technology outlook 2020
Who wouldn’t want to know which technologies will be in play towards the end of this decade? With today’s speed of innovation and introduction of new technologies, anticipating the future is no easy task.

DNV’s Research and Innovation unit has a long tradition of publishing Technology Outlook, where we try to look into the crystal ball for selected industry sectors. Last time was in 2008, and then we looked towards 2015. Already we can see that many of our predictions were right, but we also see that we have been proven wrong in a few areas. For example, the development of wind energy has been much more rapid than we anticipated.

Our objective of Technology Outlook 2020 is to share our views and to stimulate discussion about future technologies towards 2020. The views and analyses have been formed by the Research and Innovation unit and might not be shared by all parts of the DNV organisation. We don’t claim to have all the answers, but we have based our opinions on our expertise and competence in a broad range of areas.

Technology Outlook 2020 looks at future technologies in four main areas: shipping, fossil energy, renewable and nuclear energy, and power systems. A supplement covering technologies related to healthcare will be published at a later stage. We start by summarising the most important global trends affecting all these industries. A visualisation of how a sustainable coastal community of the future might look like is given at the end.

We firmly believe that technology is a vital part of the solution for many of the global and industry challenges facing us today. We also believe that the best way to be prepared for the future is to have a broad view over technologies from many industry sectors.

I hope you will use this publication to engage in a discussion about the future with us.

Enjoy the read!

Elisabeth Harstad
Managing Director, Research & Innovation
research and innovation in dnv

The objective of our strategic research is to enable long term innovation and business growth through new knowledge and services in support of the overall strategy of DNV. Such research is carried out in selected areas that are believed to be of particular significance for DNV in the future.

this is dnv

DNV is a global provider of services for managing risk. Established in 1864, DNV is an independent foundation with the purpose of safeguarding life, property and the environment. DNV comprises 300 offices in 100 countries with more than 8,000 employees.
GLOBAL MEGATRENDS 06
Population 08
Economy 10
Governance 12
Information technology 14
Energy 16
Natural resources 18
Climate change 20

FROM MEGATRENDS TO SCENARIOS 22
Scenarios for the maritime and energy sectors 24

TECHNOLOGY UPTAKE 26
MARITIME 28
The low energy ship 30
The green-fuelled ship 32
The electric ship 34
The digital ship 36
The Arctic ship 38
The virtual ship 40

OIL, GAS & COAL 42
Offshore drilling technology 44
Subsea production 46
Arctic offshore development 48
Unconventional oil and gas 50
Future refineries 52
Gas-fired power plants 54
Coal-fired power plants 56
Carbon capture and storage 58

RENEWABLES AND NUCLEAR 60
Wind energy 62
Solar heat and power 64
Biofuels for the future 66
Geothermal energy 68
Nuclear energy 70

POWER SYSTEMS 72
Integration of renewables 74
Super grids 76
Offshore transmission grids 78
Smart grids 80

SUSTAINABLE COASTAL COMMUNITIES 82
Challenges for sustainable coastal communities 84
Floating districts 86
Energy systems 88
Future ports 90
Vision 2020 92
GLOBAL MEGATRENDS
GLOBAL MEGATRENDS

The adoption of future technologies is heavily dependent on how the world will develop. Many factors influence which technologies will be implemented and in use by 2020. Some factors may exert only a brief, but strong, influence, whereas others may have a weaker, but more prolonged, effect.

We have identified and summarised seven global megatrends that are generally considered as certain. The trend descriptions are based on our interpretation of a wide variety of material from sources outside DNV. In our view, these seven megatrends have an enormous potential for impacting on the development and uptake of new technologies.

INDEX

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>8</td>
</tr>
<tr>
<td>Economy</td>
<td>10</td>
</tr>
<tr>
<td>Governance</td>
<td>12</td>
</tr>
<tr>
<td>Information technology</td>
<td>14</td>
</tr>
<tr>
<td>Energy</td>
<td>16</td>
</tr>
<tr>
<td>Natural resources</td>
<td>18</td>
</tr>
<tr>
<td>Climate change</td>
<td>20</td>
</tr>
</tbody>
</table>
most populations out of balance

THE WORLD POPULATION continues to grow fast and will pass 7.5 billion people by 2020. Whilst populations in the West, China, and Japan are greying, the Middle East is becoming younger; in most developed countries a smaller declining working-age force will have to support more elderlies, and a growing and younger population will aggregate in urban areas.

The pressures on natural resources, urbanization of exposed areas, natural disasters, and conflicts will be motivating factors for migrations – both domestic and international.

FUNDAMENTAL CHANGES

Four demographic changes will intensify and fundamentally alter the world’s population in the decades to come:

- the demographic weight will shift from developed regions towards developing regions,
- labour forces in developed countries will age and decline - potentially constraining economic growth,
- the world’s population growth will be mainly concentrated in today’s poorest, youngest, and least developed countries,
- the majority of the world’s population will live in cities.

MORE PEOPLE – MORE ELDERLY

Every year over the next 10 years, about 57 million people (i.e. approximately equal to today’s population of Italy) will be added to the world population. The current global fertility rate of 3.11 children per woman will gradually fall to 2.5 by 2020, adding 500 million people to the world’s population, and resulting in 7.5 billion. This growth will mainly occur in today’s developing countries, and by 2020 approximately 19 % of the world’s population (or 1.4 billion people) will live in China.

In contrast, the proportion of elderly people (older than 65 years) in most industrialized countries will rise, increasing in Europe, for example, from the current level of 14.7 % to about 22 % by 2020. The US, however, will be an exception, due to high net migration and higher fertility levels.

The unfunded nationwide Chinese pension system combined with the one-child policy may result in a special situation, as nearly 400 million Chinese will be over 65 years by 2020.

A greying population will put more strains on national economies through increased pensions, healthcare, social insurance, and labour shortages. By 2020, around 40 regions will show a 10 % decline in the workforce, whereas countries such as Bulgaria and Poland may even have to cope with reductions exceeding 25 %. Not all effects of a greying population are negative. For example, the wealth accumulated by the elderly (goods, savings) may be gradually released into the national economy. Also, the currently high unemployment of 10-20 % in many developed countries may automatically drop.

MIGRATION TO A BETTER LIFE - OR NOT?

The lure of prosperity, hopes for a better life, resource shortages, violence, and natural disasters are the main driving forces behind migration. In 2008, there were more than 200 million migrants, 2.5 times more than in 1965; by 2020, this number is likely to have increased to 260 million. In the long-term, climate change could add another 150-200 million refugees, as people try to escape from severe weather events, flooding, droughts, or agricultural disruptions.

A larger workforce in a developing country could provide new opportunities for economic growth, but if the people remain unemployed may also lead to rising poverty levels, social unrest, or the development of extremism. A lack of labour forces in Western Europe will act as a magnet, attracting several million workers over the next 10 years. Only if migration is maintained at its current level, will the working-age population in most OECD countries not have declined by 2020. This will challenge the strict immigration policies of many countries, e.g. EU.

On the other hand, the brain drain, which results from the migration of skilled workers from developing countries to developed ones, will assist in cementing the economic differences. Traditional migrant-sending countries are likely to become migrant-receiving countries, leading to a shift from a South-North to a South-South migration pattern.

There will be an estimated 260 million global migrants worldwide, or about 3.5% of the world’s population. Source: pstalker.com

Population in millions. Source: US Census Bureau

There will be an estimated 260 million global migrants worldwide, or about 3.5% of the world’s population. Source: pstalker.com
URBAN JUNGLE — THE BITTER-SWEET LIFE

Currently more than 50% of the world’s population live in cities and this number will further increase by 5%, or 715 million people, before 2020. In 1900, there were 11 cities with more than 1 million residents; in 1950 there were 80; in 1990 there were 276; and this had climbed to about 400 by year 2000. In 2020, there will probably be more than 600, but most of the urbanisation will occur in smaller cities, and in the world’s poorest countries. These cities may not have the resources needed to cope with the influx. Currently, more than 50% of the urban population in South Asia and 40% in Sub-Saharan Africa lack access to sanitation services, highlighting the need for adequate health care, and basic infrastructures.

Cities are already responsible for 70% of all global greenhouse gas (GHG) emissions and 70% of the world’s energy consumption. One billion people live in slums, and 66% of the world’s population live within 100 km of the ocean; the urbanisation rate is much faster in the more prosperous coastal regions. For city development to be sustainable focus will need to increase on environmental consequences (habitat destruction, poor air quality, sewage, waste), as well as on more typical urban problems (traffic congestion, housing, crime).

The congregating of people from the countryside in urban areas will continue to weaken traditional family ties and values. This, together with greater exposure to the egocentric Western way of self definition, suggest that a further growth in demand of consumer goods should be expected.

THE RELIGIOUS GLUE

Over the next 10 years, religion and new ageism are likely to play more prominent roles in how people define themselves. The reasons for this can be found in greater uncertainty, higher mobility, and growing diversity of hostile groups, enabled by the use of modern IT, especially the Internet. In 2020, some of the largest Christian communities will be found in China and Nigeria, which may transform the traditionally Western-based Christian institutions towards a more African or Asian style.

In most regions with youth bulges, the number of religious “activists” with a rather black-white worldview is likely to rise. By 2020, radical religious groups might be expected to be making a significant global impact through the creation of transnational organisations.

Every year over the next 10 years, about 57 million people (i.e. approximately the current Italian population) will be added to the world’s population.

ORGANIZED CRIME

Crime, particularly organized crime, thrives in resource-rich states that have either a weak government or that are being destabilised by significant political and economic transformations.

Weak governmental control is likely to lead to increased corruption.

