally or within the organisation if they can be masked or grouped anonymously in a trusted manner to avoid the risk of re-identification.

Data Integrity and Data Quality
Data integrity and data quality are important for maintaining daily work cycles. However, the current data collection in the marine industry is inconsistent, patchy, and sometimes unreliable. Definitions of terminology used in different fields may vary. Data fusion will therefore be a challenging step to incorporate a multi-disciplinary dataset. Erroneous data will lead to bad decision-making. Data should therefore be reliable and comply with high standards.

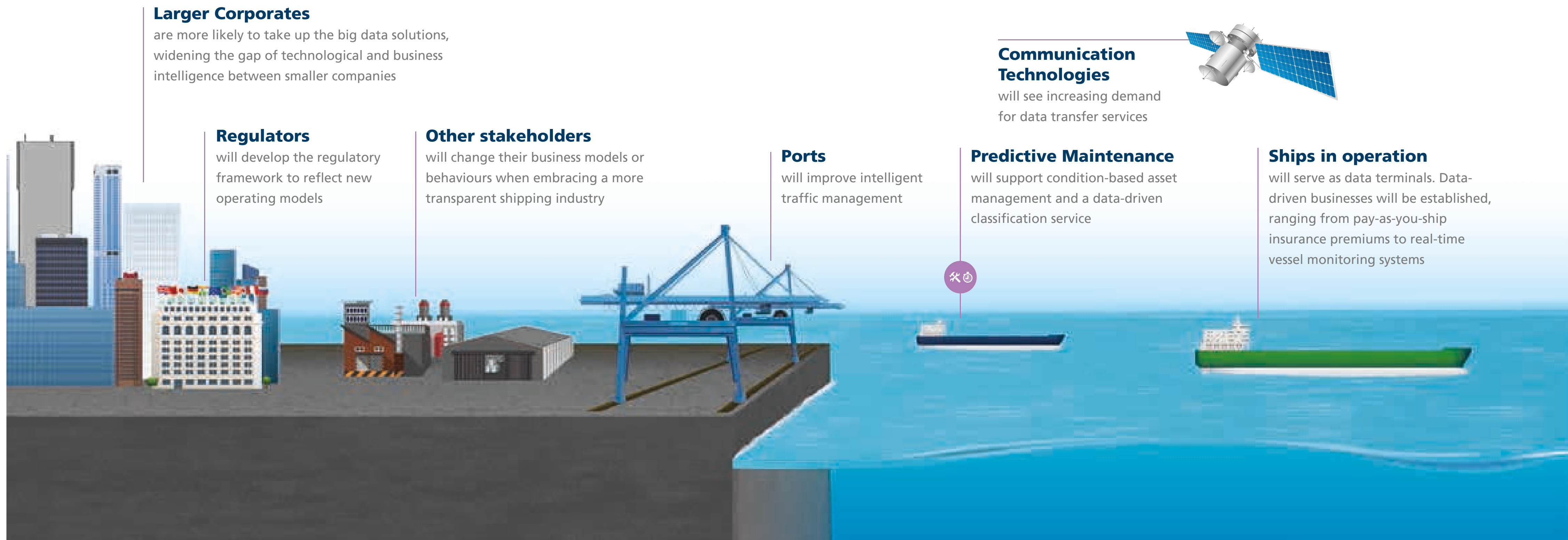
Restriction in Communication Tools
The realisation of data analytics will be constrained by issues such as low bandwidth and high implementation costs.

Self-Learning Algorithms Change Business Models
Shipping companies, flag states, port states, and shipyards will become data-driven businesses. Data analytics will foster condition-based asset management and predictive maintenance. Companies will be under pressure to provide high-quality self-learning algorithmic packages that can learn from data in order to stay competitive. Action will be taken quickly following events or incidents in maintenance planning, pricing, and logistics arrangement.

The shipping industry will become more transparent. This implies a change in the industry's business and operation model. Transparency will also assure companies and individuals that the process is lawful and that their data is protected.

New services will be created, and new professional skills will be required. Enhanced operational efficiency and safety will be achieved by real-time monitoring of vessel performance, asset management, compliance, emergency response, and incident or accident investigation. The connectivity between ship to shore, ship to ship, and people to ship or shore will be strengthened.

Regulators should consider standardising digital reporting methodologies and taxonomy for data to ensure data synergy and to assist subsequent data mining that will offer reliable information.



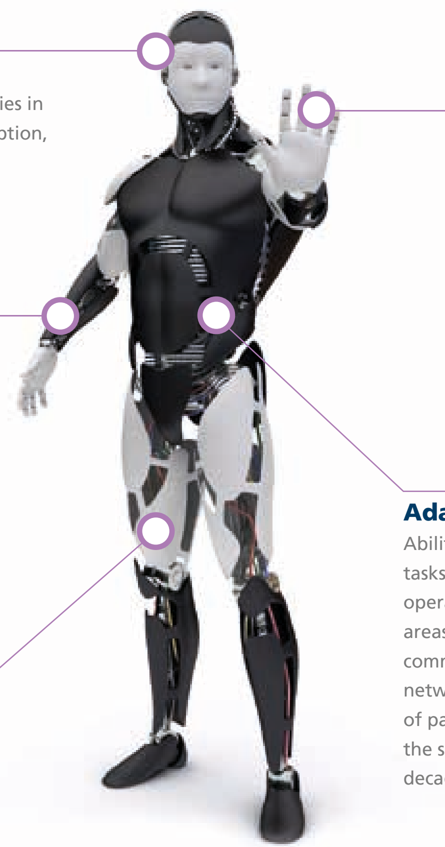
Robotics

In recent years, the technical potential of robotics has been demonstrated in various areas in commercial shipping. For the short- to mid-term future, autonomous robots will only see application in a limited range of rather specific areas. In fields where autonomous robotics is not a realistic option, at least for the foreseeable future, remote-controlled robots are a promising alternative.

There are three new types of robots that will be in use by 2030. The first will be a learning robot, the second will be a practical robot (one that can handle an asset), and the third type will be a mini-robot, useful for inspections in harsh, dangerous environments.

The development of these types of robots is very closely linked to the development of other technologies, like sensors and remote controls. These solutions require system response times (including network delays) of less than a few milliseconds.

Cognitive robots will deal with changing environments and situations that cannot be predicted a priori



Cognition
Robots will have cognitive capabilities in terms of attention, dialogue, perception, memory and decision making

Senses
Speaking, touching, seeing, listening senses will enhance robots' capabilities

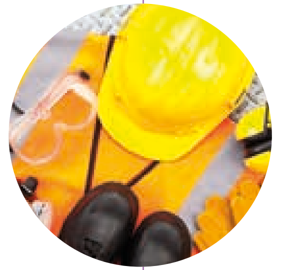
Versatile
Swim, fly and climb functions will provide a multitude of resources to researchers and engineers both onboard and onshore

Adaptability
Ability to carry out specific tasks autonomously, ability to operate in subtropical and Arctic areas, battery-powered, wireless communication with other networks: these features will be of paramount importance for the shipping industry over the decades to come

Imitation
The re-creation of animal–human actions, like soft arms inspired by an octopus or articulations inspired by human fingers, will provide a full range of capabilities

Drivers

Industry Acceptance
Robotics technologies will integrate assets with other emerging technologies like big data and The Internet of Things, helping to cope with the industry's aspirations



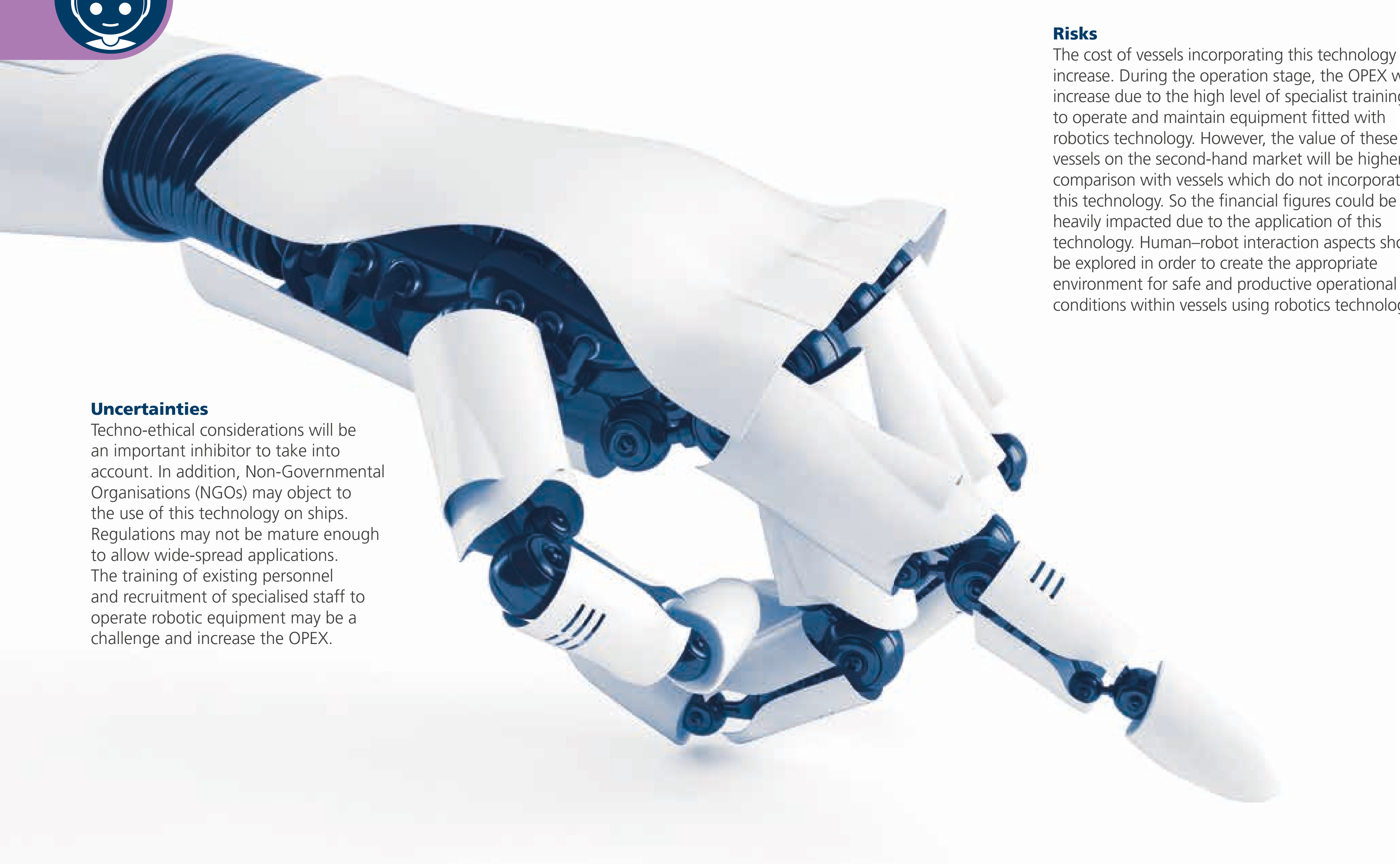
Safety
Ensuring safety in new and more challenging operations will be important. Humans' direct interaction with dangerous activities will be diminished

Human Intervention
The operation of the assets will be done on a 24/7 basis without disruptions. The risk of human error due to tiredness or lack of concentration will be significantly reduced

Future Recruitment
The recruitment of capable and highly-skilled crews will be even more difficult in 2030, so the reduction of human intervention will be a growing trend over the coming decades

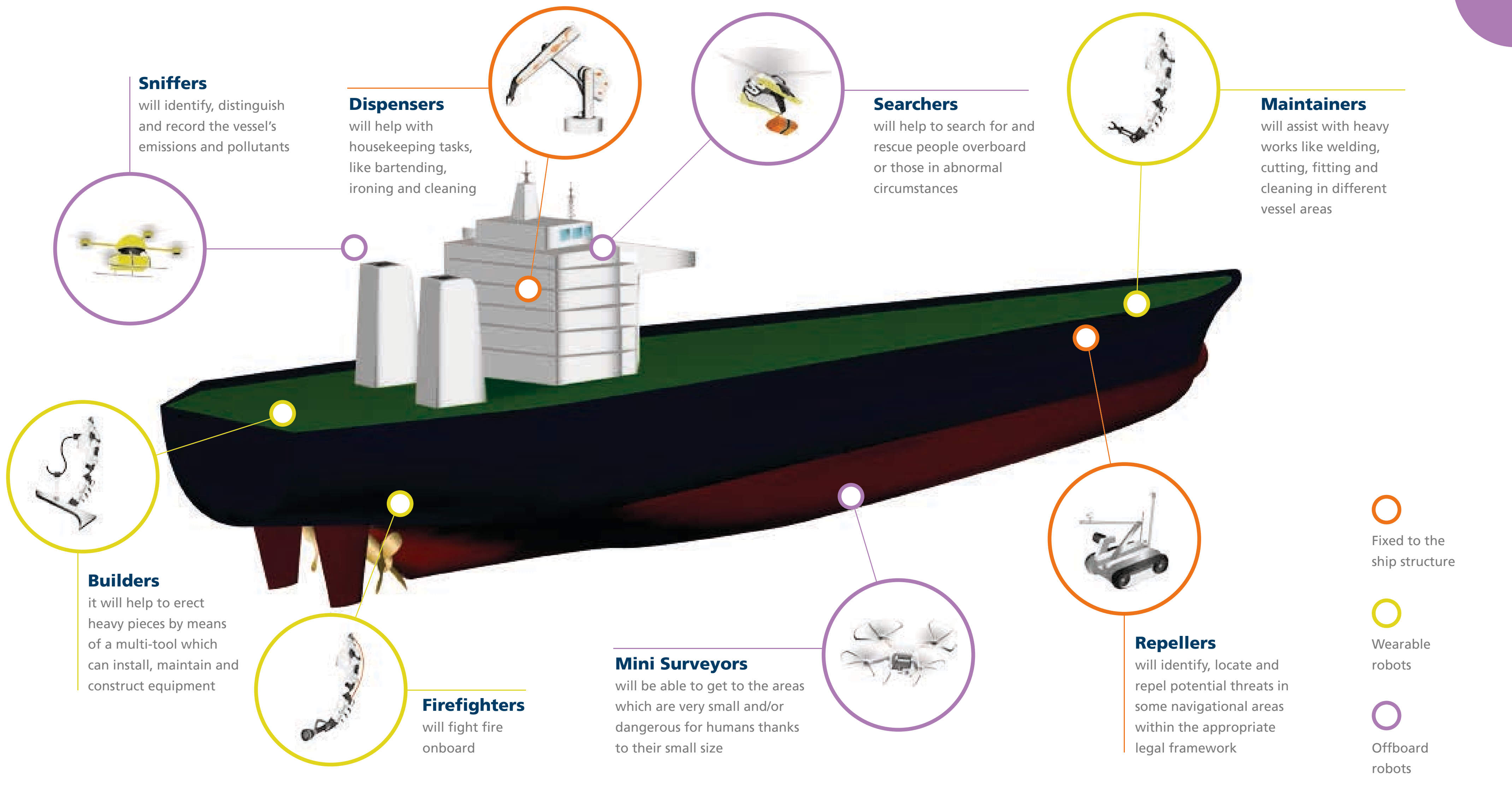
Cost-Effectiveness
Crewing is the second largest cost in vessel operation. The use of robotics can lead to reduction of required manpower onboard

Legal
Governmental and non-governmental bodies will aim for a safer and more sustainable marine industry that is able to reach technological standards of the mid-21st century

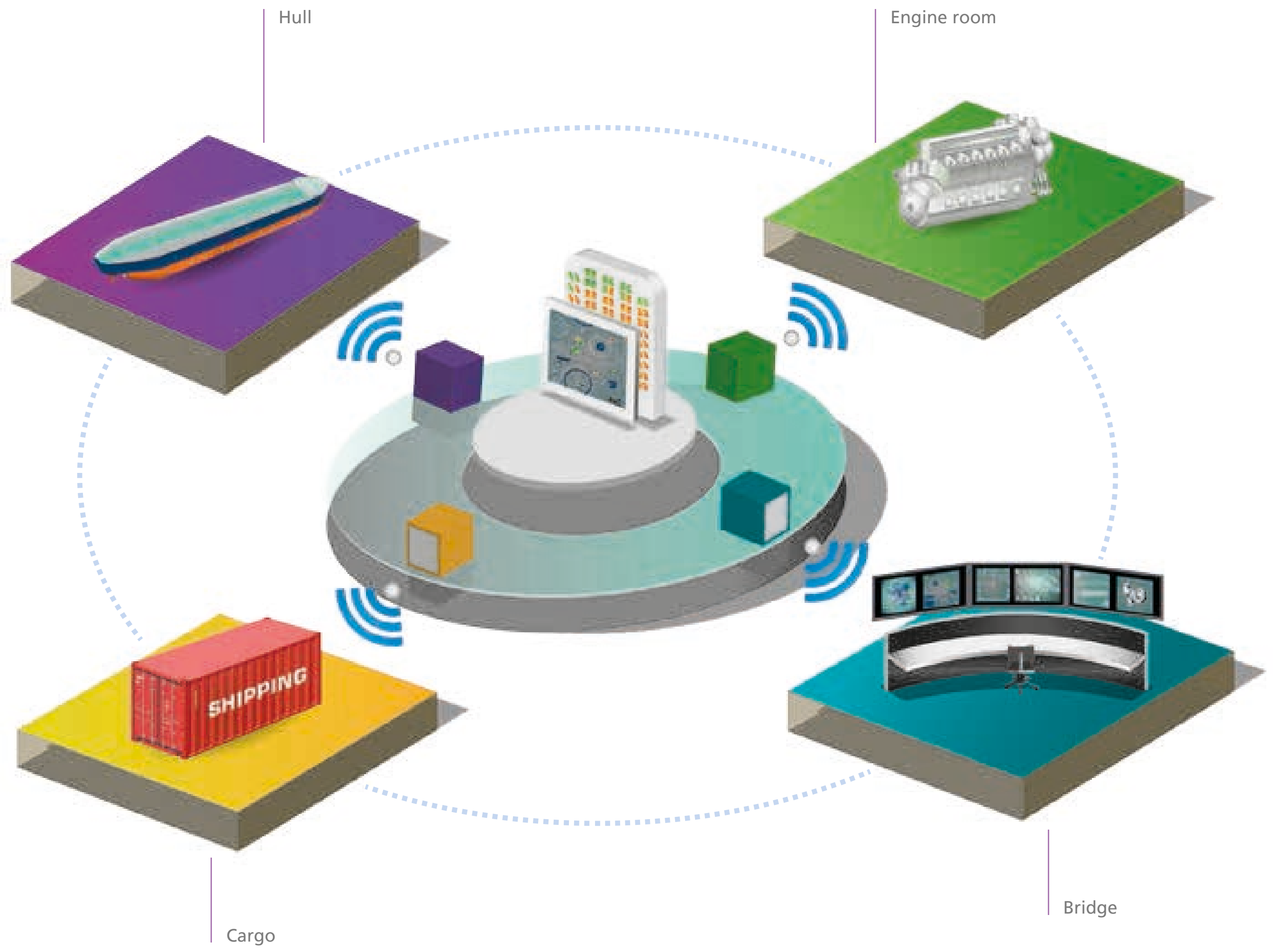


Risks
The cost of vessels incorporating this technology will increase. During the operation stage, the OPEX will increase due to the high level of specialist training to operate and maintain equipment fitted with robotics technology. However, the value of these vessels on the second-hand market will be higher in comparison with vessels which do not incorporate this technology. So the financial figures could be heavily impacted due to the application of this technology. Human–robot interaction aspects should be explored in order to create the appropriate environment for safe and productive operational conditions within vessels using robotics technology.

Uncertainties
Techno-ethical considerations will be an important inhibitor to take into account. In addition, Non-Governmental Organisations (NGOs) may object to the use of this technology on ships. Regulations may not be mature enough to allow wide-spread applications. The training of existing personnel and recruitment of specialised staff to operate robotic equipment may be a challenge and increase the OPEX.



Sensors



Robust and Wireless
The rate of application of sensors technology will rapidly increase and will raise a number of technological challenges. The capabilities of low-cost computational elements will create a wide spectrum of opportunities for the industry and for research activities. Devices will be able to operate in a network connected to a remote unit for data collection and processing.

Wireless sensor technology and the development of a new generation of micro- and nano-mechanical sensors will be at the cusp of revolutionising environmental monitoring and data collection.

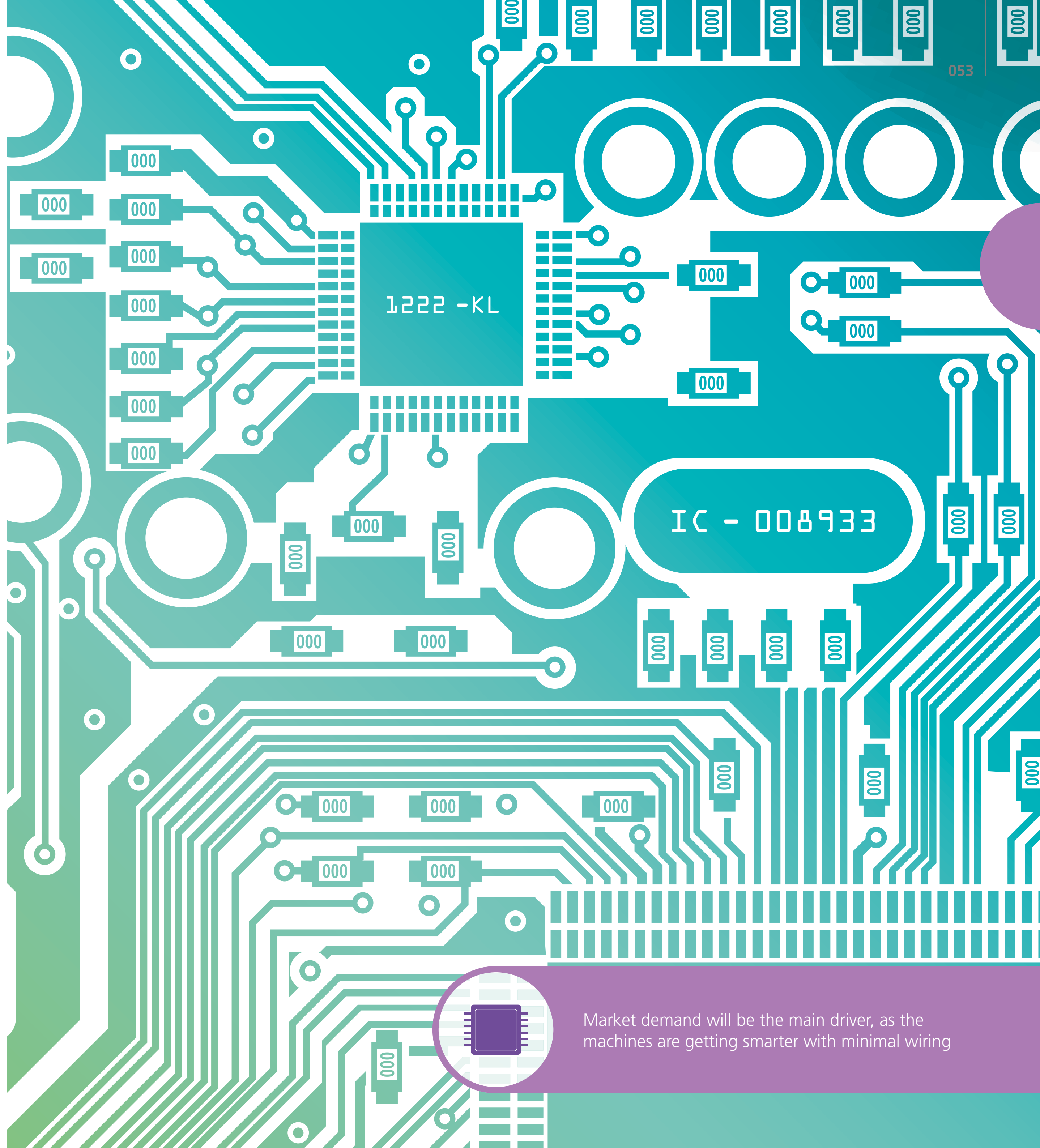
Remote Sensing
It will no longer be necessary to repeatedly visit remote locations in order to upload data or collect samples for analysis, as data will be collected autonomously by the deployment of a network of remote sensors capable of communication and data transmission in real time. A robust wireless networking architecture for the shipping industry will require sensors with a number of characteristics: self-calibration, fault tolerance, high transmission capabilities, wireless capabilities, environmentally friendly materials for easy disposal, robustness, ultra-low energy consumption, miniaturised, ability to provide active behaviour, and ability to work on network modules (master-slave layouts).

Essential and non-essential equipment onboard will be able to monitor, manage and control its status. Furthermore, equipment will be able to warn operators when they are about to run out of circulating liquids, or when they are about to require maintenance.

Operational Drivers
Condition monitoring (CM) and condition-based monitoring (CBM) will be improved. Sensors will help to follow up an asset along its life span through an early warning system strategy and the optimisation of operation and maintenance practices.

Financial Drivers
Equipment's life cycle period will be improved. This will have an influence in the associated capital expenditure (CAPEX). The application of this technology will help to closely keep track of the asset during its life span, and consequently, the financial figures will be improved. Last but not least, sensors technology represents an affordable option for mass implementation.

Technologies' Connectivity Drivers
The quality of data will be exponentially improved, and the data from sensors will be welcome from a statutory perspective. The development of sensors technology will be key for other developments such as smart ship, big data and robotics.



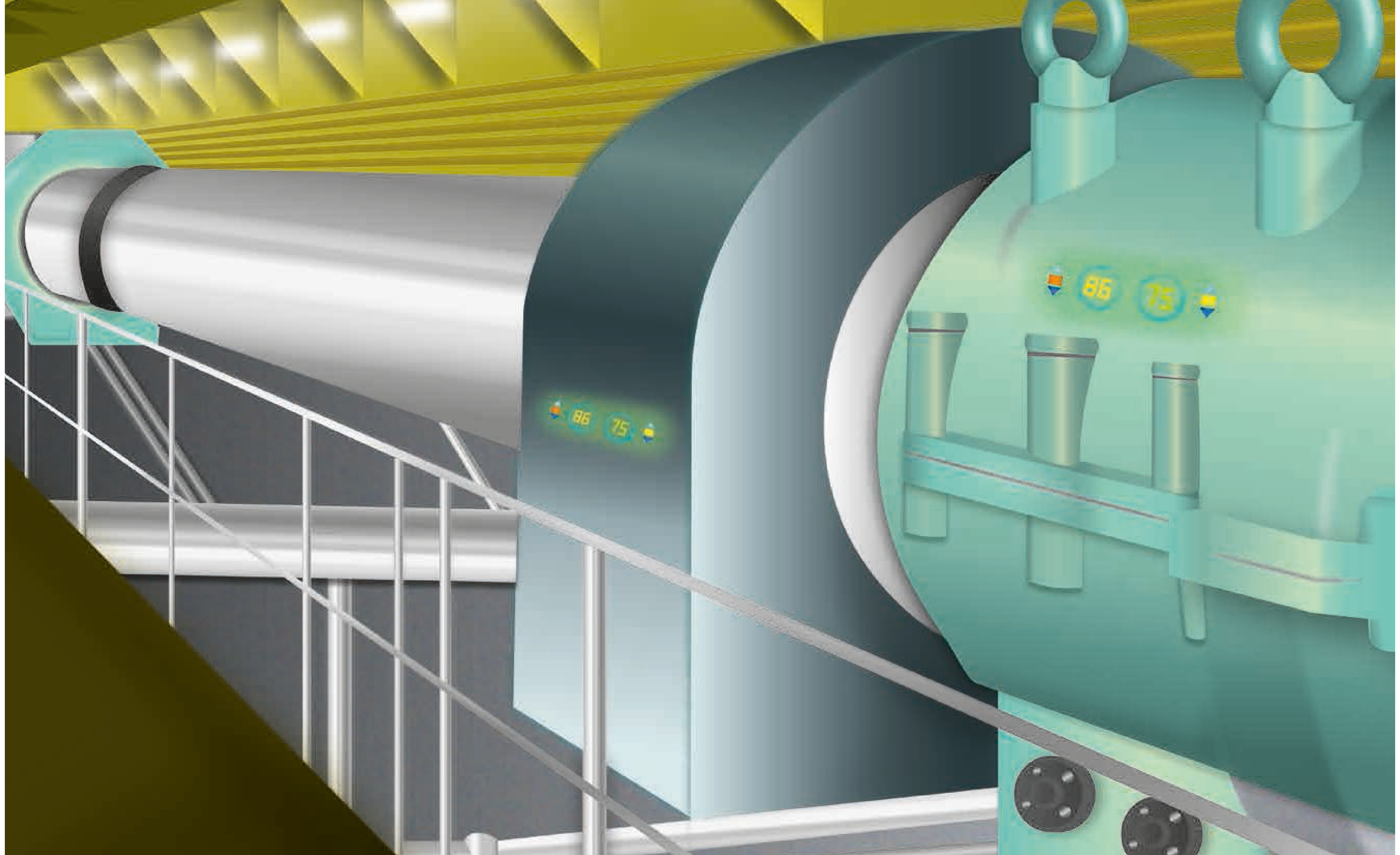
Market demand will be the main driver, as the machines are getting smarter with minimal wiring

Data Transfer

The major technical uncertainty will come from the communication bandwidth that the sensors will use. This network will need to be agile and fast. Power supply will be another point to consider for the practical implementation of the sensor networks. The power demanded by these types of grids will need to be commensurate with the energy supply in the system. It will be of paramount importance to have proper data communication and loading on the databases provided.

Data Quality and Cybersecurity

The database will not be able to keep track of the actual values of the entities, and will use the old values instead. Queries that use these old values will produce incorrect answers. However, if the degree of uncertainty between the actual data value and the database value is limited, there will be greater confidence in the answers to the queries. Depending on the amount of uncertain information given to the application, different levels of imprecision could appear. As the data network and data management will become vital to shipping, the safety and security of such systems will need to be carefully protected from external interferences, especially viruses, piracy and terrorist attacks. A potential cyber attack on the sensors' network would create great losses to a given business, and would disrupt the working conditions of the systems and equipment.



Impact on Efficiency

The utilisation of sensors will represent a powerful opportunity for improvements in the efficiency and safety of vessels and associated equipments. Sensors and the data they generate will have enormous potential within the commercial shipping sector. Real-time monitoring and analysis strategies will be the key to improving the commercial shipping sector. The capture of vessels' top-quality data by means of robust and reliable sensors will open up new ways of optimising vessels' life cycles. One outcome will be to make possible the ability to extend the life cycle of a vessel following top-standard operational criteria.

Impact on Operation

This technology will provide data which will need to be properly transferred, stored and analysed. Moreover, this will improve the operation and maintenance of vessels and ancillary equipment during a vessel's life span. Gradually, we will move towards the utilisation of sensors with characteristics which will remain stable as time goes by, even in spite of possible external disturbances (i.e., vibrations, extreme temperatures, noise). Their integration into neural networks will help to provide a certain level of intelligence for industrial control systems based in wireless communication paths. When combined with other technologies, sensors will be seen as a powerful tool for the commercial shipping sector.

New sensor networks will be small, inexpensive, and passive, and will require very little power

Communications

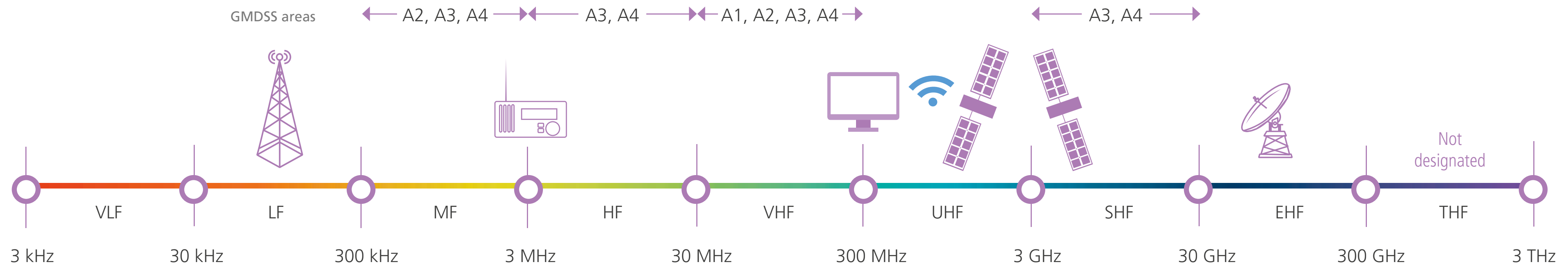
Spectrum Congestion and Bandwidth Challenges

Today, ships generate, collect and transmit an ever-increasing volume of data. To achieve efficient data transfer, wireless communications have been widely adopted for many years. Marine very high frequency (VHF) installations, satellites and WiFi are just a few examples.

By modulating electromagnetic waves, data will be embedded and transmitted from one location to another without cables. However, the deployment of wireless communication is challenging. The congestion of shared spectra is an example. Maximising the use of allocated spectral band will therefore become an important topic. High-order modulation, pulse shaping, as well as dynamic spectrum sharing and management are some techniques that will be used to overcome such constraints. Network topology will also be optimised to improve communication between systems onboard.

Using higher frequency band, especially the section which hasn't been allocated by regulators such as terahertz, will be driven by trend. It will be capable of transferring multiple signals at a higher data transmission speed. However, higher-frequency band will only propagate at a limited distance and will be more susceptible to rain fade, the absorption of radio signals by atmospheric phenomena.

Meanwhile, satellite development will benefit from higher-resolution sensors, more accurate time references, high throughput and high-frequency re-uses. Broadband satellite services will continue to expand. EuroConsult estimated that very small aperture terminals (VSAT) will quickly take over the conventional mobile satellite service (MSS) in five years' time.



Frequency bands of electromagnetic radiation

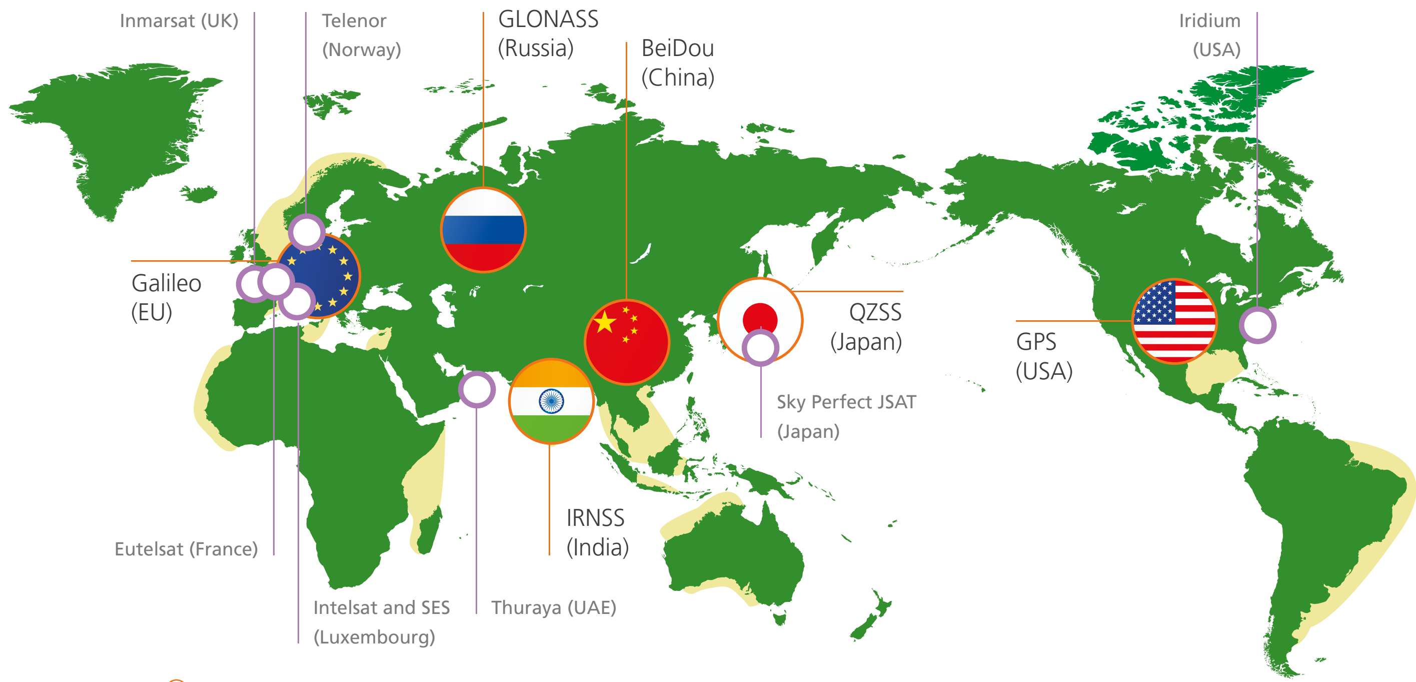
Using a higher frequency band will be capable of transferring multiple signals at a higher data transmission speed

Lower	Throughput	Higher
Larger	Antenna size	Smaller
Less susceptible	Rain fade	More susceptible
Increase	Range	Decrease

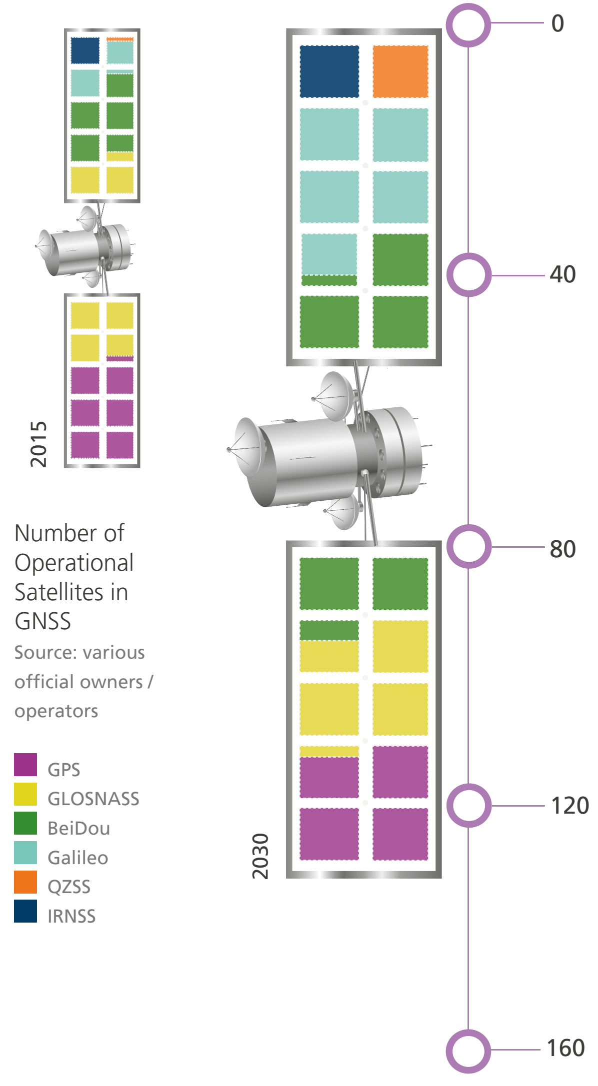
Proliferation of Communication Network

Future marine communications will be driven by the increasing need for data transfer between vessels and onshore bases for optimal operational efficiency, safety, and security. More countries will enter the space market by 2030, leading to affordable satellite services. Interoperability between different hosts, such as GPS and Galileo, will boost the number of satellites in range, providing more usable frequencies and ensuring satellite transmission reliability. Satellite services will therefore be able to handle data from expanding global fleets and provide enhanced accuracy.