ORGANIZED CRIME

Crime, particularly organized crime, thrives in resource-rich states that have either a weak government or that are being destabilised by significant political and economic transformations.

Weak governmental control is likely to lead to increased corruption.

Every year over the next 10 years, about 57 million people (i.e. approximately the current Italian population) will be added to the world’s population.

ORGANIZED CRIME

Crime, particularly organized crime, thrives in resource-rich states that have either a weak government or that are being destabilised by significant political and economic transformations.

Weak governmental control is likely to lead to increased corruption.

ORGANIZED CRIME

Crime, particularly organized crime, thrives in resource-rich states that have either a weak government or that are being destabilised by significant political and economic transformations.

Weak governmental control is likely to lead to increased corruption.

ORGANIZED CRIME

Crime, particularly organized crime, thrives in resource-rich states that have either a weak government or that are being destabilised by significant political and economic transformations.

Weak governmental control is likely to lead to increased corruption.

ORGANIZED CRIME

Crime, particularly organized crime, thrives in resource-rich states that have either a weak government or that are being destabilised by significant political and economic transformations.

Weak governmental control is likely to lead to increased corruption.

ORGANIZED CRIME

Crime, particularly organized crime, thrives in resource-rich states that have either a weak government or that are being destabilised by significant political and economic transformations.

Weak governmental control is likely to lead to increased corruption.
from $, € to ¥ and ₹

THE INDUSTRIAL REVOLUTION shifted the economic centre of the world from Asia to the West, but this is now being reversed. Favourable demographic transition periods imply that relatively more of the economic outputs will occur outside the currently developed economies.

This is likely to result in larger societal changes and generate new business opportunities, but at the same time will impose further pressures on the environment. By 2020, it is possible that the size of the global middleclass will have doubled, with Asia accounting for 50%.

AN ONGOING TRANSFORMATION

The world is in a period of massive shifts in economic power and influence, and these are likely to result in a significant future transformation in the structure of world production, global consumption, and financial power. Since the end of the Cold War, a large proportion of global production has moved to Asia, particularly China, while the share of global economic output from developed economies has simultaneously decreased from 70 % to 53 % today.

These historical shifts in global economic gravity that have occurred over the last decades have brought with them changes in the various institutions of the world economy. Demand for commodities has surged, largely due to strong growth from China. Indeed, in 2008, a milestone was reached when non-OECD energy consumption exceeded that of OECD countries for the first time, largely due to developments in Asia. Development in capital markets has also flourished. Brazil, Russia, India, and China’s (BRICs) share of global capital markets has increased ten-fold over the last ten years, and in 2009 these countries attracted more investments than America and Europe combined.

The reasons for high capital influx include the opening up of markets in Asia; they are already large in terms of volume (e.g. car sales, mobile phones sales), and they are predicted to grow strongly in the years ahead.

Patterns of global trade and international relations are also changing. During recent decades there has been a growing tendency for developing countries to cooperate directly with each other. So-called “South-South” trade, i.e. trade exclusively between developing countries, has expanded faster than world trade, driven by an increasing demand for food, energy, and semi-finished products. In this context, regional/bilateral trade agreements have grown rapidly.

Although many of the trade agreements are registered through the World Trade Organisation, there is a tendency for direct bilateral-engagements, beyond the domain of international organisations, particularly with respect to the relationships between China and parts of Africa. This may suggest a general trend for a higher degree of political autonomy being exerted, as particular developing countries increase their relative global economic power. Thus, factors concerning international relations may grow in importance towards 2020, as new economic powers become more visible on the world stage. These factors include shifts in military power, increased prominence of politically-controlled corporations, economic protectionism, and the push for transparency and accountability in international resource trade agreements and infrastructure developments.

SHIFT FROM WEST TO EAST AND THE SOUTH

Fundamental changes are likely to continue towards 2020, as fast-growing economies are in a favourable demographic period that fosters continuous economic growth. Largely due to aging populations and risks such as large existing debt levels, most OECD countries are likely to experience lower levels of economic growth in the future, and those shifts in economic gravity that are already evident are likely only to intensify. According to estimates by Goldman Sachs, the combined economic outputs of the BRIC countries may constitute 50 % of G7 by 2020, conservatively representing a doubling of economic outputs from China and India. Countries such as Vietnam, Turkey, South Korea, Mexico, Indonesia, and South Africa may also become more prominent on the global economic stage.

To varying extents, high economic growth rates are likely to continue to boost infrastructure development as the populations in these economies expand, urbanise, and enjoy increases in their disposable income. Towards 2020, the investments of the fastest growing economies in infrastructure may be worth US$ 4.35 trillion, of which 60 % may be spent in China. A further growth in foreign capital inflows targeted infrastructure and capital markets may therefore occur, but much of the increase in activity levels may benefit local/regional companies. Indeed, according to some estimates, by 2020, Asia may very well produce half of the biggest Western multinational sales and profits, about a doubling from today’s levels. It is therefore not only likely that Asia and other fast developing economies will constitute the future battleground for business, but it is possible that Asian multinationals will become increasingly significant players in the developed world.

NEW ECONOMIC SUPERPOWERS

SHIFT FROM WEST TO EAST AND THE SOUTH


China India

UK Germany Japan France Italy

2009 2020 2030

Middle East and North Africa Sub-Saharan Africa Asia Pacific Central and South America Europe North America


Year when China and India’s GDP’s will exceed today’s rich countries. Source: Goldman Sachs
Towards 2020, the investment of the fastest growing economies in infrastructure may be worth US$ 4.35 trillion, of which 60% may be spent in China.
old structures struggling with new challenges

**CURRENT GOVERNANCE STRUCTURES** were mainly created in a post World War II setting, and designed for concerns of an earlier and different time. Phenomena such as the EU, BRIC countries, Wikileaks and Facebook did not exist then, but are now shaping agendas worldwide. Handling the “goods and bads” of globalisation is a major challenge, and governance structures for collective action have yet to be developed. The lack of effective and inclusive governance on global issues, such as financial stability, trade, climate change, water, and security, will be a source of increasing risks towards 2020.

**CHALLENGES AND GOVERNANCE GAPS**

Globalisation, population, and economic growth have created a world with high interdependency and complexity, leading to global challenges and systemic risks. Technological progress has integrated markets and created economic structures with global reach. The meltdown of the global economy in 2008 revealed a series of vulnerabilities in our governmental systems.

An integrated global economy has also generated challenging systemic risks, such as pandemics, security crises, and threats from global terrorism. Additional risks are overpopulation, poverty, social-environmental and economic consequences of resource shortage, pollution, and climate change; governance structures are struggling to address all of these challenges.

Global integration and free market ideology continue to reduce national governments’ role in direct management of the economy. Regulators are mainly national, and global institutions, where they exist, have failed to respond. Political agendas and interest constellations of today are not those of the post-world war and cold war era. Thus outdated governance structures not adapted to the new world order are ill-equipped to address global challenges. The lack of agreement on collective actions magnifies the risks yet further.

**MULTIPLE ACTORS AND NEW ARENAS**

Many governance frameworks, global, regional, and functional, will continue to exist in parallel. Global governance will continue to be a mix of governmental and non-governmental activities that shape political and economic life.

In the current global deregulated economy, business is at the heart of decision-making, and political involvement from business will continue in fora such as the World Economic Forum in Davos and the World Business Council for Sustainable Development.

Meanwhile, civil society will attempt to act as a force that counterbalances corporate power. Civil society organisations, promoting values and purposes, will push agendas and have an important role in research and information exchange. New forms of global media, such as Whyweprotest, Changapants, Facebook, Wikileaks, and various blogs, will continue to put pressure on governments to adopt sound policies.

Social media may advance democracy and participation by promoting accountability in the political arena. On the flip side, social media democracy is shaped by ad hoc mobilisation and rapid shifts in attention. It is likely to promote a short-term and reactive mode of governance, at the expense of long-term strategies and political commitment. Thus, in combination with short-term electoral cycles, politicians may be pushed into a ‘symptom cure’ mode of action, rather than being forced to address underlying root causes.

National focus: By the middle of 2010, Global Trade Alert had identified 300 new protectionist measures among G20-members, pointing to crisis-era protectionism.

**NEW GOVERNANCE STRUCTURE?**

Political agendas are not the same as the post-world war and cold war agenda of aligned and non-aligned nations. The governance structure from that era cannot manage the new world order and is ill-equipped to face current global challenges.

**FACEBOOK POPULATION COMPARED TO COUNTRIES**

![Facebook Population Compared to Countries](source: clickymedia.co.uk / Wikipedia (2011))
TOWARDS A FUTURE WITH HIGHER RISKS

Technological progress and the flow of capital will continue to integrate markets, creating interdependent global economic structures. How will the global world be governed by 2020 and what are the consequences of failure?

Governance innovations will have to manage interrelated problems. International health regulation (WHO) on health security is one area where global collaboration has been achieved and created win-win situations. For initiatives concerned with energy and climate change, however, consensus will be less viable, as the economic impacts of regulation are tied to existing industry structures, economic interests, and resource use. A major challenge will be to develop frameworks for handling burden-sharing and for distribution of costs and benefits.

Without global agreements, national and regional governments will remain centralised towards 2020. There is no automatic transition to global governance, and any fragile commitment to global cooperation is continuously threatened by protectionism and nationalist sentiments. A key concern for regulation and governance will be obtaining sufficient anchoring in public support and legitimacy at the local and individual level. Legitimacy has to be built into the system.

The world is changing faster than our global governance structures can adjust. The lack of effective and inclusive governance on global issues, such as economic crises, climate change, water, and security, will be a source of increasing risk towards 2020.