The booming offshore platforms and wind farms will support the extension of the most advanced communication networks from land to the sea.



Global or regional navigation satellite systems
Major maritime communication satellite operators
Potential locations for offshore infrastructures offering marine communication services

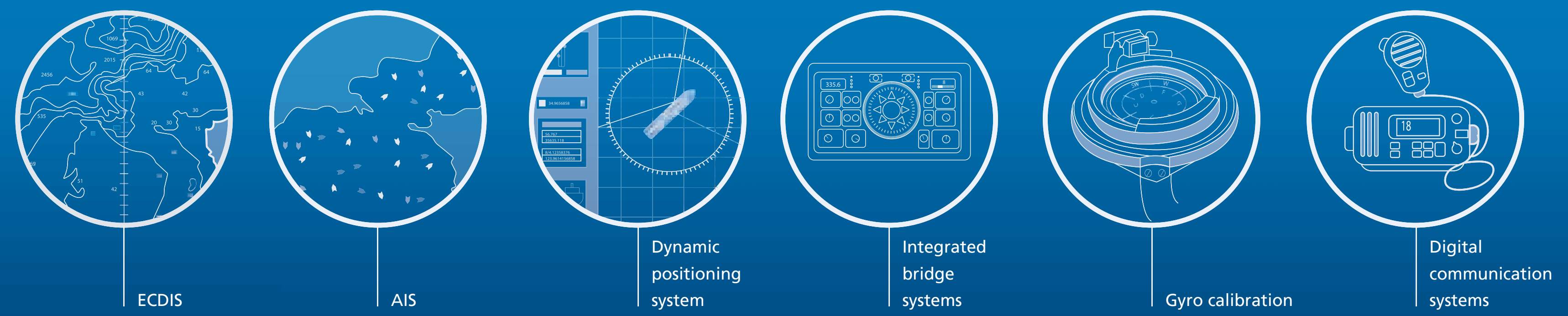


Reliability, Security and Cost

There will be a risk of wireless communications being eavesdropped on or interfered with by malicious parties. Intentional or unintentional interference may occur, causing misleading situational awareness, the sabotaging of vessel traffic service, or the endangering of integrated bridge and autopilot systems.

Using higher power and wider frequency may be a way forward. Researchers will be challenged to enhance security, improve orbital debris tracking for satellites, and to offer robust and flexible networks without bringing complexities or delays to the system. Above all, the industry's ability to lower the price and ensure transmission reliability will be critical. We will also see the deployment of hybrid systems, for instance eLoran being merged with other communication and navigation systems.

Dependency on Global Navigation Satellite Systems



Connected Ship

With the integration of 5G, WiFi and new-generation satellites, as well as conventional marine radiocommunication networks, we will see transformation everywhere. Stakeholders will be able to monitor live audio and high definition (HD) or 3D video collected onboard. Radio-frequency identification (RFID) tags will support through-life asset management, including the tracking status of cargoes, as well as structural and machinery components. Crew will need to be trained to operate multiple communication tools.

Evolution will take place in the workflow process. Physical onboard surveys will be replaced by remote monitoring. Regulatory compliance and enforcement will be achieved remotely without visiting the ship. Real-time decision-making in ship management and autonomous operation will become feasible. Emergency evacuation will be conducted more quickly and in a more transparent manner. Consumers will be able to track product supply chains from factories to retailers and scrutinise the shipping footprint along the journey. Meanwhile, we will see an improvement in the quality of interpersonal communication between ship and shore, as well as an improvement in the wellbeing of the crew.

Shipbuilding

The shipbuilding industry in 2030 will feature higher levels of automation, high-fidelity design software integration, human-computer interfaces, morphing structures, and the introduction of additive manufacturing.

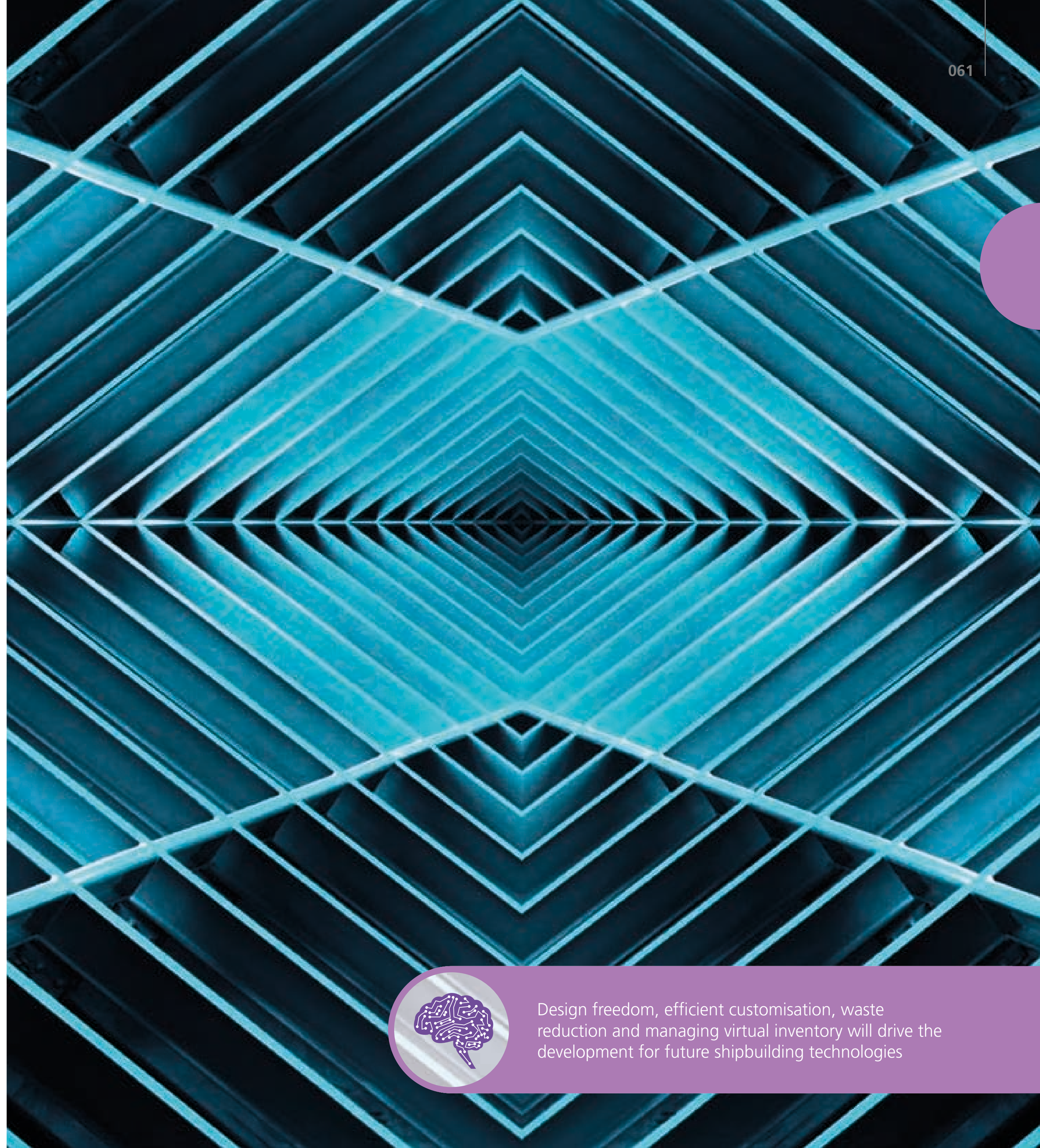
Intelligent algorithms will accelerate the ship design process, and 2D design will be easily converted into 3D. Complex construction and inspection tasks will be supported by augmented reality. More natural and intuitive human-computer interfaces will encourage innovation and efficient design workflow. Multi-touch, voice, gesture, eye movement and even brain control are only a few examples of the human-computer interfaces of the future.

Additive manufacturing, sometimes called 3D printing, is an emerging paradigm of manufacturing materials layer-by-layer. The manufacturing process will not need to be changed while altering the geometry of the design. Additive manufacturing will also provide a greater design freedom. It will be possible to manufacture objects with complex geometry; for example, non-linear holes and honeycombs which would have been too costly to produce traditionally. Boeing has used more than 30 different components produced through additive manufacturing in its 787 Dreamliner planes. Recently, additive manufacturing has demonstrated its capability to produce large objects such as the body of a car.

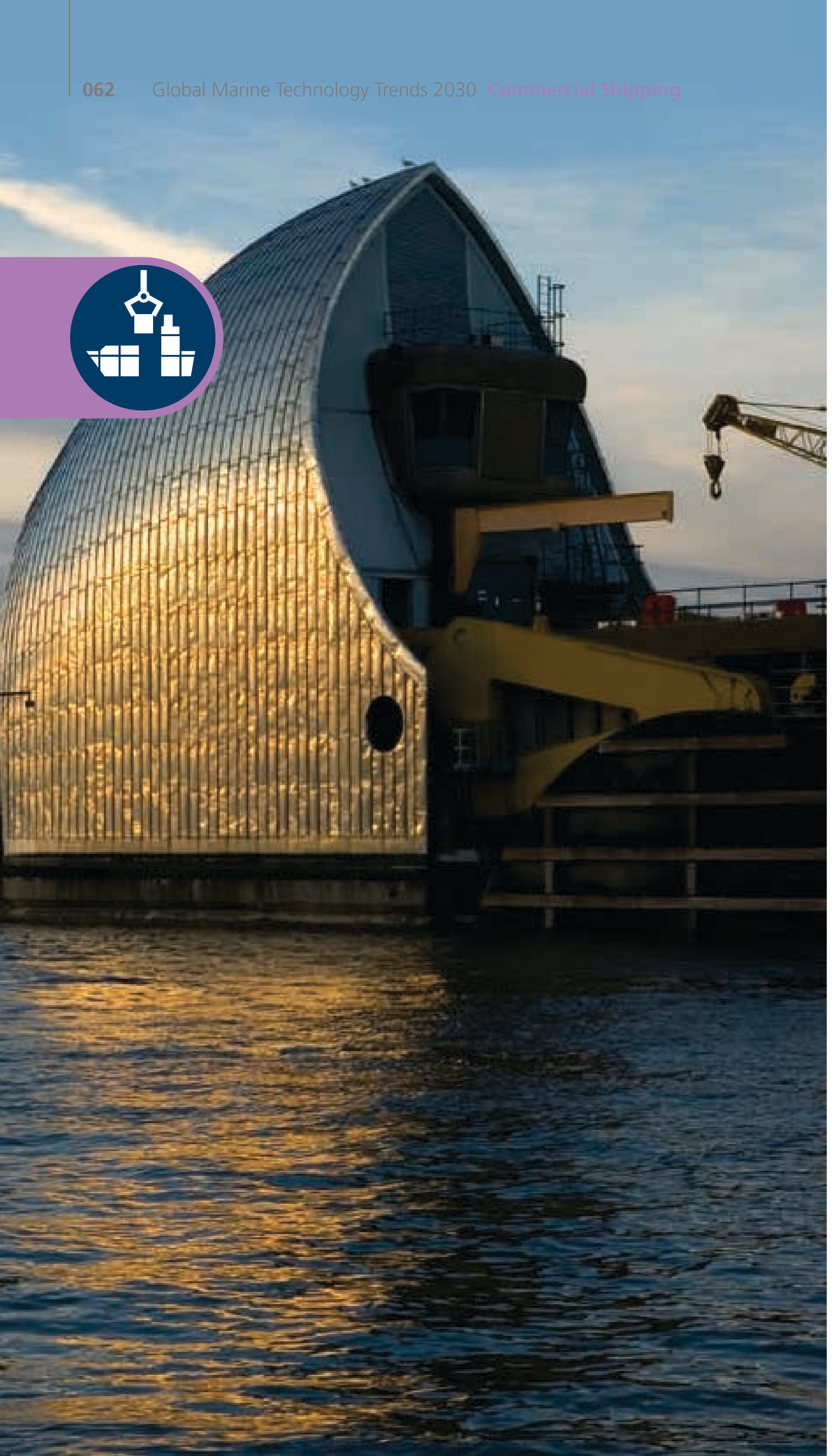
Adaptable hull forms will be developed to better tackle changing loading conditions and speed profiles. A less ballast or a ballast free design will be further developed, which reduces the transfer of marine invasive species across different waters.

Better Products with Less Waste
Effectiveness, efficiency, and satisfaction are the three measures used to determine the usability of human-computer interfaces. With the information overflow and the increasing complexity of ship systems, new technologies will be developed to improve shipyard design and production efficiency. Thanks to the design freedom offered by additive manufacturing, it will be possible to optimise the geometry of a product or component. Fewer parts will be produced, which will lead to weight reduction. Such techniques will initially apply to engine and other machinery components, leading to flow optimisation of the fuels during ship operations. The aviation industry has already begun manufacturing jet engine parts through additive manufacturing. General Electric stated that up to 28% of weight reduction could be achieved by their new fuel nozzle on jet engines, which was made through additive manufacturing.

Apart from the breakthrough in products' operational efficiency, environmental impact is a major driver in adopting new shipbuilding technologies. For instance, 90% of raw materials may be in traditional subtractive manufacturing methods. By contrast, additive manufacturing deposits materials only where they are required.



Design freedom, efficient customisation, waste reduction and managing virtual inventory will drive the development for future shipbuilding technologies



New Challenges
Overlaying a wealth of complex digital information may lead to cognitive overloading. Displaying all pertinent information on a resource-limited hand-held or wearable device in 3D may be difficult. Designing a system that is all-embracing while considering the diversity of data and users will be yet another socio-technical challenge.

The protection of intellectual property may be a barrier especially when sharing data between different players along the supply chain. A policy will need to be set up for protecting the intellectual property of the design.

A layered structure, rather than a homogeneously smooth material will be created using current additive manufacturing technology. Unintentionally introduced defects such as cracks and porosity will be eliminated. Additive manufacturing is a slow process and is currently not able to support quick, large-scale manufacturing. The energy consumption of additive manufacturing in comparison to subtractive manufacturing is also unknown.

New technologies supporting shipbuilding do not come at a low cost. Nevertheless, such disparity will be reduced, mainly due to market expansion in other industries.

Tougher Competition
Metal-based additive manufacturing is currently led by the USA, Japan, and Germany. Other governments around the world are investing hugely in this area, hoping to be at the forefront of additive manufacturing. Components and products can now be presented and stored as design specifications. Ship operators or ship owners can then purchase products quickly at the next port of call or even aboard ships.

CHALLENGES

- Protecting intellectual property
- Cognitive overloading and ergonomics
- Production efficiency
- Integration with legacy systems
- Quality control
- Cost reduction

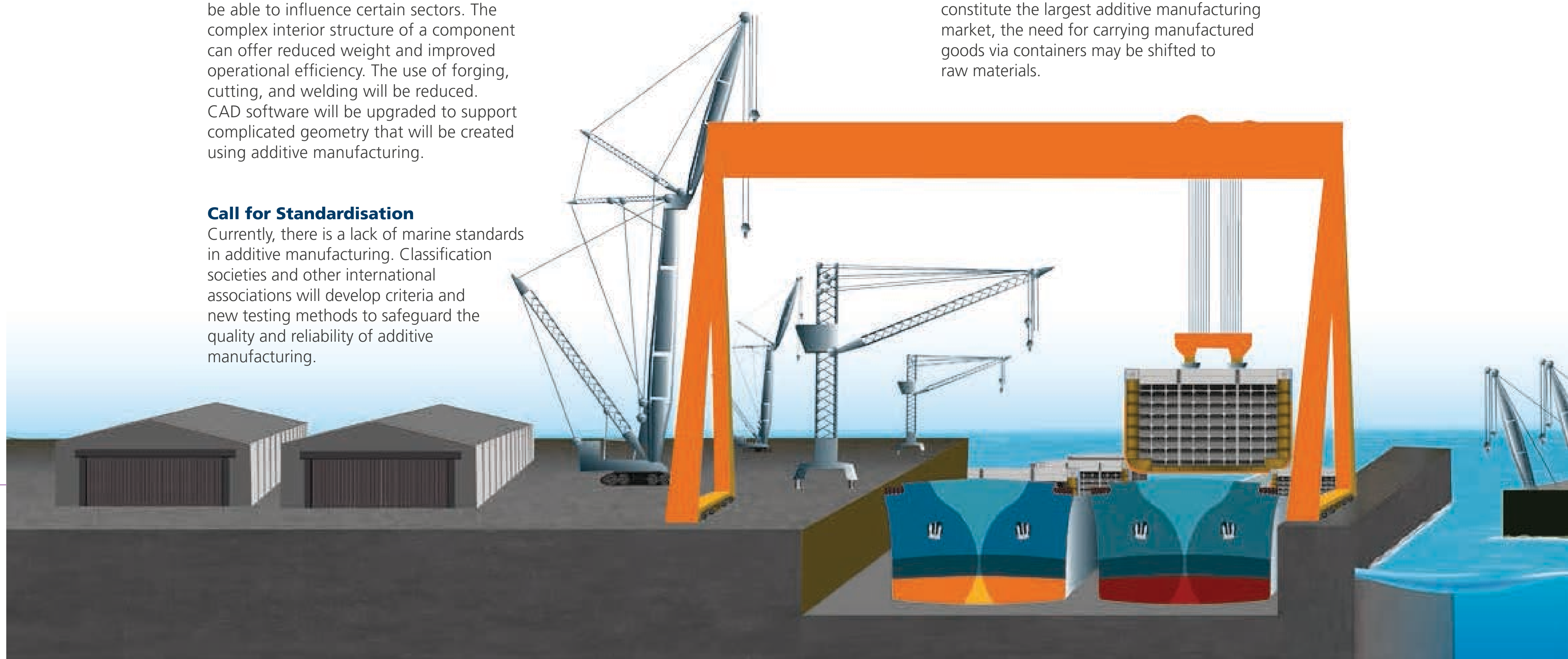
Future Shipbuilding
Future shipyards will be able to digitally integrate design and construction. Shipyards will continue to pursue higher automation levels to stay competitive.

Additive manufacturing will not be able to replace the entire production line, but will be able to influence certain sectors. The complex interior structure of a component can offer reduced weight and improved operational efficiency. The use of forging, cutting, and welding will be reduced. CAD software will be upgraded to support complicated geometry that will be created using additive manufacturing.

Call for Standardisation
Currently, there is a lack of marine standards in additive manufacturing. Classification societies and other international associations will develop criteria and new testing methods to safeguard the quality and reliability of additive manufacturing.

Training from Scratch
Computers and software will be powerful, but not always stable. Increasing dependency on automation and virtual engineering may lead to design omission. Shipyards will need to train engineers to build ships from scratch to gain a systematic and holistic view of the ship design.

Changing Logistics
Additive manufacturing will offer greater flexibility in the location of the manufacturing. In terms of ship repair, the conventional practice of stocking components and tooling goods onboard will be replaced by storing additive manufacturing machinery and feedstock materials. As consumer products constitute the largest additive manufacturing market, the need for carrying manufactured goods via containers may be shifted to raw materials.



Propulsion and Powering

Ship propulsion and power generation will be a significant area of technological development between now and 2030.

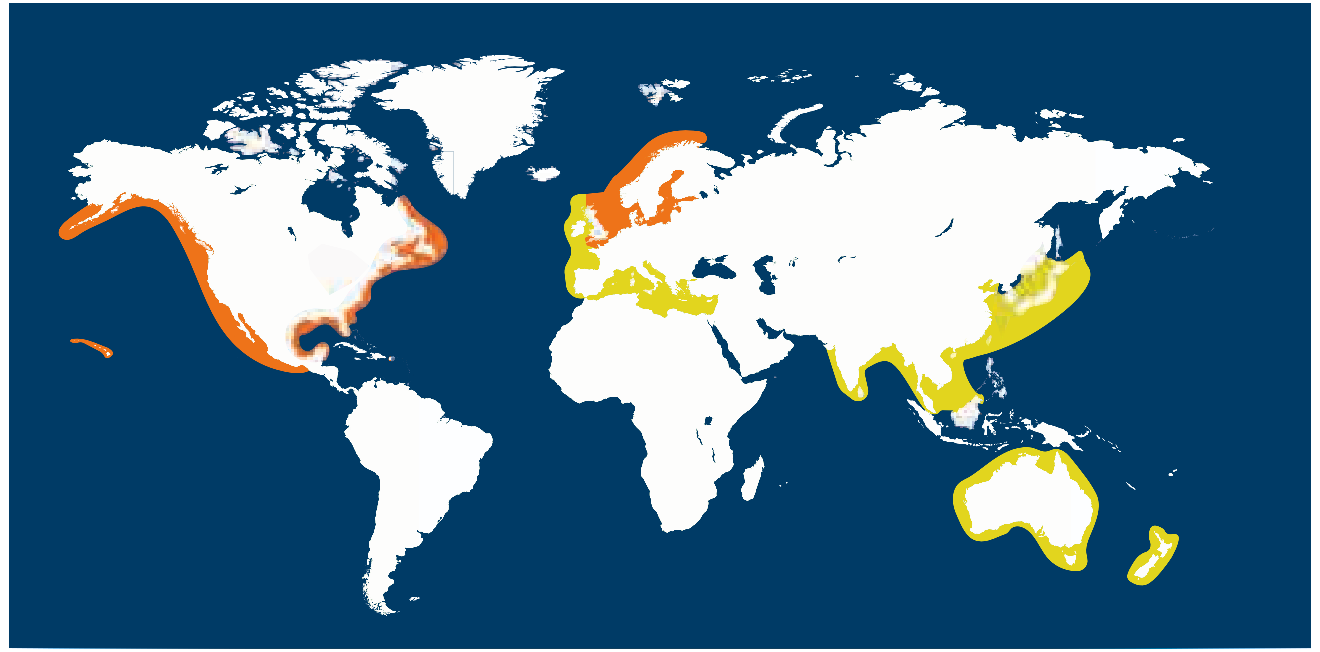
It is not only the scope of applicable technology, which includes future engines, alternative fuels, propulsion energy-saving devices, renewable sources of energy, hybrid power generation, and emissions abatement technology. It is also, and perhaps more importantly, the scale of future challenges for commercial shipping which makes propulsion and powering a key technological theme.

These challenges are not only environmental (exhaust gas emissions and climate change), but also commercial (rising fuel costs and fleet overcapacity).

Further incremental improvements and the uptake of proven technology in deep-sea, commercial fleets is expected. At the same time, specialised shipping segments present significant potential for the development of more novel solutions.

At some point in time, proven technology will reach a saturation point and a shift towards novel solutions will be required.

Ship segments, including short-sea ships, passenger ships and specialised segments (such as tugs, offshore support vessels, yachts and inland waterway vessels) will probably become the 'test-bed' for novel technologies and an enabler for their adoption to deep-sea commercial shipping.

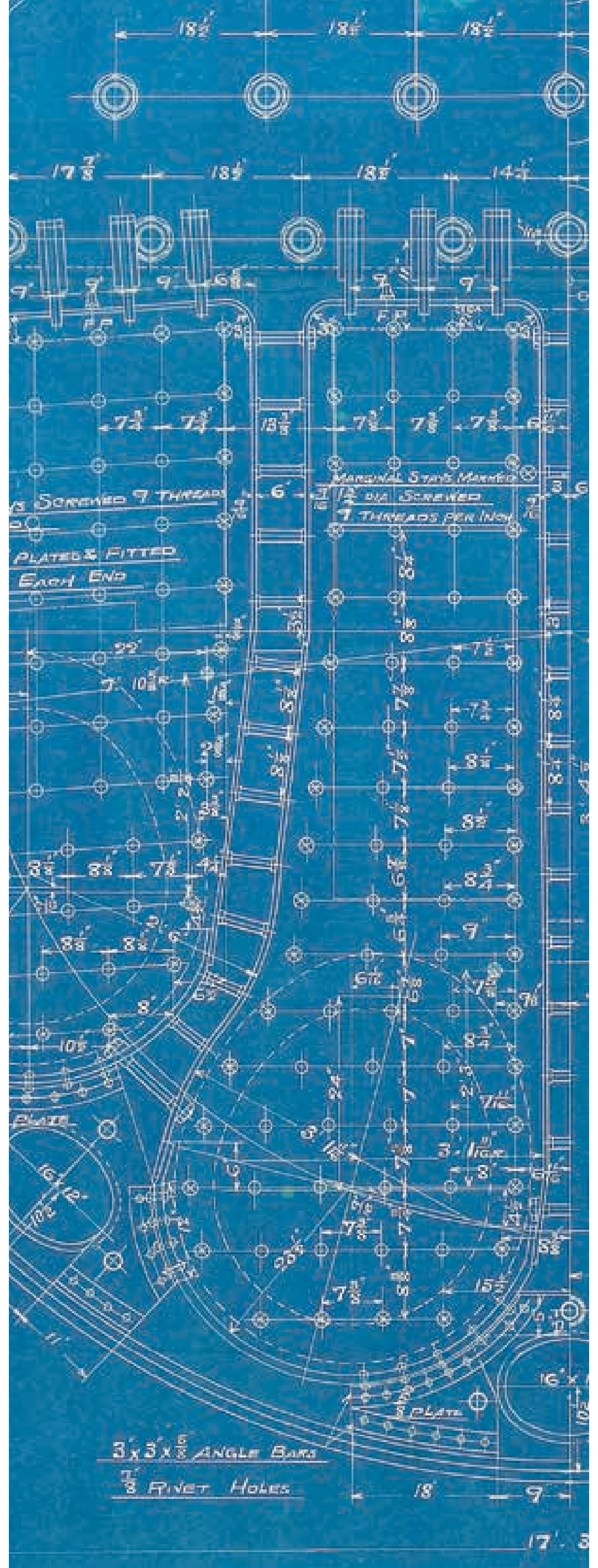


	Non ECAs – focus on proven technology	Future and Existing ECAs – focus on novel technology
Marine fuels and non-renewable energy sources	Use of distillates (MGO) and low-sulphur heavy fuel oil Start of adoption of LNG as a marine fuel	LNG, methanol, Bio-diesel Fuel cells (with hydrogen or methanol) Nuclear energy
Prime Movers and auxiliary systems	Main engine re-rating Advanced/intelligent engine tuning and electronic control	Diesel-electric and hybrid propulsion Waste heat recovery (Rankine Cycle)

Non ECAs

Existing ECAs

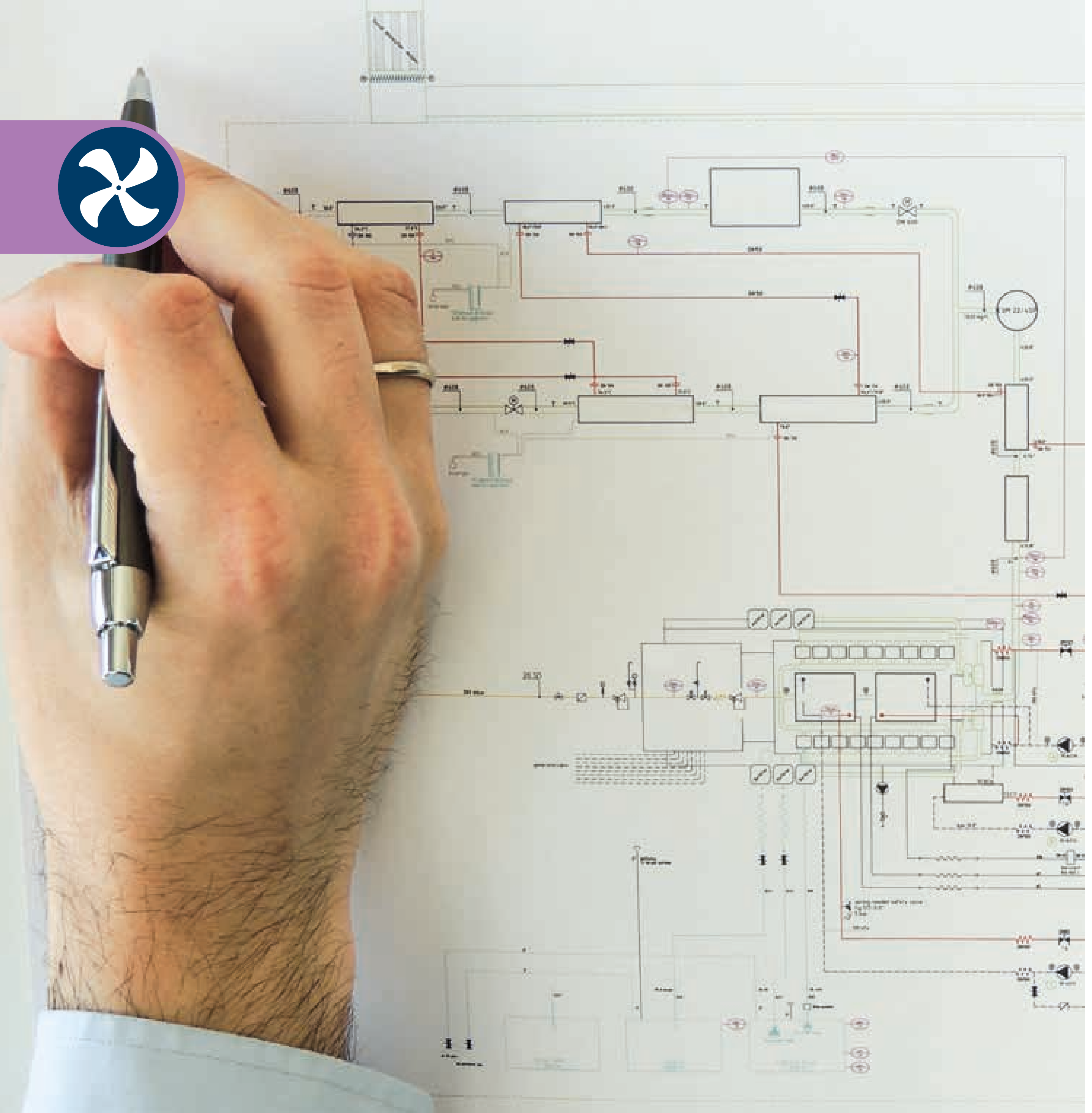
2030 ECAs



Commercial Environment
The global fleet growth outlook remains positive towards 2030. If the transport supply grows faster than its demand, this will further increase the overcapacity we currently observe in most shipping segments. This will create cost pressure and, arguably, a non-favourable environment for testing novel concepts. On the other hand, it also creates a necessity for technology differentiators that reduce operational costs.

Societal Pressure and Future Regulations
Increasing public awareness of the environment and climate change will continue to put pressure on governments to respond with a regulatory policy. As identified in GMFT2030, future carbon policies could drive the uptake of alternative fuels such as hydrogen fuel cells. Although shipping has already introduced mandatory Green House Gas (GHG) reduction mechanisms (EEDI), the expected fleet growth indicates that further policies will be required for shipping.

Current Regulations
Requirements for the reduction of GHG emissions (EEDI) and exhaust emissions (SOx/NOx) are already influencing propulsion and powering technology development. The widespread uptake of alternative fuels and abatement technology will mainly be driven by emissions limits, while the requirements in Emission Control Areas will mostly influence short-sea shipping. The EEDI will, in part, have an influence on the further uptake of engine technology and resistance/propulsion/ESDs.



Risks and Uncertainties

The commercial environment and the timing/stringency of emerging regulations on GHG emissions will impact the uptake of low-carbon technologies. While efficient in terms of energy conservation, diesel or Liquefied Natural Gas (LNG) engines will become inefficient if GHG-reduction policies are applied.

The focus on proven technology for deep-sea fleet will limit innovation to specialised/niche ship types.

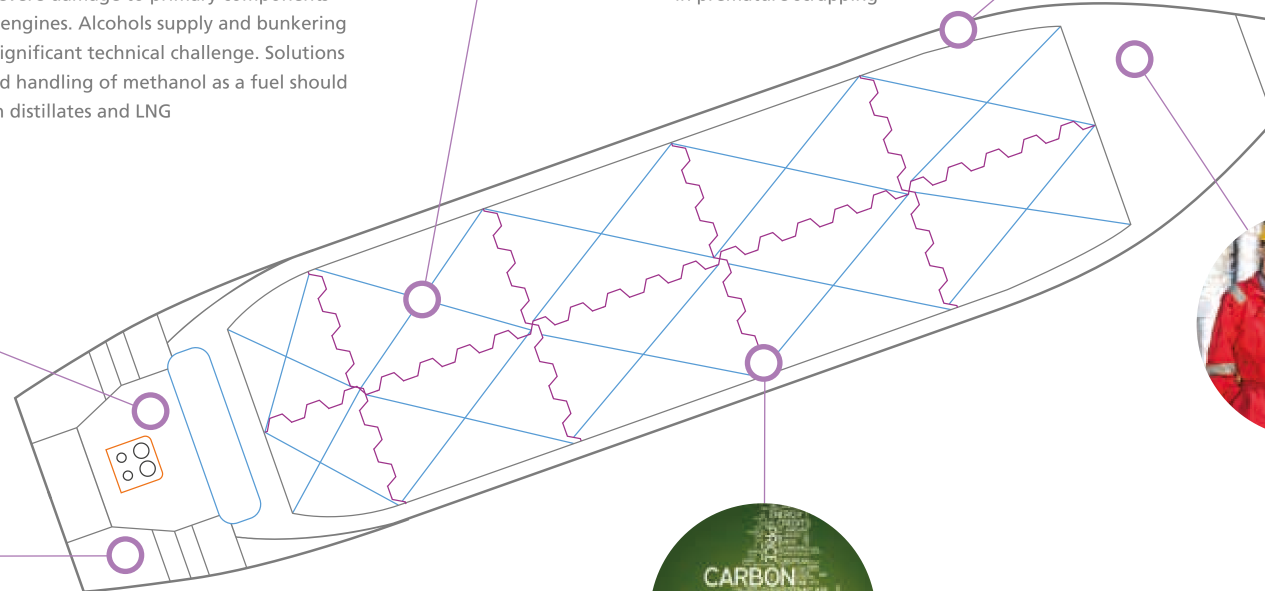
Low fuel prices will lower the incentive to innovate as with what happened with wind-assisted propulsion in the 1980s.

A peak in trade demand (and an associated increase in freight rates and ship speeds) will make energy efficiency a lower priority.

A lack of a defined regulatory framework for the application of novel technologies (for example, LNG as a marine fuel has been widely discussed for the past 5–10 years, but it was only in September 2014 that the IGF Code draft was finally agreed upon).

Technology is developing at a faster pace than prescriptive regulations. The industry is not entirely ready for goal-based standards.

Ships will become more complex and the shortage of technical skills will need to be addressed.

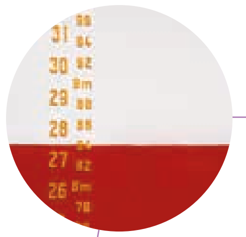


Prime Movers

The current dual-fuel engines market portfolio will increase with Dist-Meth, Dist-Eth and Dist-Gly pairs. These engines will be fully electronically controlled, incorporating a network of control modules and sensors, able to manage the engine under different load and fuel conditions. High-pressure fuel supply networks will be necessary for the utilisation of these alcohol-based fuels. So, technologies like common rail would be revisited in order to accommodate these new fuel types. The use of alcohol as fuel will require new lubricating oil formulations to avoid severe damage to primary components of internal combustion engines. Alcohols supply and bunkering will not represent any significant technical challenge. Solutions for the containment and handling of methanol as a fuel should lie somewhere between distillates and LNG

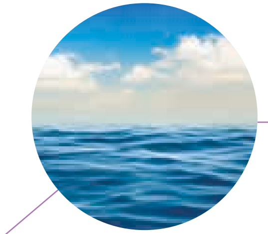
Fleet Renewal

As new tonnage adopts innovative propulsion and powering technologies, the existing fleet will become less competitive, resulting in premature scrapping



Waste Management

An infrastructure to handle the new waste streams will be required: moving from oily sludge to scrubber wash-water sludge, and from economiser ash to catalyst reactors or dust particle filter ash



Impact on Crew

The role of marine engineers will evolve and a demand for new skills will be created: gas, fuel cell and advanced electrical specialisations will be added to the role of marine engineers. Traditional roles will disappear together with obsolete technology

Efficiency and Environment

Ships will become even more efficient and will reduce their carbon footprint. A gradual decarbonisation will be achieved thanks to combination of incremental improvements using proven technology and step-changes using novel technology

Fuels to Come

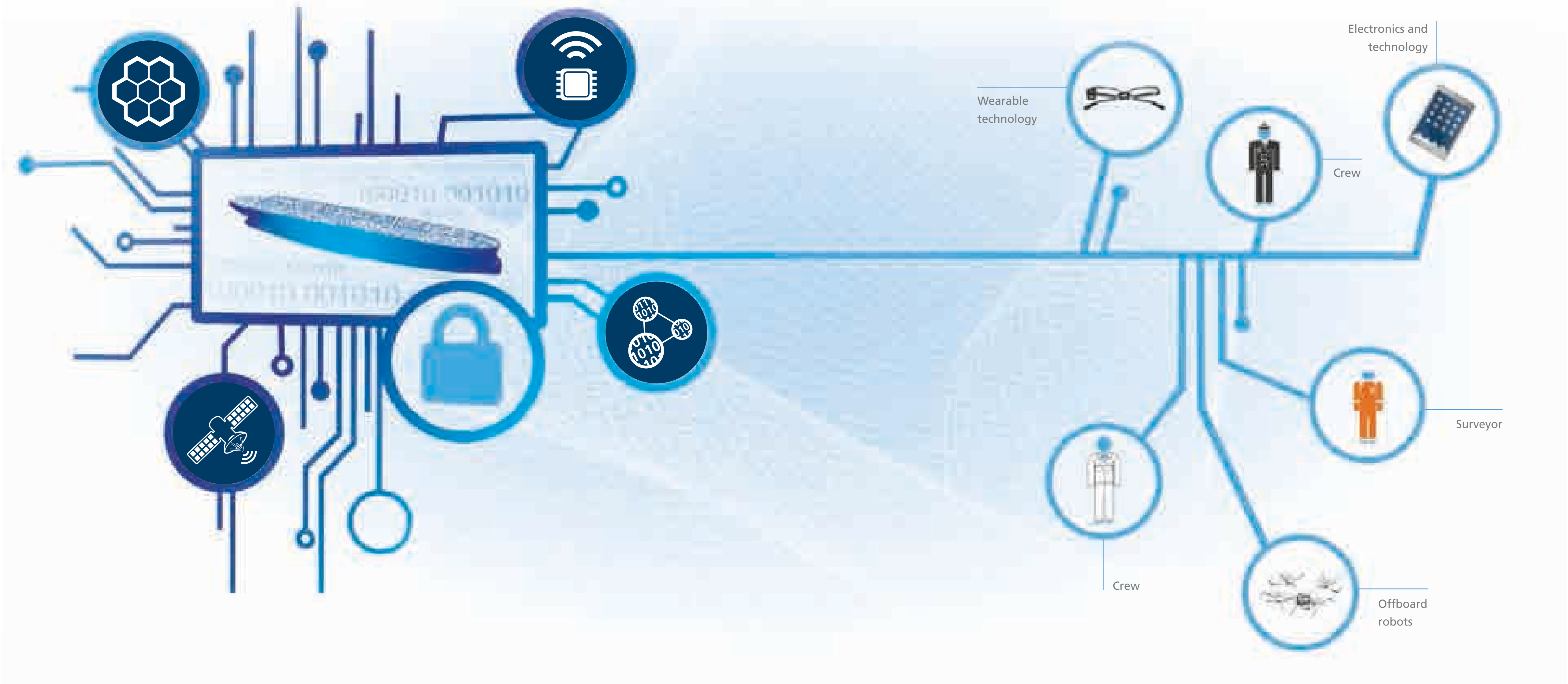
With today's marine fuels being gradually replaced by alternatives, land-based infrastructures and bunkering infrastructures will be developed

Smart Ship

Arguably, smart ships are not a revolution but an evolution that can be traced back to more than a century ago: a diesel-powered ship was 'smarter' than a coal-powered one in that there was no longer the need for a crew of firemen to feed coal to the furnaces. Today's concept of unmanned machinery spaces may be considered another manifestation of the smart ship, as are data-driven services such as vessel-performance monitoring and weather routeing.

However, there are still immense opportunities from digital technology and automation that shipping hasn't embraced. We have more efficient engines and we are able to build larger ships. Yet, the way that we manage, operate and maintain ships hasn't been revolutionised to reap the full benefits of these technologies. Operators are concerned about ships becoming more complex with a shortage of skills and, as an industry, we are still challenged by an ever-increasing amount of paperwork and data that we can't extract value from.

This is what the concept of smart ship is trying to change. Technologies already considered mainstream in automotive, aerospace and even consumer electronics are, generally speaking, at their infancy in shipping. Smart ship technologies will deliver major benefits to commercial shipping.



The Tools are Here

The components required for a smart ship revolution already exist and are cost-effective. Commercial aircraft flies autonomously without pilot interference. At the size of a wallet and for less than US$200, a smartphone is a fully connected computer containing any conceivable sensor: including an accelerometer, gyroscope, magnetic compass, proximity, light, GPS, barometer, thermometer, hydrometer, infrared and more.

Increasing Shortage of Maritime Skills/Resources

There are over 104,000 ocean-going merchant ships. The shortage of highly-qualified sea-going staff is an increasing concern, especially as ships become more complex due to environmental requirements. The lack of gas engineers is quoted as a major barrier for the gas-fuelled shipping transition. Smart shipping is not necessarily about removing people from ships, but about better connecting ships and their crews with specialised onshore resources.

Physical Shipping Technology has Peaked

It is possible that we have already approached the limits of what physical technology (engine, hull, propulsion) can deliver in terms of absolute efficiency (tonnes/day). Smart ship technologies will provide an opportunity to deliver higher efficiency gains.

10% of the new buildings will be smart ships

Cybersecurity
Remotely transmitting every conceivable aspect of ship operation and management introduces cybersecurity risks for which today's commercial shipping sector is ill-prepared. Technical, financial, reputational and regulatory risks originate from a) exposing sensitive machinery, performance, maintenance, commercial and compliance data and b) remotely operating machinery (or ships). Regulators will play a key role in providing support to all stakeholders in this field.

Job Creation or Job Losses
While new technology will create the demand for new skills, the smart ship efficiencies achieved may render some maritime professions obsolete, as with other technological evolutions. Only time will tell if the net effect will be positive or negative. However, new skills are already being requested, mostly linked to data management and analysis. Other jobs linked to the engineering side of the technology to come will include: data grid engineer, remote automation engineer, engineering and naval crew, onboard support technician, shore support specialist or cyber-attack specialist.

Conservatism
In an industry where 'paperwork is king', a digital revolution is likely to be met with resistance. However, the change is going to be more natural as a new, 'smartphone generation' of maritime professionals and management is introduced to the industry. Smart ship technology will make it possible to improve many bureaucratic processes and procedures within the maritime industry. Highly dynamic maritime operations will demand new approaches. A new state of mind will be needed for all stakeholders in order to enable the practical application of smart ship technology.

Regulatory Frameworks
From a regulatory perspective, the industry does not seem to be designed for a digital revolution. Regulatory developments have long lead times and often follow technological developments, rather than drive them. This should not pose an obstacle for smart ships. It should be recognised, however, that regulatory debates on topics such as autonomous ships and/ or cybersecurity will be challenging. Through a combined stakeholder effort it will be possible to reach agreements; expert committees/panels will be created, and international bodies will need to provide legislative support for the technical developments.

Impacts

Reduction in the number of resources required for ship management

Creation of a new service industry and new market opportunities

Streamlined regulations

Real-time, fact-based decision-making support during vessel operations

Utilisation of operational data during ship design and construction

Streamlined compliance monitoring and enforcement, and a reduced need for onboard visits

Risk management through the minimisation of human errors

Maintenance optimisation through condition-based monitoring

New career pathways, making the industry accessible to a new generation of maritime professionals, thereby addressing the skills gap

Operational optimisation using vessel performance data and environmental data

Commercial Shipping Transformed

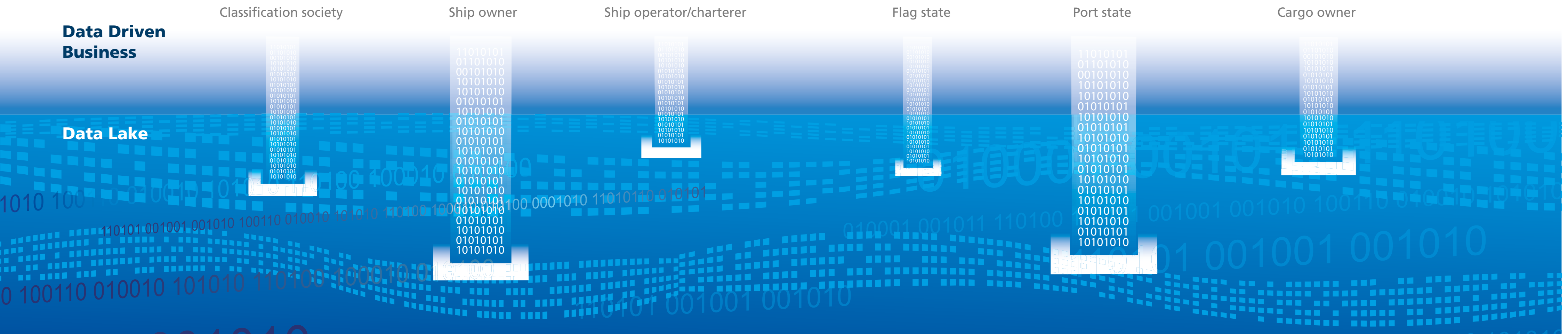
Containerisation revolutionised shipping, as it fundamentally changed the way consumer goods were transported around the world. A new class of ship with an associated logistics infrastructure (such as port machinery and land transportation using articulated lorries) had to be put in place to service the container trade. New opportunities were offered for job and wealth creation.

As the world economy continues to expand, the world's population is getting wealthier and wants new ranges of goods from different parts of the globe. These consumers are demanding and technologically savvy, driving suppliers to seek a new approach to shipping. Price is only one factor driving their behaviours; other factors such as schedule reliability, intuitive self-service wherever possible, environmentally sustainability and ease of business are also important to today's consumers. The coming digital revolution will help the shipping sector to meet these challenges.

In terms of ship hull and engineering design, evolution rather than revolution seems to be the future in the near to medium term. Major improvements to cost-effectiveness, energy efficiency, and regulatory compliance will be necessary in order to meet changing consumer demands, and to allow ship operators to harness the maturing digital technology.

The complexity of modern ship systems has taxed crews' ability to manage them making full automation increasingly attractive. The sophisticated analysis of the deluge of data from intelligent, wireless sensors and extensive communication and satellite systems has the potential to further reduce operating costs, increase safety, and enhance environmental protection.

The availability of the eight transformational technologies — advanced materials, big data analytics, robotics, sensors, propulsion and powering, communications, shipbuilding, and smart ships will have a profound impact on ship system design and operation in the next 15 years. With faster technological advances, there will be a move towards delegating authority from the human operator to the machine. Machines will perform many more of the tasks which are considered dull, dirty and dangerous to achieve a higher level of safety and efficiency. There are varying degrees by which a human can delegate responsibility to a machine, depending on the nature of the task and goal they wish to accomplish, and depending on the levels of automation and autonomy built into a ship.



It is envisaged that these eight technologies will be implemented differently from ship type to ship type. These ships will be called TechnoMax Ships, as technology implementation will be at its most appropriate and fullest level in 2030. They will be operated differently from in the past, and will be smarter, data-driven, and greener, with flexible powering options, full on-board wireless connections, and digital connections through global satellites.

TechnoMax Ships will fundamentally change the business model of the shipping industry, in that it will be possible to obtain bespoke information and data on a 24/7 basis, thereby increasing commercial and regulatory effectiveness. For example:

- Classification societies will have access to data for safety and classification purposes, or for other additional services as driven by client demand
- Ship owners will have access to the full material state of the ship
- Operators will have full control of operational and performance data
- Cargo owners will have full access to the material state of their cargoes and schedules
- Regulatory authorities such as flag states will be able to obtain full statutory compliance information
- Port states will have access to safety, cargo and personnel information.

The shipping world in 2030 will be very different from today.

TechnoMax Ships will be designed by technologically advanced shipbuilders, and will be ordered and operated by owners who are prepared to invest in sharpening their competitiveness and boosting their corporate social responsibility credential.

The shipping industry will need to reconsider its business model in terms of the way ships are designed, built and operated. This will affect the education and training of the new generation of naval architects, engineers, seafarers and managers. Ship operations will be conducted partially or entirely onshore, and will be remotely manned by personnel with university degrees and maybe even with doctorate degrees, as ships will have become so smart and complex.

Ship system design and construction will become so sophisticated that few countries will be able to master it, slowing past in which shipbuilding moved from developed countries to developing ones. This will also lead to structural changes in shipping industry organisations to the extent that middle-level management may disappear partially or completely, resulting in an hourglass-type organisational structure connected by data analytic systems.

Many new issues such as cybersecurity, port operations and societal concerns regarding jobs and safety will arise and will need to be addressed. Investments in technology and capacity building will be required.

With an aging population, rising wages and the availability of affordable, mature, enabled technologies, TechnoMax Ships will slowly and surely become part of the routine shipping scene.

Ship operations will be conducted partially or entirely onshore and remotely manned by personnel with doctorate degrees

TECHNOMAX LIQUEFIED NATURAL GAS (LNG) CARRIER 2030

The main characteristics of TechnoMax LNG carriers will be heavily influenced by two technical aspects. The first aspect will be the adoption of advanced materials, which will favour the reduction of the boil off gas (BOG) rate. This factor will have a direct impact on the type of propulsion utilised onboard. The second aspect will be the future development of different canals around the globe (Suez, Panama, Nicaragua). This factor will have a direct impact on the size of the vessels, as well as their main dimensions and cargo capacity.

A

Advanced Materials

As graphene is an excellent conductor of heat, so it can be used to manufacture products that would be a fraction of the weight of the ones currently produced – some alloys like copper-graphene and iridium-graphene could be applied. The utilisation of graphene specifically manufactured for a given application, the enhancement of heat-transfer properties, will be developed for several components in the engine room, including heat exchanger pipes, filters, sea chests, condensers and boilers.

B

Big Data Analytics

Visualisation aid for machinery control will be heavily influenced by big data. Visual stations, located around the engine room and tanks of the vessel, will be able to record, store and display the featured parameters. By means of infrequent reporting structures, they will unleash the data they contain on the major data centre, based on the dome and back-up device. Later on, data will be easily accessible for remote monitoring purposes.

C

Smart Ship

Graphene sensors will be used to detect traces of atmospheric pollutants and emissions of the vessel for monitoring and reporting purposes.

D

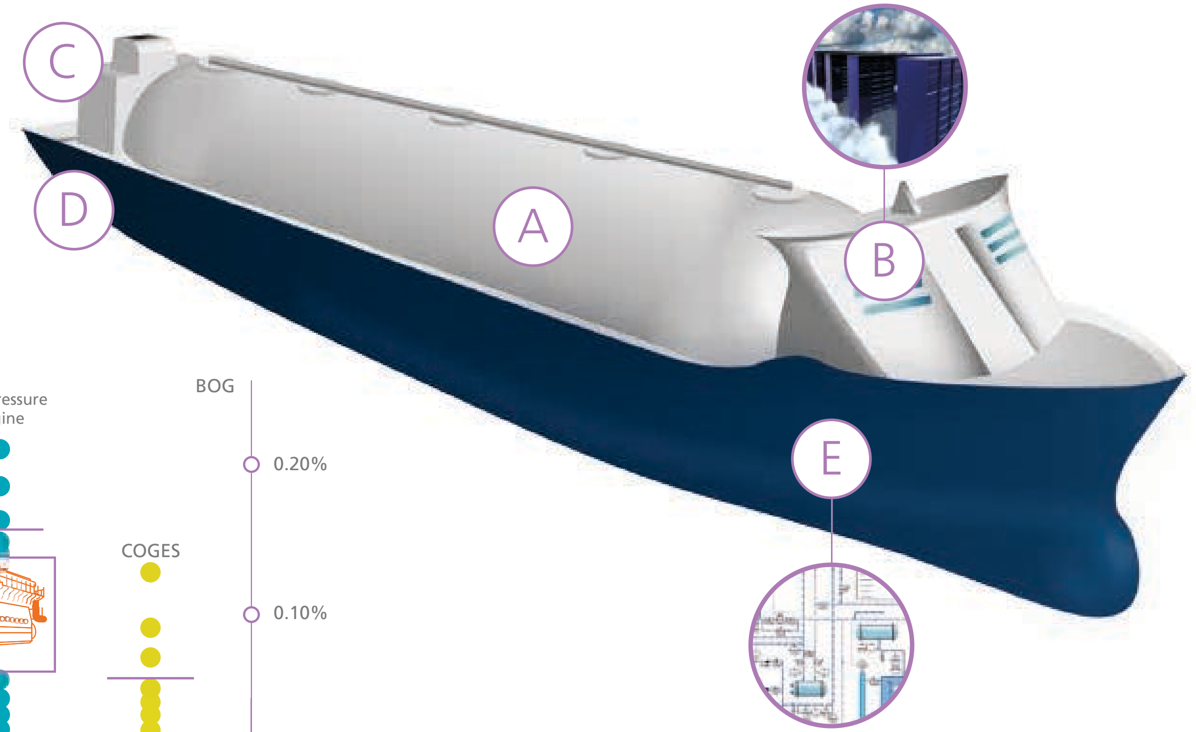
Propulsion and Powering

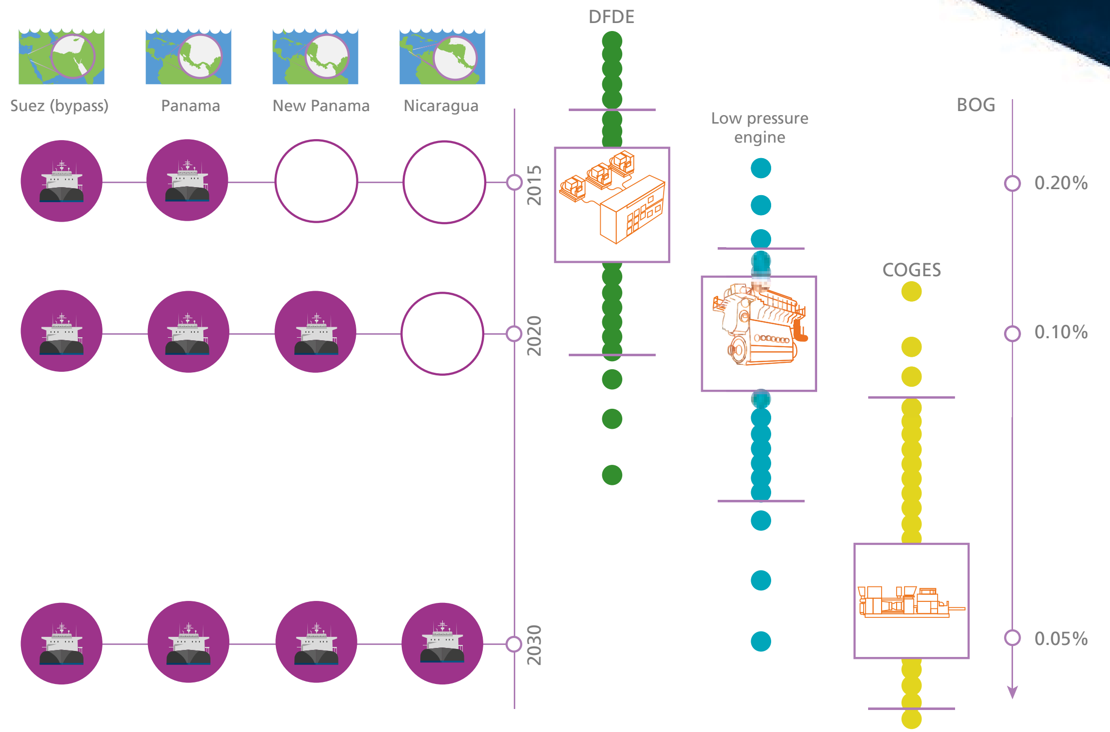
LNG carriers will be heavily affected by future technology developments in relation to propulsion. Combined utilisation of dual-fuel diesel generators together with batteries and fuel cells will be commonplace. These engines will be fully electronically controlled, incorporating a number of electronic control modules and a sensor network able to control and manage the engine under the different load and fuel conditions. Methanol, ethanol and glycerol use will be common, alongside the current and new ECA areas around the globe. Graphene holds the key to an energy storage revolution. Highly porous graphene-based supercapacitors have been developed, which can fully charge in just 16 seconds and undergo this some 10,000 times without a significant reduction in capacitance. The collating of various power-generation and propulsion systems will therefore be key for this ship type.

E

Advanced Design Assistance

Combing virtual reality applications with classic design tools like CAD will help to design and allocate onboard equipment. Engine room circuits and cargo circuits will be easily designed, minimising cost and space. The use of productive augmented reality in technical assignments will be commonplace: from the visualisation of future facilities within a current production environment to the deviation measurement between a CAD model and the related assembly part. The use of augmented reality will also facilitate the negotiation phase of the vessel before the construction by means of electronic catalogues offered to the customers, showing the main vessel capabilities/arrangements. As such digital catalogues will help during the contract and design stage of the vessel. Visual tracking will be a commonly used tool for pose purposes.





Future developments of canals will determine design characteristics according to new route specifications provided by vessel owners.

Advanced materials development will favour BOG reduction to values close to 0.05%/day. It will be coupled with new types of propulsion systems.

TECHNOMAX TANKER 2030

Technologies applied on the TechnoMax Tanker will be influenced by the implementation of emerging ECA and SECA areas in the traditional routes of this ship type. The potential implementation of the Mediterranean as one of them could have a big impact on the design of this vessel type and the exploration of new propulsion alternatives and the vessel's dimensions.

A

Propulsion and Powering

The main propulsion package fitted onboard large tankers will still be large-bore 2S engines. Combustion mapping, heat flows, re-tuning, the self-adjusting and close monitoring of essential and non-essential parts, and remote monitoring will be possible with the new, intelligent large bore engines range. The overall efficiency of the propulsion plant will be enhanced with the use of new materials, such as graphene and its alloys, in heat exchangers and condenser piping. This will improve the overall thermal efficiency of that equipment and will reduce associated maintenance and chemical dosing. 3D-printing devices for expensive spare parts (i.e., engine sensors, connectors, pump casings, impellers, etc.) will improve repair activities onboard and will consequently reduce OPEX. Lighter propulsion packages, using lighter materials together with optimised maintenance strategies, will have an influence on the fuel bill.

B

Fuels

Operations in current and emerging ECAs will see the diversification of marine fuels that can comply with ever-stricter emissions limits. This will lead to an increase in the use of gas as a marine fuel and in potential novel and local fuel supply solutions emerging. In this way, the utilisation of alternative fuels will become feasible from both technical and financial angles, for use in ECAs and near-shore operations. These alternative fuels include methanol and ethanol, but also more traditional fuel types such as fatty acid methyl esters (FAME), and even non-traditional fuels such as glycerol.

C

Advanced Materials

Graphene's anti-bacterial properties will create new opportunities for application in fields like hull coating. By means of graphene films, hull surfaces will be covered, avoiding micro- and macro-fouling attachments. The robustness and resistance of graphene are useful characteristics for this type of application.

D

Intelligent Tanks

Sensor networks will be embedded on bulkheads and vessel structures. Graphene batteries will help networks to operate independently and for long periods of time. An intelligent tank-cleaning schedule will be easy to track using sensor networks. This will help to optimise cargo schedules and to properly monitor the state of the tanks.

E

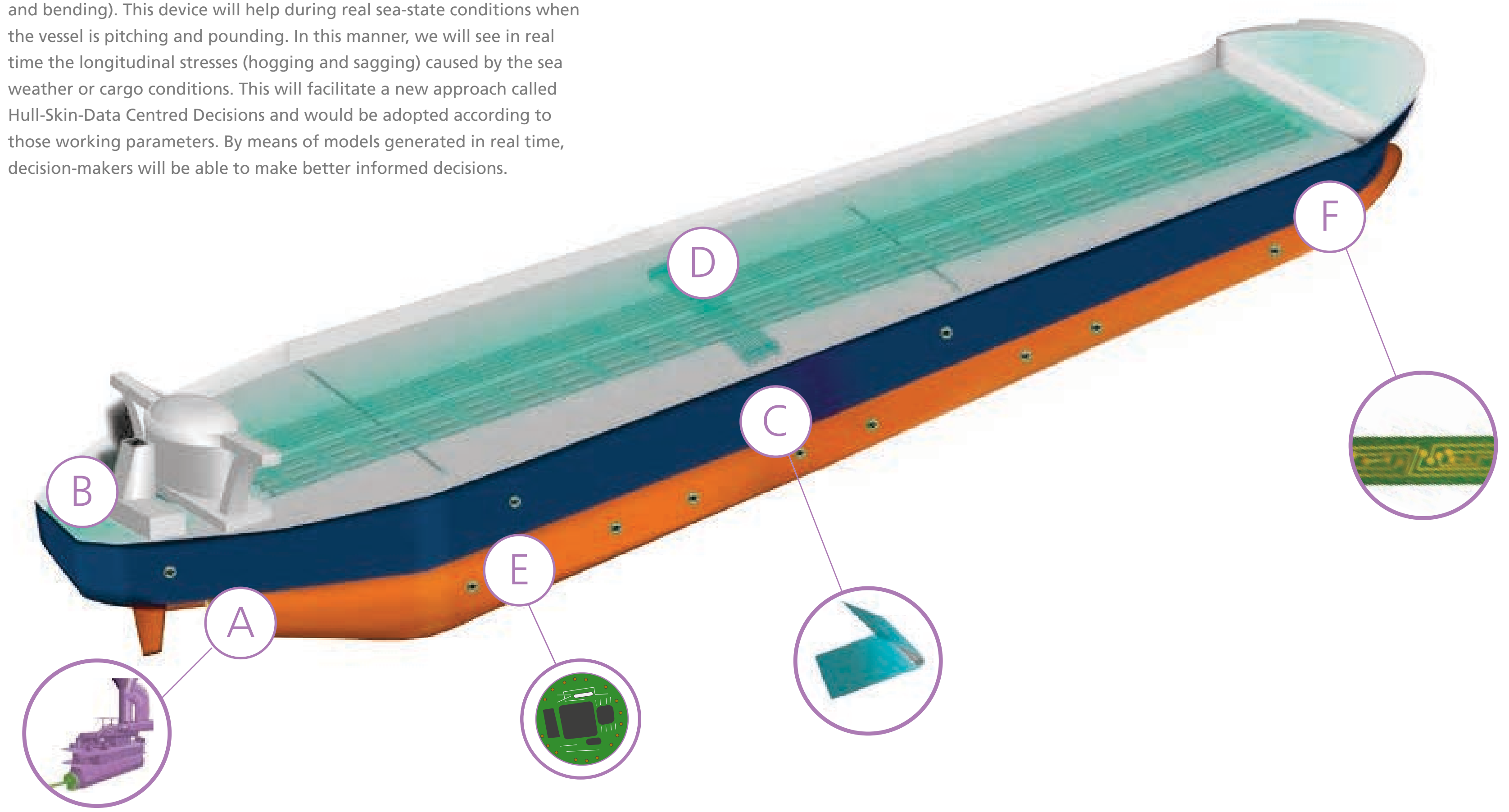
Sensor Networks

Smart dust-sensor networks will comprise a vast number of ultra-small, fully autonomous computing and communication devices which will work together to accomplish large sensing tasks. The length of the type of vessel drops into the operational distance these type of devices are able to operate within.

F

Hull Data

Graphene is strong, conductive, thin and stretchable. Graphene strips, with allocated sensors, alongside the hull will provide more accurate data about the hull's working conditions. Not only will they monitor external factors (seawater temperature, sloshing, impacts and fouling), but they will also monitor internal factors (stresses, microbial induced corrosion, and bending). This device will help during real sea-state conditions when the vessel is pitching and pounding. In this manner, we will see in real time the longitudinal stresses (hogging and sagging) caused by the sea weather or cargo conditions. This will facilitate a new approach called Hull-Skin-Data Centred Decisions and would be adopted according to those working parameters. By means of models generated in real time, decision-makers will be able to make better informed decisions.



TECHNOMAX BULK CARRIER 2030

In 2030, as the global dry bulk market is expected to grow in the long run, we will see a heightened demand for larger ship sizes reaching around 450,000 DWT.

A Auxiliary Propulsion and Powering

Rigid wingsails, wind turbines, rotors, or kites could potentially be added onto the freeboard deck. Aerodynamic interference with the superstructure in different wind conditions will be minimised. The potentially increased heeling moment, however, should be carefully handled during different weather conditions. Together with solar panels, renewable energy sources can directly harness wind and solar energy to assist the auxiliary powering system of a bulk carrier.

B Superstructures

Job roles in maintenance, safe navigation and communications with surrounding vessels or objects will be replaced by autonomous technologies. The space requirement for cabins will be reduced. Together with the use of lightweight materials, such as aluminium or carbon fibre composites, the weight of superstructures will be reduced.

C Propulsion and Powering

Bulk carriers' major trade routes will still be found between Australia and Brazil to the Asia-Pacific, Indian Ocean and Europe. As the majority of these regions may join the ECA region by 2030, fuels consumed onboard will need to comply with the new ECA requirements. Hybrid LNG and marine diesel fuels mixed with biofuels will be designed as the main contributors to propulsion and powering.

D Ballast Water

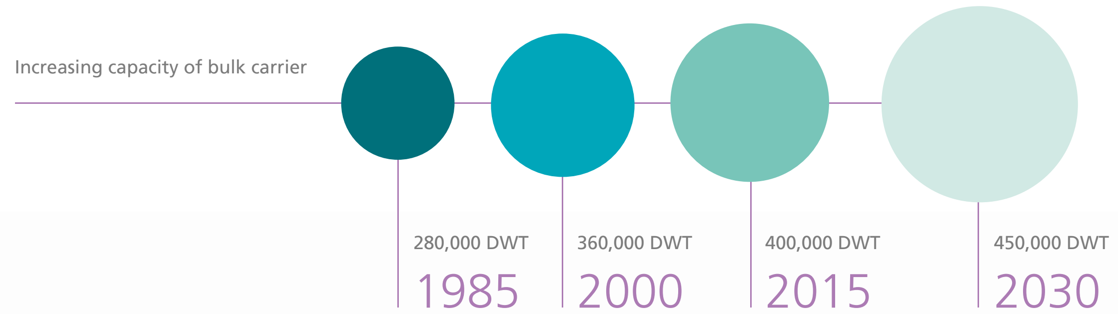
Several methods will be implemented to solve ballast water issues. These will include continuous flow systems, stability tanks at the aft, and wider-beam V-hull forms. Alternatively, the industry may continue using ballast water tanks by adopting effective mechanical, physical, or chemical ballast water treatment systems. A bulk carrier is a ship type that will be more likely to adopt radical ballast water designs.

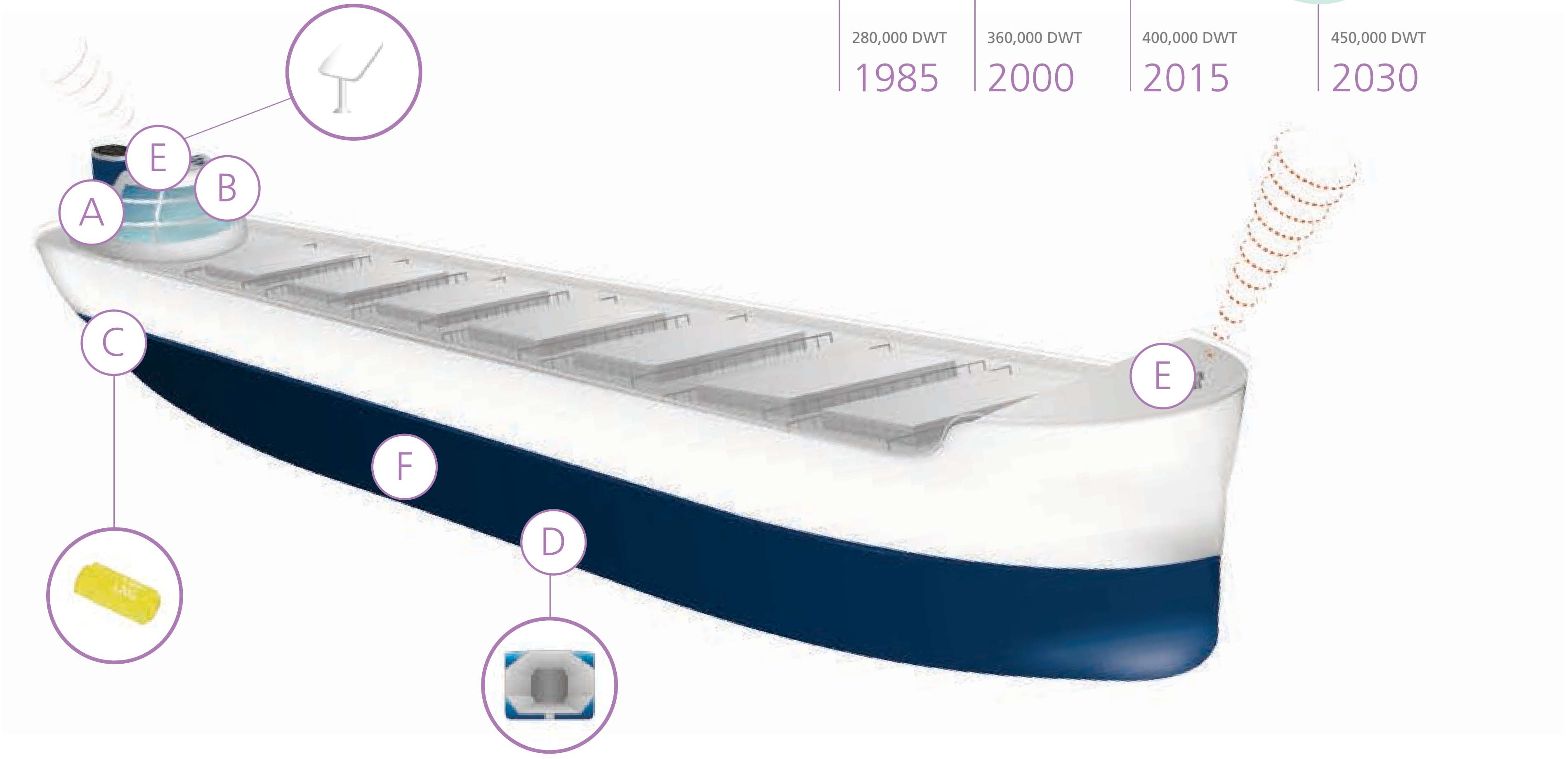
E Communications

A smaller flat antenna equipped with communication signal receivers and sensors will be designed to warn of upcoming obstacles, and will capture and submit data that supports optimum ship operation. Rotating sensors can scan in all directions, using radar/lidar, camera and sonar to assist with collision avoidance and autonomous operation.

F Condition Monitoring

Embedded Non-Destructive Examination (NDE) sensors will be placed around hull structures. Other sensors may also be found in machinery. With the support of wireless communication, it will be possible to track ship structures, machinery and cargo storage anywhere onboard or onshore.





TECHNOMAX CONTAINER SHIP 2030

The search for reduced costs per container mile and minimised environmental impact is putting ever-increasing pressure on owners to increase freight-carrying capacity and implement innovative solutions to be greener. In the last 15 years, the freight capacity of a container ship has increased by more than 240%, from 8,000 in 2000 to more than 19,200 twenty-foot equivalent unit (TEU) 2015. This trend is expected to continue. Cost-effective innovative solutions to reduce emissions will be quickly adopted as ship owners and ship builders respond to demands from their customers and comply with regulations. In response to decreased availability of quality personnel for ship operations, coupled with increased complexity of ship systems, new decision support systems that help manage the fleet efficiently will be prime candidates for early adoption . In 2030, container ships will be smarter and greener, with a flexible powering option, and fully connected onboard and onshore sensor and communication technologies. These are TechnoMax Container Ships. Owners will have an increasingly high number of them in their fleet to sharpen their competitiveness and boost their corporate social responsibility credentials.

A

Propulsion and Powering

Flexibility of powering options, such as hybrid LNG and marine fuels mixed with biofuels, will be key features in order to reduce emissions and comply with regulations.

B

Propulsion and Powering

Efficient innovative rudder and propeller designs with embedded sensors will be connected to the main systems for efficient operational control.

C

Condition Monitoring

Condition monitoring and full situation awareness will be provided by wirelessly connected embedded sensors locally and globally to assist in achieving higher operational efficiency. This will help to monitor structural safety and cargo securing arrangement performance.

D

Collision Avoidance and Manoeuvring

Collision avoidance and manoeuvring systems will be implemented to achieve higher levels of safety and manoeuvrability.

E

Smart Ship

Maintenance, navigations and communications managed by onboard data analytics machines connected to onboard and onshore decision support systems will enhance effectiveness of operational scheduling.

F

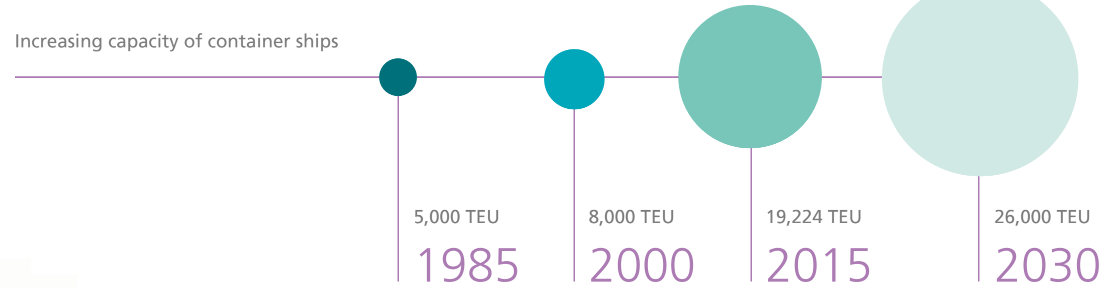
Radar System

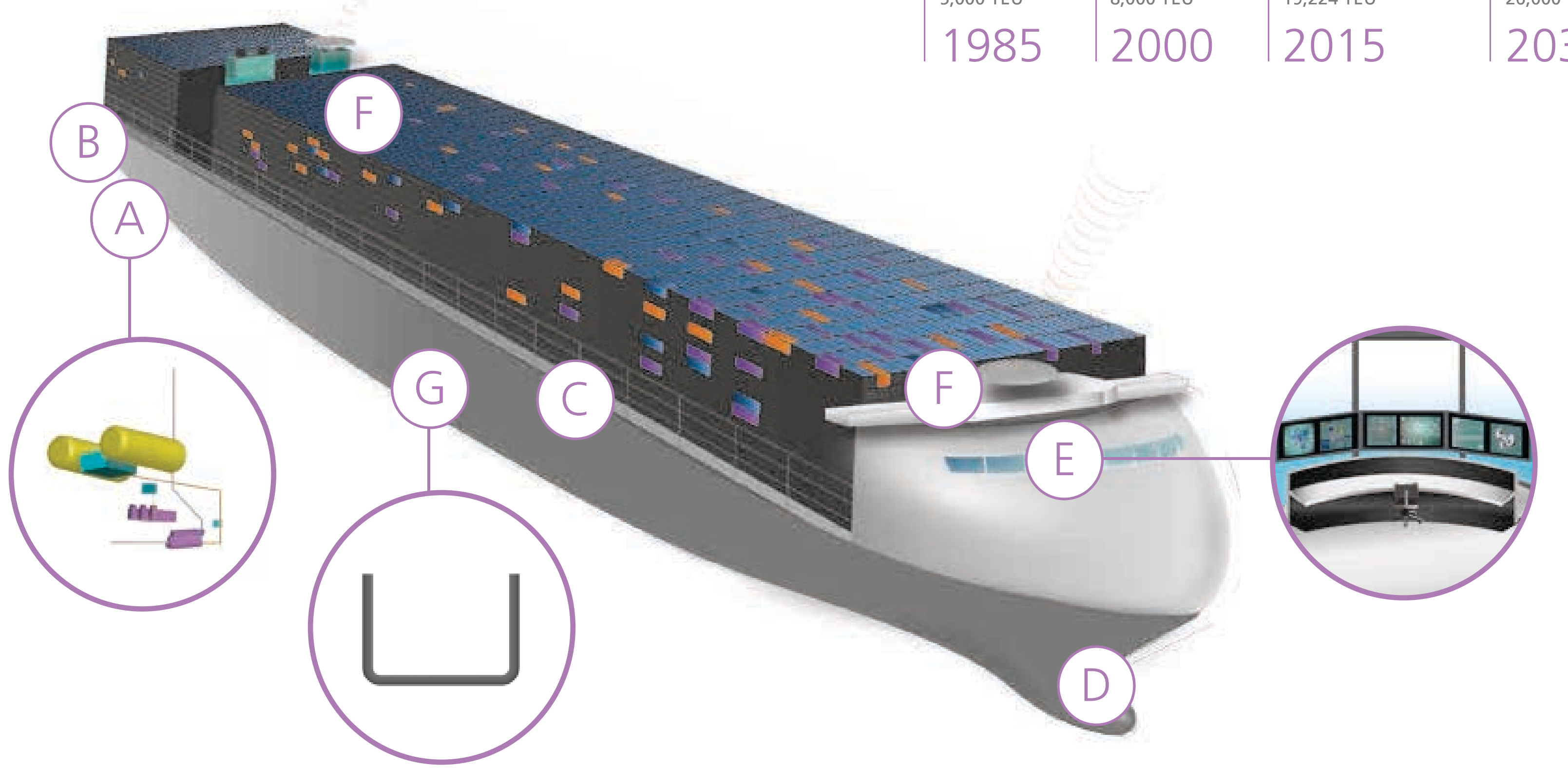
An advanced radar system with local and global communication links will achieve higher levels of operational resilience, commercial effectiveness, and safety.

G

Hull

A full body hull form similar to other deep draft ships, with smart materials such as innovative paint, will be implemented to increase cargo capacity and achieve higher efficiency, which will, in turn, reduce operation expenditure.





Construction

Future ship construction will be more efficient, more focused on electricity to enhance automation, and more environmentally friendly. The bottom-up integration of digital data with advanced manufacturing will ensure more transparent, streamlined and flexible future ship construction. Less time will be spent, higher-quality control will be achieved, and less waste will be produced. Increased processing power and data storage capacity, big data analytics, and human-computer interface are the major technological changes that will speed up ship design cycles. Designers will be able to interact with the design without a keyboard or mouse. Training for developing 'know-it-all' designers will be crucial in order to maintain a systematic view. Due to the increasing level of automation, the shipbuilding industry will not necessary be a major employer for local regions. Competition in innovation will push shipyards to invest in future technologies.