GOVERNANCE DIRECTIONS TOWARDS 2020

International institutions will have to be reformed, reflecting power changes. Countries with the power to make a difference will be less likely to be Western, will have fewer common interests, and will be more ideologically and culturally diverse. The contours of three possible developments are emerging.

G20 Power: G20 could expand its role in monitoring, regulating, and intervening in industrial and economic activities that pose risks to economic stability, and also address global volatility from effects of poverty, environmental security issues, and climate change. This would require the creation of new institutions, possibly inspired by the EU, with a Commission to initiate common policy and with executive capacity. The G20 arena would gather economic heavyweights and delegate decision-making to smaller groups towards 2020. Success would depend on willingness to give up national sovereignty to a supranational authority. The current UN logic of ‘one country, one vote’ would be abandoned, probably resulting in tension among countries without access. However, this may encourage participation in regional organisations in order to obtain representation in the G20 arena.

Economic Nationalism: With uncertain economic recovery, public interest is likely to concentrate on national conditions, pressurising politicians to ‘do something at home’. Political priorities would be focused on domestic innovation and renewal of industry structures to create employment. By the middle of 2010, Global Trade Alert had already identified 300 new protectionist measures among G20 members, pointing to “crisis-era protectionism”. Trade barriers against countries that have not implemented measures to reduce greenhouse gas emissions, less stringent state-aid rules to fund investments, R&D, ‘buy national’ provisions, and stimulus packages - all indicate the rise of economic nationalism. With these developments, public and political attention on global cooperation and on slowly evolving global crises is likely to dwindle.

Regional Cooperation: Regional cooperative structures could become central for handling security issues and resolving territorial and bilateral disputes. As competition for energy, water, food, and mineral resources continues to grow, security of supply will become a primary concern and create territorial hotspots. Regional cooperative structures would govern access to critical resources and territory. Emerging regional cooperations would reflect the shift in power balances, trade patterns, resource locations, and geographical hotspots.

LARGE CASCADING FAILURES

Systemic risks refer to breakdowns in an entire system, and are evidenced by co-movements amongst most or all of the parts. Concepts that describe systemic risks are: macro-shocks that are triggered when relatively modest tipping points hit their threshold and produce large, cascading failures on most or all of the system. Source: Goldin, Ian, et al 2010.

- Droughts resulting in food scarcity and rationing of supply in the Western world
- A climate induced major disaster in China, Europe, or USA
- The financial drain from the “war on terrorism” forces global commitment to collective action
- A major accident at a nuclear power plant
- A technology breakthrough, resulting in low cost renewable energy
- Breakdown of the internet over prolonged periods

UNCERTAINTIES AND DISRUPTORS

LARGE CASCADING FAILURES

Systemic risks refer to breakdowns in an entire system, and are evidenced by co-movements amongst most or all of the parts. Concepts that describe systemic risks are: macro-shocks that are triggered when relatively modest tipping points hit their threshold and produce large, cascading failures on most or all of the system. Source: Goldin, Ian, et al 2010.
moore’s law still valid in 2020

INFORMATION TECHNOLOGY (IT), has had an enormous impact on personal life, business, and society at large. Easy production and sharing of information results in an exponential growth in data, and thus to challenges related to retrieval and security.

The proliferation of cheaper, smaller, more powerful computers, plus increased wireless connectivity, will not only result in greater automation and ubiquitous computing, but also to safety and (cyber)security issues associated with integrated software-intensive systems.

INFORMATION EXPLOSION

Information quantity is growing exponentially, and almost all of it is in digital form. In 2006, roughly 161 billion GB of new data were stored, and this will have increased by six-fold by 2010. The major drivers are cost reduction and replacement of analogue/paper-based practices with digital processes. Miniaturization and embedding software in “Things”, together with social media arenas, will further accelerate this trend.

IT is being increasingly applied to new areas, both private (recreational, gaming, personal relationships) and industrial (healthcare, tourism, simulation), and by 2020 it is expected that 200 times more data will be generated annually than in 2008.

With an expected price of less than US$ 100 for sequencing your own genome, several GB are likely to be added to your medical record. Advances in storage technology (10-fold increase in storage capacity roughly every 4 years) will lead to storage costs of 0.5$/TB by 2020.

The need for automated data management will become increasingly apparent, as will advanced search capabilities and knowledge discovery.

The limited support-time for storage hardware, of generally 3 years, is likely to emerge as a significant frustration factor.

POWERING UP

Today’s mobile phones have the processing power of desktop computers 10 years ago. In 2020, mobile phones will have the power of today’s PCs. Cheap, small distributed sensors will have the abilities of today’s mobile phones.

Moore’s Law from the 1960s, with the doubling of numbers of transistors every two years, will hold true until 2020. Further shrinkage is prohibited by quantum effects, but a continuation of the exponential growth in processor performance will be achieved beyond 2020 by stacking, multicore and multithreaded central processing units (CPU), grid and cloud computing, virtualisation, and use of memristors in integrated circuits.

The raw processing power will impact data collection, and will allow intelligent monitoring and control. Local, real-time data processing will highlight the need for new data formats and process models. Power computing will give rise to new requirements for programs and programming languages. The first quantum computers will probably be commercially available by 2020.

CONNECT(H)ING

“Connectivity” encompasses Internet access, mobile telephony, and all kinds of gadgets with wireless connectivity. In 2000, the total Internet traffic was just over 1 exabyte, and in 2010 will be about 256 exabytes, corresponding to an annual growth rate of 70% over ten years. Although this rate of growth will reduce somewhat, it will reach more than 1 zettabyte well before 2020.

In 2008, China surpassed the US in number of Internet subscribers. As only 30% of China’s population currently have Internet access (in contrast with 74% of the population of USA), a further increase in Chinese Internet users is expected. This will result in Chinese becoming the dominant Internet language before 2014.

An increasing proportion of information (news, books, real-time data, TV, entertainment) will be accessed via various handheld devices, and these will form ad hoc wireless networks with other autonomous gadgets in the vicinity. Thus, wherever a user goes, they will leave behind them a trail of digital traces.

In developing countries, the focus will be on telephony and messaging rather than Internet access, leapfrogging beyond industrialized countries in the use of mobile phones by simply dropping wired telephone infrastructures. Urban 4G mobile phone telephony networks will be increasingly deployed, supporting between 100 Mbit/s and 1 Gbit/s for high mobility.

STORAGE

storage capacity will cost 1000 times less in 2020 than in 2011

1 giga byte (GB) = 1024 MB = ½ movie on a DVD
1 tera byte (TB) = 1024 GB = 50,000 trees made into printed paper
1 peta byte (PB) = 1024 TB = 50% of all U.S. Academic research libraries
1 exa byte (EB) = 1024 PB = 20% of all printed material
1 zetta byte (ZB) = 1024 EB = volume of digital information created & duplicated in 2010
1 yotta byte (YB) = 1024 ZB = 1.3 Yotta spits required to fill all the oceans

536.6 mill. English 27%
444.9 mill. Chinese 23%
153.3 mill. Spanish 8%
99.1 mill. Japanese 5%
75.2 mill. German 4%
657.4 mill. Rest 38%


CHINESE CATCHING UP WITH ENGLISH

In 2008, China surpassed the US in number of Internet subscribers. As only 30% of China’s population currently have Internet access (in contrast with 74% of the population of USA), a further increase in Chinese Internet users is expected. This will result in Chinese becoming the dominant Internet language before 2014.

An increasing proportion of information (news, books, real-time data, TV, entertainment) will be accessed via various handheld devices, and these will form ad hoc wireless networks with other autonomous gadgets in the vicinity. Thus, wherever a user goes, they will leave behind them a trail of digital traces.

In developing countries, the focus will be on telephony and messaging rather than Internet access, leapfrogging beyond industrialized countries in the use of mobile phones by simply dropping wired telephone infrastructures. Urban 4G mobile phone telephony networks will be increasingly deployed, supporting between 100 Mbit/s and 1 Gbit/s for high mobility.

536.6 mill. English 27%
444.9 mill. Chinese 23%
153.3 mill. Spanish 8%
99.1 mill. Japanese 5%
75.2 mill. German 4%
657.4 mill. Rest 38%
SOFTWARE EVERYWHERE
High product flexibility, adaptivity, and robustness, at reduced cost and time-to-market, result in an ever increasing number of products containing embedded software. Mechanical control is replaced by digital control systems, and these are found everywhere, e.g. in washing machines, cars, telephones, even fitness accessories. In 2000, a car may have contained software with one million code lines, by 2010 this number increased a 100-fold, and by 2020 an equivalent car will probably contain 10 billion lines. Software engineering will face higher demands regarding effectiveness and cost-efficiency. Goal-based software synthesis and model-driven frameworks will increasingly replace prescriptive models, and multicore processors will try to utilize parallel processor capabilities.

The need for scalable product version management, release control, verification, and validation will rise enormously. More autonomous, decentralized software applications (i.e. inhabitant software), combined with high processor power, will make central control increasingly difficult. Ensuring security, identity, and resource management will be of growing concern as users will put more trust in them. Electronic gadgets containing inhabitant software will become a part of, and utilize, cloud computing and grid networking. Judgement will be more momentary, resulting in higher demands for product quality assessment methods.

THE DARK SIDE OF CYBERSPACE
New technology, in combination with a double digit growth rate in inexperienced users, will attract criminals. Cyber threats range from fraud, ID theft, and credit card misuse, to money laundering, industrial espionage, and terrorism. Cybercrime attacks rose by 800 % between 2002 and 2008. Most cybercrimes are still economically motivated, but an increasing proportion target infrastructures such as power production and distribution, even hospitals.