Steel-Cutting and Piping Installation

New laser technology development will speed up the cutting process. An increasing number of embedded sensors will be fitted to other piping at this early stage. Meanwhile, robotics will streamline and speed up the cutting process. They will also control the curvature of materials more precisely, thus offering optimal hull form

Block Assembly and Integration

Instead of leaving the majority of outfitting tasks until after launching, some outfitting, such as piping and heavy machinery, will be developed together with the hull structure. This will speed up the building process

Erection

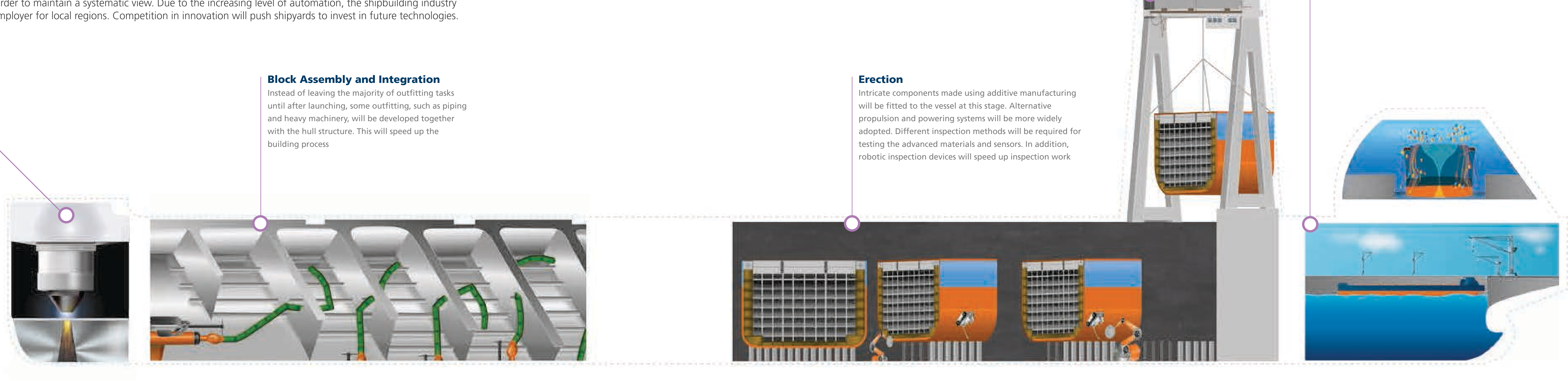
Intricate components made using additive manufacturing will be fitted to the vessel at this stage. Alternative propulsion and powering systems will be more widely adopted. Different inspection methods will be required for testing the advanced materials and sensors. In addition, robotic inspection devices will speed up inspection work

Crane-Handling

Enhanced crane-lifting capability and flexibility will speed up production time

Outfitting

Time spent on the outfitting along the quay will be minimised. Robotics will capture 3D imagery throughout the vessel and will establish a reference dataset to support real-time ship operations and through-life maintenance



Operation

Trade
Ship owners prepared to invest will have an increasing number of TechnoMax Ships in their fleets to sharpen their competitiveness and boost their corporate social responsibility credentials.

Crew
Due to the concurrent application of different kinds of technologies at different levels, a highly qualified and multi-skilled crew will be needed. The benefits of the balanced combination between a TechnoMax Ship managed by a highly skilled crew will be recognised by ship owners and ship operators. Effective action on the human element will require effort at the conception, design and construction stages of a ship's life, as well as throughout its operation.

Vessel
In terms of propulsion, the main propulsion packages and ancillary equipment fitted onboard will be monitored both locally and remotely. Advanced electronically controlled assets and sensor networks will regularly monitor and control the equipment. By means of service agreements with Original Equipment Manufacturers (OEMs) and suppliers, vessels will be remotely monitored and served. This will lead to a change in the exploitation model of the TechonoMax Ships, creating a new figure as a permanent service provider.

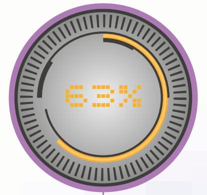
Maintenance
Every part in the engine room will be electronically tagged. This will provide valuable information for maintenance and repair purposes. Electronic tagging will help to control stock and spare parts onboard. Maintenance activities will be also boosted by the combined application of 4D-printing technology, exoskeleton robots and augmented reality. As such, service teams attending ships will have everything ready (tools, parts) upon their arrival with the help of 4D printers. The utilisation of exoskeleton robots and robotic arms will also be of help.

Data
Data will be a key element of remote monitoring, but the translation of data into information, of information into recommendations, and of recommendations into decisions will also be of paramount importance.

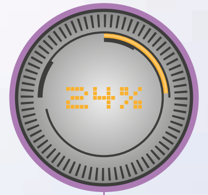
Support
A combination of legal, technical and commercial solutions will make it possible to provide a service to the vessels and their equipment by means of remote and onsite flying crews. These service crews will be specialised in the assets and will be mobilised by the service provider of the Technomax Ship. But service solutions will not be focused only upon corrective actions: it will help to carry out a vessel's health management. This implies that selling service solutions will move OEMs and equipment suppliers to a proactive approach.

Supply Chain

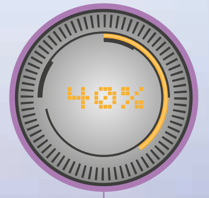
The implementation of these technologies onboard ships will lead to the coexistence of two main different types of vessel: a vessel type with highly technological specifications, including all the most advanced technologies for monitoring, supervising and manning the vessel (TechoMax Ship); and a vessel type that partially includes some of these technologies as a part of minor modifications or overhauls (pre-TechoMax Ship). As a result of the development of these two types of vessel, two different categories will be created within the marine industry in terms of chartering and contracting one type of vessel or the other. This will lead to a change in the business model. A pool of ship owners, ship operators, ports and OEMs will be at the top of the industry. This elite club pool will increase operational availability by chartering, contracting external services, giving out bonuses, cargo-handling, and, taking advantage of the new technologies.



The rise in oil supply by 2030

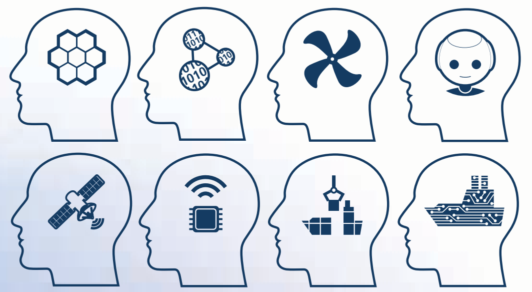


The percentage of fleets under China's ownership in 2030



The percentage of the world's grain which will be exported by the USA in 2030

Source:
GMT2030 Lloyd's Register report



Fleets of the future

The most advanced vessels of the future will be TechoMax Ships. These vessels will have many sensors and will be monitored. They will have sensor networks which will help to monitor cargo, machinery and equipment conditions. Sensor networks will place precise information at the fingertips of ship owners and operators. Through digital round-the-clock watchkeeping, the vessel will be fully monitored. Crews will be drastically reduced and they will need to allocate a set of unified skills, making the traditional distinction between the engine and deck departments fade away. TechoMax Ships will be techno-ships that will use techno-rules and techno-vetting for their daily operations

Regulation Aspects

Regulators will play a major role in the supervision and surveying of data belts linked to supply chains. All these data streams will provide a snapshot of the vessel health status

Data Belts

The data lake will be mined, shared and analysed by different parties using big data analytics. They will be able to share access to the data belt connecting the data lake to the parties. All the parties will interact, providing information back and forth. Data belts will have different levels of security and accessibility. Collaborative access to the data belts will transform the maritime industry into a more dynamic, efficient and sustainable one

Ports and the Environment

A sustainable supply chain will need port facilities fully integrated with ships through digital and communication technologies. This will keep the ship operations at the optimal standards in terms of efficiency, optimal safety, security, and sustainability. For example, the implementation of automated berthing devices will help to achieve this. An integrated logistics supply chain will allow ships to operate at optimum speed and to comply with existing and forthcoming emission control regulations

New Skills

New skills will be required to maximise the benefits of a fully integrated logistics supply chain. These skills will include:

- Big data management
- Big data analytics
- Automated operation and maintenance (O&M)
- Management of complex service constructs
- Management of data belts to keep them safe from cyber attacks and maintain its integrity

Naval

Sarah Kenny
Managing Director
QinetiQ

In our previous work on Global Marine Trends 2030 we looked at the impact of major global drivers on the naval sector. In Global Marine Technology Trends 2030, the team focused specifically on eight technology areas with the potential to transform future naval operations.

The environment navies will be operating in is likely to be increasingly complex, ambiguous, and congested, principally in areas close to littorals. Naval forces will be called upon to act or intercede with greater frequency in responding to environmental and humanitarian crises.

Their work has illustrated the accelerating pace of technology development that we are likely to experience in the coming decades. With the increasing proliferation of consumer technologies having the potential to disrupt, disarm and disable naval operations, navies around the world will need to swiftly contend with these new threats and opportunities. In particular, the exploitation of the space, cyber and electromagnetic spectra means that navies will need to have the resilience to operate under the most hostile cyber and electromagnetic conditions.

Traditionally, naval platforms are expected to have an operational lifespan of 25 years or more, so their design and concepts of operation need to cope with the rapid introduction of new technologies that will inevitably transform naval capabilities. This will have far-reaching consequences for all stakeholders involved in the naval sector.

In conducting future naval operations, there will be a need for highly skilled personnel with the ability and resourcefulness to respond effectively to surprise. In designing new systems and equipment there will need to be sufficient flexibility and adaptability to manage frequent technology upgrades and re-purposing. In testing capability and delivering training, there will need to be closer relationships between naval personnel and technology providers to feed back on effectiveness and new capability requirements. In the procurement of new platforms, systems and equipment, commercial models will need to adapt to deal with the faster integration and delivery of new capabilities.

Irrespective of the outcome of future global scenarios, the increased interdependency and availability of technologies will have a transformational effect on naval operations. Our aim has been to highlight key transformational technology areas and provide an illustration of how technology will be applied in the future. We aimed to make this document stimulating and provocative, and we look forward to your reaction to it.

Eight Technologies: Naval

Technology has always had a transformational effect on naval operations, and this will continue to be the case in the coming decades. Based on our understanding of current naval trends, challenges and constraints, we have selected eight technologies with the potential to transform naval operations in 2030. The combination of these technologies will be as transformational as when navies transitioned from sail to steam.

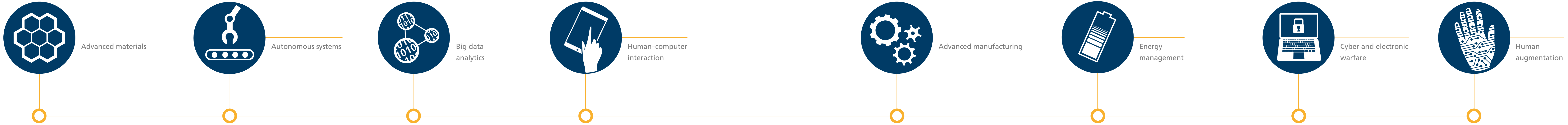
Many naval vessels which will be operating in 2030 are already being planned, procured and, in some cases, are about to enter service. Navies will be faced with the challenge of how to maintain the relevance of these vessels while transitioning capabilities and concepts of operation to exploit and defend against both evolutionary and disruptive technologies. The timely exploitation of technologies to enable planned platforms to operate in this future space will be a key requirement.

The diversity of maritime security challenges and the potential for contested global commons will drive the demand for improved situational awareness to meet the increasingly sophisticated threats above and below the water. Enhanced and persistent maritime surveillance is likely, with the continuous improvement of sensors, distributed sensor networks, and improved data fusion techniques to support human and automated decision-making.

Naval command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR) capabilities will be impacted by the development of a number of underpinning technologies. During collection and transmission, data will be vulnerable to attack, and so one of the distinct technology areas for the naval domain will be cyber and electronic warfare. With the rise in the volume of data, the science of data management, or ‘big data’, is becoming increasingly important. This will include the analysis of human activity from the shore as well as platform operational state. Equally important is the technology area of HCI to enable more efficient decision-making.

The general trend towards smaller crews will drive the potential application of technologies to enhance crew capabilities, so we have also focused on the area of human augmentation. Supporting the lean-manning theme, we have considered how current developments in robotics and manufacturing technologies, such as 3D printing, will have an impact onboard vessels. Recruitment, training and sustainment of personnel should also be considered.

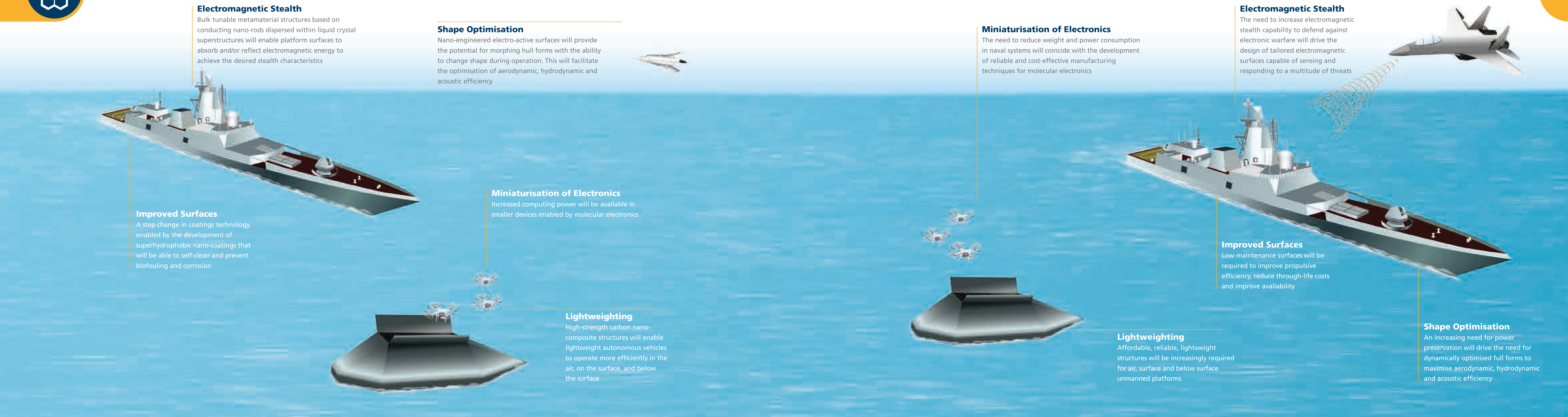
The role of the warship in 2030 will be starting to change with the use of autonomous systems and remotely piloted systems, delivering effect at greater range with less risk to the host vessel. In addition, the need for greater mission flexibility and energy efficiency in naval vessels is seeing the development and application of technologies associated with energy storage, production, delivery and re-use or ‘energy management’.



Finally, advanced materials have the potential to transform all of the other technology areas either through providing lighter, stiffer, stronger, tougher, stealthier structures or by enabling improved electrical conductance and enhanced computing capabilities.

While it is difficult to predict which technologies will have the greatest impact on naval operations, through this work we have attempted to provoke a constructive debate around the potential application of emerging technologies in the naval sector.

Advanced Materials



RISKS AND UNCERTAINTIES

Lightweighting
The cost benefit and reliability of large-scale carbon nano-tube reinforced structures needs to be proven. Issues such as repairability, maintainability and disposal also need to be addressed.

Shape Optimisation
The reliable scalability of electro-active nano-materials needs to be proven. Most research and development in morphing structures is currently in aerospace. The benefits of improved fuel efficiency in waterborne vehicles need to be quantified.

Miniaturisation of Electronics
Challenges exist in reliably scaling molecular-sized circuits to bulk electrodes. Significant increases in computing power may also be achieved through more efficient software programming.

Electromagnetic Stealth
The large-scale application of bulk tunable metamaterial structures needs to be evaluated to determine whether the improvement in electromagnetic stealth is worth the investment in the application of these materials.

Improved Surfaces
The large-scale application of superhydrophobic nano-surfaces needs to be evaluated to optimise performance and determine reliability, and cost benefit.

For all of the above, survivability and repairability will be an essential requirement for naval platforms and systems.

IMPACT

Lightweighting
Carbon nano-tube reinforced composites will allow structures to be one third lighter than conventional composites.

Shape Optimisation
The in-transit modification of the external surfaces of ships, submarines and autonomous vehicles on, below and above the water will optimise power usage and improve fuel efficiency.

Miniaturisation of Electronics
Significantly smaller, faster, more efficient electronic circuits based on the nano-structured forms of conductive polymers will enable the miniaturisation of components in naval systems. The increasing computational power of devices will support the technological developments of other naval capabilities.

Electromagnetic Stealth
The ability to manipulate the transmission, reflection and absorption of electromagnetic energy across a broad-frequency spectrum will make it possible to reconfigure surfaces during operation and reduce susceptibility and vulnerability to attack.

Improved Surfaces
Self-cleaning anti-corrosion surfaces will improve maintainability and reduce through-life costs.

Big Data Analytics

As the volume of data continues to rise exponentially and new data types emerge from a variety of sources, increased pressure will be put on both the naval computer systems required to manage and process this data, and those members of the ship's company who will be required to understand, assess and make informed, timely decisions on the nature of the threat.

The field of big data analytics coupled with the rise of so-called 'smart machine' technology and improved machine intelligence will make a huge impact in reducing this data to useful information that can be subsequently exploited by the ship's decision-makers.

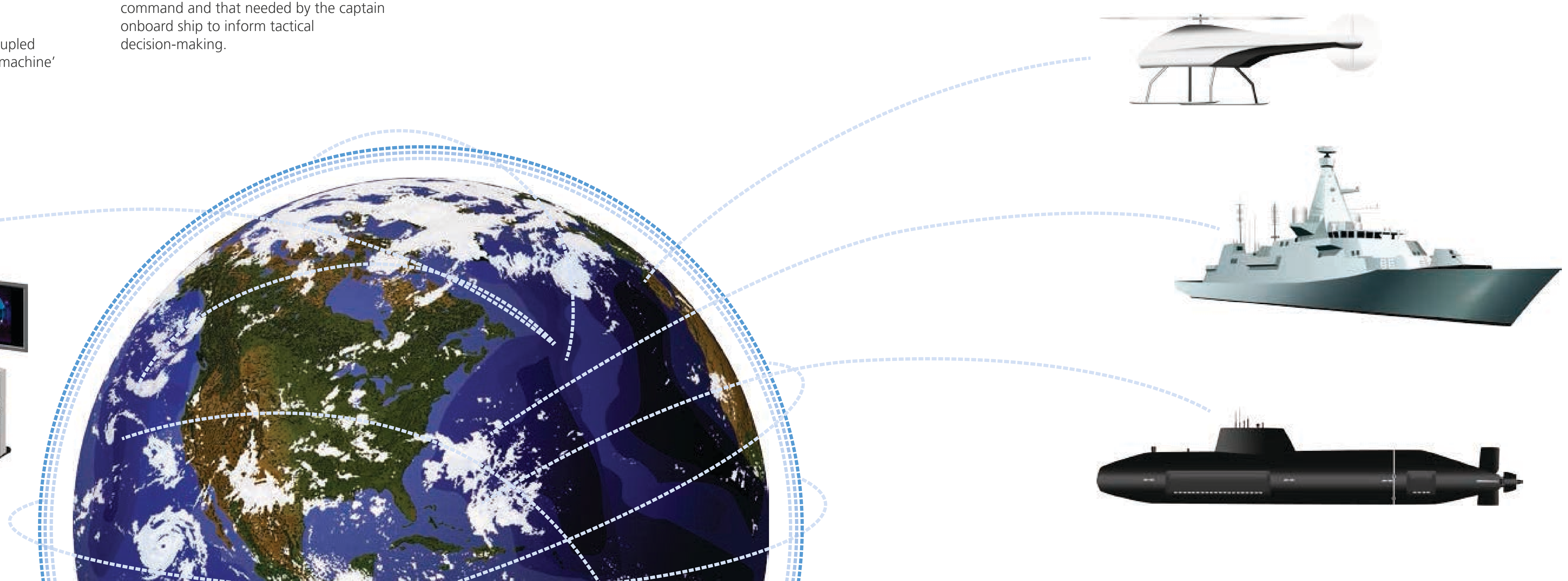
The balance of analysis of data is between information needed to inform shore-based command and that needed by the captain onboard ship to inform tactical decision-making.

The exploitation of technologies to address the big data challenge, coupled with the adoption of a knowledge-based approach to warfare, is already underway, with the continuing development of systems to provide high-quality situational awareness complemented by decision support tools to aid decision-making.

Commercial trends and technologies that enable information management, information exploitation and knowledge-building through the use of autonomous systems and big data analytics will offer a change in the level of situational awareness available to platforms, making it possible to exploit a broad range of sensing systems and knowledge sources.

In producing these systems, the ability to bring together a range of emerging technologies will be critical in developing robust, reliable and efficient solutions capable of exploiting both data and information from a wide range of sources in varying and constantly changing structures and architectures.

Knowledge-based industries are already exploiting big data solutions, encompassing big data management and analytics, and are developing advanced decision support systems with the objective of gaining competitive intelligence and information superiority over competitors.



The demand for decision support will drive development in a number of allied areas:

- Visualisation and human–computer interaction
- Artificial Intelligence and machine learning
- Information management and prioritisation methods
- Autonomous systems
- Trust-based computing systems
- Continuous training of crew.

The development of a number of transformational technologies is underway:

- Natural language query-and-answer systems
- Predictive analytics
- Smart pattern-discovery techniques
- Neuromorphic processing
- Context-aware computing.

Industries seeking to exploit big data analytics for improved decision-making include:

- Crime prevention
- Emergency services
- Healthcare
- Insurance
- Banking
- Ocean sciences.

There is already an inherent and recognised complexity in military communications and information systems. To realise and exploit decision support systems will require the development of appropriate enterprise architectures. These must take into account aspects such as organisation, information, processes and procedures.

There is an increasing reliance on high-bandwidth, secure, robust communications augmented by voice operation systems, natural language systems, and sophisticated analytics to augment highly skilled operators.

Security and cyber aspects may dominate and constrain overall solution options and exploitation routes. Other considerations may include the ability to operate in a denied environment.

UNCERTAINTIES

- Data and information management issues
- Integration with legacy systems
- Data quality and trust issues
- Cybersecurity aspects
- Adoption and management of standards
- Human factor and continuous training issues
- Technology management issues

Advanced big data analytics will enable the in-depth monitoring of systems, and pre-emptive repair maintenance action will increase reliability.

The increased exploitation of wireless communications, novel sensor technologies, and the creation of ad hoc networks within and between naval vessels will generate large volumes of data that will be dependent on big data solutions.

The proliferation of big data solutions and associated analytics may well increase the risk of detection and vulnerability of naval vessels. This could be through widespread knowledge of their location, or through the ability of the public to draw conclusions of vessels' operational state and intent from the analytical capabilities available.

IMPACT

- Improved tempo through greater agility
- Improved information superiority
- Improved decision-making
- Enhanced situational awareness
- Improved reliability and availability

Autonomous Systems

Autonomous systems will play an increasingly important role in future naval systems. They will be operating above, on and below the surface of the sea, will drive innovative concepts for conducting naval operations, and will offer the potential to radically change the nature of maritime security. However, many of the naval vessels in service by 2030 will have been designed without these concepts in mind. The principal challenge will therefore be the integration of autonomous systems into current force structures and vessels.

At the forefront of the many technologies supporting and enabling such systems will be the so-called ‘Smart Machine’ technologies that exploit Artificial Intelligence (AI) and machine-learning techniques.

Significant regulatory and legislative challenges will need to be addressed; social challenges will be dominated by public perception and issues arising in other areas of autonomy (e.g., driverless cars and the use of robotics). As with combat unmanned air vehicles (UAVs), ethical areas will cause concern in the general public and governments alike. The wider application of autonomy into workplace automation (e.g., knowledge-working and decision-making) will be more commonplace. Autonomous systems are likely to have a wider range of application than simply cueing weapon systems. There is a risk that autonomous systems will be countered by both proliferation and by cheap, simple countermeasures.

Current warships will need to be continuously adapted as the technologies emerge and mature

The principal challenge will be the integration of autonomous systems into existing force structures and vessels

At the forefront will be the so-called ‘Smart Machine’ technologies that exploit AI and machine learning techniques

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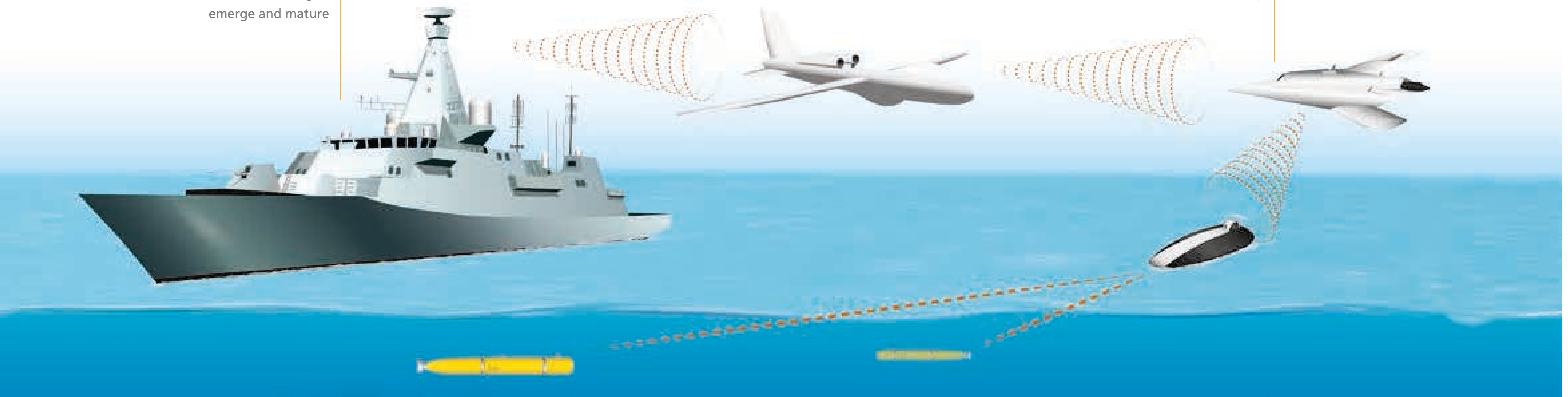


Regulation and Legislation

As with combat UAVs, ethical areas will cause concern in the general public and governments alike. The wider application of autonomy into workplace automation (e.g., knowledge-working and decision-making) will be more commonplace.

Social Acceptance

Autonomy will be driven by applications and experiences outside of the naval arena; although, ethical issues about the degree of autonomy, especially for any weapon-carrying systems, will continue to be an concern for the general public and governments.

New Operator Skills

The full exploitation of autonomous systems will require: the development of a potentially new range of skills and capabilities within naval communities and joint service operators; the constant drive to reduce crew levels; a change in the demographic from which the community will be drawn; the adoption of emerging technologies in consumer markets to be reflected in training and operating practices, branch structures and role developments.

Culture and Practice

The potential for the command and control to be geographically displaced from the vessel will require behavioural and cultural changes within military communities.

Integration

Naval systems are complex and require significant levels of integration, testing and evaluation in order to ensure that they work as expected and are reliable and effective.

The wider roles for autonomy will include support solutions for naval operations.

Testing and Evaluation

The adoption of increasing levels of automation will require innovation to change existing testing and evaluation practices. The ability to provide assurance that systems will behave predictably and safely will be a dominant factor in system selection and validation.

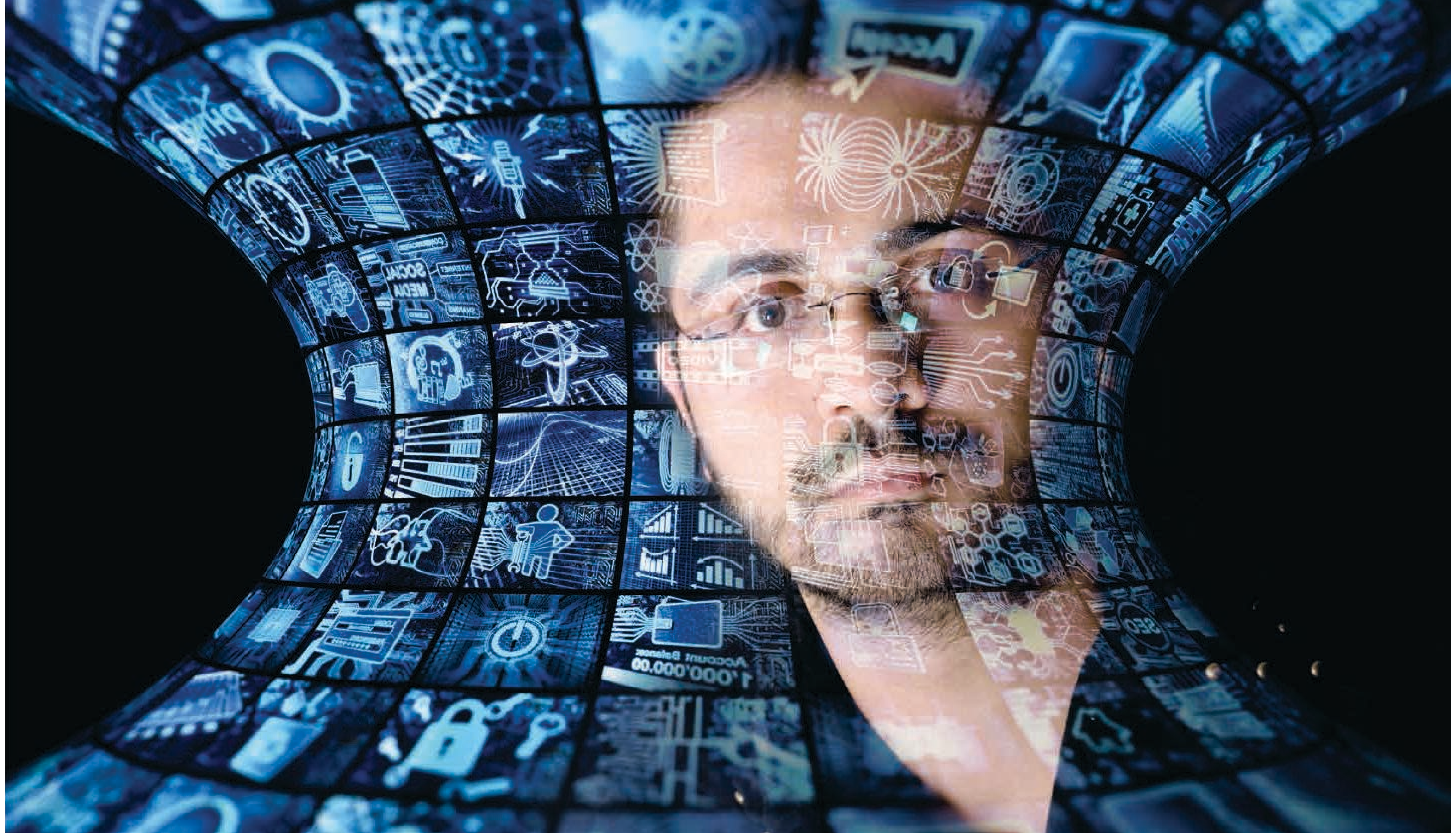
The application of autonomous systems within the naval arena will require changes to current vessels and the integration of a range of emerging technologies.

Autonomous systems will also be widely available for general consumer use, providing low-cost technologies that could be exploited by smaller nations, terrorist organisations, and non-state actors, many of which will not be compliant with legal and ethical constraints.

As the systems are adopted and their applications develop, we would expect to see the proliferation of systems, with low-cost, high-quality sensing and communication systems, augmented by big data technologies becoming a major challenge for covert military operations.

In the commercial sectors, maritime autonomous systems will be in widespread use in many diverse sectors. The inherent competition in these markets will continue to drive innovation, as they will require solutions which can operate in more extreme environments.

Advances in non-maritime autonomy will be widespread by this time, with driverless cars, the increased use of robotic systems, and other emerging technologies, all of which will change the nature of business and the workplace.



When coupled with other emerging technologies that are driven by commercial and consumer demands, we expect that autonomy will introduce a major change to work practices as well as changing the nature and balance of skills across the workforce.

New working practices centred on the balance between autonomy and human decision-making will be starting to change the nature of systems engineering practices, management and logistics support.

Crew training covering the autonomous system operation, data management, launch, recovery and maintenance will all need to be considered.

The ultimate goals of autonomy will be driven by the 'business value' to be derived from its exploitation. As with a number of consumer products, the development of highly innovative solutions and new concepts will be driven by small and medium-sized enterprises, entrepreneurs and highly agile science-based companies.

The integration of traditional naval defence contractors and these intellectual foundries will be challenging. To maintain leading-edge capabilities, a new supply chain (value chain) paradigm will be required. This will need to be reflected by introducing more agile defence procurement processes and modified relationships throughout this supply chain.

Human–Computer Interaction

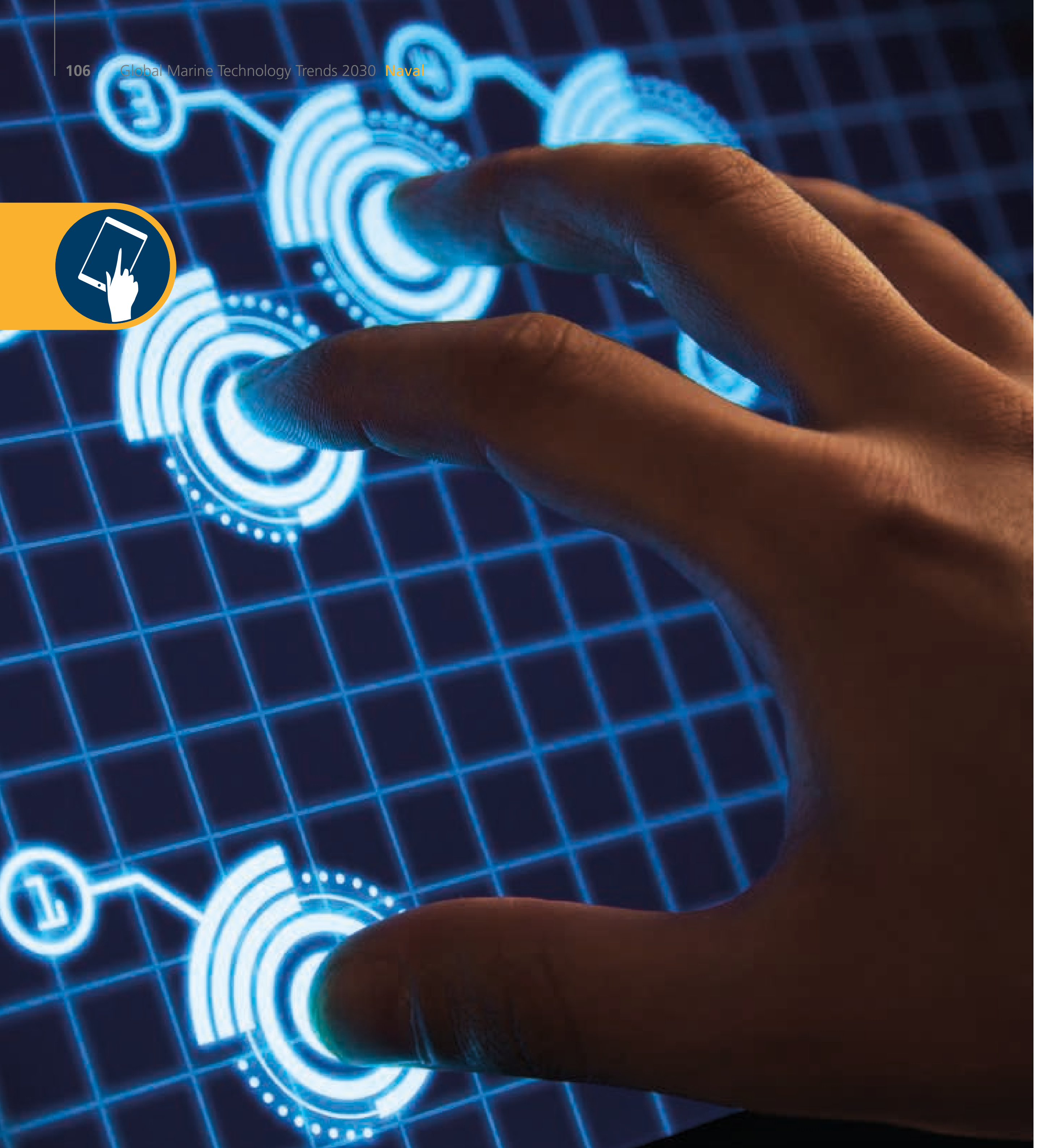
Human–computer interaction (HCI) refers to the study and design of the interface between people and computers. For any system where people are 'in the loop' with computers, HCI plays a crucial role in ensuring that the system serves its purpose effectively. HCI as a discipline is challenging; there are fundamental differences between how the human brain and computer processors work: HCI seeks to bridge this gap. HCI is necessarily multi-disciplinary, encompassing aspects of, for example, computer science, psychology, cognitive science, design and visualisation.

In recent years, HCI technologies have developed most rapidly on consumer devices such as smartphones and tablets, with their multi-touch displays. In contrast, the majority of traditional fixed workstations and personal computers still use the ubiquitous mouse, keyboard and video display. These technologies will not be replaced overnight, but we can expect that, by 2030, a number of new HCI technologies will have emerged to replace or augment those that we currently use, both in fixed locations as well as on the move. These technologies will enable us to interact with computer systems in new ways and will be smart enough to recognise our requirements and our personal preferences.

Many new HCI technologies are becoming familiar to us now and include gesture control, eye tracking and haptic technologies that exploit the sense of touch. When combined, these technologies promise to dramatically improve our experience of working with computers. Other technologies likely to make an impact over the next decade include brain–computer interfaces and affective computing, which allows computers to 'understand' human emotions.

In 2030, warship crew will be reduced as more automation is introduced into ship systems. Crew members will become Information Managers rather than Equipment Operators, creating the need for a new training paradigm and skill set. Remaining crew members will require an enhanced situational awareness of ship operations and systems. Moreover, some may need to be 'connected' to such systems while moving about the ship. Technologies such as contact-lens displays will provide information to mobile users and, in some applications, will serve to augment reality, supplementing the real world with pertinent information. Natural user interfaces will serve most fixed crew stations, where curved 3D organic light emitting diode (OLED) displays will be supported by form factors that take advantage of capabilities such as speech, handwriting, touch and gesture. Such interfaces will be able to support more natural modes of interaction and will be more intuitive and therefore easier to operate, reducing the need for training.

Human–computer interaction enables greater utility of the systems and personnel onboard



The development of HCI technology is dependent on many factors. Some of these factors are unpredictable and include consumer tastes, culture and fashion. In addition, there appears to have been a slowing down in the gathering of the key research required to support many HCI concepts.

An HCI breakthrough that releases us from the current 'lock in' to the ubiquitous keyboard and mouse is long overdue.

By 2030, warships will benefit enormously from improved HCI. The natural user interfaces in fixed-crew stations, such as the operations room, will be personalised, role-based interfaces tailored to individual crew members. This technology could also support these individuals whilst they are moving around the ship. The crew will also be supported by intelligent software entities known as 'Interface Agents' or 'Intelligent Personal Assistants' that can learn through monitoring user behaviour and can communicate in natural language. Such agents will work closely with their human counterparts by managing information on their behalf and helping them with their everyday tasks. These agents will also be able to recognise and respond to the human emotional state through affective computing and cognitive state through neural activity sensors and brain–computer interface technology.

The key drivers for HCI technology in the naval environment will be: minimising user error, enhancing user experience, and improving situational awareness. The exploitation of powerful HCI technologies will greatly enhance the user's ability to comprehend and extract meaning from large amounts of data and information. Such interfaces will minimise misinterpretation without adversely affecting either the individual or the shared situational awareness.

Along with technologies supporting automation and human augmentation, HCI technologies will contribute towards improving overall crew performance, and increase the efficiency of operation, and the decision-making on deployment.

Advanced Manufacturing

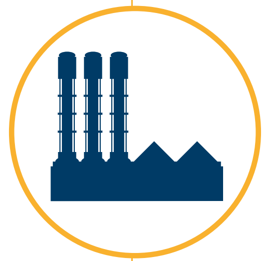
Emerging and transformational technologies are expected to have a major impact upon the ability of manufacturers to change to less resource-intensive manufacturing techniques and to develop lower-cost products. Advanced manufacturing technologies will move us away from more traditional manufacturing systems and techniques.

Advanced manufacturing will require the rethinking of traditional approaches and supply chains, as it will provide more integrated solutions that exploit a range of technologies, services and software-based systems.

Materials
Developments in this area will be required to support the new manufacturing challenges brought about by the use of novel materials and technologies

The exploitation of 3D printing technologies will make it possible to deliver high-quality, low-cost products and systems

Cloud computing applications for product data will enable the effective use of resources internationally, and will contribute to greater product mobility, thereby overcoming short-term localisation constraints



The adoption of lean processes to exploit emerging technologies in response to ever-increasing global and economic competition will provide highly responsive and adaptable products

Manufacturing solutions will seek to exploit developments in additive manufacturing systems and 'to use robotic production systems (already a mainstay of automotive production) coupled with machine assembly techniques capable of self-adapting and reconfiguring to meet 'just in time' demands

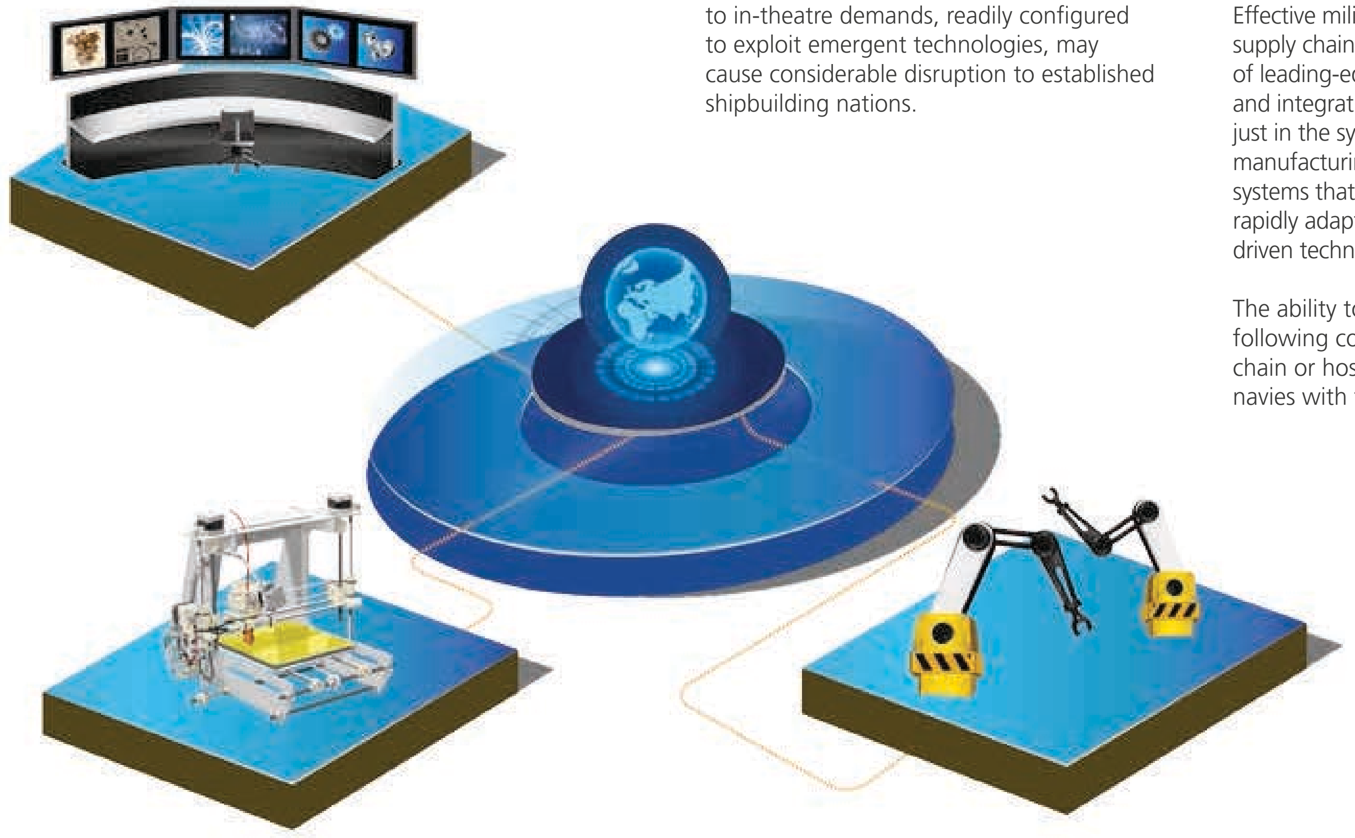
Advanced manufacturing will offer immense opportunities in areas such as on-board maintenance and repair, extending into the 'over the air' implementation of design and configuration changes and on-demand spares production onboard vessels

In an increasingly consumer-dominated technology world, the use of advanced manufacturing solutions to deliver market advantages through tailored, leading-edge products is going to increase. This will lead to the exploitation of these technologies in order to deliver high-quality, low-cost products and systems through emerging trends such as open source designs for use with 3D and 4D printing.

Coupled with advanced material technologies and the furtherance of additive manufacturing to create more exotic and difficult materials, significant cost reductions will be likely, as labour costs will rapidly reduce and combinations of emerging technologies will be applied to traditional industrial processes (e.g., the use of additive manufacturing and robotic assembly), providing flexibility in manufacturing from different geographical locations, with short set-up times and flexible configurations.

Many forecasters anticipate a significant reduction in manufacturing and knowledge-working jobs over the next 20 years. This will create a seismic change to the balance of global economics, where knowledge-rich countries with high technology skills will be the industrial foundries of the future. The use of innovative manufacturing technologies will enable these countries to compete with low-cost, resource-intensive industries in other countries.

Many developments in this area are expected to deliver highly bespoke consumer-driven products that are personally tailored to individual requirements. For military applications, the viability and robustness of products created using these techniques has yet to be proven, as far more stringent durability and robustness will be required for warfighting systems.



Ultimately, the adoption of these systems and technologies will be driven by high-volume consumer markets such as the automotive market, where considerable cost savings are forecast. This will have an impact on the defence markets, and will require significant rethinking of the procurement and support aspects of naval vessels. Ultimately, in the longer term, the possibility of short-life disposable ships, capable of rapid adaption to in-theatre demands, readily configured to exploit emergent technologies, may cause considerable disruption to established shipbuilding nations.

Low-cost 3D and 4D printing is emerging, together with robotic-based self-assembly systems, but the ability to scale up the technologies to large-scale shipbuilding has yet to be proven. The social impact of labour reductions and the replacement of skilled jobs by automated machines will prove to be problematic and will take longer than anticipated.

Effective military capability will extend into the supply chain and will require the maintenance of leading-edge capabilities through exploiting and integrating emerging technologies – not just in the systems, but also in underpinning the manufacturing infrastructure – to create military systems that remain ahead and that are able to rapidly adapt to the exploitation of consumer-driven technologies by potential threats.

The ability to organically regenerate capability following combat, independent of the supply chain or host nation support, will provide navies with flexibility and resilience.

The adoption of emerging manufacturing technologies, coupled with cloud-based computing environments, automated systems and robotics, will make it possible to generate low-cost, exploitable technologies that will enable a change in approach to, and the reduction of, naval vessel procurement costs. In through-life terms, the reduction of ownership costs and the geographically independent manufacture of spares due to automated and robotic systems,will make it possible to change the nature and volume of skills required to operate future ships.

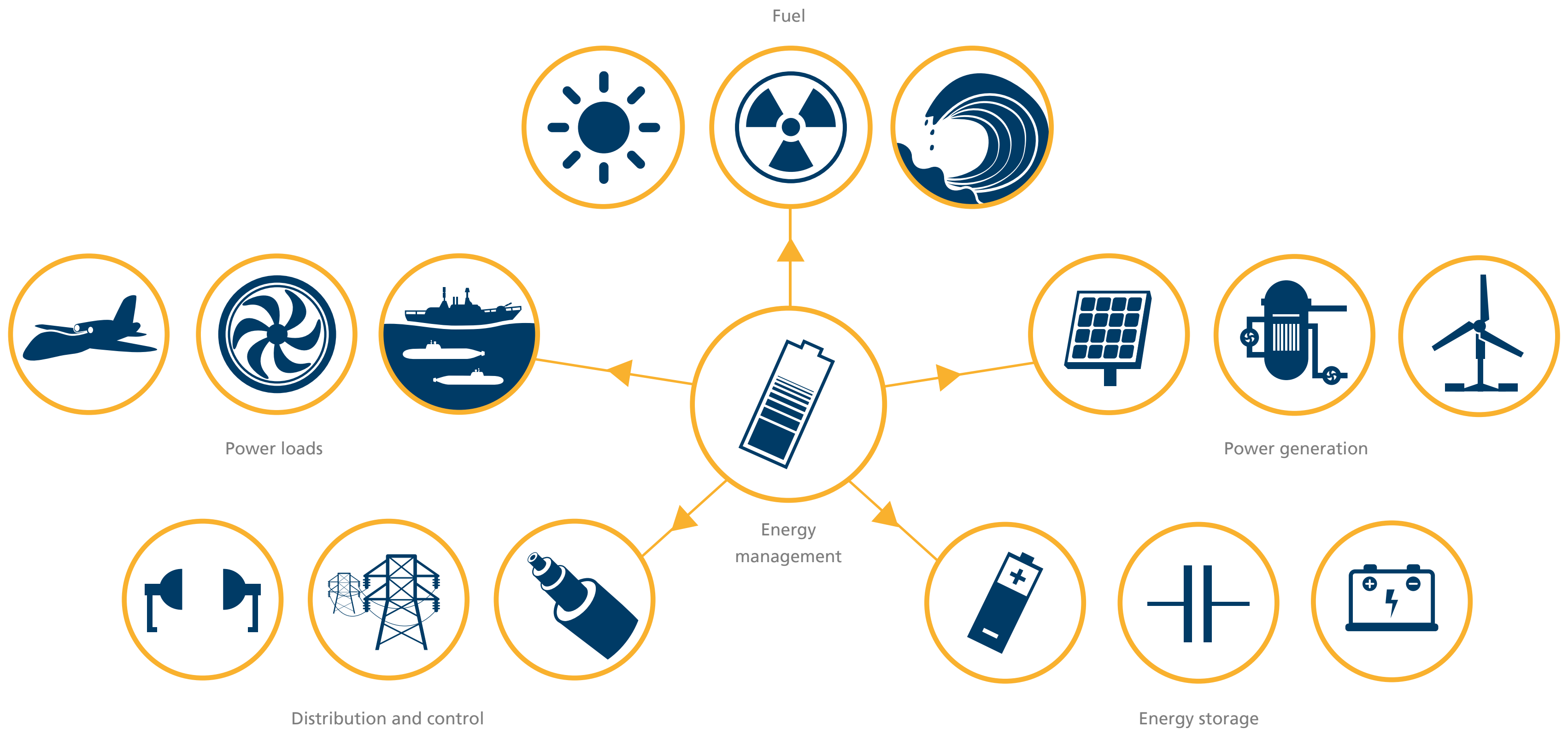
We see an increasing scope for complex parts and efficient designs to be developed and manufactured without the constraint of underdeveloped machinery, leading to reductions in labour costs, the use of novel materials, and greater flexibility of design. Ultimately, we will see the production of mission system solutions while en route to operations, increasing the flexibility and adaptability of naval warships.

Energy Management

Energy management encompasses the entire energy value chain, from exploiting energy sources, through to energy conversion, storage and delivery in a coherent and structured energy architecture and in management systems, maximising the efficient and flexible use of energy throughout a vessel.

The cost of fuel will increasingly constrain the ability of navies to operate at sea for long periods and to cover 'the required areas. As such, there will be greater emphasis on electrical power systems in 2030, with the aim being to remove other forms of actuation, and to ensure a rapid transfer of power that will enable short-duration, high-speed chase scenarios.

The balance between power availability and reversionary modes will be controlled to enable continued fighting capability in the case of damage.



The ever-rising cost of fuel together with the need to comply with environmental legislation on emissions dominates the operating costs of both merchant and naval vessels. The application of full electrical systems is expected to be a major commercial driver for alternative energy generation and delivery. The demand for power will increase as the levels of comfort in the commercial sector and the more widespread adoption of technologies for the provision of market advantages will enable the adoption and militarisation of the systems.

Specifically for naval vessels, the demands of energy-intensive systems (e.g., directed energy weapons) and the increasing levels of automation and robotic applications within vessels for a wide variety of tasks, will continue to call for more and more power, requiring the extraction (and re-use) of heat as well as significant levels of charge to power/energy architectures.

Other industries, including the automotive and aerospace industries, are developing a range of technologies, including fuel cells and battery technology, to meet the expected environmental legislation, and to reduce the size and cost of the available technologies which will have increased applicability in the naval domain.

Endurance and robustness are the key elements of remotely piloted and autonomous systems; considerable scientific and technological research is being undertaken to meet future needs.

High-energy demands in future naval warships

A number of technical challenges will need to be overcome. Whilst not all of these have solutions under development, some will mature in the available timescales, limiting their ability to provide the degree of flexibility required. The first of these solutions will be the ability to develop practical power-distribution and control systems capable of matching the power and energy volumes required.

Compact nuclear fusion will not be sufficiently developed to achieve a viable means of energy supply, but much work is ongoing in this field.

Most technology research in this field is aimed at the delivery of more efficient systems at a lower cost, with a focus on commercial applications. Specific activity will be required to deliver the power infrastructure components for naval vessels capable of supporting vessel (and crew) survivability. It will also be necessary to have adequate reversionary modes for managing power under damage conditions. Effective energy management will remain a key characteristic in ensuring electric, magnetic and acoustic stealth.

Current classification rules and design standards for naval vessels will need to be reviewed as the technologies develop. We anticipate that the ability to implement changes to major electrical and power systems in service will be a significant constraint to exploiting the emerging power-management and delivery technologies.

Running counter to these benefits will be increased complexity of electrical systems and the complex architectures needed to provide the likely dynamic demands and rapid adaptability of power throughout the naval vessel.

We foresee a number of benefits for future maritime security needs, primarily those related to the ability to provide increased endurance with higher efficiency at a reduced cost, particularly for major surface combatants and smaller patrol vessels. Further benefits will include reduced signatures, increased survivability, and less reliance on high-risk power sources (e.g., hydraulics).

Safety and reliability levels are expected to increase with the adoption of more innovative energy architectures and components, which, coupled with other emerging technologies, could reduce the number of future crew members, but may also drive up their skills and competencies required to operate these systems.

Cyber and Electronic Warfare

Cyber Warfare
Growth in the capability of countering cyber attacks is expected, with enhanced software detection techniques based on advanced evasion-resistant machine-learning algorithms.

Electronic Warfare
The purpose of electronic warfare is to deny an opponent the advantage of, and ensure friendly unimpeded access to, the electromagnetic spectrum for the transmission of data, information and communications.

CYBER WARFARE

Software
Strategically designed malware, otherwise known as an 'Advanced Persistent Threat', will move from software-code exploitation to the manipulation of data, attacks on operational processes, and the introduction of systematic effects at the time of an attacker's choosing.

Hardware
The malicious modification of circuitry in integrated circuits, with the ability to be triggered to perform actions when required, will continue to be a threat to the naval systems of the future.

People
Social engineering, designed to manipulate the psychology of people in the information loop, will increase in sophistication and will remain a critical vulnerability.

Blended cyber attacks capitalising on the vulnerability of software systems, hardware systems and people can be expected.

ELECTRONIC WARFARE

Electronic Attack
This involves the use of electromagnetic energy, directed energy or anti-radiation weapons to degrade, neutralise or destroy enemy capabilities.

Electronic Protection
This involves actions to protect personnel, facilities and equipment from the effects of an electronic attack.

Electronic Warfare Support
This involves the searching, interception, identification, location and localisation of electromagnetic energy for the purpose of threat recognition and targeting.

In an electronic attack, the trend is for the active jamming and spoofing of signals and communications in order to disrupt operations. A range of electromagnetic energy weapons already exist and are being enhanced. These include radio frequency weapons, laser weapons, particle beam weapons and sonic weapons.

In electronic protection, or 'electronic countermeasures', system development will occur equally rapidly to counter the technological developments in an electronic attack. As well as improved electromagnetic emissions control, active frequency manipulation will continue to become more sophisticated, and low-observable stealth materials will enable the real-time transmission, reflection and absorption of electromagnetic energy.

Cyber Warfare
The hostile infiltration of information systems to disrupt and damage operations will continue to be a major threat to navies worldwide.

With an increasing dependence on the Internet for essential communications and operations, the resilience of naval systems to cyber attack will be continually tested by criminals, terrorists, malicious individuals and rogue states.

As naval operations depend on reliable and trustworthy communications for command information, cyber attacks will become a cost-effective weapon of preference. It is regarded as both a force multiplier and an Achilles heel.

A digital arms race will be fuelled by a significant increase in computing power and increasingly intelligent software with the capability to learn, spoof and evade detection within a computer network.

Electronic Warfare
With the increasing importance, volume and speed of data transmission expected to underpin naval situational awareness, electronic warfare technologies will continue to be essential tools to enable future naval operations.

The importance of information security, coupled with the expected rapid increase in computing power as an available and affordable public commodity, means that future electronic warfare will be a major aspect of naval technology development.

Further increases in computing capability will see the widespread use of electronic warfare systems to achieve ultra-fast tuning and big data processing capabilities as well as reduced size, weight, power and cost. This will support their proliferation and use on many small-scale, unmanned autonomous systems.

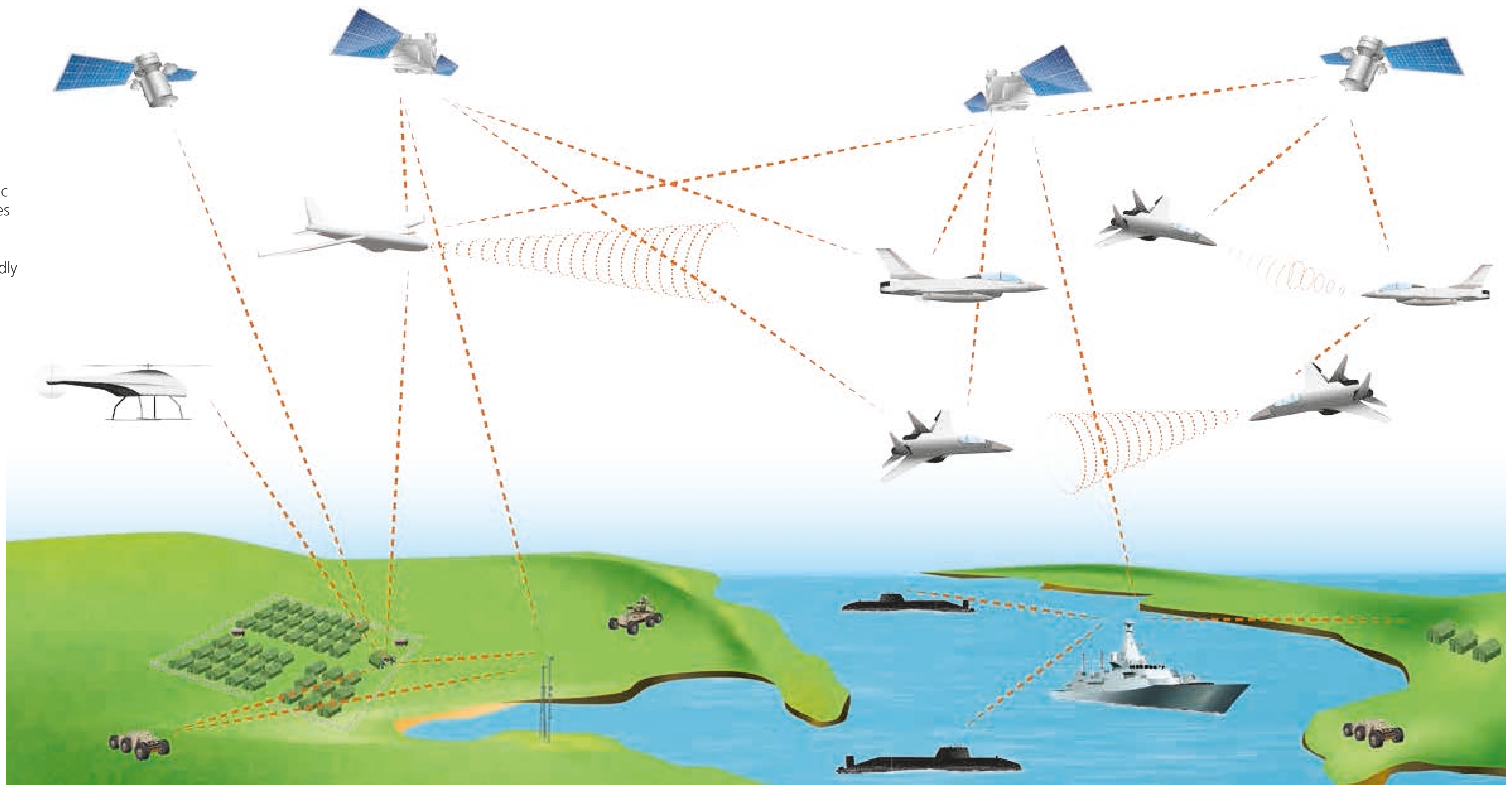
Electronic warfare technologies will develop rapidly to contend with a signal environment that will continue to be more complex and congested in particular in the littoral.

Electronic warfare systems will become more portable, flexible, modular and affordable. This will mean that rapid technology development and acquisition will be essential to maintain spectrum dominance.

UNCERTAINTIES

- The pace of cyber and electronic warfare technology development is difficult to predict
- The ability of an enemy to defend against electromagnetic incursion is likely to improve
- The capability of evasion-resistant machine-learning algorithms to detect all cyber attacks is not yet known
- A critical and unpredictable vulnerability is the exposure of people in the information loop to cyber attacks
- New cyber and electromagnetic attack strategies may not be anticipated or countered rapidly enough

The speed of decision making is likely to be significantly compressed compared to that of current systems



IMPACT

- Increase agility and maintain electromagnetic spectrum dominance
- Gain tactical and operational advantage/ element of surprise. Degrade and neutralise enemy threats
- Ensure reliable and trustworthy communications for command information
- Efficiently manage secure communication in a complex and congested signal environment
- Reduce the risk of disruption and/ or disablement of operations

Human Augmentation

Human augmentation (or human enhancement) encompasses a wide range of technologies and relies upon a broad swathe of scientific disciplines, particularly from the field of medicine. It promises to raise human performance beyond the normal level, as well as helping individuals reclaim functions lost due to illness or injury. It can involve the use of pharmaceuticals, implants, prosthetics and exoskeletons. It promises to enhance both human physical performance and cognitive capability.

By 2030, physical augmentation will be available to naval crews in the form of lightweight modular exoskeleton devices to increase musculoskeletal strength for selected operations, a priority where crew members need to carry heavy loads, in addition to reducing fatigue and potential injury. The majority of these devices will be unpowered and will operate by transferring the weight of heavy loads from the user's body directly to the ground.

In 2030, it is likely that some crew members within the operations room of a navy warship will be supported by a cognitive augmentation device. This device will assess whether the crew member is operating under stress or is fatigued. Through exploiting a closed-loop brain–computer interface system, the device will regulate the information sent to users depending on their cognitive state. When required, the augmentation device could also stimulate certain areas of users' brains, through technology such as transcranial direct current stimulation (tDCS), to enhance their attention.

One of the key drivers, for human augmentation is the need to do more in operations with fewer crew members. This means increased reliance on automation and on systems that can augment human capability, both cognitively and physically.

The health and safety of valuable human crew members drives their protection and health monitoring during operations. The need to function at a higher rate with increased speed of decision-making and increased information rates will require systems to monitor cognitive state and enhance performance when required.

Augmentation that reliably delivers moderately improved human capabilities is likely to become a multi-billion-dollar market over the next few decades. Much of the research and development will be used in non-defence applications, but will drive the use and tailoring of human augmentation devices in naval operations.

Potential Barriers to Human Augmentation

Legal and Ethical
The social acceptability of individuals being augmented, either physically and/or cognitively, may delay or impede the technology's introduction into use. Added to which, there will need to be clear legal guidance established on the ethics of augmenting crew members and measuring performance throughout a deployment. Chemical enhancement to human cognitive and physical ability needs to be better understood, particularly with regard to human health.

Social
There may be unacceptable variability in the human adaptability to enhancements (particularly in a cognitive sense) which will prevent widespread use. Also, any benefit will need to be assessed against potential harm and human safety. For example, there is the risk that individuals could become 'over-enhanced', which would produce undesired effects.

Financial
The cost–benefit of human augmentation may not always exceed that of alternative solutions. For example, the physical augmentation of crew members may not be as cost-effective or as beneficial as a robotic solution.

A rigorous cost–benefit study will need to be undertaken that takes into account alternative technologies, the impact on the individual, the cost of development and regulatory considerations.

Along with automation, human augmentation can make a significant contribution to reducing the size of the crew in naval ships. Augmentation technologies also promise to counter the demographic issues in allowing crew members to serve for longer.

Cognitive human augmentation may increase the overall crew performance by increasing the speed and efficiency of operations and decision-making on deployment.

Human augmentation will also increase the mental and physical endurance of crew as well as their resilience during a deployment.

Navies Transformed

To explore how emerging technologies are likely to impact navies in 2030, three broad naval roles have been used to establish the relevance, importance and contribution of each of the eight technologies. These roles are:

Warfighting
The successful ability to project military power is directly dependent on gaining battlespace access and the capacity to coerce, deter and intervene. The naval warfighting role is to ensure access and to use the necessary force when required to protect national interests.

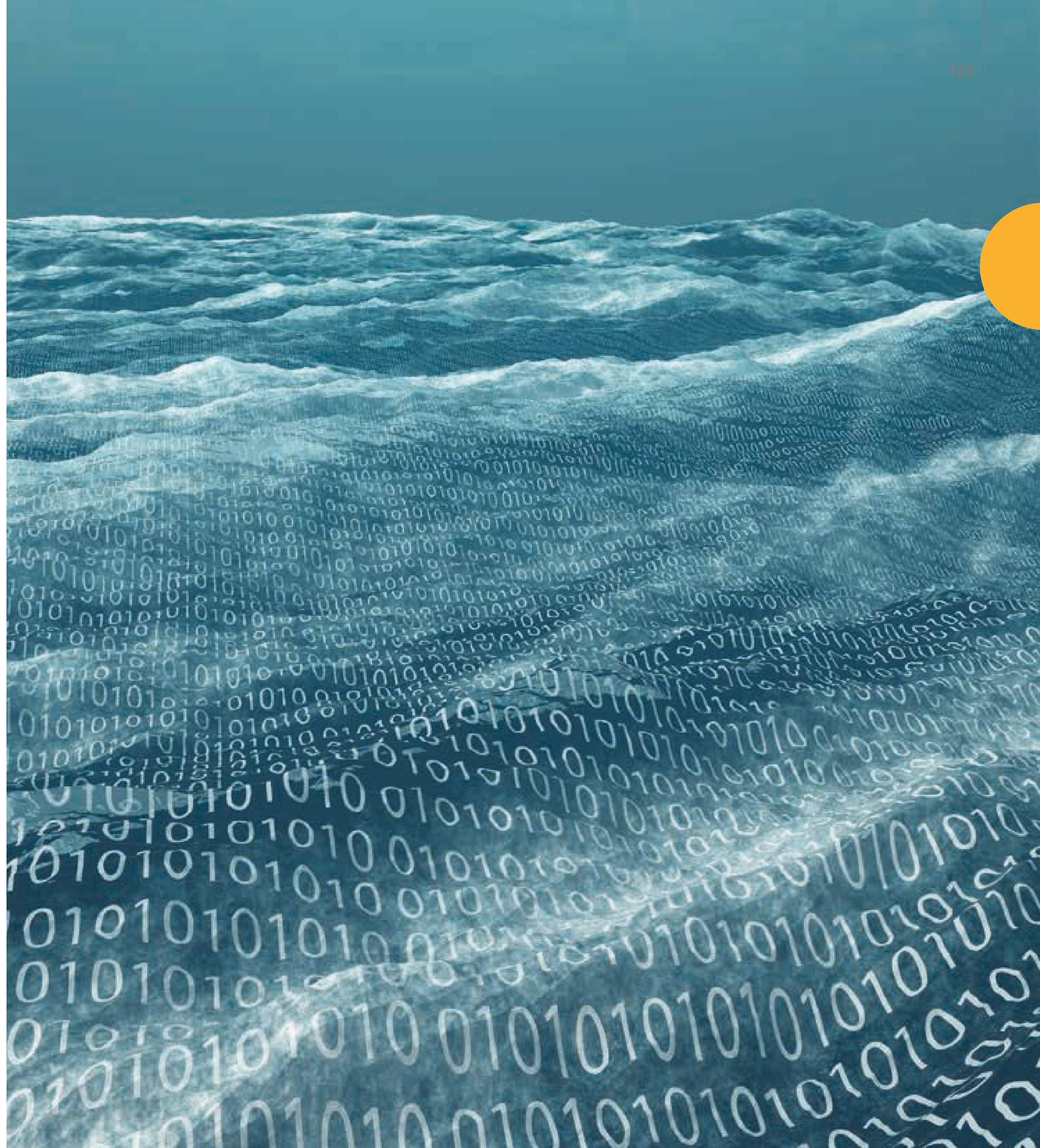
Humanitarian Operations
Delivering humanitarian aid and disaster relief in times of crisis is an important international strategic role where naval capability can make a significant contribution. The naval role involves working with international partners and civil authorities to provide evacuations and repatriations, vital aid, and the restoration of infrastructure.

Maritime Security
Security in the maritime domain is required to protect a nation's citizens, territory and trade from terrorists, criminals, pirates, state-sponsored insurgents and illegal restrictions on the freedom of navigation. The naval role is to support the identification of national security threats and prevent unlawful acts, both independently and with international partners.

These interdependent roles have been chosen to describe how emerging technologies can be applied to deliver efficiencies and operational advantages to national defence and security forces. The roles are often conducted concurrently and so it is important to bear in mind that some technologies can have great value and utility across more than one naval role.

Future visions for these roles have been developed using a number of factors to qualitatively assess the beneficial impact of technologies and how they interact to support naval missions. These relative factors for each technology include:

- Benefit
- Maturity
- Availability
- Cost
- Force multiplier potential
- Accessibility.



Published analysis by international organisations and states predict a changing and turbulent future with ever-increasing demands on the navies of the world. To meet these demands, the rapid exploitation and integration of emerging technologies identified in this report will be essential in order to maintain the ability to defend and protect the freedom of the seas.

We expect that the interdependent roles of navies, summarised as naval warfighting, humanitarian operations and maritime security, will undergo a significant transformation in the coming decades, driven by the development and application of new and emerging technologies from consumer markets.

Together, the eight selected technologies identified will have a substantial and potentially disruptive effect on future naval missions. Through examining the relative impact of each technology, we have identified three common themes running through all future naval operations:

- The interdependence of technologies
- The rapid pace of technology development
- The growing need for highly skilled personnel.

We have consciously not considered the implications of space-based technologies (other than for GNSS) or weapons technologies, specifically cruise and ballistic missiles and directed energy weapons.

The Interdependence of Technologies
No technology is independent from developments in other technologies. This is both a benefit and a vulnerability.

To achieve enhanced decision-making superiority, improvements in autonomy, big data analytics and human–computer interaction will rely on developments in high-performance computing, which in turn will be driven by developments in advanced materials and power management.

The challenge of technology integration and interoperability will remain. The rapid integration of new technologies into systems, and into systems of systems, will requires a flexible (and secure) software and electronics environment that will allow defence and security forces to adapt and respond to new technological developments more quickly than their adversaries.

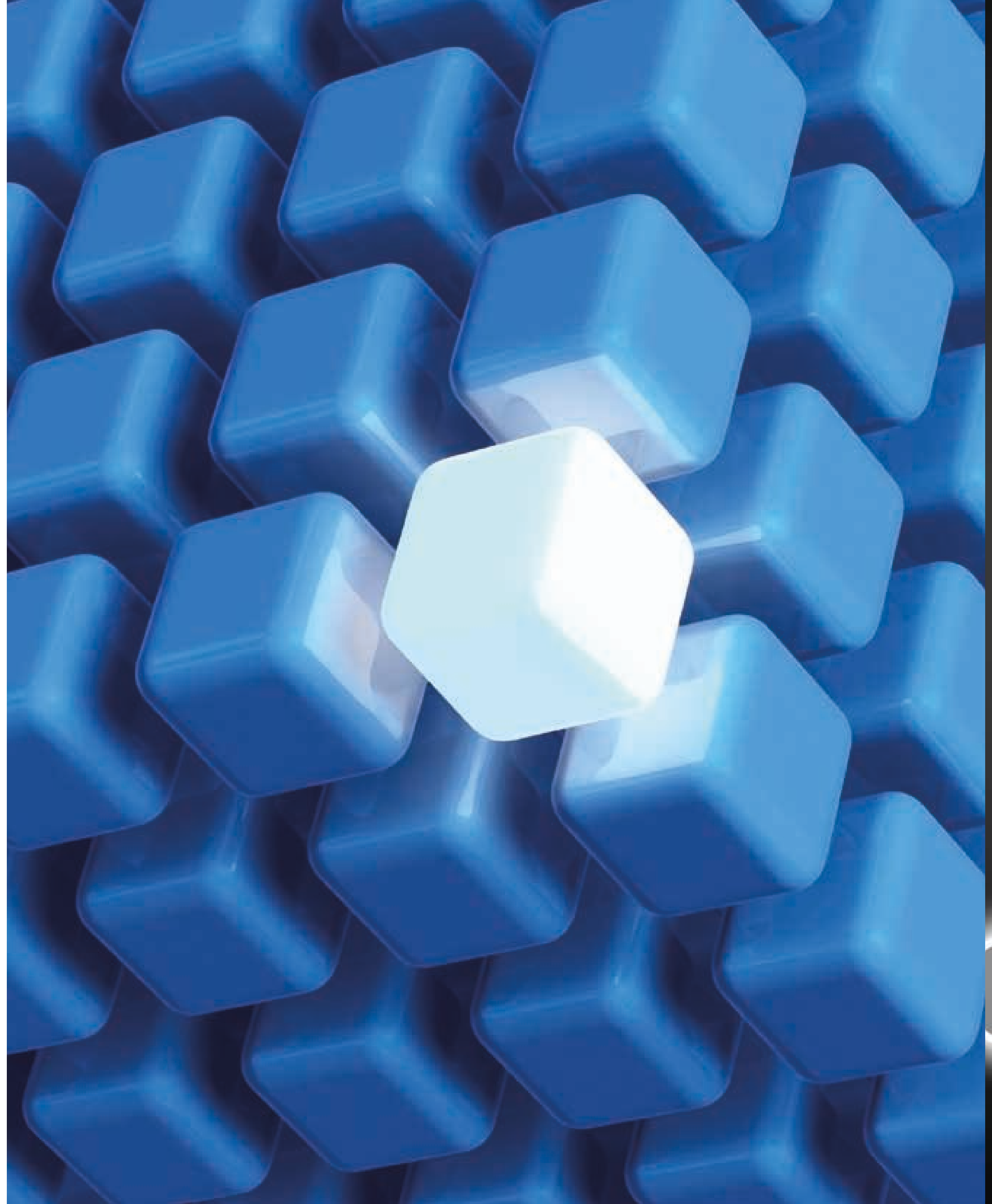
Investment in new technologies and technology innovation will need to be spread across a wide portfolio, with a strong emphasis on horizon scanning for new developments and rapid technology integration, combined with experimentation, testing and trialling to explore all possibilities and to ensure safe operation.

The Rapid Pace of Technology Development

The speed of technology development will continue to accelerate, driven by increasing computational power and growing networks of people with access to low-cost consumer technologies.

The rapid development and availability of new technologies will have consequences for navies around the world:

- The vulnerability of defence systems is likely to increase, with a multitude of new, potentially low-cost threats able to disrupt and disable systems
- Naval platforms and systems will need to be increasingly flexible and modular to constantly adapt to upgrades in technological capability
- Traditional procurement models for warships are likely to change from being asset-based to digital-based, creating new forms of supply chain
- Defence will need to adapt more quickly, with shorter periods between technology innovation and in-service exploitation



The Growing Need for Highly Skilled Personnel

The increasing application of robotics and automation will reduce the need for personnel to conduct dirty, dull and dangerous tasks.

All personnel involved in naval operations will need to be highly skilled and flexible enough to rapidly adapt to the introduction of new technologies. They will need to be comfortable with working in partnership with robotic systems and emerging forms of human–computer interaction to conduct operational tasks.

With the move towards multi-domain and borderless warfare, all personnel will need to be highly trained in the threats posed by cyber and other electromagnetic incursions.

The trend towards the rapid development and availability of technology will mean that successful missions will depend on personnel having both broad technological skills and the capability to innovate and improvise when required. Continuous training and simulation to develop resourcefulness in surprise situations is expected to become the norm for naval personnel.

The recruitment and retention of personnel will continue to be hugely important and challenging for all navies.

Warfighting

All eight technologies will play an important role in future warfighting. They are complementary to each other and interdependent.

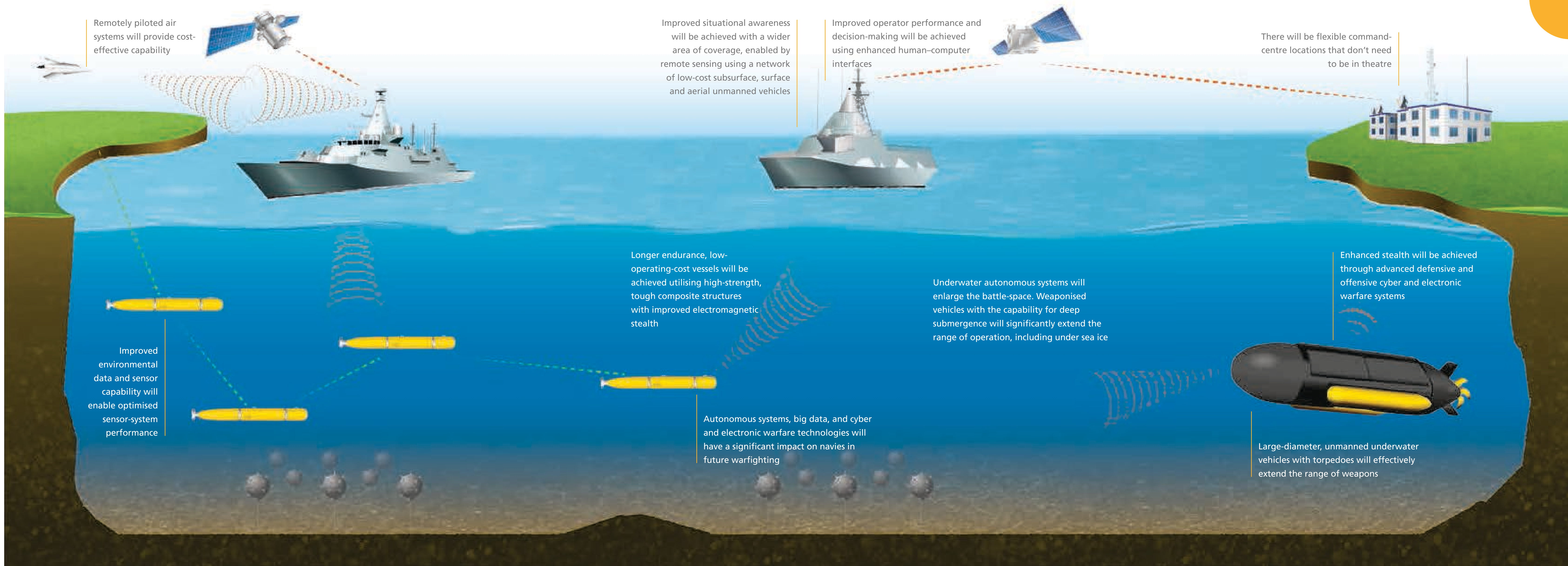
Future warfighting is expected to be heavily dependent on cyber and electronic warfare technologies to assure trustworthy data and communications.