The number of potential security breaches increases disproportionally with greater system complexity. New social media, such as Facebook or Twitter, offer new ways of exploitation. With increasing reliance on software, greater decentralization, and higher connectivity, our modern societies are becoming extremely vulnerable. Small software faults or security flaws might have the potential to propagate automatically towards huge disturbances or exploitable weak points. Remote monitoring and control, or integration of industrial process software with enterprise software will generally result in more complexity, more instability, and more vulnerability. Integrated operations, in which, for example, the control of multiple oil production platforms is operated from onshore site(s), will thus have a higher security risk.

Moore’s Law from the 1960s, with the doubling of numbers of transistors every two years, will hold true until 2020

Barriers for security attack on corporate information systems...

- Paralysation of Internet due to national or criminal attack
- Major incident caused by software fault
- Documentation of health hazards from use of wireless technology
- IT usage for serving a greying society
- Degree of spread of IT into new areas
energy - a decade of transition

PROVIDING ENOUGH ENERGY in an environmentally friendly and sustainable manner at affordable prices is one of mankind’s biggest challenges, made more complex by considerations of supply security. Global energy consumption will increase by 19% towards 2020. While the global energy mix will continue to be dominated by oil, gas and coal, the next decade will mark a transition; the first step towards a low-carbon energy future.

THE ENERGY MIX

The global energy mix will be dominated by oil (31%), coal (28%) and gas (20%). Towards 2020, global energy consumption will increase by 19%, and over 70% of the increase will be in non-OECD countries, with China in the lead. Coal will continue to dominate global energy supplies, driven by electricity generation in China. By 2020, 39% of the world’s electricity production will come from coal.

Natural gas has the potential to be a bridge towards a low-carbon energy future. Liquefied natural gas (LNG) demand is expected to grow from today’s 200 million tons per annum (mtpa) today to 350 mtpa by 2020. The main uncertainty lies in the competition from gas. It is unlikely that coal-fired power plants will be replaced by gas-fired plants in the coming decade. Hence the actual impact of natural gas as a bridge towards a low-carbon economy is probably limited in the short-term future. Under a stricter CO2 regime, in which gas would compete with new coal combined with carbon capture and storage (CCS), the bridging potential may be clearer.

Unconventional gas will have a significant impact on the global gas market. If the US stopped using coal and switched to shale gas, the reserves would last for at least 50 years. Although this is unlikely to happen in the next decade, this figure serves as a useful illustration of the vast resources available. In 2020, production of shale gas in the US may have reached 28.3 billion cubic meters.

The oil sand reserves in Canada represent one of the biggest oil reserve in the world, second only to the reserves in Saudi Arabia. Current daily production from Canada is 1.2 million barrels, whilst Saudi oil production is 10 million barrels. By 2020, oil production from oil sands will probably grow from 1.4% to 3.5% of global production.

Wind energy will remain the backbone within the renewable sector. Growth up to 2010 exceeded expectations by far, and by 2020 it is likely that 8% of the global electricity production will be based on wind energy. The UK plans to install 10,000 wind turbines in the coming decade, corresponding to an investment of 100 – 150 billion Euros. By 2020, wind power investments in USA and China will reach $150 billion and $300 billion, respectively.

Biofuels and biomass-based energy generation are strongly supported by national and regional governments. Additionally, many of the leading oil and gas majors are investing heavily in research on 2nd generation and advanced biofuels that do not compete with food production. However, the biofuel part of the total energy mix will vary significantly between regions. Considerable investment in infrastructure is necessary for enabling the large quantities of biofuels to be delivered to the consumers in many parts of the world.

Nuclear power today provides 5.5% of global energy production. Deployment of generation III nuclear reactors will continue to represent an abatement potential of 20 Giga tons of CO2 in 2020.

Towards 2020: Energy demand will grow by 19% (in New Policies Scenario).

Source: OECD/IEA
THE COST of exploiting gas resources.
Source: IEA

PULLING IN THE SAME DIRECTION
Renewables provide more energy from domestic resources, and hence reduce the need for imported energy. Part of the reason for both the EU Renewables Directive and the U.S. Energy Independence and Security Act is to reduce dependence on imported energy through the development of domestic renewable sources.

Another reason is to build strong local suppliers that can compete in the global arena. Similar initiatives can be seen in China, India, and Singapore. However, current renewable energy sources usually deliver energy at a higher price than traditional carbon-based sources. Thus, there is the risk of being tempted to protect domestic industries by offering traditional energy at a more competitive price, rather than switching to renewable sources.

The winners in this scenario will be those who can balance the transition to renewables, while simultaneously maintaining a strong GDP growth. Several countries have shown that this is possible.

LEADING COMPANIES ARE SHOWING THE WAY
In their report “Vision 2050”, The World Business Council for Sustainable Development describes various ways in which the world can cut its CO₂ emissions by 50% before 2050. The report has been endorsed by the CEOs of 29 leading companies. However, the report presents very few solutions for the coming decade, considering instead the 2050 perspective.

A survey among leading Nordic companies has shown that the majority of the companies have energy / environment sustainability as part of their business agenda and strategy. Best-in-class companies create significant value by adapting the way in which they conduct business, and 70% of the companies have achieved cost reduction through focusing on carbon pricing, promotion of CCS, and financial and employment incentives for nuclear and renewable energies.

UNCERTAINTIES AND DISRUPTORS

• Increase in frequency and intensity of extreme weather events and subsequent damage to property and lives
• Changes in seasonal rains that seriously disturb agriculture that depends on being directly rain-fed (no irrigation is available)
• Ocean acidification as a result of increasing atmospheric CO₂ concentrations
• Cool winters over several years in NE USA and Europe due to changing winds and ocean currents connected to the Arctic
• Temporary cooling due to volcanic eruptions (e.g. Pinatubo 1991) provide false sense of security from longer-term climate change
natural resources under increasing stress

THE OVER-EXPLOITATION of resources is one of the most important challenges facing us. Water will come under stress and alternative technologies may be hampered by scarcity of rare earth elements.

OVEREXPLOITATION OF THE PLANET
If humanity’s demands on the planet continue at the same rate as today, by the 2020s the equivalent of two planets will be needed in order to maintain our lifestyles. Key building blocks for civilisation, arable land and water, will come under increasing pressure as the global population and standards of living continue to increase towards 2020. With emerging countries adopting the same consumption patterns as their industrialised neighbours, population growth is likely to exacerbate resource disparity further and impose additional pressures on already distressed ecosystems.

UNEVEN GLOBAL WATER CHALLENGES
The water challenge is a question of supply, demand, and uneven distribution. The current rate of construction of new water infrastructure will result in a significant supply deficit. Northern China, southern and central India, southern Australia, the South West United States and the Middle East will be the regions that are most affected by water shortages.

Towards 2020, new, more cost-effective and energy-efficient desalination plants will have to be developed, as well as more efficient distribution networks. Currently, between 25 % to 40 % of distributed water is lost due to leakages, requiring clearly large-scale investment in new infrastructure towards 2020. Regardless of improvements on the supply side, more efforts are needed to reduce demand. Globally, the greatest water use today is for agriculture (70 %), while industrial activities use 17 %, and domestic requirements and municipalities use 13 %. The demands of the two last categories quadrupled in the second half of the 20th century. Financially, it is 3-4 times more effective to create better demand solutions then to focus on the supply side.

Towards 2020, the importance of water for power generation will also come into focus. In 2007-2008, power plants in USA were within days of being forced to shut down due to a lack of water for cooling. The frequency of this type of event is expected to increase towards 2020. Moreover, most of the alternative energy and climate change technologies require considerable amount of water.

FOOD FOR THOUGHT
The proportion of people worldwide that are undernourished has decreased from 24 % in 1970 to 14 % in 2010. However, more than a billion people still do not have enough to eat.

The UN Food and Agricultural Organization (FAO) reports that current world food production should be able to sustain twice the world's population, but one of the major challenges is efficient food distribution.

In areas where food is abundant, enormous quantities of food are discarded at all steps of the food supply chain and also from households, and wasted food also means wasted water. In the US alone, as much as 30 % of food is thrown away. This corresponds to about 40 trillion litres of direct water usage in agriculture and processing operations, corresponding to the household needs of 500 million people.

The economic crisis pushed millions of people into starvation; while the global demand for food, feed and fibre is expected to grow rapidly. Annual cereal and meat production will need to grow by 20 and 5 million tons at a time when production is disrupted by increasingly frequent and severe extreme weather events.

Industrialized food production is completely dependent on the use of manufactured fertilizers. Biofuel production has increased the pressure on fertilizers, in particular the macronutrients nitrogen, phosphorus, and potassium. Nitrogen is readily available, but the production of ammonia for fertilizer is a large consumer of fossil fuels, using 2% of the worlds energy production. Mining of phosphorous and potassium rapidly consumes these minerals; current known resources of phosphorous are likely to...
CHANGING GLOBAL FOREST COVER:
Deforestation, estimated at above 13 million hectares a year, or an area roughly equivalent to the size of Greece.
Source: UNEP/GRID-Arendal

Two planets will be needed in order to support humanity’s lifestyles in 2020.

RARE MATERIALS RARER
An integral part of many alternative-energy solutions is the use of permanent magnets in electric generators and motors. The production of these requires relatively large quantities of exotic and semi-exotic materials often referred to as Rare Earth Elements (REE). Neodymium, dysprosium, and samarium are used in permanent magnet motors, yttrium is used in LEDs, lanthanum is used as the anode in nickel metal–hydride (NiMH) batteries, cerium used in catalytic converters, and other REE are used as alloying elements, semiconductor dopants, and in welding applications.

The global annual production of REE is concentrated in China, whose mines account for 97% of global supplies (see table), at an all-time historical high. Until new mines are opened to satisfy the exponentially growing demand the production of hybrid cars and electric vehicles as well as new generation wind turbines may be constrained by limited production of permanent magnets.

The photovoltaic industry is changing rapidly as solar cells are no longer just exclusively sawed wafers of pure silicon. Although thin film technologies are cheaper, they rely on tellurium, cadmium, selenium, and indium, elements that could become a limiting factor. None of the rare materials will be depleted by 2020, but the realization that access to these resources will not last forever may generate an innovation pressure.

URBAN MINING
The waste stream represents a risk to the environment, public health and safety. However, the waste stream can also be considered as a resource stream. The largest challenge with the waste stream is separating the vast range components, compounds and elements that are otherwise conmingled. Landfills contain chemical, biological, biodegradable, non-biodegradable, electronic, wastes in liquid or solid form, some of which are hazardous or toxic. For most of these materials, present recycling rates are low, but high demand combined with limited resources is likely to encourage recycling.

Theoretically, many streams, such as aluminium, steel, glass and some plastics, could be recycled indefinitely. Recycling these materials could result in significant energy savings; as much as 75% less GHG emissions can be realized for recycled steel.

Managing materials’ wastes is directly linked to the recycling stream, but waste management is cumbersome. Most municipal recycling programmes rely on selective sorting by consumers and industries, which requires education, legislation, and suitable infrastructure. Currently 33% of municipal waste in USA is recycled (up from 10% in 1980), and many countries in Europe recycle 50% of their waste but globally, only 10% of aluminium foil is recycled. Towards 2020, goods will be increasingly designed to be reused and recycled in an automated way, and “urban mining” will become a growing focus area.

CONSUMPTION
Uncertainties and Disruptors

- Trade wars on rare materials
- Severe water shortages in developed countries pushing the agenda towards more sustainable solutions
- More cost and energy efficient desalination technologies
- Breakthrough or fatigue with respect to recycling and energy efficiency
- The discovery of harmful effects for certain substances – like it happened for asbestos – could lead to their ban and impact producing regions
- Hybrid technologies will eventually lead to a shift toward new energy systems requiring different resources
CLIMATE CHANGE INDICATORS WILL BE CLEARER THAN EVER

As individuals, we experience local weather and seasons, but we cannot directly sense global climate and how it changes. This can only be understood through monitoring systemic parameters across the entire globe over a long period. These parameters include air temperature throughout all levels of the atmosphere, ice thickness, extent and mass over continental scales, water temperatures across oceans at depths of hundreds of meters, changes in forests and groundcover that can be monitored by satellite imaging, gas, aerosol, and particle composition for the entire atmosphere, and more. Data accrued from these measurements over the next decade will show that most of the main indicators of climate change are following a more worrying trend than the worst case IPCC forecast published in 2007. The primary examples (already confirmed) are loss of polar sea ice cover and net melting of the Greenland and Antarctic land ice. These trends will continue to accelerate. Satellite data will show new, globally-averaged high temperature records. New local high temperature records will be registered at many places across the globe, outnumbering by a clear margin new local record low temperatures.

One of the most disturbing observations will be that the rise in atmospheric CO₂ concentration will probably exceed the 2010 rate of increase of 3 ppm/year, after a decade of increasing by about 2 ppm/year. Positive feedback processes will be confirmed to be operating, as indicated by a clear increase in atmospheric methane concentration, in addition to increases in CO₂. By 2020, the extent of summer ice over the Arctic sea may be less than 10 % of that which has been considered as normal for the last 800 thousand years, further enhancing warming of Arctic surface waters. Dramatic climate change will appear to be unavoidable in the 30-100 year time-frame and the only remaining uncertainty will be how fast and how negative the global consequences will be. A climate change “tipping point”, after which warming continues despite complete elimination of anthropogenic GHG emissions, may be confirmed to be unavoidable.

The mechanisms and processes responsible for long-term climate change are relatively well understood, but current climate models do not include all the relevant 1st and 2nd order effects and therefore are not yet fully predictive. However, as simulation methodology improves and computing power increases, climate models will become much more reliable and will be able to provide relevant guidance for long-term planning. Such models may even provide new insights into how responses to climate change can be managed in more effective ways than are currently being considered. Before this, real-world risk management decisions will need to be made in order to start the long process of mitigating and adapting to inevitable changes.

HOW CLIMATE CHANGE WILL CHANGE THE PLANET

The current, globally-averaged sea-level rise is about 4 mm/year, and, if extrapolated linearly, will result in manageable changes in sea-level even as far ahead as 2100. However, the sea-level rise will accelerate, and evidence of faster melt of Arctic and Antarctic land ice will grow. Hence, the 2010 worst-case sea-level rise scenario, of 1.8 meters by 2100, may become more probable.

The latest climate modelling results show that the frequency of extreme weather events will probably rise over the next 10 years, and a noticeable increase in damage, injuries, and losses from these should be expected. The global insurance industry is already adapting to this scenario.

Warming ocean waters may transform the seafood industry by forcing the permanent migration of those wild fish stocks that are able to do so, to oceans with more favourable conditions.

Boreal forests will face destruction from invasions of pests that were previously held in check by cold winters, and this will be compounded with unusual summer heat and periods of drought that are unprecedented for the last several millennia.

Two degrees...  
...too optimistic
THE ARCTIC SEA ICE melts considerably faster than predicted. The average summer ice volume in 2009 was 55% less compared to the 1979-2000 average. First-year ice is now the dominant ice type which is less resistant to waves resulting in a further increasing decay. The Arctic may indeed be free of summer ice already by 2020. 
*Source: DNV, Natl. Snow and Data Center*

CLIMATE CHANGE MITIGATION

In the absence of strong international agreements, unilateral, regional, and bilateral commitments to emission reduction (e.g. EU) will become more important in the period up to 2014. It is also possible that the lack of political action may be balanced by strong shifts in consumer and corporate attitudes, resulting in a privatisation of climate change mitigation through voluntary shifts in consumption.

In all cases, peaking of society’s GHG emissions (either before or after 2020) will require fundamental changes in the way humans produce and use energy and organise their activities, especially in the electric utility, transport, and building sectors. By 2020, it will become clear which technological solutions and strategies are most cost-effective, and which technologies can be scaled-up. In parallel, a range of low-hanging fruit will be picked to reduce emissions, primarily energy efficiency improvements in the transport and building sectors.

For each year that peaking of global emissions is delayed increases the acceleration of climate change due to positive feedback, and thereby ever more stringent measures will be required to reverse the climate change trends. By 2020, the level of anticipated damage in the next 25-50 years due to unavoidable climate change may become high enough to motivate in-depth evaluation of a range of geo-engineering concepts and solutions.

Technological innovations will steadily reduce the cost of several key climate change mitigation strategies. Publicly supported research will be essential for achieving the required innovations, but it will also be necessary to adjust market signals through pricing of GHG emissions.

THE CASE FOR ADAPTATION PLANNING

For the world to have a fair chance of keeping the average temperature increase below 2 ºC over the next 100 years, global GHG emissions need to peak before 2020. Current strategies for permanently reducing GHG emissions are progressing too slowly.

The EU-funded study PLANETS concluded that the best likely CO₂ concentration obtainable is 530 ppm, with an expected temperature increase of 2.5 ºC. It is therefore expected that in the next decade, negative consequences from climate change will impact the most highly exposed regions. Even if all anthropogenic emissions totally ceased from today, global average temperatures would continue to rise for centuries, due to the inherent inertia in the climate system and the long residence time of CO₂ in the atmosphere.

The shipping and offshore industries as well as other industries with infrastructure along coastal areas will need to expand their adaptation measures in order to resist higher environmental loads and floods.

Coastal cities with hundreds of millions of inhabitants will probably be overwhelmed in the next 50 years, unless they take serious measures. Such upgrading and enhancement of flood protection systems are typically 10-30 year projects, so in order that they are effective in time for unavoidable climate changes, then they must be initiated within the next decade.

A range of agricultural practices will be exposed to drier and hotter summers, less predictable rainfall in the spring, and reduced access to irrigation as competition for fresh water resources increases. Radical regional-scale changes in agricultural production will be unavoidable, requiring considerable planned and coordinated responses on both the national and international levels. By 2020, yields from rain-fed agriculture (the dominant method) in some African countries, could be reduced by 50 % from already inadequate levels.

Sea Level Rise: Observations and Model

Sea Level Change in cm

<table>
<thead>
<tr>
<th>Year</th>
<th>Tide Gauges Measurements</th>
<th>Sea Level Observations</th>
<th>IPCC projections (2009)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>0</td>
<td>0</td>
<td>-0.1</td>
</tr>
<tr>
<td>1980</td>
<td>0.1</td>
<td>0.2</td>
<td>-0.2</td>
</tr>
<tr>
<td>1990</td>
<td>0.2</td>
<td>0.3</td>
<td>-0.3</td>
</tr>
<tr>
<td>2000</td>
<td>0.3</td>
<td>0.4</td>
<td>-0.4</td>
</tr>
<tr>
<td>2010</td>
<td>0.4</td>
<td>0.5</td>
<td>-0.5</td>
</tr>
</tbody>
</table>

The measured sea level rise is on the upper extreme of IPCC’s projections.
*Source: IPCC (2009)*

Global Warming is inevitable due to the thermal inertia of the oceans.

Source: Science, Wigley

Uncertainties and Disruptors

- Large quantities of methane and CO₂ are released from thawing of Siberian peat bogs
- The melt water of Greenland permanently disrupts ocean currents, e.g. Gulf stream or the deep water conveyor belt
- Major vulcanic erruption that (temporarily) reverses or halts global warming
- There is still uncertainty about the strength and effect of different feedbacks in the climate system that could result in tipping points where unforeseeable cascading effects can occur.
- A warmer ocean could also lead to the emission of methane from clathrate hydrates in ocean sediments.
INTRODUCTION

Global megatrends will influence the development and uptake of future technologies, both directly and indirectly.