The availability of capable low-cost commercial technology will see a gradual transition from traditional asset-based warfare to digital-based warfare.

The rapid integration and assurance of commercially available technology will be essential in order to achieve and maintain dominance in the maritime battlespace.

Significant risks and uncertainties will remain, and in many cases, become more challenging. These will include: increasing threats due to the proliferation of commercial technologies; increased threats from countermeasures based on simple technology; increased challenges in identifying intent and dealing with legal implications, especially with respect to the use of autonomous systems, and the increased risks of operating in an electromagnetically-denied or electromagnetically-constrained environment.

The availability and proliferation of current weapons, adaptation or exploitation by state or non-state actors remains a threat.



Humanitarian Operations

All eight technologies will play an important role in humanitarian operations. They will be complementary of each other and interdependent.

Future humanitarian operations are expected to be heavily dependent on the reliable fusing of disparate data sources and rapid decision-making supported by improved human–computer interaction.

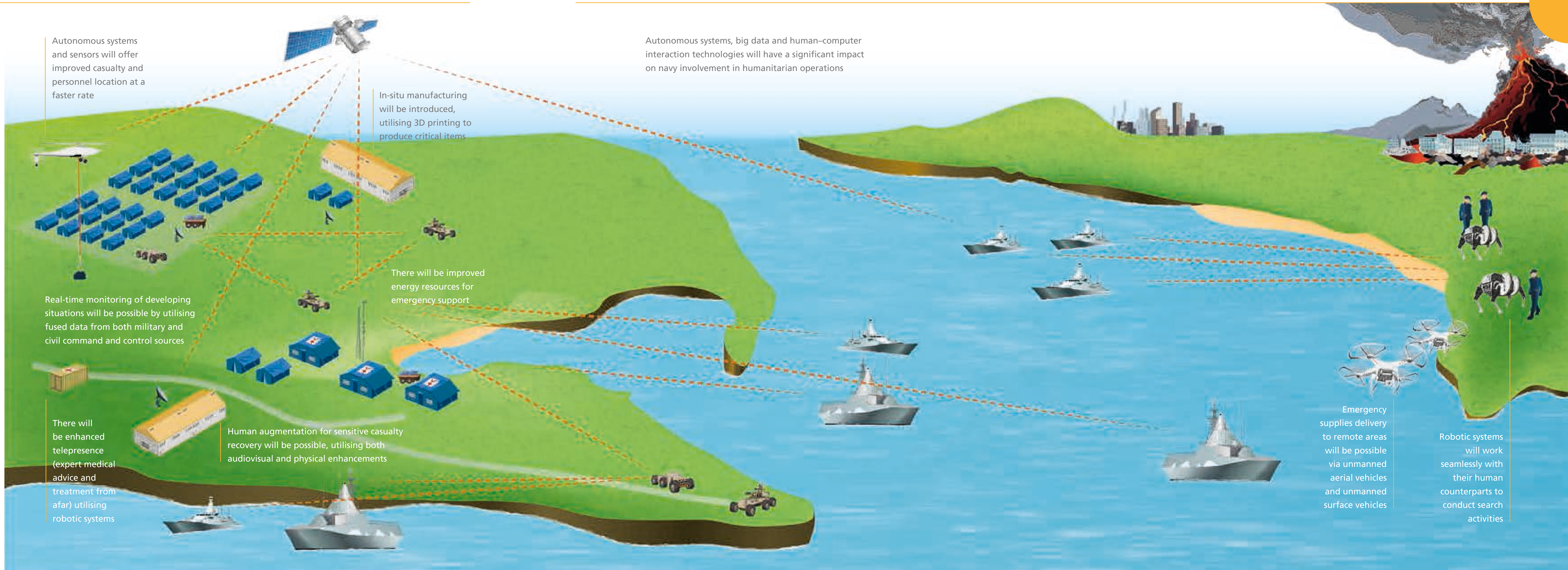
The speed of response and recovery will increase with improved data and communications, supported by networked autonomous systems and sensors.

However, achieving an adequate understanding of the environment will remain an issue, and the ability to operate in a sustained ambiguous threat environment (which may also be communications-denied) will continue to pose risks and challenges.

Operating in such environments will require continuous revisions of and references to an appropriate legal framework with a clear understanding of liabilities.

Personnel involved in humanitarian operations will work seamlessly with robotic systems to safely deliver vital aid and support.

The ability to provide an enduring capability to intervene and deliver aid will continue to be a key requirement for navies



Maritime Security

All eight technologies will play an important role in maritime security. They will be complementary of each other and interdependent.

Future maritime security operations are expected to be heavily dependent on the reliable fusing of disparate data sources and rapid decision-making supported by improved human–computer interaction.

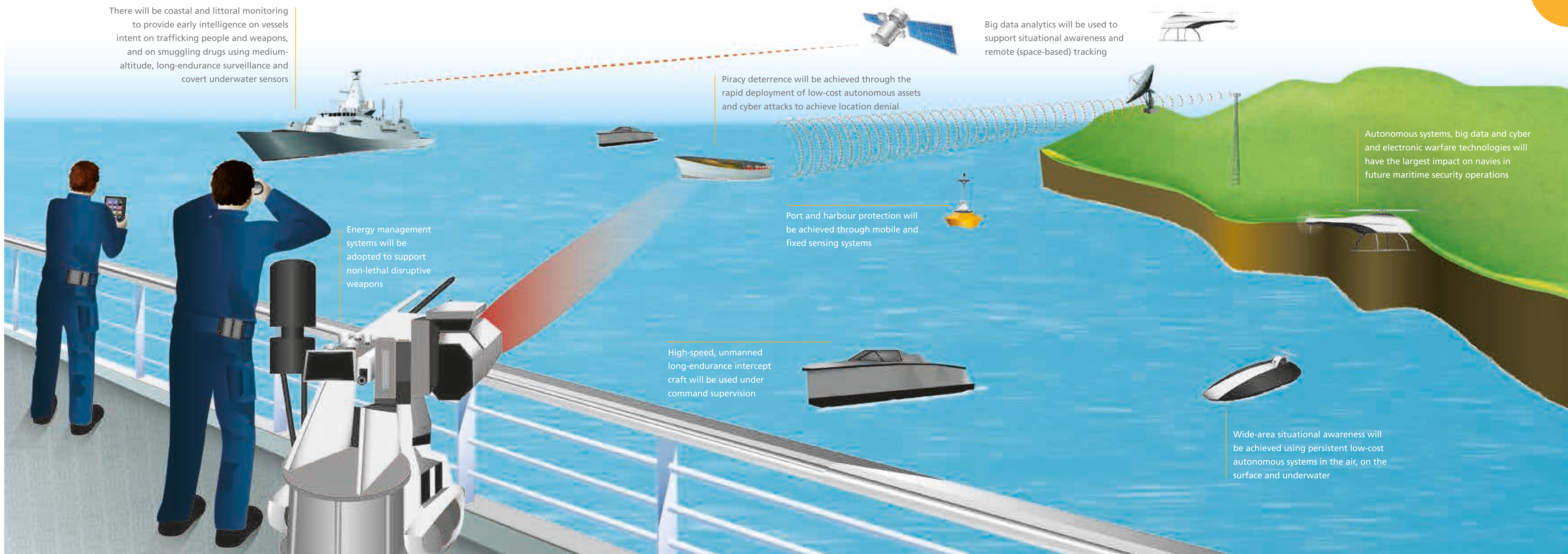
The speed of response will increase with improved data and communications, supported by a wide area of networked autonomous systems and sensors.

Personnel involved in maritime security operations will increasingly utilise big data analytics to identify emerging threats.

Understanding intent will remain a vital aspect in the limited decision space against often undefined enemies. Providing cost-effective, persistent surveillance, coupled with the secure transmittance of data, will continue to be a challenging endeavour.

The transition between maritime security and warfighting is likely to remain ambiguous and offer decision-makers the option to escalate and de-escalate by altering posture.

Maritime security is fundamentally enabled by the ability to successfully exploit all of these technologies to deliver an enduring capability



Ocean Space

Professor Judith Petts
Pro-Vice-Chancellor
Research and Enterprise
University of Southampton

A greater understanding and appreciation of the oceans is essential for the wellbeing of the world's population. The oceans are vast and largely inaccessible. Our awareness and understanding of them is correspondingly small. This is especially remarkable when we consider that: the oceans critically influence our climate; the oceans are the sources of considerable food, energy and mineral resources; and the seas are highways of global trade.

The oceans cover around 70% of our planet's surface. Thus, they play an important role in the Earth's climate and global warming. One important function is to transport heat from the tropics to the higher latitudes. They also absorb large amounts of anthropogenic carbon dioxide, with consequential effects for ocean life.

Global warming will result in significant sea-level rises in the future. As a result, many low-lying coastal areas around the world will be lost to the sea over the coming centuries. Wealthy, industrialised nations may be able to defend themselves from the encroaching waters for a time, albeit with massive technological effort and expense. Nevertheless, affordable and practical solutions are needed for all.

The oceans are an important source of proteins in our diet; about 16% of global protein intake comes from fish. Fisheries also represent an important sector of the global economy. However, in many of the world's maritime regions, overfishing is putting stocks at risk. The development of a low-impact, ecologically and financially sustainable fisheries sector is vital.

Human appetite for energy and mineral resources seems insatiable. As land-based resources become increasingly scarce, ocean-based resources are attracting greater interest. Already, more than a third of the world's oil and gas extraction comes from offshore sources. Oceanic wind, wave, tidal, biological and thermal sources can all meet a portion of our energy needs. With resource price increases, the appeal of ocean mining for ores and minerals rises.

Solutions to such important issues require deployment of new, appropriate, sustainable and advanced technologies. This section of GMTT 2030 explores eight technologies that are likely to have the most significant impact on the mutual relationship between the oceans and mankind.

Eight Technologies: Ocean Space

The ocean space has affected many lives over the centuries. It has provided the means to sustain and grow, as well as travel and explore. However, it has also brought death and destruction to unsecured coastal areas. As we venture into the 21st century, these challenges and opportunities will become even more pronounced. With bigger coastal populations and a higher expected frequency and severity of extreme weather events to cope with, the oceans have the potential to transform the global economy. The emerging and developing technologies that we have explored in this report offer us the means to firmly face these challenges and grab opportunities in the future. We have identified the following to be the key transformational Ocean Space technologies:

- Advanced materials
- Big data analytics
- Autonomous systems
- Sensors and communications
- Carbon capture and storage
- Sustainable energy generation
- Deep ocean mining
- Marine biotechnology

90% of life on Earth is aquatic

2 times as many offshore structures will exist by 2030

50% of oil will be produced offshore by 2030

100 times more wind turbines will be in operation by 2030

4kg of gold per person sits on the seabed

30% increase in ocean acidity since the Industrial Revolution

pH

<5% of the Earth's ocean has been explored

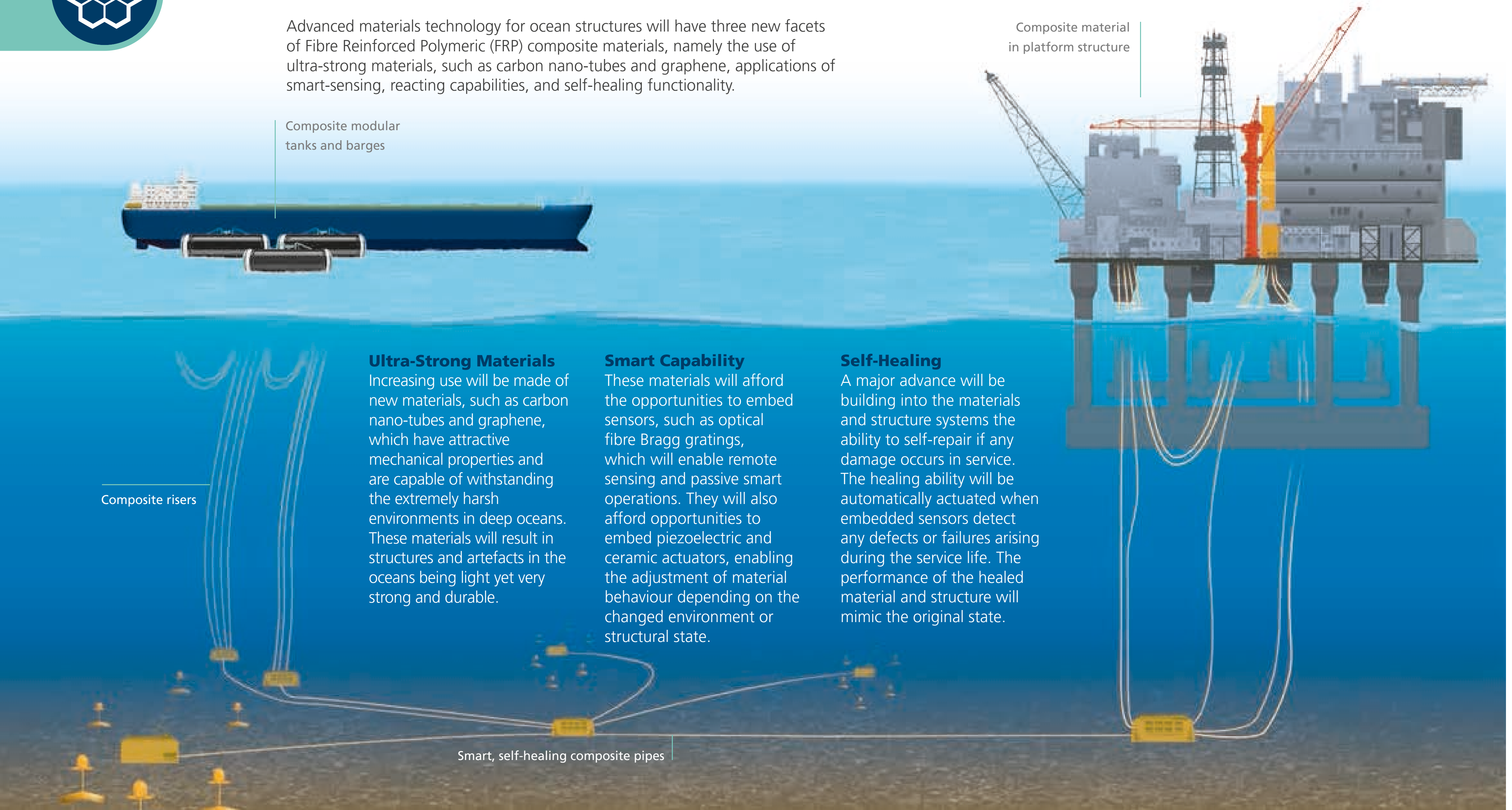
25% of atmospheric CO_2 is absorbed by the ocean

CO_2

50% of the global population live in coastal regions

Advanced Materials

Advanced materials technology for ocean structures will have three new facets of Fibre Reinforced Polymeric (FRP) composite materials, namely the use of ultra-strong materials, such as carbon nano-tubes and graphene, applications of smart-sensing, reacting capabilities, and self-healing functionality.

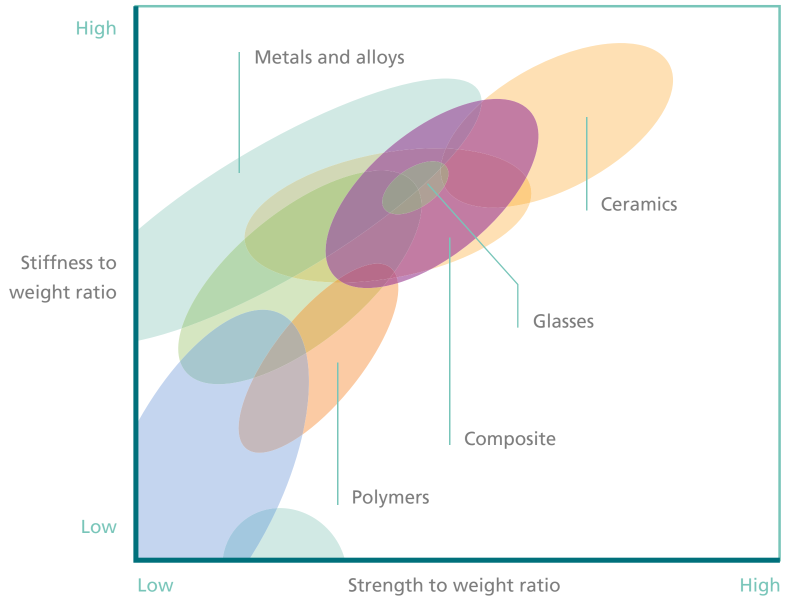


Ultra-Strong Materials
Increasing use will be made of new materials, such as carbon nano-tubes and graphene, which have attractive mechanical properties and are capable of withstanding the extremely harsh environments in deep oceans. These materials will result in structures and artefacts in the oceans being light yet very strong and durable.

Smart Capability
These materials will afford the opportunities to embed sensors, such as optical fibre Bragg gratings, which will enable remote sensing and passive smart operations. They will also afford opportunities to embed piezoelectric and ceramic actuators, enabling the adjustment of material behaviour depending on the changed environment or structural state.

Self-Healing
A major advance will be building into the materials and structure systems the ability to self-repair if any damage occurs in service. The healing ability will be automatically actuated when embedded sensors detect any defects or failures arising during the service life. The performance of the healed material and structure will mimic the original state.

Smart materials, with the support of embedded sensors, will improve operations and maintenance of offshore structures, reducing the maintenance cost and improving safety.



Technology Enablers
FRP composites are mature materials in terms of modelling and manufacture. Technologies that have been used for successful development and operation of large structures and their components, such as pipes, wind turbines, aeroplanes and ships, can now be applied to offshore constructions.

Cost and Efficiency
FRP composite materials are widely available, giving an opportunity for practical installation on site that can be done in a modular manner with the maintenance, repair and through-life costs being significantly lower.

Safety
Amended and inbuilt sensors will provide information about the condition of the structures and materials, while autonomous vehicles with roving sensors will bring further means for condition monitoring. Current procedures for metallic components can be adapted and extended to cover FRP composites.

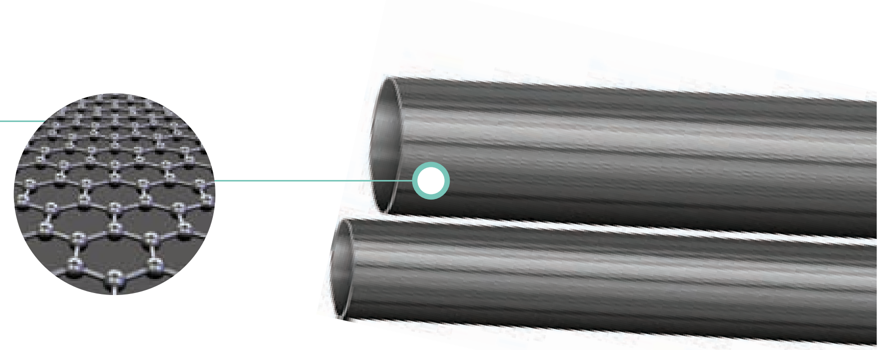
These new smart, lightweight materials pose some risks, despite the positive economic and environmental impacts.

Uncertainties
For these new technologies to happen, the current existing regulations need to be developed to cover smart materials. The progress in development and use of such materials is dependent on such factors as fuel price, safety and durability.

Economy
These new smart materials and technologies will enable more affordable installation, operation and maintenance of offshore structures.

Environment
The specific design process of new structures made of smart materials will allow for the whole life cycle, control of the whole life cycle, from production to the end-of-life stage.

The development of emerging graphene and carbon nano-tubes in structural materials will have a positive impact on the development of novel composites

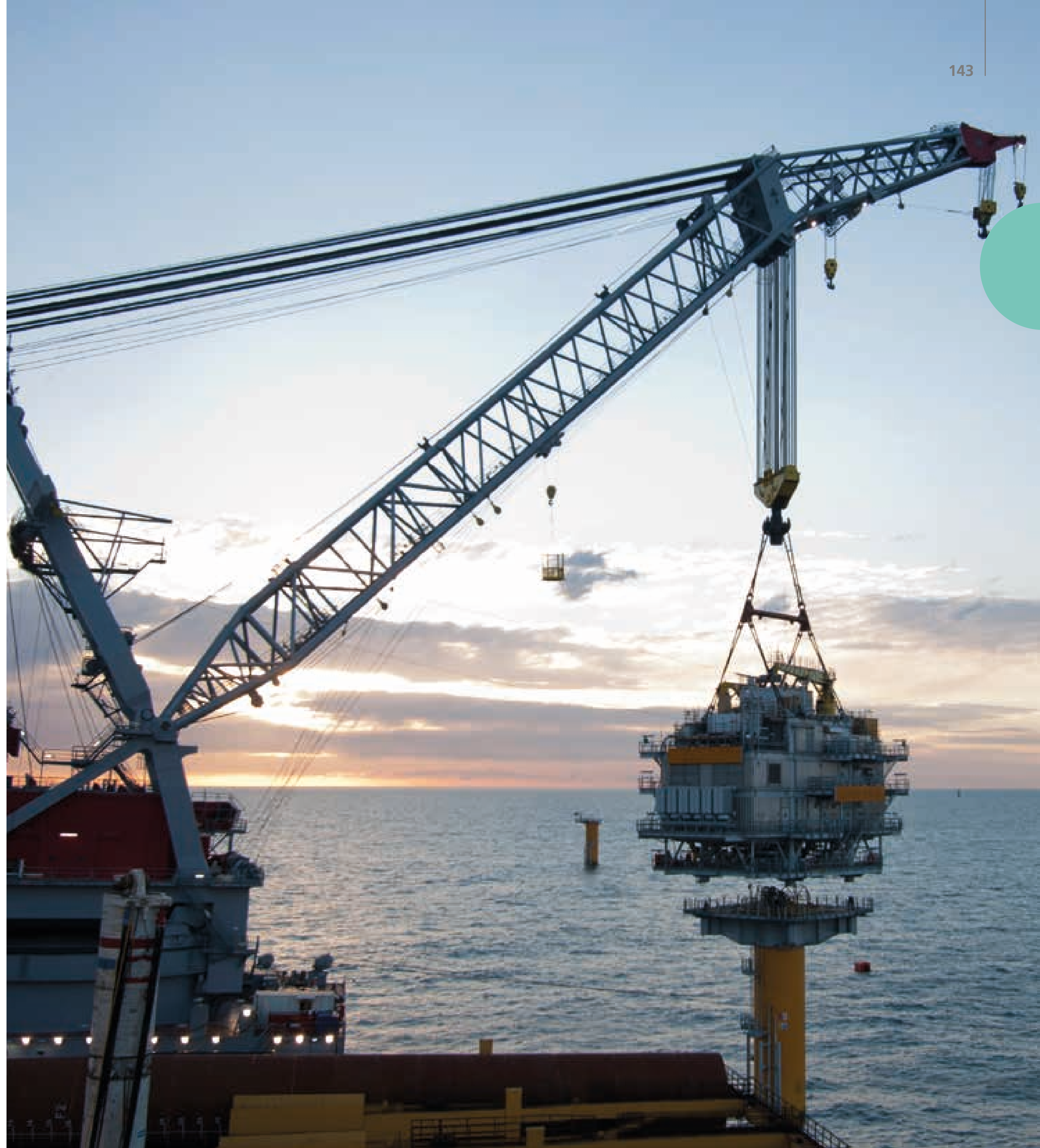


These new smart and extremely lightweight materials will enable:

- Higher levels of durability
- Reduced downtime for maintenance
- Lower operational costs
- Increased levels of robustness
- More reliable operations.

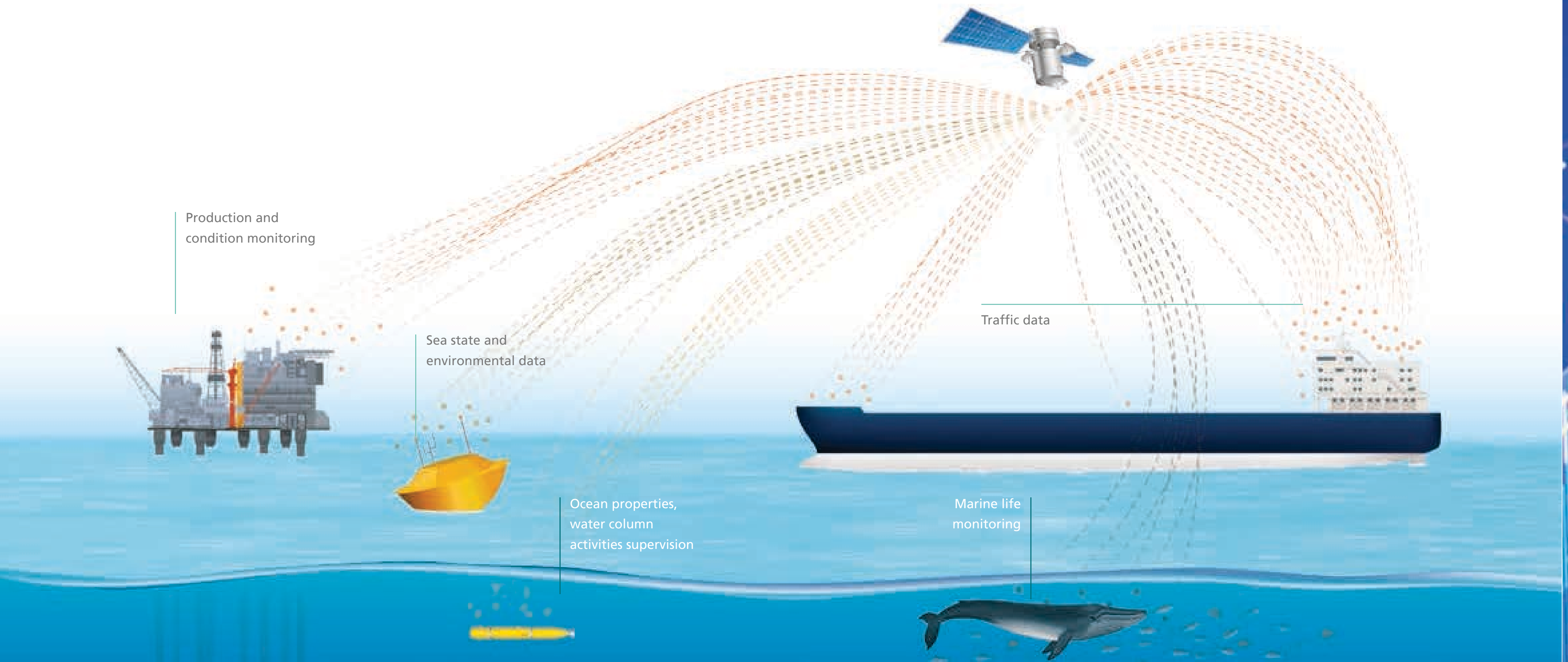
Other Industries
- A precedent to be set for bespoke structures in other industries, including civil construction and shipbuilding
- Profitability of the composite supply chain, increasing and improving job prospects in the sector
- Opportunities for small companies to grow.

Oil and Gas
- Enhanced capability of the offshore construction yards
- Development of novel design technologies
- Increased opportunities for the value chain industries.



Big Data Analytics

All human activities performed in the ocean space, such as resource extraction, exploration, or environmental protection, lead to the generation of vast amounts of data. Such information will be high volume, with variable information streams arriving at high velocities. Using advanced communication and computing technologies, together with appropriate analysis techniques, will significantly influence the way humankind perceives and interacts with the oceans by unveiling the global mechanisms described by big data.



In order to benefit from big data, one first has to deal with securing the ability to communicate and process it at a sufficiently high rate to implement an appropriate action. Each of the stages of the process pose certain challenges, but, when harmonised, they may make the decision-making process far more efficient.

Data Gathering

Data obtained from the ocean space will include features of wind, wave and weather statistics, wildlife observations, ocean chemistry, salinity, temperatures, geological characteristics, seabed terrestrial characteristics, etc. The proliferation of small and affordable sensors will allow for more data to be gathered from a wider range of locations.

Data Transfer

Transferring large volumes of data from a wide range of sources and a variety of remote locations requires a technologically advanced approach to provide sufficient bandwidths at a low enough cost. Transmissions have to be made from locations such as offshore platforms and ships, wave buoys, floating and submerged autonomous systems, marine infrastructures, and so on. The advancements in satellite and related communication technologies will be a key enabler of big data analytics in the ocean space.

Data Processing

Extracting valuable information from complex data streams requires a suitable software and hardware infrastructure. Some of it may be present on site for offshore platforms, for instance, but most will be delivered by high-performance computing (HPC) centres onshore. Access to such resources is continually becoming cheaper, making large-scale deployment of big data analytics more realistic than ever before.

Data Analysis

Drawing conclusions from seemingly unrelated sets of data requires appropriate modelling and analysis approaches, supported by appropriate software tools. The speed at which a decision is made following the analysis and the responsiveness of the system being controlled, be it a network of offshore platforms or a survey operation, is crucial to the effectiveness of big data analytics. The adoption of more flexible management structures in the ocean space is expected to support the introduction of this technology.

Industry Configuration Challenge
Utilising big data analytics in the ocean space is likely to require a restructuring of business and legal practices. Mechanisms for trading data and information will need to be developed at an increasing pace. This is likely to bridge the traditional business sectors and create new opportunities. National governmental, as well as international entities, are also likely to play a role in enabling or deterring the introduction of this technology by means of regulation.

Economics
Significant capital expenditure will be required in establishing big data analytics in the ocean space. This will be largely associated with developing data transfer and processing capabilities. The operational costs may include fees for data transfer and outsourced processing and analysis. The progressing development and increased affordability of satellite communications and high-performance computing technologies will be a major enabler in this context.

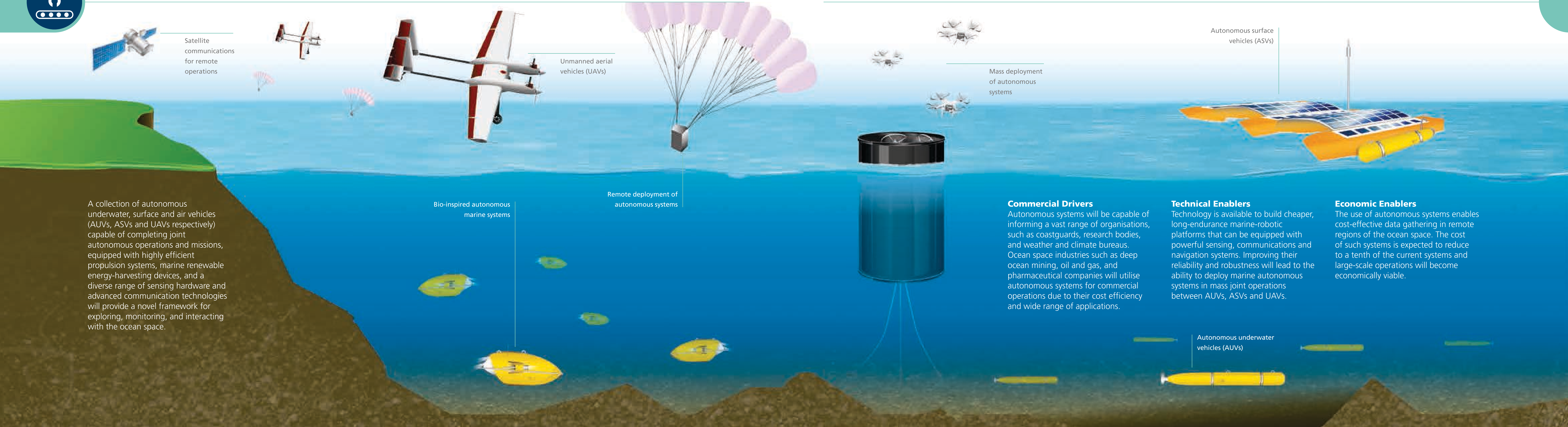
Data Openness Versus Data Protection
Protection of the data, especially in terms of sensitive internal company information, is a persistent issue in all information technologies. In order to fully utilise the potential of big data analytics, one will have to carefully weigh the cost of performing the critical analysis internally against the possibility of data theft when outsourcing the process.

Enhanced Safety Of Ocean Infrastructure
One of the primary benefits that big data analytics would provide is the enhancement of risk-management strategies. The rapid capture and transfer of large volumes of a variety of data would allow real-time monitoring of ocean infrastructure. This could constitute the next big step in the introduction of predictive and condition-based maintenance, reducing the costs of operating marine structures in the oceans and vastly increasing their safety.

Enhanced Monitoring of Ocean Environment
With a wide set of data streams describing winds, tides, currents, temperatures and water properties, big data analytics could be used to better monitor the Earth's climate. This could be used to improve the weather forecasting ability, particularly with regard to extreme natural events. Such data would also help to nurture the marine environment, by tracking its condition and allowing better measures to be taken in response to any emergent problems.

Enhanced Anthropogenic Environmental Footprint
In order for system and component optimisation of energy production or resource extraction processes, an understanding of a vast range of factors needs to be developed. This could be achieved through the use of big data analytics. It would make the deployment, utilisation, and disposal of assets in the ocean space significantly more efficient, with the environmental footprint being minimised.

Autonomous Systems



A collection of autonomous underwater, surface and air vehicles (AUVs, ASVs and UAVs respectively) capable of completing joint autonomous operations and missions, equipped with highly efficient propulsion systems, marine renewable energy-harvesting devices, and a diverse range of sensing hardware and advanced communication technologies will provide a novel framework for exploring, monitoring, and interacting with the ocean space.

Commercial Drivers
Autonomous systems will be capable of informing a vast range of organisations, such as coastguards, research bodies, and weather and climate bureaus. Ocean space industries such as deep ocean mining, oil and gas, and pharmaceutical companies will utilise autonomous systems for commercial operations due to their cost efficiency and wide range of applications.

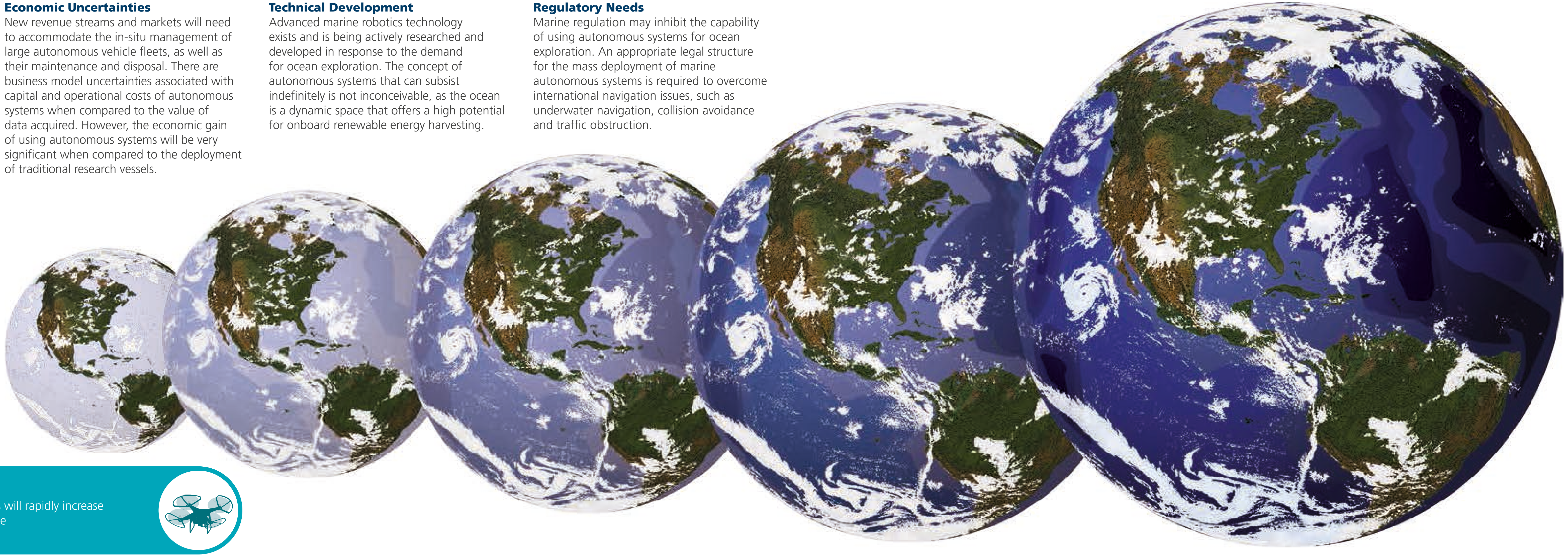
Technical Enablers
Technology is available to build cheaper, long-endurance marine-robotic platforms that can be equipped with powerful sensing, communications and navigation systems. Improving their reliability and robustness will lead to the ability to deploy marine autonomous systems in mass joint operations between AUVs, ASVs and UAVs.

Economic Enablers
The use of autonomous systems enables cost-effective data gathering in remote regions of the ocean space. The cost of such systems is expected to reduce to a tenth of the current systems and large-scale operations will become economically viable.

Economic Uncertainties
New revenue streams and markets will need to accommodate the in-situ management of large autonomous vehicle fleets, as well as their maintenance and disposal. There are business model uncertainties associated with capital and operational costs of autonomous systems when compared to the value of data acquired. However, the economic gain of using autonomous systems will be very significant when compared to the deployment of traditional research vessels.

Technical Development
Advanced marine robotics technology exists and is being actively researched and developed in response to the demand for ocean exploration. The concept of autonomous systems that can subsist indefinitely is not inconceivable, as the ocean is a dynamic space that offers a high potential for onboard renewable energy harvesting.

Regulatory Needs
Marine regulation may inhibit the capability of using autonomous systems for ocean exploration. An appropriate legal structure for the mass deployment of marine autonomous systems is required to overcome international navigation issues, such as underwater navigation, collision avoidance and traffic obstruction.



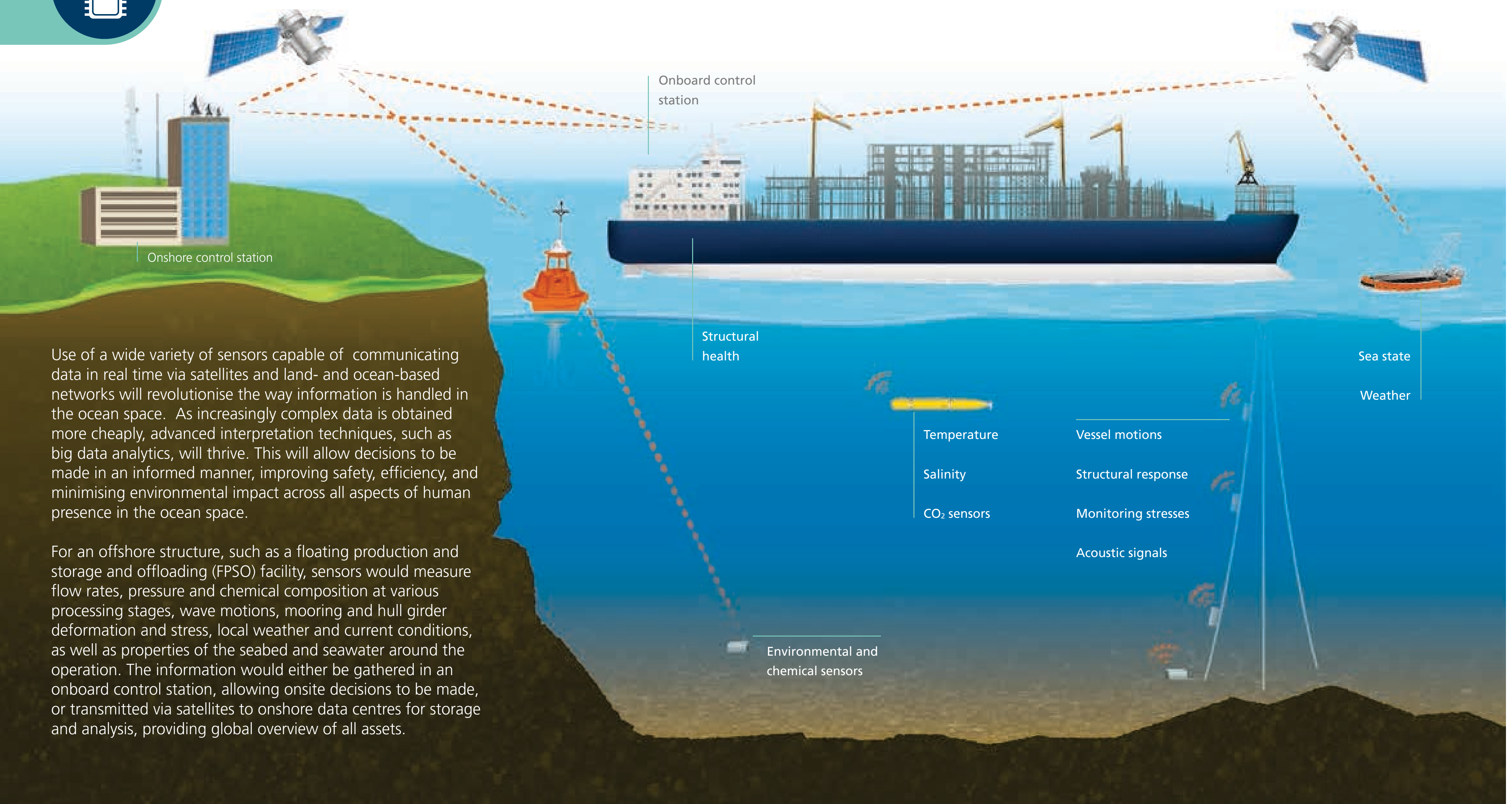
Advances in autonomous systems will rapidly increase our knowledge of the ocean space

Society and People
The deployment of autonomous marine systems can help prepare coastal communities for extreme weather with advance warnings and improve our understanding of the ocean's role in the climate and environment. Autonomous marine systems will lead future exploration of the ocean space, with the goal of discovering vast subsea resources and making them available to the people.

Environment
Through subsea exploration, autonomous marine systems will help scientists expand their understanding of the ocean environment and ecosystems. Therefore, the autonomous systems will teach us how to effectively nurture the ocean space environment and could potentially actively work to protect it against damaging human activity, such as pollution or over-exploitation.

Economy
Advances in this technology will make it feasible to effectively gather large volumes of data from the ocean space. This data will become a valuable commodity for governments, research organisations and associated industries that plan to extract value from the ocean space. New markets will emerge to complete the value chain, from the mass deployment of autonomous marine systems to big data analytics.

Sensors and Communications



Use of a wide variety of sensors capable of communicating data in real time via satellites and land- and ocean-based networks will revolutionise the way information is handled in the ocean space. As increasingly complex data is obtained more cheaply, advanced interpretation techniques, such as big data analytics, will thrive. This will allow decisions to be made in an informed manner, improving safety, efficiency, and minimising environmental impact across all aspects of human presence in the ocean space.

For an offshore structure, such as a floating production and storage and offloading (FPSO) facility, sensors would measure flow rates, pressure and chemical composition at various processing stages, wave motions, mooring and hull girder deformation and stress, local weather and current conditions, as well as properties of the seabed and seawater around the operation. The information would either be gathered in an onboard control station, allowing onsite decisions to be made, or transmitted via satellites to onshore data centres for storage and analysis, providing global overview of all assets.

Sensors

Miniaturisation of sensors is expected to allow their easier and cheaper deployment on large scales. The associated economics of scale and emergence of new vast markets will likely further enhance this effect.

Reduction of the physical size of the sensors and their improved affordability, together with improvements in advanced materials, will lead to the deployment of embedded sensors. Their use is expected to revolutionise the through-life condition monitoring of structures.

Maintaining a large and diverse array of sensors will become more economical, with networking technologies becoming more affordable and autonomous systems offering low-cost repairs and deployment, even in remote areas of the globe.

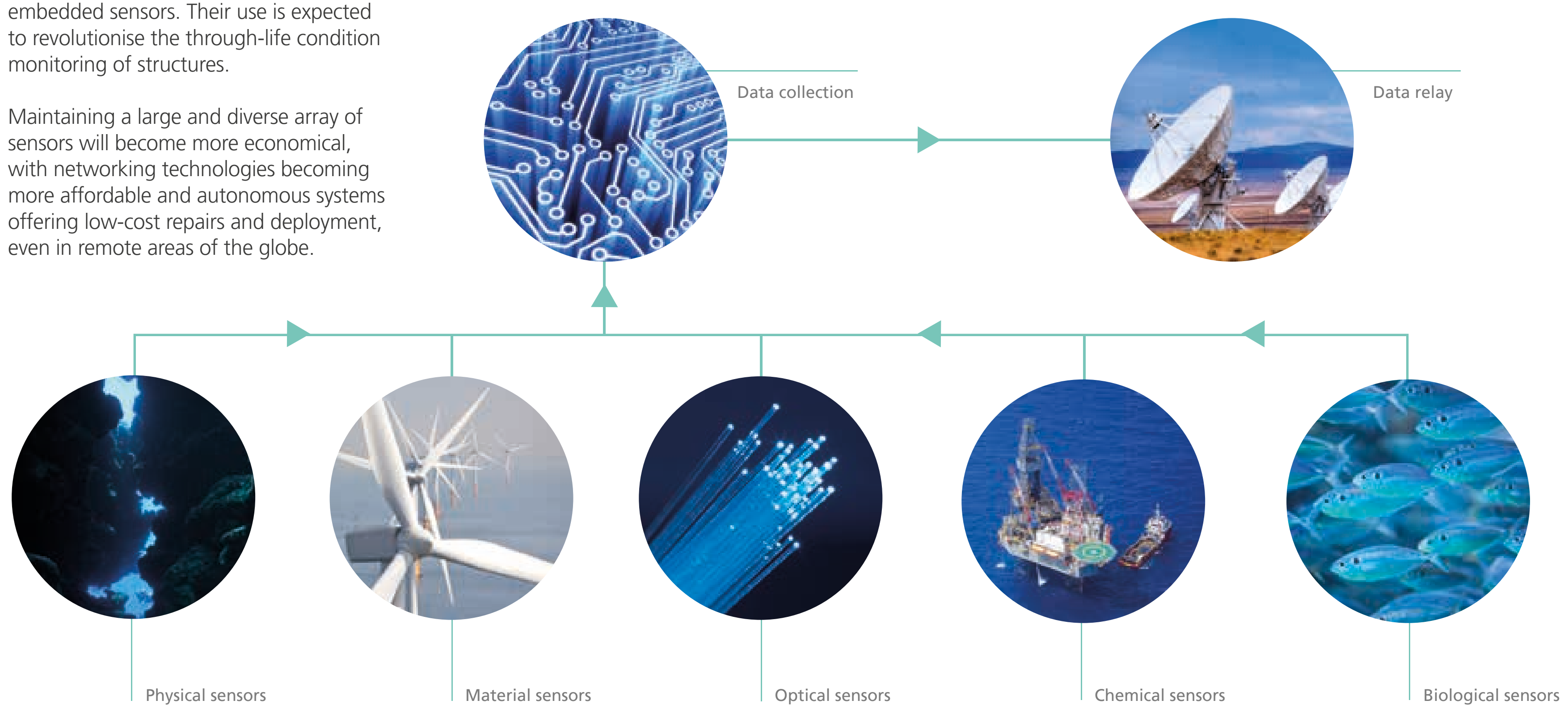
Data Transfer and Storage

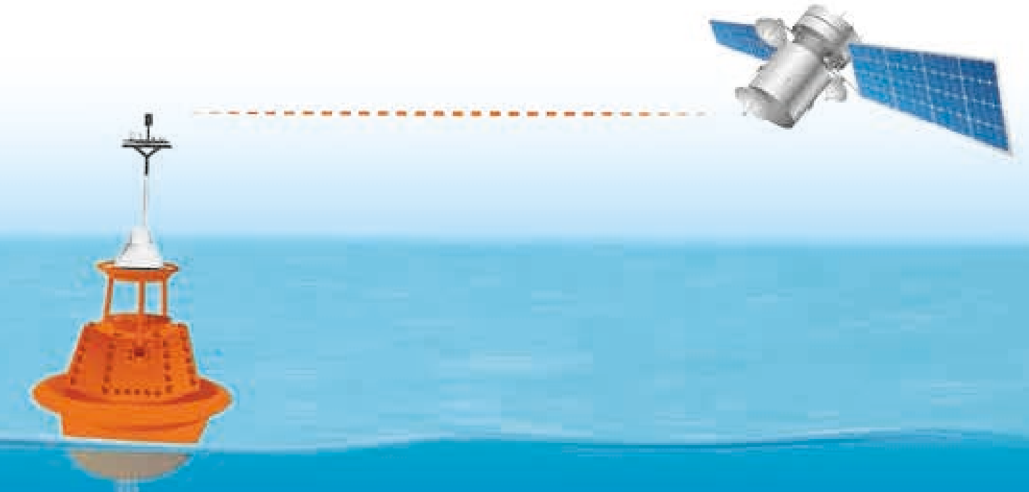
Cheaper worldwide transfer of information, even from remote locations, will be more accessible owing to dedicated satellite networks and their improved capabilities, such as those provided by laser data links. An increased data-storing capability, particularly for independent sensors, will allow more data to be collected per deployment, increasing efficiency.

Economic Drivers

Information will become an important resource in the ocean space, given the pressure from decision-makers, both private and government-related, to be more aware of the state of reality.

Interest in environment preservation will push for a better understanding of the ocean space, which may only be achieved through the deployment of sensors.





RISKS

Investment will be needed to provide new and better satellites and, in extreme cases, perhaps involving their ownership by ocean space-related stakeholders.

Deployment of sensors will require a considerable investment and their retrofitting may not always be straightforward.

New business models related to the information becoming a commodity, desired not only by companies but also by governments and public organisations, will need to be developed.

New infrastructure, based on- and off-site, will need to be put in place for the data to be accumulated and analysed.

The global nature of the ocean space and the involved parties and their conflicting interests may impede the rate at which this technology is embraced.

MITIGATIONS

Costs of satellite communications are expected to continue to reduce, and a significant proportion of the required investment will be shared with other industry sectors.

Development costs and regulatory hurdles related to many aspects of sensing and communication technologies will be managed, not only by companies but also by governments and independent organisations.

The transfer of knowledge and business models from other industries will support the introduction of sensors and communications on a large scale in the ocean space.

Extended Lifetime of Offshore Facilities
One of the key benefits of the introduction of sensors and communications technology on a large scale in the ocean space will be the extended lifespan of offshore facilities. This will be achieved through better planning of maintenance thanks to operational practices and the life of marine structures being better understood and monitored.

Improved Operational Efficiency
Data collected from the sensors will lead to an improvement of future designs and operations, owing to the better use of hindcast – experiential data applied to benchmark new solutions.

More Relevant Regulations
A better understanding of complex systems will help the introduction of more apt regulations. Sensors will also help to ensure better enforcement of safety regulations using real-time data monitoring and analytics.

Better Understanding of Marine Ecosystems
Sensors and communications will help to reduce any negative impact of anthropogenic activity on the environment by improved monitoring. An enhanced understanding of marine ecosystems will allow for them to be better nurtured and protected.

Increased Safety
A large array of permanent sensors will provide forewarnings of extreme natural events. Safer and cleaner working environments for workers in the ocean space will also become more achievable.

6
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carbon
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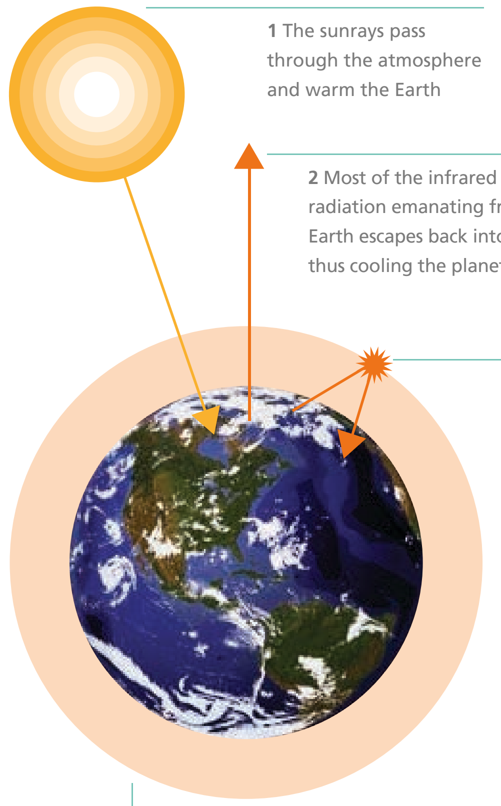
Carbon Capture and Storage

The term carbon capture and storage (CCS) refers to a process of capturing CO_2 that comes from large point sources (LPS), such as electrical power generating plants, and transporting it for storage in geological sites.

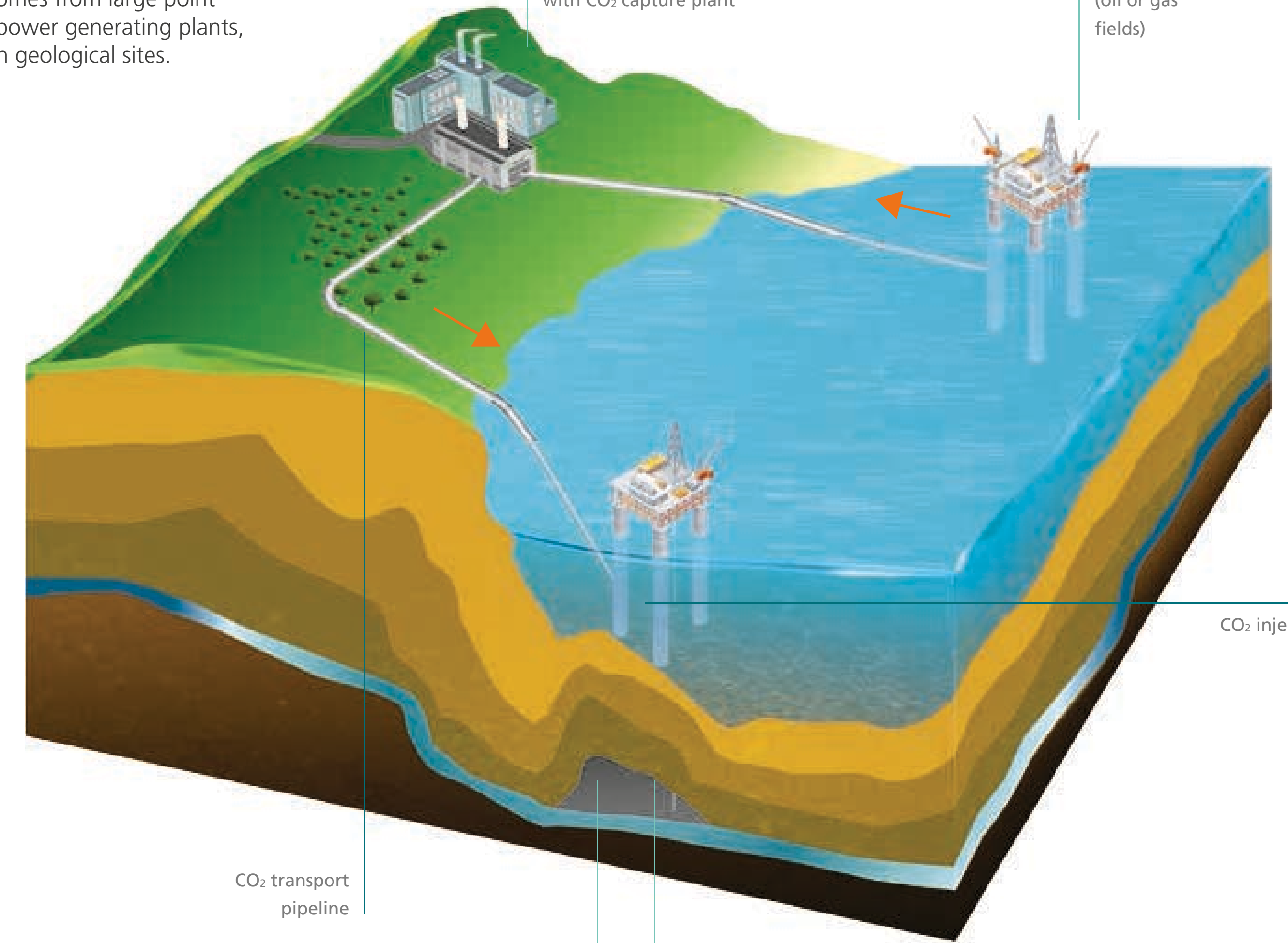


1 The sunrays pass through the atmosphere and warm the Earth

2 Most of the infrared radiation emanating from the Earth escapes back into space, thus cooling the planet

3 However, some of this infrared radiation is trapped by the atmospheric gases, especially CO_2, and this reduces the cooling effect

4 Higher quantities of atmospheric CO_2 increase the amount of heat retained and thus cause the atmosphere and Earth's surface to heat up



Coal- or gas-fired power station with CO_2 capture plant

Fuel mining (oil or gas fields)

CO_2 injection

CO_2 transport pipeline

Depleted oil or gas fields

CO_2 storage sites

Capture

Capturing CO_2 is best done by separating it from the flue gases emanating from the power station processes. This technology is well understood and is used in other industrial applications at present, although not on the same scale as might be required in commercial-scale power stations.

Transport

Because the major industrial point sources of CO_2 are located at long distances from potential storage sites, transportation of the captured and then liquefied CO_2 will be required. The transport modes could be road, rail, ships, and pipelines. It is expected that road and rail transport will prove uneconomical. Therefore, a mix of pipelines and ships will be required.

Storage

CO_2 can be stored in geological formations such as depleted oil and gas fields, deep coal seams, and deep saline aquifers (underground rock formations that contain water). Generally, this will be at depths of more than 800m, where ambient temperatures and pressures will mostly keep the CO_2 in a liquid state.

6
C
carbon
12.011

Technical feasibility

Environmental friendliness

Economic viability

Expected public acceptance

Political support and governmental funding and legal viability

Carbon accounting and verification

Safety

RISKS

Experience with Carbon Capture

– 13 plants capture CO_2 using combustion processes, of which 11 use pre-combustion, one uses post-combustion, and one uses oxy-fuel
– Nine projects source CO_2 from industrial processing
– CCS has an application in reducing point-sourced waste emissions from a range of fuels, from coal and natural gas to biomass.

Experience with CO_2 Transport

Strong evidence of existing practice in transport by:

– Pipeline: single-source sink pipeline and multiple-source multiple-sink pipeline networks
– Lorry.

Experience with Monitoring Stored CO_2

There is extensive experience of monitoring tools and expertise using:

– 2D, 3D, 4D, crosswell and passive seismic approaches
– Satellite imaging
– Interferometry
– Detector arrays
– Well temperature and pressure loggings.

Climate Change

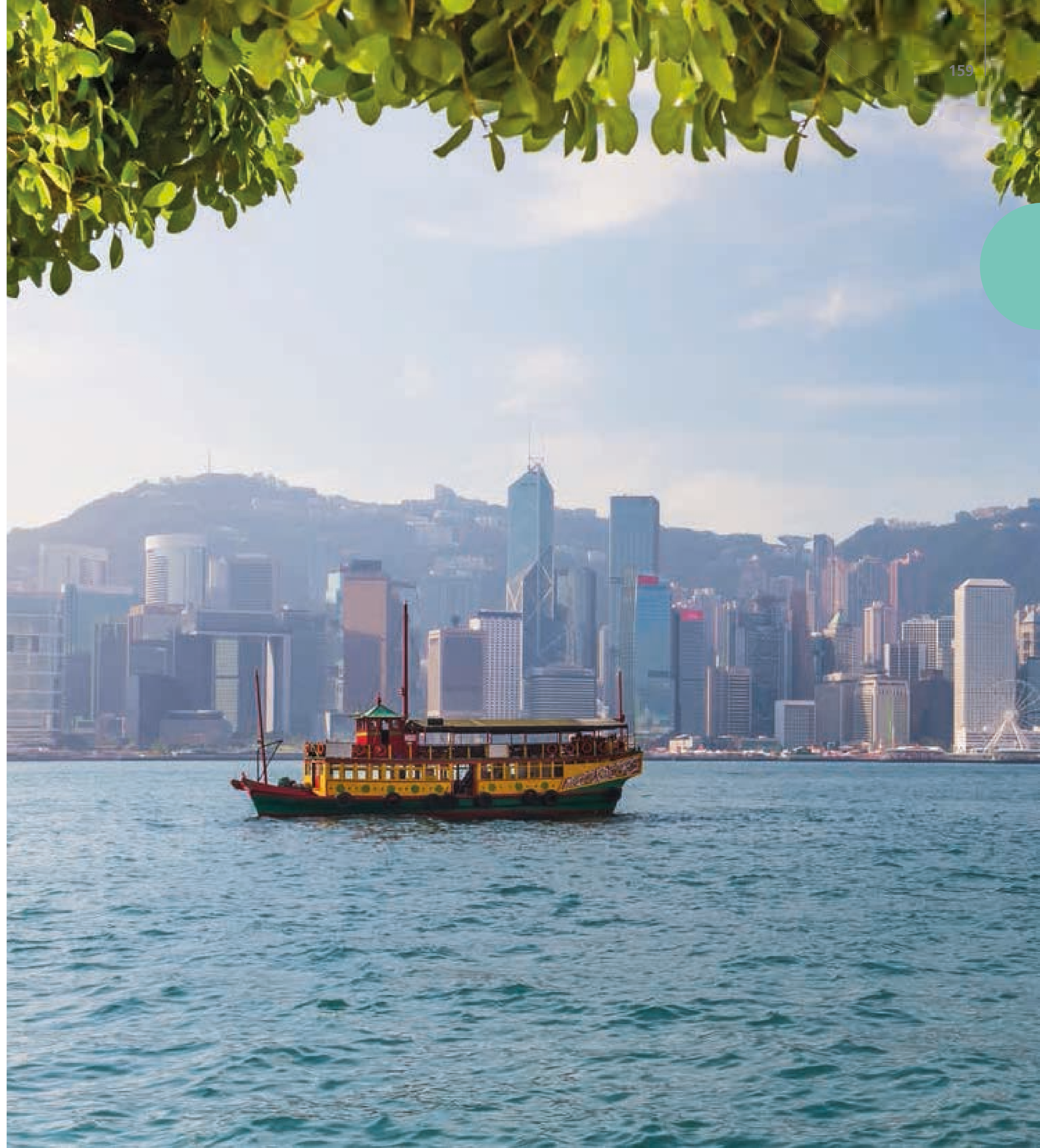
– Positive contribution to battling climate change and global warming
– Will help governments to meet the international and domestic pressures for cutting emissions
– Will protect marine life from the effects of ocean acidification.

Industry

– Will offer an opportunity to reuse existing oil and gas infrastructure, extending the value chain of certain otherwise unusable assets
– Will allow for cheap energy sources, such as coal or gas, to be used in a more sustainable manner
– May reduce the pressure on scaling down production of fossil fuels, securing value of current mining and processing facilities.

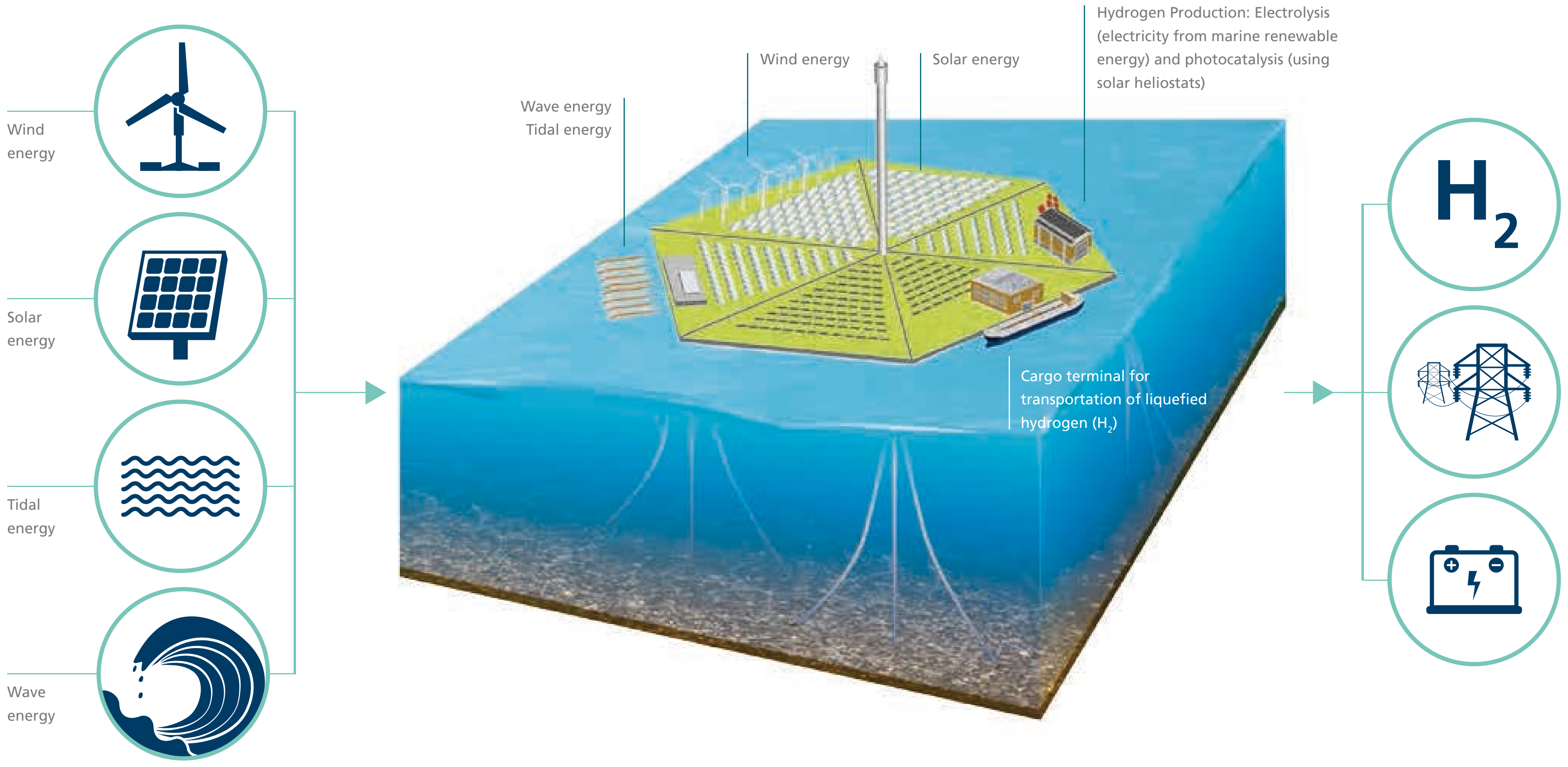
Society

– Every CCS plant would generate thousands of jobs in operation, maintenance and supply chain
– Continued access to cheap energy sources promoting economic growth
– Improved air quality and reduced pollution in densely populated areas
– 15% reduction in wholesale electricity prices, especially in combination with enabling carbon tax schemes.



Sustainable Energy Generation

This technology comprises an offshore floating platform housing energy-generation plants, processing plants and storage plants, as well as living accommodation and docks for ships. The energy production plant is used for solar, wind, wave, and, possibly ocean thermal energy conversion. Some of this marine energy can be directed to a water-splitting site where hydrogen can be harvested as fuel from seawater. Remaining energy can be directed to the grid or stored in batteries or fuel cells.



Financial

As measures promoting clean energy sources, such as carbon taxes, become more widespread, sustainable energy generation is likely to become increasingly more profitable.

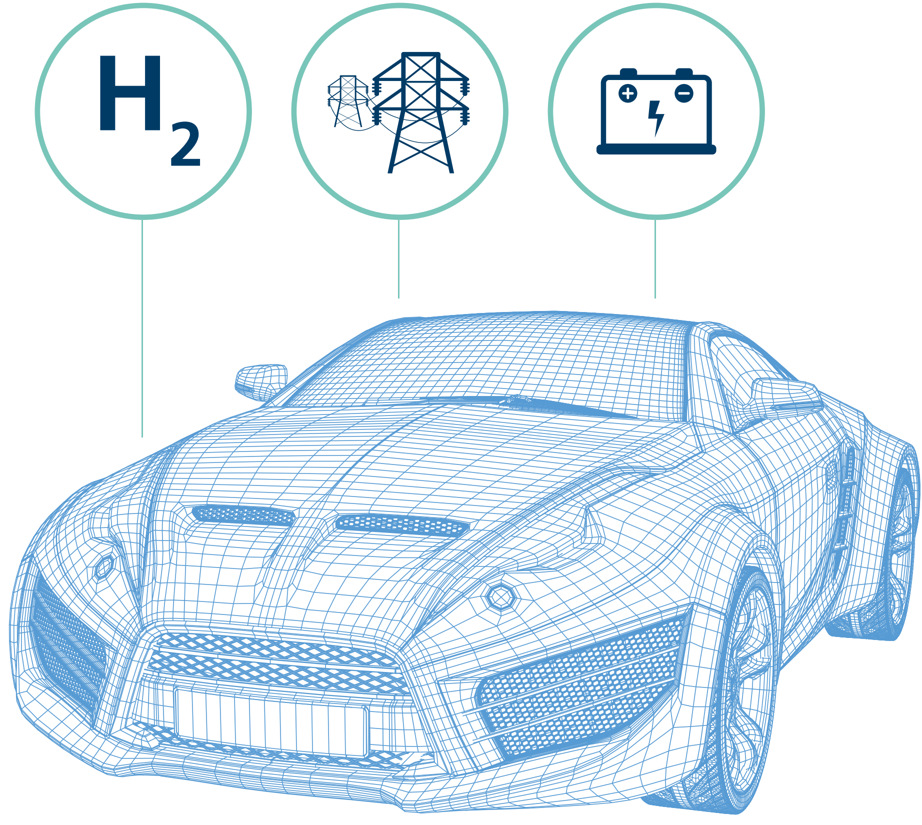
Due to the utilisation of several types of energy at one location, concentrated generation of sustainable energy in the ocean space is likely to be more competitive than traditional installations.

Social and Governmental

Offshore energy generation is within easy reach due to the relative abundance of raw material and space for offshore plants. The platforms will supply fuel and energy resources regardless of geopolitical situation and provide green technologies for energy companies.

Environmental

This platform of energy generation leads to zero emissions of greenhouse gases and carbon footprint reduction of the supply chains; therefore the demand will be high in households and transportation systems, such as ferries, buses, taxis and ships.



RISKS

The **construction and installation** of offshore sustainable energy production plants will entail significant capital expenditure with attendant risks and uncertainties.

Safety risks, especially those associated with hydrogen production and storage, need to be mitigated.

MITIGATIONS

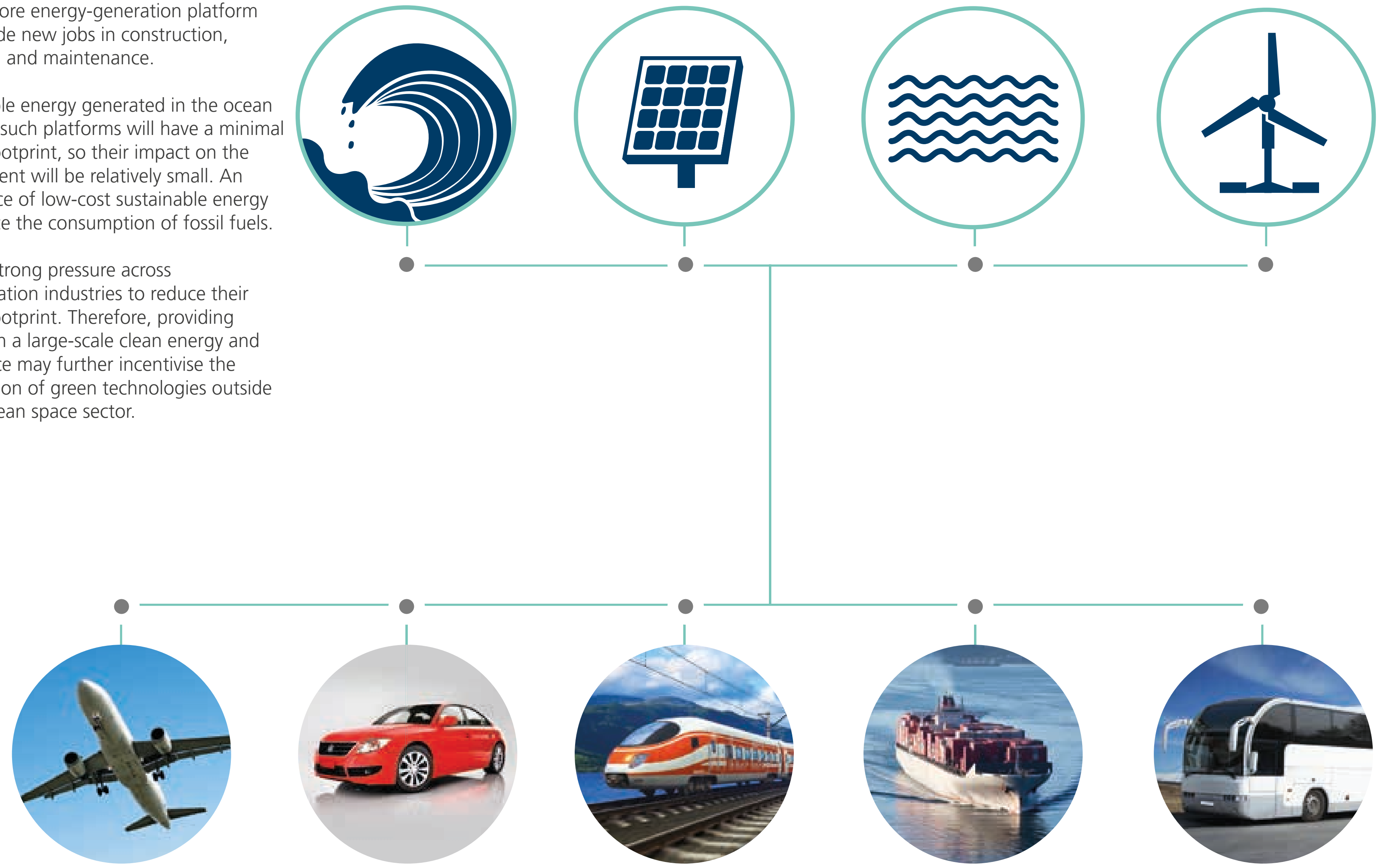
Social and political attitudes are likely to be most favourable for sustainable energy generation in comparison with other 'clean' forms of energy, such as nuclear fission.

Operational practices in through-life management of such facilities can draw on the experiences of existing, comparable chemical and oil and gas industries.

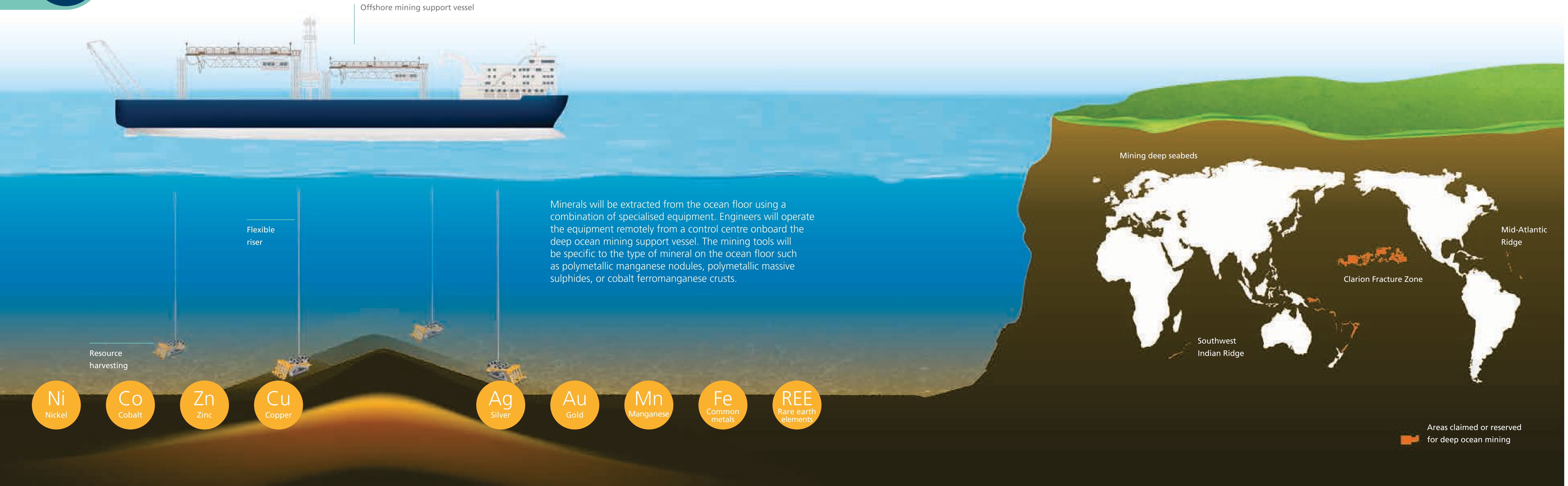
The offshore energy-generation platform will provide new jobs in construction, operation and maintenance.

Sustainable energy generated in the ocean space on such platforms will have a minimal carbon footprint, so their impact on the environment will be relatively small. An abundance of low-cost sustainable energy will reduce the consumption of fossil fuels.

There is strong pressure across transportation industries to reduce their carbon footprint. Therefore, providing them with a large-scale clean energy and fuel source may further incentivise the introduction of green technologies outside of the ocean space sector.



Deep Ocean Mining



Minerals will be extracted from the ocean floor using a combination of specialised equipment. Engineers will operate the equipment remotely from a control centre onboard the deep ocean mining support vessel. The mining tools will be specific to the type of mineral on the ocean floor such as polymetallic manganese nodules, polymetallic massive sulphides, or cobalt ferromanganese crusts.