However, other important issues associated with significant uncertainty from a 2020 perspective, might also have a considerable impact on the industries and associated technology uptake.

We have therefore used a scenario approach in which we explore combinations of drivers with a high impact and a high degree of uncertainty for the maritime and energy sectors. Economic growth (robust/fragile) and climate change (action/inaction) were selected as the two main drivers. Together, they form four possible alternative futures.
HOW TO READ THE SCENARIO CHART:

Our two main drivers divide the future into four scenario quadrants. These four scenarios will be referred to in the following section, when analysing to what extent technologies will be used by 2020.

The three circles in the scenario chart symbolize varying degrees of technology uptake. The inner, smallest circle denotes low uptake, the outer circle high uptake, and medium uptake is the middle circle. This illustrates how the uptake of a particular technology will vary according to our position on the scenario scales.

VERTICAL AXIS
Climate change action
Effective and aggressive agreements for CO₂ emission reduction have been agreed and implemented, on local, regional, and global levels.

Climate change inaction
Regulation of emissions is limited, with very little willingness to engage in collective actions. Future generations are left to solve environmental challenges.

HORIZONTAL AXIS
Fragile economic growth
The world experiences a fragile economic situation, in which some countries manage well, while others struggle. GDP annual growth is typically less than 2 % in the Western world and below 5 % in China and India.

Robust economic growth
Growth has taken off globally. GDP annual growth typically exceeds 4 % in the Western world, and is over 8 % in China and India.
scenarios for the maritime and energy sectors

GLOBAL DIVERSITY

IMPACTS
- New incentives for alternatives to the current energy mix initiated and accelerated by regulators on a national or regional level.
- Strong consumer pressure for "short-travelled" goods with lower CO2 footprint.
- Consumer acceptance of higher energy prices as a necessity for fighting future climate changes.
- Shipping of oil and coal reduced as more energy is produced and consumed locally.
- New regional shipping activities emerge due to increased regional trade and focus on "CO2 footprint".
- New IMO energy requirements for ship design and operation introduced.
- EU sets the scene globally for implementation of alternative energy sources and energy efficiency.
- Major actors, like China and USA, strengthen their domestic renewable energy sectors.

INDICATORS
- A new binding emission agreement signed, including by China and USA, aiming at a 2°C stabilisation target.
- Global carbon price is between 30 - 50 US$/tonne CO2.
- The world has recovered from the 2008/2009 financial turmoil, but growth remains low, at typically less than 2% in the western world and less than 5% in China and India.
- Capital is made available for investment in greenhouse gas (GHG) mitigation technology.
- Stricter regulatory regimes related to emissions of GHG, loss of biodiversity, and local environmental impacts.

STORYLINE - GLOBAL DIVERSITY

In this scenario, the world experiences a fragile economic situation. Although the world has recovered from the 2008/2009 financial turmoil, growth has not taken off globally. Some countries manage well in this scenario, whereas others struggle.

Focus on climate change and sustainability results in many local and regional energy solutions being employed. The result is a diverse introduction and application of new technologies with a better carbon footprint than the "business-as-usual" energy mix.

The success of creating a global agreement on climate change does not create positive spill-over effects regarding more goodwill for international negotiations. Hence, there are more bilateral agreements and regulations related to trade and access to resources, rather than global agreements.

Due to fragile economic conditions, coupled with a high focus on effective recycling and energy efficiency, raw material and energy needs are kept at a moderate consumption level.

Due to weak economic growth, the difference between rich and poor, both between countries as well as within countries, is maintained. This results in increased migration and tension, as well as development of radical movements.

LOCAL FIRST

IMPACTS
- Oil, gas, and coal dominate the global energy mix, but there is a tendency to push for more local energy solutions.
- Renewable energy, along with nuclear and unconventional fossil fuels, are pursued as means to support domestic growth and for supply security, not as approaches to solving global climate challenges.
- Protectionism increases the strength of National Oil Companies.
- Incentives for energy efficiency improvements as savings may help the local economy.
- Virtually no incentive for Carbon Capture and Storage.
- Fewer ships are built.
- Few (if any) incentives for CO2 emission regulation in shipping.
- An increase in shipping nationalism.
- Stronger push for adaptation measures.

INDICATORS
- The economies of Portugal, Ireland, Greece, and/or Spain collapse.
- Breakdown of the Euro cooperation.
- The world economy (measured as GDP) grows annually at least 2% in the western world, and less than 5% in China and India.
- No new global Emission Trading Scheme agreed upon by 2012, nor global regulatory mechanisms.
- Global carbon price is zero.
- The Chinese economic bubble bursts.

STORYLINE - LOCAL FIRST

In this scenario, there is greater disparity in wealth distribution due to fragile economic conditions. As a means to achieve/maintain economic growth, governments no longer continue with stimulus spending, largely due to high debt levels. With fewer options for market interventions, governments pursue more protectionist strategies that focus on taking care of their own national interests and people. This, in turn, diminishes willingness to engage in international collective actions between societies, leading to a reduction in international technology transfer and less labour mobility. Investments in technology, education, and R&D also decrease. There is volatility in commodity prices, due to imperfect market conditions caused by a more fragmented and isolated world. In this scenario, there is a negative self-enforcing cycle in which protectionism leads to less collective action, resulting in less cooperation, which again leads to more protectionism, and so forth. Future generations are left to solve environmental challenges, related to CO2 emissions and loss of biodiversity, and local challenges related to air and water pollution.

Hard economic conditions result in more people trying to migrate to a better life. However, as the receiving countries face tough economic conditions, willingness to receive immigrants is limited. This results in the development of more extremist movements in poorer countries with large unemployment rates, and a less inclusive world. Limited global support for strengthening global governance structures and institutions, as public interests focus on national conditions, and politicians are pressurised into “doing something at home”.
FUELLED BY CARBON

IMPACTS
- Fossil fuels remain the main energy source.
- Oil and gas are in high demand, and sensitive areas are opened up for exploitation.
- Focus on nuclear and large power-plants.
- Renewable energies applied if they are financially competitive.
- Maritime transport increases with demand for raw material and consumer goods, as well as the cruise segment.
- Some national protectionism.
- The high demand for oil and gas results in high energy prices towards the end of the period.
- Lack of support for strengthening global governance structures and institutions.

INDICATORS
- No new global Emission Trading Scheme agreed upon by 2012, nor regular regulatory mechanisms.
- Global carbon price is zero.
- The world economy (measured as GDP) grows annually at 4% in the western world, and more than 8% in China and India.
- Unemployment rates continuously decrease.
- Transition to renewable energy is slower than predicted by the IPCC.
- EU and California do not meet their environmental goals.

STORYLINE - FUELLED BY CARBON

In this scenario, there is a strong belief in free market forces as the overriding principles for economic governance, and global regulations of trade and emissions are limited. Market forces are seen as effective in addressing societal challenges, leading to focus on exploiting short-term opportunities and solving short-term problems, rather than taking responsibility for future sustainability. Nations tend to prioritise nation-building, creating a healthy labour market, and bridging the gap between rich and poor, rather than trying to solve those environmental challenges that do not directly affect domestic matters. Energy and other resources are not regarded as limitations. Instead, resource exploitation is based on the needs for economic growth, both domestically and in the global economy.

Thus, future generations are left to solve environmental challenges. Following robust economic growth, there is a consequent increase in global wealth, particularly demonstrated by a vast increase in the global middle class. This, in turn, leads to higher consumption, and further pressures being imposed on the climate, environment, and natural resources. In this market-liberal world, both capital and labour flow almost unrestricted between countries. In this scenario, both the “West” and the “East” enjoy adequate economic growth rates. The West maintains its wealth, whereas wealth increases in the East, along with political and military power. Thus, more long-term decisions, especially related to resource security, are taken by the fast-growing economies, usually through bilateral agreements, rather than through global governance.

GREEN WEALTH

IMPACTS
- The energy mix is changing. The use of fossil fuels has been reduced to 70% of the 2010 level, and continues to fall fast after 2020.
- Shipping of oil and coal is reduced, as more energy is produced and consumed locally.
- Harmonised carbon taxes stimulate investment in, and performance of, renewable energies.
- The saving potential in energy efficiency is fully exploited.
- Alternative sources of energy are wind, solar, bio and nuclear.
- Transparency and sustainability become critical components in a competitive corporate strategy.
- New emission requirements drive innovative and energy-efficient ship designs.
- Electric cars become the norm in replacing the existing car fleet.
- Strict regulations drive breakthroughs in battery technology and other means of energy storage.
- Higher energy prices are globally accepted as a necessity to fight future climate changes.

INDICATORS
- International, ambitious, and binding emission agreement signed and ratified soon after 2010.
- Global carbon price is between 50 – 100 US$/tonne CO₂
- Successful passage of a comprehensive energy-climate bill in the U.S. early in the decade.
- EU and its member countries strengthen the Renewable Energy Directive.
- Sensitive areas closed for oil and gas exploration.

STORYLINE - GREEN WEALTH

Following the introduction of effective and aggressive agreements for CO₂ emission reduction, there have been several years of strong and sustainable economic growth, largely based on low carbon energy and technologies. The success of creating a global agreement on climate change has created positive spill-over effects, with more goodwill towards international negotiations (IMO, UN, etc.). This, in turn, has a positive contribution to stimulating economic activity, as it requires new investments in technology transformations to replace old and dirty alternatives.