Technical Enablers

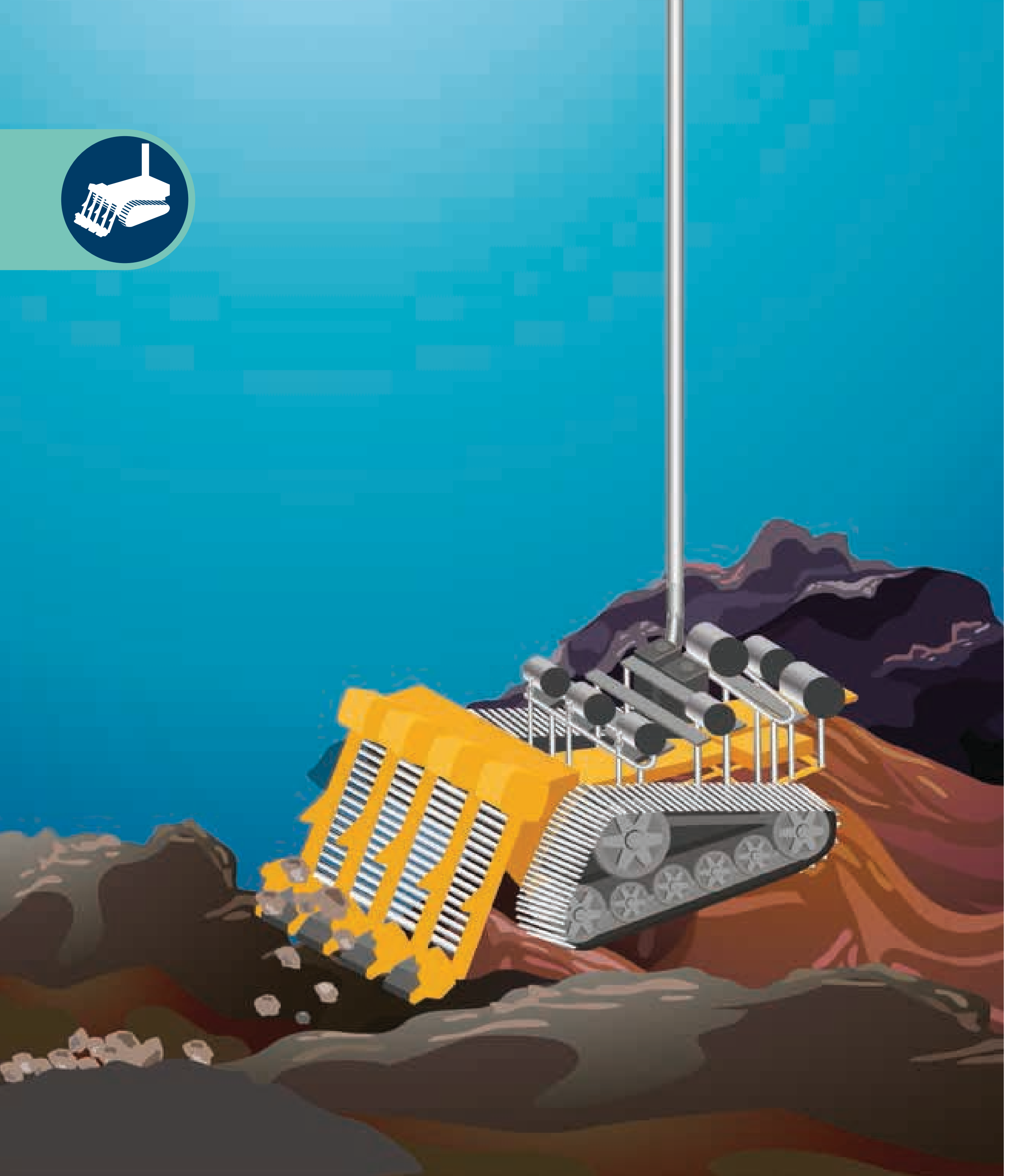
The approximate size, location and value of various potential mining sites have been identified throughout the ocean space. Advances in offshore and underwater technologies, such as the use of autonomous systems, will enable the economic harvest of valuable minerals from the ocean floor.

Economic Drivers

There is a growing demand for rare earth elements and precious metals found on the ocean floor. As new technologies emerge, particularly in the electronics industry, exploiting expensive mining sites will become more economically viable. Availability of affordable autonomous deep ocean mining equipment will offer a significant reduction in operational costs and investment risks. For example, ore deposits found around a hydrothermal vent that is 60m high and 300m in diameter could yield minerals of around 4 million tonnes, with a potentially exploitable economic value of billions of US dollars.

Societal Drivers

A reliable material supply to the manufacturing industry is of critical importance to the world economy. Deep ocean mining will provide a viable alternative source, bringing potential benefits to the consumers as onshore resources shrink. Exploration of the ocean floors will need to be carried out sustainably. This will attract substantial investment for research in fields such as geology, meteorology and ecology. This research will be carried out both individually and as interconnected sciences. Apart from having a greater understanding of deep ocean mining's potential impact, the knowledge and data gained will assist humankind in developing policies and regulations to protect the ocean space.

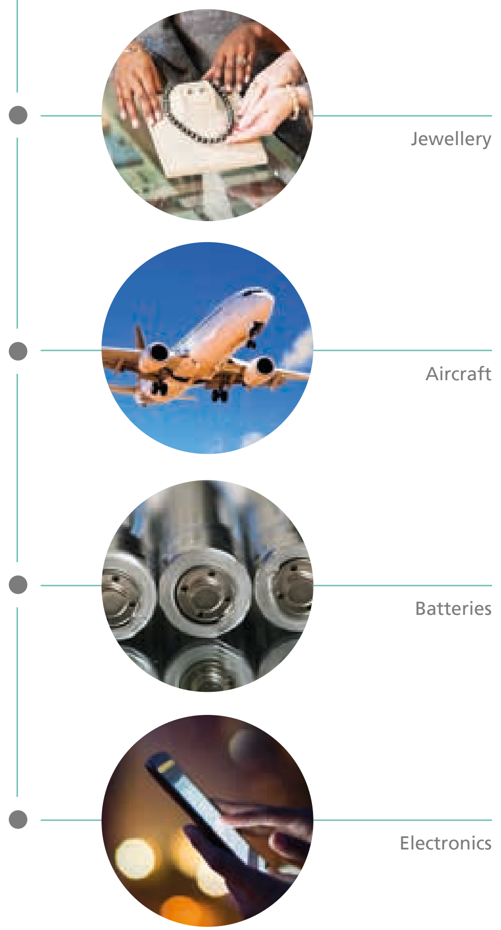


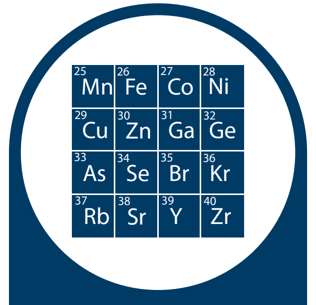
Economy
The development of industrial-scale processes for extracting valuable minerals from deep ocean resources entails potentially high expenditure during procurement and operation. Price fluctuations in the global mineral market may cause concerns over the potential risks associated with investing in this new industry and its supply chain.

Policies and Environment
The environmental impacts from deep ocean mining, such as water pollution, noise, ocean floor degradation and disturbances to deep ocean habitats, will need to be limited and regulated for the realisation of this technology. Knowledge regarding the deep ocean environment will need to be acquired, analysed and monitored. Therefore, subsea exploration with autonomous systems is a key enabler for the advancement of deep ocean mining technologies.

Mitigation
The International Seabed Authority (ISA), which has an observer status at IMO, outlines a set of comprehensive rules, regulations and procedures that regulates prospecting, exploration and extraction of marine minerals in the international ocean space. The ISA has issued licences to contractors for the seabed exploration for polymetallic nodules, polymetallic sulphides and cobalt-rich ferromanganese crusts, showing strong incentive for the development of this industry.

Everyday uses for deep ocean minerals





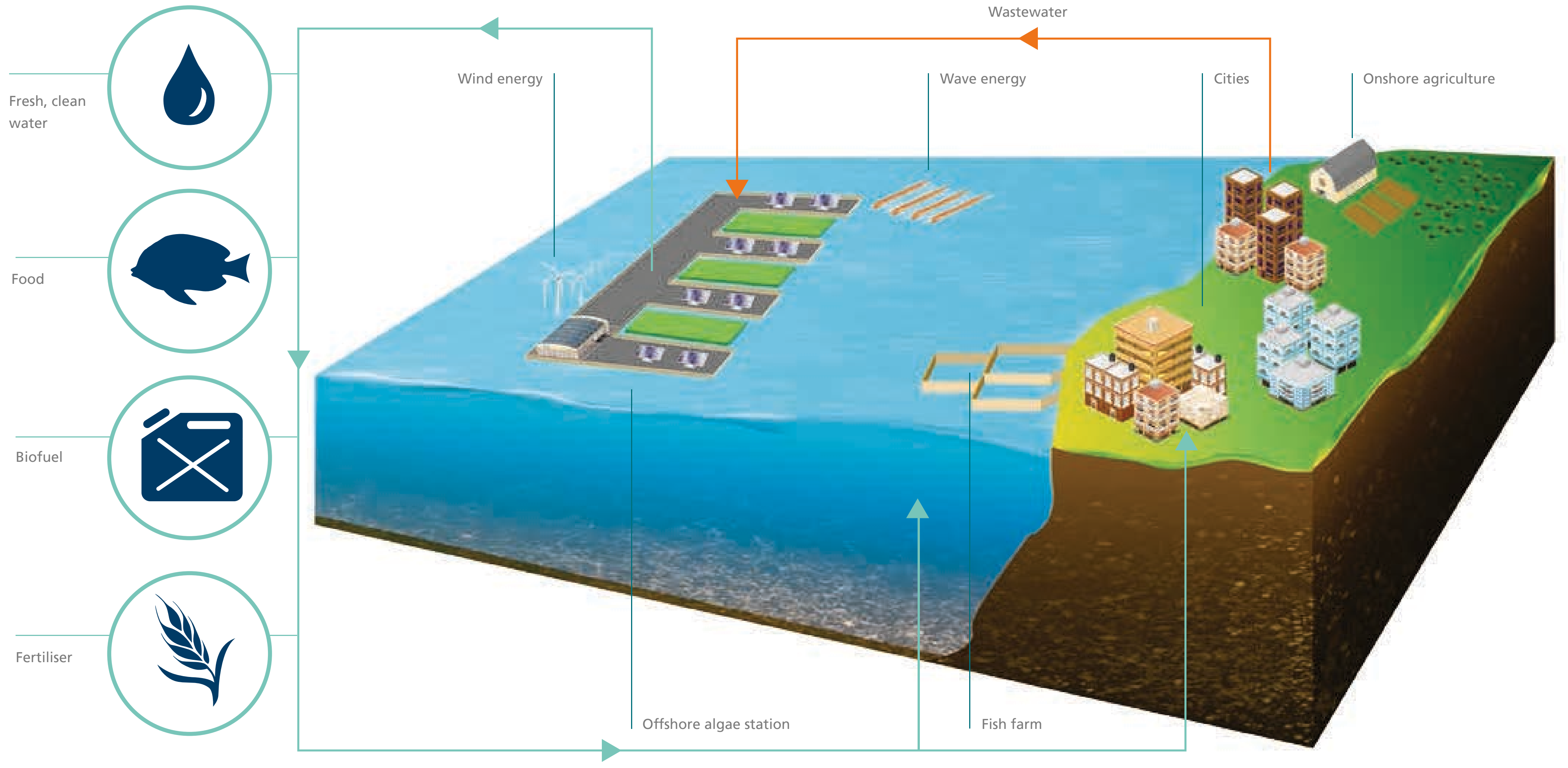
The applications of minerals from deep ocean resources expand across all aspects of everyday life. Cobalt, for example, has a range of uses, from jet engines to the sterilisation of medical equipment. Copper is in demand for electrical applications but is also used extensively in agriculture and water purification. More significantly, the rise of high-tech culture, such as the prominence of smartphones, relies on the supply of rare earth elements. Deep ocean mining has the potential to provide a new frontier for the demand of valuable resources.

The emergence of deep ocean mining will drive new industries and technologies through the development of a new supply chain. It will also enable further development of advanced technologies by increasing the availability of rare minerals. The technology will generate new jobs in the deep ocean mining sector directly and in the newly established supply chain industries.

Through careful employment of deep ocean mining, society will learn more about the ocean environment and develop effective methods to responsibly extract mineral resources from the ocean floor. International consensus, established through regulatory bodies such as the ISA, will accelerate promotion of this technology.

Marine Biotechnology

This technology is based around harvesting and nurturing marine biological resources in an offshore algae station. This will reduce pollution by consuming wastewater from onshore factories, farms and households. At the same time, the algae produced will then be used for food, biofuel, fertilisers, pharmaceuticals, and cosmetics production. The energy required to run the facility will be harvested from waves, sunrays, and wind. Algae will be grown without using fresh water and agricultural land, which is needed for conventional food production.



It is estimated that there are between 30,000 and 1 million species of algae. Currently, there are 15,000 chemical compounds identified in different species of algae, which have great potential for pharmaceutical, energy and materials markets.

Wastewater treatment using algae is an attractive prospect to mitigate pollution in a sustainable way.

Algae are more efficient in production and processing than crops. Thus, it will bring a more stable fuel supply to countries in response to the rapidly growing biofuel market.

A rising social awareness and a commitment to reducing the carbon footprint, along with growing populations and increasing density of human concentration in urban areas, causes a rise in demand for food and the need for sustainable waste disposal.

Algae are easily accessible and are a rich source of proteins and fatty acids. Their production does not cause methane pollution as a side effect. They are less dependent on weather conditions than onshore agriculture, making it a robust and efficient food and energy source.

Risks
Upscaling the production facilities is likely to require a large capital investment. Regulations governing algae plants at sea will need to be developed. It will also be essential to ensure integration into coastal communities. Thus, a full life cycle assessment with regard to local ecosystems and the impact on the environment, such as fish and local plants, will need to be performed.

Currently, there is still a large cost associated with onshore algae mixing and processing which has impeded the commercialisation of this technology.

Mitigation
Offshore wave energy can be used to provide the cheap and sustainable energy required for mass algae production. This could potentially halve the operational costs.

Trends indicate that the aquaculture industry is going to see significant growth as the number of people reliant on the oceans as their main source of food will increase. Estimates suggest it may reach between US$15–20 billion by 2030.

The adaptability of the facility to produce different products will increase potential market size and provide a faster return of capital. As many of the technologies involved have been proven at a pilot scale, there is already an existing market chain allowing for easier upscaling.

A new industry and supply chain will lead to the creation of new workplaces and markets.

Robust and predictably high yields will make this branch of industry highly competitive.

This will complement land-based biotechnology industries and widen societal impact of new food, fuel and chemical products.

Potential benefits which algae offshore stations will bring to society:

- New drugs development
- Fuel security
- Goods and services from marine resources
- Food
- Fresh water
- More sustainable city development through waste processing.

Potential benefits that algae offshore stations will bring to the environment:

- Treating waste water that is deposited into the sea will mitigate the global waste production
- The encouragement of aquaculture will reduce depleting natural fish supplies and limit the damage on fragile ecosystems
- The emerging new technologies needed to monitor the ecosystem will help to manage and protect it
- Fresh water supply is a very important by-product of algae production.

Ocean Space Transformed

As humanity is faced with challenges, such as consequences of climate change, increasing population and depletion of resources, technologies will play a key part in further development of humankind. Their roles may be classified into protecting the people, protecting the environment, and providing for the people.

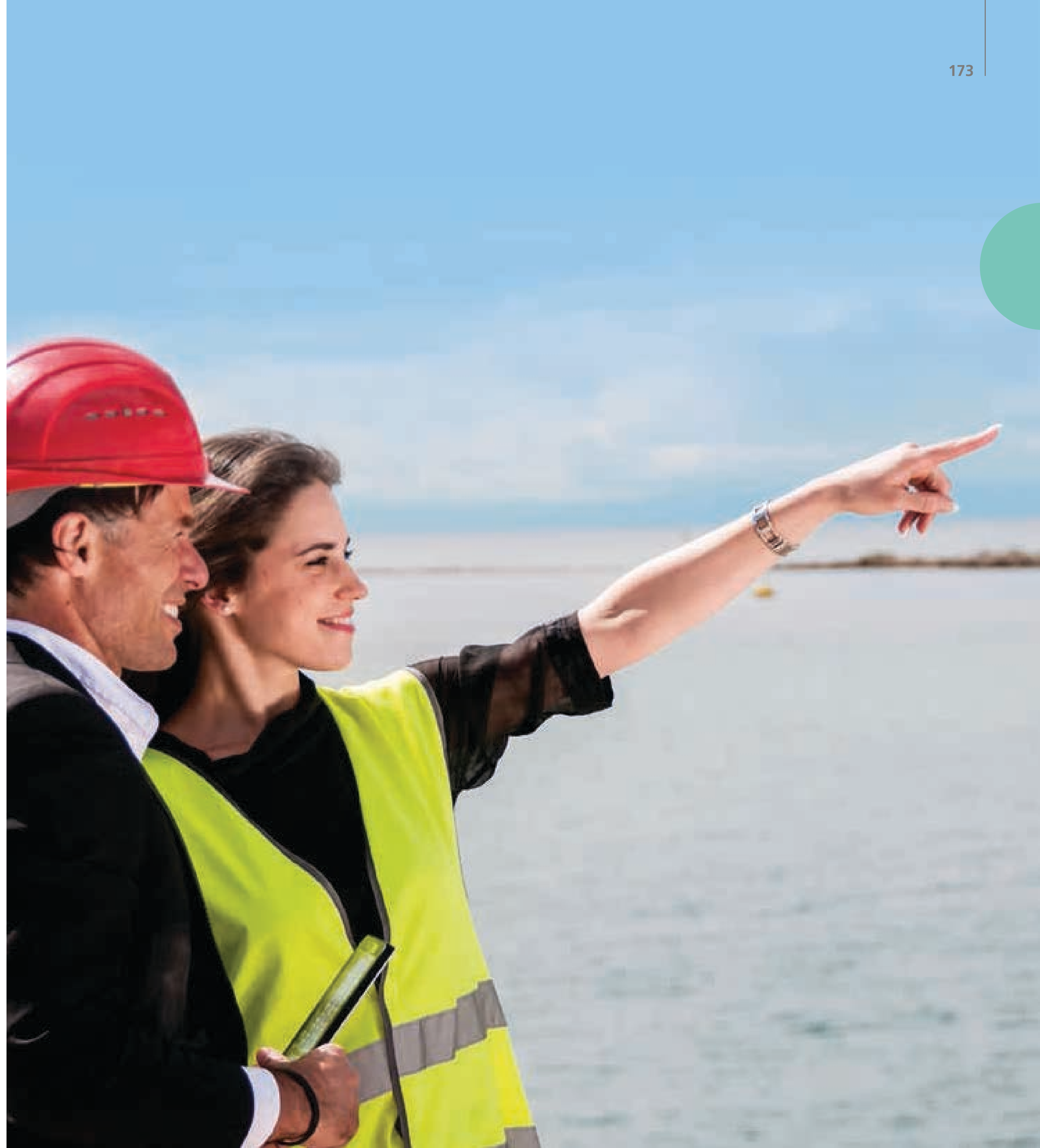
Protecting the People
It is accepted that one of the consequences of climate change and global warming is the increase in sea levels. This will affect a significant proportion of the world's population living close to the coasts. Furthermore, it is likely that coastal communities will continue to experience extreme weather events, such as cyclones, hurricanes and tsunamis. Thus, it is imperative to identify and develop technologies that protect the populace.

Protecting the Environment
Anthropogenic activity, especially over the past 100 years, has affected the oceanic environment in a detrimental manner. It is important to sustain marine life and nurture the oceans for sustainable growth. To achieve this, a deeper understanding of the geological, meteorological and ecological mechanisms that define the ocean space is needed. The full power of new technologies therefore needs to be brought to bear on this issue.

Providing for the People
The potential of the ocean space to provide food, materials, energy and medicines is, to some extent, already being realised. Given the continuing depletion of land-based mineral and energy resources, it is likely that people will increasingly look to the oceans for these. Introducing and applying appropriate technologies to harvest oceanic resources to provide for the people will therefore become essential.

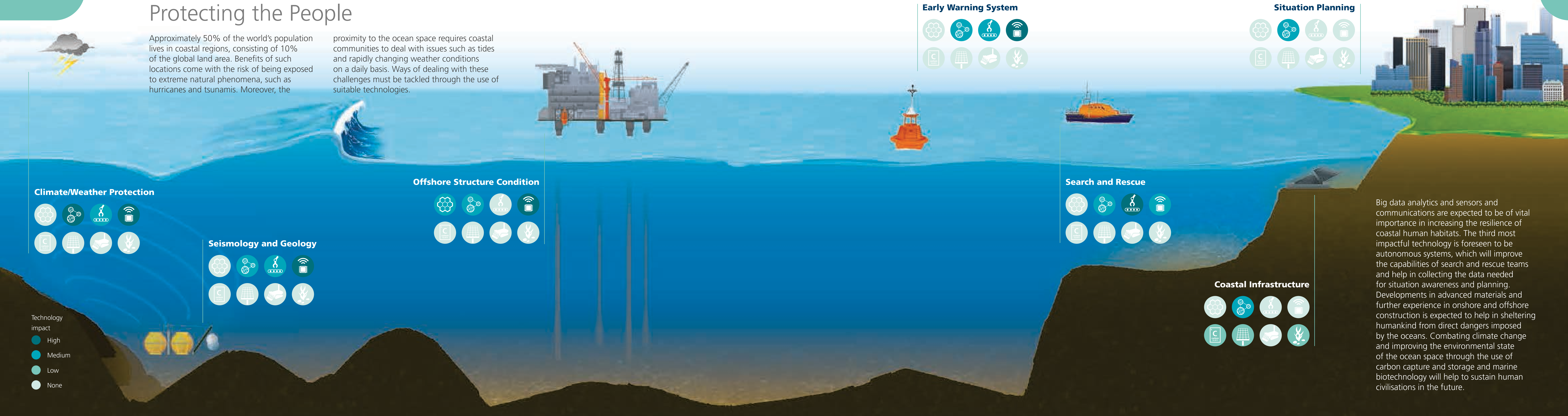
It is clear that, as a species we will have to deal with the combined effects of climate change and reduction of land-based resources. It is also evident that the ocean environment is a vital biosphere for sustaining human and other life. We therefore need to develop and deploy appropriate technologies to enable both the sustenance of the natural environment in the oceans and the wellbeing of humans.

Significant interlinkage and interdependency may be seen between the eight identified key technologies. For instance, deep ocean mining is less likely to become possible without the use of autonomous systems and advanced materials. However, it is the sensors and communications technology that appears to underpin the introduction of the remaining ones by allowing The Internet of Things, which revolutionised onshore human activities at the beginning of the 21st century, to spread widely into the ocean space sectors.



Protecting the People

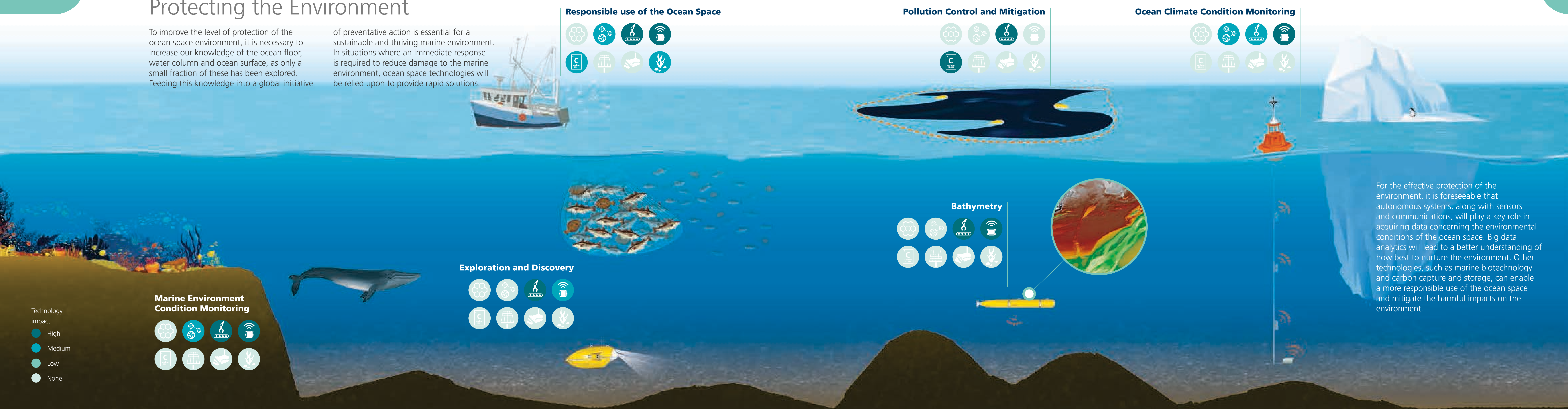
Approximately 50% of the world's population lives in coastal regions, consisting of 10% of the global land area. Benefits of such locations come with the risk of being exposed to extreme natural phenomena, such as hurricanes and tsunamis. Moreover, the proximity to the ocean space requires coastal communities to deal with issues such as tides and rapidly changing weather conditions on a daily basis. Ways of dealing with these challenges must be tackled through the use of suitable technologies.



Big data analytics and sensors and communications are expected to be of vital importance in increasing the resilience of coastal human habitats. The third most impactful technology is foreseen to be autonomous systems, which will improve the capabilities of search and rescue teams and help in collecting the data needed for situation awareness and planning. Developments in advanced materials and further experience in onshore and offshore construction is expected to help in sheltering humankind from direct dangers imposed by the oceans. Combating climate change and improving the environmental state of the ocean space through the use of carbon capture and storage and marine biotechnology will help to sustain human civilisations in the future.

Protecting the Environment

To improve the level of protection of the ocean space environment, it is necessary to increase our knowledge of the ocean floor, water column and ocean surface, as only a small fraction of these has been explored. Feeding this knowledge into a global initiative of preventative action is essential for a sustainable and thriving marine environment. In situations where an immediate response is required to reduce damage to the marine environment, ocean space technologies will be relied upon to provide rapid solutions.

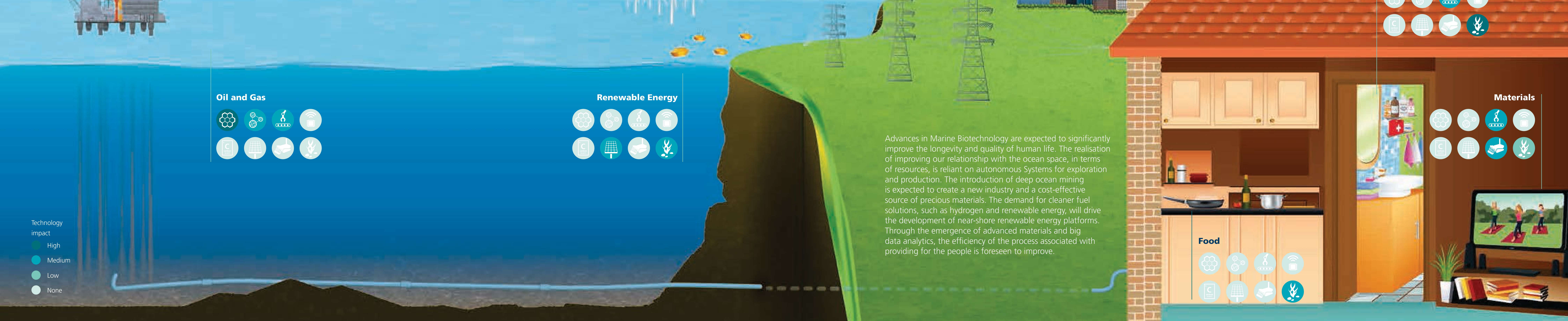


For the effective protection of the environment, it is foreseeable that autonomous systems, along with sensors and communications, will play a key role in acquiring data concerning the environmental conditions of the ocean space. Big data analytics will lead to a better understanding of how best to nurture the environment. Other technologies, such as marine biotechnology and carbon capture and storage, can enable a more responsible use of the ocean space and mitigate the harmful impacts on the environment.

Providing for the People

Resources available in the ocean space, such as fuels, renewable energy, materials, or food, are used by the entire human race. The oceans do not only provide people with the basic necessities required for life, but also offer improved wellbeing by allowing for new medicines to be developed or more cost-effective energy solutions to be found. The introduction of new and better technologies may have a significant positive impact on the quality of human lives around the world by enabling the fuller exploration and harvesting of the ocean's potential.

Advances in Marine Biotechnology are expected to significantly improve the longevity and quality of human life. The realisation of improving our relationship with the ocean space, in terms of resources, is reliant on autonomous Systems for exploration and production. The introduction of deep ocean mining is expected to create a new industry and a cost-effective source of precious materials. The demand for cleaner fuel solutions, such as hydrogen and renewable energy, will drive the development of near-shore renewable energy platforms. Through the emergence of advanced materials and big data analytics, the efficiency of the process associated with providing for the people is foreseen to improve.



Postscript

Tim Kent
Technical Director, Marine
Lloyd's Register Group Limited

The foundation of marine operations is technology: beginning with the invention of the first floating hull that carried people and cargo across the waterways at the dawn of civilisation. No one can predict the 21st century counterparts of diesel engines, welded steel and containerisation. But there is little doubt that advances in science and technology will continue to transform the marine sectors of commercial shipping, naval and ocean space operations. These will enable us to become more secure, safer, more competitive and more sustainable to meet the demands from the stakeholders and to protect the planet for future generations.

Fifteen years into this century, the world is slowly recovering from a severe financial crisis. Technologies for the next generation of ship design and operation are rising up in the policy agenda. There is an increasing need to develop sustainable technologies for ocean space exploitation for resources and food. In the naval world, ease of access and the affordability of civilian technology pose a threat to the existing capability hierarchy at national and subnational levels. Countries such as China, India and Brazil are reshaping the technological, economic and political landscape, as illustrated in our first report, GMT2030.

The world is in the midst of a global technology revolution. For the past 30 years, advances in computer and information technology, biotechnology, nanotechnology and materials technology have been occurring at an accelerating pace, with the potential to bring about radical changes in all dimensions of life. The pace of these developments shows no sign of abating over the next 15 years, and it appears that their effects will be ever more remarkable. The marine technology of 2030 will integrate developments from multiple scientific disciplines in ways that could transform the quality of design, construction and operation. We envisage that a future marine world will be a connected and digital one, bringing closer integration between people, software and hardware in a way that could transform the way we operate and interact. A new operation paradigm will need to be created to meet these challenges across the shipping, naval and ocean space sectors.

What do we hope to achieve with this publication? We hope the eight technologies identified in each sector will generate debate and discussion as to their true significance, encouraging investment to make them resilient, affordable and safely implementable. We hope there will be parallel investment in infrastructure, such as logistics support and regulatory framework development. We need to invest in capacity building, such as the education and training of people working in these sectors. We have identified risks and uncertainties and raised awareness and understanding within the marine communities of the complexities of these technologies and the profound changes they may bring about.

We are making Marine Global Technology Trends 2030 freely available to the wider public, in addition to the marine stakeholders in the shipping, naval and ocean space sectors, to encourage people from diverse backgrounds to engage in a productive discussion of these technologies, helping them to identify risks and opportunities in their respective areas at different levels from their perspectives.

GMTT Team

Glossary

2D Two-Dimensional Space.

3D Three-Dimensional Space.

4D Four-Dimensional Space.

4G The fourth generation of mobile telecommunication technology.

5G The fifth generation of mobile telecommunication technology.

Ag Silver.

AI Artificial Intelligence.

AIS Automatic Identification System is designed to provide information about the ship to other ships and to coastal authorities automatically.

Areas of operation for the GMDSS
- Sea area A1: Within range of VHF coast stations with continuous Digital Selective Calling alerting available (about 20-30 miles).
- Sea area A2: Beyond area A1, but within range of MF coastal stations with continuous Digital Selective Calling alerting available (about 100 miles)
- Sea area A3: Beyond area A1 and A2, but within coverage of geostationary maritime communication satellites. This covers areas roughly between 70 °N and 70 °S
- Sea area A4: The remaining sea areas, the most important of which is the sea around the North Pole.

ASV Autonomous Surface Vehicle.

Au Gold.

AUV Autonomous Underwater Vehicle.

BOG Boil Off Gas.

C4ISR Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance.

CAD Computer-Aided Design.

CAPEX Capital expenditure.

CCS Carbon Capture and Storage.

Co Cobalt.

CO_2 Carbon Dioxide.

COGES Combined Gas turbine Electric and Stream.

Cu Copper.

Data belt Data stream from the data lake to the data driven business.

Data driven business Business decisions can be backed up by verified data rather than solely on intuition and/or experience. The data-driven approach is gaining popularity within enterprise as the amount of available data increases in tandem with commercial and regulatory pressures. The success of the data-driven approach is reliant upon the quality of the data gathered.

Data lake A repository that holds a vast amount of raw data in its native format until it is needed. A data lake may be owned by a single organisation or by a consortium of organisations with agreeable access and user rights.

DEW Directed Energy Weapons.

DFDE Dual Fuel Diesel Electric.

DWT Deadweight tonnage is the maximum weight a ship can carry safely.

ECA Emissions Control Area.

ECDIS Electronic Chart Display and Information System is a computer-based navigation system.

EEDI Energy Efficiency Design Index.

EHF Extremely High Frequency is a radio frequency range of 30 GHz and 300 GHz.

eLoran Enhanced low-frequency and long-range navigation system.

ESD Energy Saving Devices.

Exoskeleton The external skeleton which contains rigid and resistant components that fulfil a set of functional roles.

FAME Fatty Acid Methyl Ester.

Fe Iron.

Fibre Bragg gratings These gratings are fabricated in optical fibre cores which diffract the optical signal at specific wavelengths, creating periodic modulation of the refractive index. Embedded sensors using such techniques can be developed to measure physical, chemical or biological parameters such as strain, temperature, concentration, acoustic and biosensing.

FPSO Floating Production, Storage and Offloading.

FRP Fibre Reinforced Polymeric materials.

G Giga- is a unit prefix of 10^9.

GHG Greeenhouse Gas.

GMDSS Global Maritime Distress and Safety System is an integrated communication system adopted by the IMO.

GMFT 2030 Global Marine Fuel Trends 2030.

GMT 2030 Global Marine Trends 2030.

GNSS Global Navigation Satellite System is a space-based or satellite navigation system that is designed to offer autonomous geo-spatial positioning.

GPS Global Positioning System is a space-based navigation system developed by the United States of America.

H_2 Hydrogen.

HCI Human-Computer Interaction.

HD High Definition

HF High Frequency is a radio frequency range of 3 MHz and 30 MHz.

High strength steel The minimum yield strength of a high strength steel is 420 MPa according to the Lloyd's Register Rules and Regulations – Rules for the Manufacture, Testing and Certification of Materials, July 2015.

HPC High-Proformance Computing.

HVAC Heating, Ventilating, and Air Conditioning.

IGF Code International Code of Safety for Ships using Gases or other Low flashpoint Fuels (IGF Code).

IMO International Maritime Organization.

IRNSS Indian Regional Navigation Satellite System is a space-based navigation system developed by India.

ISA International Seabed Authority.

IT Information Technology.

k A unit prefix of 10^3.

LF Low Frequency is a radio frequency range of 30 kHz and 300 kHz.

Lightship The weight of an empty vessel that is made ready for service.

LNG Liquefied Natural Gas.

LPS Large Point Sources; in CCS context this refers to significant sources of carbon dioxide with relatively small footprint.

M Mega- is a unit prefix of 10^6.

MEMS Micro Electrical Mechanical System.

MF Medium Frequency is a radio frequency range of 300 kHz and 3 MHz.

Micro- A unit prefix of 10^{-6}.

Mn Manganese.

MSS Mobile Satellite Service.

NDE Non-Destructive Examination.

NGO Non-Governmental Organization.

Ni Nickel.

NMR Nuclear Magnetic Resonance.

NOx Nitrogen oxides.

Nano- Unit prefix of 10^{-9}.

O&M Operation and Maintenance.

OECD Organisation for Economic Co-operation and Development.

OEM Original Equipment Manufacturer.

OLED Organic Light Emitting Diode.

OPEX Operating expenditure.

Oxy-fuel Combustion CCS technology of burning fuel in oxygen reach atmosphere.

pH Measurement of the acidity or alkalinity of a solution or substance.

QZSS Quasi-Zenith Satellite System is a space-based navigation system developed by Japan.

Radar Radio Detective And Ranging is an object detection system that usually deploys radio waves or microwaves.

REE Rare Earth Material.

RFID Radio-frequency Identification.

SECA Sulphur Emission Control Area.

SHF Super High Frequency is a radio frequency range of 3 GHz and 30 GHz.

SMEs Small and Medium Sized Enterprises.

Sonar Sound Navigation And Ranging is an object detection system that deploys sound pulses.

SOx Sulphur oxides.

T Tera- is a unit prefix of 10^{12}.

tDCS transcranial Direct Current Stimulation is a treatment that applies direct electric currents to stimulate the brain.

TEU Twenty-foot equivalent unit.

THF Tremendously High Frequency is a radio frequency range of 300 GHz and 3 THz.

UAV Unmanned Aerial Vehicle.

UHF Ultra High Frequency is a radio frequency range of 300 MHz and 3 GHz.

UNCLOS United Nations Convention on the Law of the Sea.

UNEP United Nations Environment Programme.

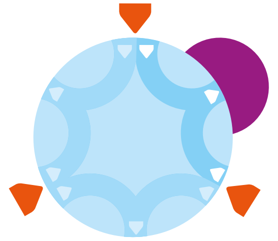
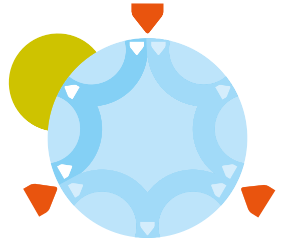
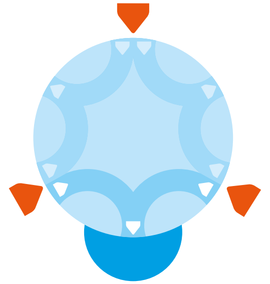
VHF Very High Frequency is a radio frequency range of 30 MHz and 300 MHz.

VLF Very Low Frequency is a radio frequency range of 3 kHz and 30 kHz.

VSAT Very Small Aperture Terminals.

Zn Zinc.

GMT2030 Scenarios

Scenario		Characteristics	Impact
Status Quo		Reactive and short-term solutions Absence of market solutions to the crisis of security and trust Rapid regulatory changes Overlapping jurisdictions and conflicting laws lead to checks and controls All recognise a reversal to inward looking and protectionism is detrimental to all parties	No single trade power dominates Heightened tensions between major powers causes other countries to hedge their security needs Short-term portfolio optimisation and vertical integration Superior risk management is essential and maximum flexibility is called for in the shipping community Naval power grows with economic power
Global Commons		Built-in security and compliance certification Regulatory harmonisation Mutual recognition Independent media Voluntary best-practice codes Close links between investors and civil society Major agreement on international trade and environmental protection	Accelerated expansion of globalisation Strong international institutions regulate and arbitrate international affairs fairly and transparently A win-win world with rising living standards and an expanding world economy Networking skills and superior reputation management are essential for the shipping community Naval power increases
Competing Nations		Dogmatic approaches Regulatory fragmentation National preference, conflicts over values and religion give insiders an advantage A brake on globalisation Rise in protectionism, encouraging local production and consumption Gate communities Patronage and national standards exacerbate fragmentation Self-interest and zero-sum games	Reduction in demand Disappearance of a level playing field Competing demands from national interests make life complicated Shipping community will suffer with the roll-back of globalisation Local presence for shipping is necessary Naval power increases

Lloyd's Register QinetiQ UNIVERSITY OF Southampton

Lloyd's Register Group Limited

Lloyd's Register Global Technology Centre
Southampton Boldrewood Innovation Campus
Burgess Road
Southampton
SO16 7QF

Tel: +44 (0)207 7099 166
E-mail: info@lr.org
www.lr.org

QinetiQ

Cody Technology Park
Ively Road, Farnborough
Hampshire
GU14 OLX

Tel: +44 (0)23 9231 2279
E-mail: maritime@QinetiQ.com
www.QinetiQ.com/maritime

University of Southampton

Southampton Boldrewood Innovation Campus
Burgess Road
Southampton
SO16 7QF

Tel: +44 (0)23 8059 2316
E-mail: smmi@southampton.ac.uk
www.southampton.ac.uk/smmi

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