As a consequence, international institutions grow in power and respect; conflicts are minimised and global security improves. Some of the funding released from lower investments in arms and security is channelled into renewable energy solutions. With increased security, nuclear technology becomes acceptable, and the nuclear building programme, together with extensive programmes in wind, solar, and bio-energies, enables the use of fossil fuels to be reduced by 70%, and this rate is still falling fast after 2020.

Rare minerals are essentially fully recycled, significantly reducing the need for extraction. Thus, the risks associated with negative environmental impacts and social conflicts related to rare mineral extraction are significantly reduced. This scenario describes an optimistic and positive world where most things work.

Last updated: 2023-04-17
License: Attribution 4.0 International (CC BY 4.0)
TECHNOLOGY UPTAKE
TECHNOLOGY UPTAKE

The central section of Technology Outlook discusses technologies that are considered to become pertinent for selected segments within the maritime and energy sectors.

Most of the technologies described are not revolutionary. Many may have been around for some years, but have had little impact to date in certain industry sectors. Others may progress more rapidly from development to implementation.

Depending on how the future develops (and which scenarios emerge and dominate) certain technologies might become recognised as important innovations towards 2020. The extent to which a particular technology will be used in the various scenarios is qualitatively indicated as “low”, “medium”, or “high”.

Our description is by no means a ranking of the most important future technologies. It is a selection of those technologies that we consider to have great innovation potential when applied at the right time and in the right industries.

INDEX

<table>
<thead>
<tr>
<th>Index</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maritime</td>
<td>28</td>
</tr>
<tr>
<td>Oil, gas and coal</td>
<td>42</td>
</tr>
<tr>
<td>Renewables and nuclear</td>
<td>60</td>
</tr>
<tr>
<td>Power systems</td>
<td>72</td>
</tr>
</tbody>
</table>
Mature and emerging economies will become increasingly dissimilar in terms of demography and development as the world population approaches 7.5 billion in total by 2020. In a world with more resource-intensive lifestyles and increased population, demand for maritime transport is bound to grow. The world fleet will continue to expand, but demand will vary among regions and ship types.

As the industry is facing pressure to offer more sustainable transport solutions, new ships with improved environmental, safety and security performance will be needed. This will require more focus on developing and implementing innovative technical and operational solutions, with particular attention to achieving greater environmental performance and energy efficiency.
The low energy ship

Which technological developments in materials science, drag reduction, and propulsion will contribute towards the development of new low energy ship concepts needed in 2020?

The green-fuelled ship

Environmental regulations and rising bunker oil prices could make natural gas and biofuel blends viable solutions. But what about wind and nuclear as possible energy sources for shipping?

The electric ship

Hybrid electric ship concepts, incorporating many types of renewable energy sources, will be implemented on specialised ships. Will cold ironing, marine fuel cells, and high temperature superconductors also take off?

The digital ship

E-navigation solutions will be widely used to enhance safety and to optimise operations with respect to security, economy, and environmental performance. But which are the key technologies?

The Arctic ship

With the prospect of ice-free summers in the Arctic, ship traffic in that region is set to increase. Which novel systems and software, not to mention new types of vessels, will Arctic shipping demand?

The virtual ship

Advanced, model-based techniques for assessing technical and economic performance of a ship from a lifecycle perspective enable better management of the complexity and uncertainties related to design. How can these be achieved?
the low energy ship – attacking energy losses

**HIGH BUNKER COSTS**, new market realities, the cross-industrial focus on the environment, along with stricter regulations regarding emissions and ballast water, will result in radical changes in ships. Technological developments in materials science, drag reduction, propulsion, and energy efficiency, will provide the basis for the key specifications of new ship concepts. The applicability of different, new concepts needs to be considered for each ship type, based on technical and economic assessment. New concepts could play important roles for all vessel types.

**INTRODUCTION**

The main triggers for innovation are market forces, technological advances, safety considerations, and regulatory changes. Presently, rising fuel prices, market uncertainties, intense competition, climate change, and societal pressures for greening are driving the introduction of new technologies and concepts into the world fleet towards 2020. Multifunctional ship types and/or technological advances in drag reduction, propulsion, and materials herald new ship concepts. These are not necessarily new ship types, but offer innovative solutions to “newly posed” problems in ship design. Novel technologies and demanding objectives regarding emissions, efficiency, strength, and speed or cargo flexibility, necessitate holistic designs and use of risk-based methods. In order to manage the complexity and risk inherent in new solutions, large-scale demonstrators are needed, as well as advanced, model-based techniques.

**AIR BUBBLE LUBRICATION**

Although the wave-making resistance of ships can be minimised by careful hull design, friction drag is more important for large, slow speed, commercial ships.

Air bubble lubrication systems are based on the powered injection of air beneath the ship. Several small holes on the hull's bottom are used for injection of micro air bubbles into the flow stream. By interfering with the generation of vortices, the transition to the highly dissipative turbulent flow regime, which typically occurs around the hull, is delayed. Friction drag is reduced due to the lower friction forces associated with laminar flow, compared with turbulent flow.

Uncertainties in the physical mechanisms, and the scaling and technical feasibility of this system, need to be solved by 2020. In particular, the potentially negative interactions of the dispersed bubbles with the propeller must be eliminated.

**AIR CAVITY SYSTEMS**

The injection of air beneath a ship's hull can have an alternative embodiment, but one that also results in friction drag forces being decreased.

In air cavity systems, large indentations are opened on the hull's bottom. Compressed air is pumped in to fill the void space and establish a continuous air cavity. The steel-seawater interface is thus replaced by a more slippery air-seawater interface, effectively reducing the hull’s wetted surface and thereby the friction forces. A decrease in fuel consumption of around 10% is possible. As air will inevitably escape from the cavity, it has to be continuously replaced.

Negative side-effects include the generation of a destabilizing free surface under the hull. Energy will be lost, both by the formation of gravity waves on this free surface and by dispersion of bubbles into the propeller inflow.

10-20% drag reduction is possible with air injection systems by 2020.
HYBRID MATERIALS

Reducing the weight of a ship’s hull can decrease emissions and save fuel. Lightweight materials are used in smaller vessels and secondary structures, e.g. fibre reinforced plastics, aluminium, and titanium.

Hybrid materials can be formed from multiple layers of metal sheets and piles of polymer composite laminates. Fibre-metal laminates combine the qualities of metals (high impact resistance, durability, flexible manufacturing) with those of composites (high strength and stiffness to weight ratio, good resistance to fatigue and corrosion). The metal layers can be of either aluminium or steel plates, whereas the polymer core can be reinforced with carbon or glass fibres. The application of these materials in the aeronautical industry and in specialised ships provides an opening for introducing these materials into shipping. However, widespread adoption by 2020 is unlikely. The main obstacles include high costs, manufacturing and recycling challenges, and fire resistance issues.

HYBRID PROPULSORS

The high efficiency of the screw propeller is restricted to one design speed, large blades, 2-stroke diesel engines, and direct drive propulsion.

Hybrid propulsion concepts consist of combinations of shaft propellers, pods, and efficiency enhancing devices, such as pre- and post-swirl fins. Hydrodynamic optimisation can enable efficient arrangements of a contra-rotating pod propeller behind a main controllable pitch propeller, and of a feathering centre-line propeller with steerable side pods. These systems capitalise on the hydrodynamic advantages of their components, while also extending the range of efficient operation by utilising the optimum engine load.

Although design and manufacture of hybrid propulsors are expensive, this technology is expected to provide fuel savings up to 10%, depending on utilisation and ship types, e.g. container or multipurpose ships.

BALLAST WATER FREE SHIPS

Ballast water ensures sufficient draft, strength, and stability when ships sail unloaded. However, when ballast water is discharged untreated, the marine ecosystem may be threatened with the introduction of invasive species contained in the ballast water.

A trapezoidal hull with a transversely raked bottom can maintain sufficient stability and draft when unloaded, without requiring ballast water. In order to achieve the displacement of standard designs, the breadth and length are increased. The bow and stern are now critical for regulating trim under all load states. Such ships incorporate more steel, both due to their larger size and also to obtain sufficient strength under partial load conditions. Hybrids, with two small ballast tanks to aid the adjustment of trim, seem preferable.

Even after 2020, ships that do not use ballast water will be more expensive to build and have various construction challenges. Competing solutions include onboard treatment of ballast water and in-port receiving facilities.
the green-fuelled ship – the beginning of the end of traditional fuel

WITH SEA-TRANSPORT facing increasingly strict environmental regulations, and with rising bunker oil prices, natural gas, and renewables are being considered as alternative energy sources. LNG, biofuel blends, or more radical energy sources like wind or nuclear, all have the potential to be exploited.

Adoption of LNG fuelling by a considerable share of ships in short-sea shipping is expected over the next decade, especially in Emissions Control Areas (ECAs).

INTRODUCTION

Impending stricter environmental regulations that require that the emission levels of SOx, NOx, particulates are reduced, and probably CO2 also, are pushing the maritime industry towards using cleaner energy sources. Increases in bunker oil prices will probably accelerate this transition.

Abatement technologies, such as exhaust gas recirculation, scrubbers, or catalytic reduction, can meet some of these regulations, but typically CO2 emissions are increased. Alternatively, LNG, biofuel blends, or more radical energy sources, like wind or nuclear, could be exploited. The implementation of these new technologies could face significant technical and economic challenges, and the time frame ranges from a few years for LNG, to decades for nuclear.

Large-scale demonstration projects, as well as model studies, are needed to evaluate performance, and to ease implementation into the fleet.

It is anticipated that within 10 years a considerable share of new ships will have natural gas fuelling.

NATURAL GAS

A switch to natural gas could virtually eliminate emissions of SOx and particulate matter, and NOx emissions could be reduced by 90% in gas-fuelled, lean-burn, 4-stroke engines. Such engines are suitable for cruise ships, smaller cargo and service ships, and also for auxiliary power. However, for slow speed, 2-stroke engines that are typical of larger commercial ships, NOx reductions are more modest.

Although natural gas combustion can reduce CO2 emissions by up to 25% compared with bunker oil, emissions of unburned methane represent a problem. Methane is 21 times more potent greenhouse gas (GHG) than CO2. Depending on engine type, the change in CO2 equivalent emissions range from a reduction of 20% up to a net increase.

Engines fuelled by natural gas are widely used for power generation and transport on land. One challenge for shipping is that LNG tanks typically require 2 to 3 times more space than a diesel tank. Since natural gas must be stored either liquefied or compressed, these storage tanks are also more expensive. Based on recent experience, the new-build cost of LNG-fuelled ships is about 10–20% higher than for equivalent diesel-fuelled ships.

Although LNG bunkering infrastructure is currently very limited, a significant increase in the number of bunkering terminals is expected by 2020, especially within ECAs. Strict regulations on NOx and SOx emissions, combined with a more competitive gas price, will drive the uptake of gas as a marine fuel. It is anticipated that within 10 years a considerable share of new ships will have natural gas fuelling, particularly in short-sea shipping. It might also be expected that, in the coming years, some ships are retrofitted to run on LNG.
Biofuel is a renewable energy source with the potential of considerable decrease in lifecycle CO₂ emissions. In operation, SOx and particulate matter emissions are also reduced, while NOx emissions slightly increase. In principle, existing diesel engines can run on biofuel blends. The most promising biofuels for ships are biodiesel and crude plant oil. Biodiesel is most suitable for replacing marine distillate, and plant oil is suitable for replacing residual fuels. There are, however, various unresolved problems. These include fuel instability, corrosion, susceptibility to microbial growth, adverse effects on piping and instrumentation, and poor cold flow properties. Although these technical challenges could be resolved by 2020, widespread use of biofuel in shipping will depend on price, other incentives, and availability in sufficient volumes. Breakthroughs in production methods and new regulations could have a significant impact.

Kites are smaller installations and provide a thrust force directly from the wind. The system consists of the kite, control lines with a control node, a hawser connection to the forecastle, a winch, and the bridge control system. Commercial kites currently range from 160 to more than 300 m² and can substitute a propulsion power of up to 2000 kW depending on the wind conditions and ship's speed. They fly at between 100 and 420m high, at wind speeds of 3 to 8 Beaufort scale. The automatic control system actively steers and stabilizes the kite, optimising its performance. The relative ease of kite installation for wind propulsion may result in ship retrofits within the next 10 years. Kite operation entails few additional tasks for the crew. Conflicts with cargo handling equipment could arise.

Nuclear power plants have no GHG emissions during operation and are especially well suited for ships with slowly varying power demands. Although several hundred nuclear-powered navy vessels exist, few nuclear-powered merchant ships have been built. Commercial nuclear ships would have to run on low enriched uranium. Land-based prototypes offer a compact reactor (comparable to large marine diesel engines), with power output in the range of 25 MW. Fuel lifetime of around 10+ years at a price of US$ 2 mil/MW is indicated.

The extensive requirements for testing and qualifying this technology suggest that it will not be commercially available for civilian shipping by 2020. Government involvement could however accelerate the uptake process. The main barriers to nuclear shipping relate to uncontrolled proliferation of nuclear material, decommissioning and storage of radioactive waste, the significant investment costs and societal acceptance.

Biofuels are biodegradable - spills into the marine environment may have less impact.
the electric ship – the Prius of the seas

**INTRODUCTION**

The use of hybrid powering systems in marine applications has the potential to offer more efficient and environmentally friendly ship power plants. These powering systems require design, operation, and control of energy production, and conversion in an integrated manner. The ship machinery will evolve into a more complex system, with a wide range of different energy conversion and storage sub-systems.

The equipment constellation will depend upon the operational profile of each ship, even more than it does today. Supply vessels and ferries with high fluctuations in power demand are the most suitable candidates for hybrid powering systems. The implementation of these new technologies could face significant challenges, and model-based assessment techniques are important for evaluating both technical and economic performance, and for ensuring safe operation.

**HYBRID SHIPS**

Power generation works best when operating at a single, defined condition, and fluctuations in power demand or supply reduce efficiency. Switching to electric propulsion and powering will offer more flexibility at higher efficiency, as multiple power sources can be included.

The hybrid electric ship of 2020 might contain a mix of conventional and superconducting motors and generators, fuel cells, and batteries. This concept easily integrates power from alternative renewable sources, e.g. solar panels or retractable wind turbines. Performance monitoring, power management, and redundancy will be key elements.

These concepts will be applied to service, passenger, and small cargo ships by 2020. For large cargo ships, they may only be used in auxiliary power generation.

The high complexity of such a system will require maintenance strategies, control of grid stability, improved space utilisation, and weight minimisation.

**MARINE FUEL CELLS**

In order to increase efficiency in power production, alternatives to combustion have to be considered.

Fuel cells convert chemical energy directly to electricity, at a theoretical efficiency of up to 80% (hydrogen), through a series of electrochemical reactions. They can be fuelled by natural gas, bio-gas, methanol, ethanol, diesel, or hydrogen. LNG fuel cells emit up to 50% less CO₂ per kW than diesel engines. Due to the establishment of Emissions Control Areas (ECAs), installation of LNG fuel cells will be favoured. Currently, a marine fuel cell prototype delivers power in the range of 0.3 MW. Initially, fuel cells will provide auxiliary power, e.g. hotel loads. Ultimately they will provide supplementary propulsion power in hybrid electric ships. The main barriers against uptake are cost, weight, size, lifetime, and slow response to load variations. During the next decade fully commercial marine fuel cells will become available.
The use of multiple electrical power sources in vessels with frequent load changes, and the requirement to operate at optimum efficiency, requires appropriate power storage.

Batteries are one way to address network power disturbances and overall balancing, resulting in smooth and uninterrupted operation. Batteries can store surplus energy when available, and provide supply at peak demands. For instance, battery power can compensate when fuel cells cannot fulfill fast load changes. Battery storage enables dual-fuel generators to run closer to optimal loads, avoiding fast load changes and additional ship emissions. In 2020, a battery pack of 0.4 MWh, 4 MW peak load, could weigh 2-4 tonnes and occupy approximately 1 m³.

Limited availability of rare earth metals, e.g. Li, performance degradation, and prolonged charging times are the main barriers against widespread adoption. It is expected that nano-technology may play an important role achieving a break-through in battery storage.

Electrical resistance results in energy losses from components such as generators, motors, transformers, and transmission lines.

High-temperature superconductors (HTS) have zero electrical resistance (at -160 °C) and could enable significant reductions in the size of motors and generators as HTS wires allow 150 times more current than similar-sized copper wires. Storage of energy in HTS coils is another application. However, using these materials requires cryogenic cooling, by, for example, liquid nitrogen, and special thermal shielding; the main risk is failure of cryogenic cooling, resulting in loss of superconductivity. Redundancy will be a major issue in designing ships that use HTS technology.

About 5% of the world fleet’s annual fuel oil is consumed in ports. As ports are often located in highly populated areas, emissions from ships contribute to local environmental and health problems.

By replacing onboard generated electricity with shore electricity supply, cold ironing, the detrimental health and environmental effects from emissions of SO₂, NOₓ and particles are reduced. Furthermore, CO₂ emissions might also be decreased, depending on the availability of cleaner onshore power plants. Towards 2020, a standardised plug-in-connection, for use between ships and the shore electrical grid, will become available, both for existing ships and for new-builds. This connection will convert electricity to the appropriate voltage and frequency for the ship.

The main challenge will be availability of sufficient grid capacity in larger ports and the lack of infrastructure in smaller ones.
the digital ship – navigation made easy

E-NAVIGATION TECHNOLOGIES are being adopted by the front runners in shipping, and by 2020 the majority of the fleet will have followed. They combine accurate position data, weather and surveillance data, onboard and remote sensor data, ship specific characteristics, and response models. E-Navigation technologies could prevent accidents and optimise secure, economic, and environmental performance. Onboard electronic charts will become the unifying platform on the digital ship, integrating and visualising information from other applications related to areas such as security and navigation risks, port entry, and weather routing.

INTRODUCTION

From a ship perspective, e-Navigation refers to the ability to access, integrate, process, and present locally and remotely acquired maritime information onboard, and to transmit key sensor information to shore or to other ships. Key technologies relate to navigation (e.g. electronic charts, radar, sonar), condition monitoring (e.g. hull stress sensors), vessel tracking (e.g. AIS, LRIT), satellite imagery and communications, and computer software. In sum, these elements provide decision support to, for example, the ship master.

While some e-Navigation technologies are presently in use by front runners in shipping, by 2020 the majority of the fleet will have followed. e-Navigation encompasses all aspects of ship operation; from safe navigation, including avoiding extreme weather events, to minimising fuel consumption and emissions and reducing maintenance costs, as well as effective ship-port communication for optimised port entry and cargo handling. Harmonised data are processed by computer models and presented in an integrated format useful for decision-making, onboard and onshore. Thus a wide range of stakeholders are able to benefit. Most e-Navigation development is focussed towards onboard applications. However, onshore facilities can provide more computing power and additional expertise, which can complement and augment onboard systems.

Such systems can also provide support to decision makers onshore, such as the ship owner or port authorities, who also require support tools, e.g. for effective monitoring of fleets. By 2020, systems based on AIS, LRIT, and other satellite services, will enable global monitoring and tracking capabilities. This could serve as a basis for a range of support applications. Full benefits may require high data transmission rates, possibly limiting use in remote areas.

ECDIS

Ship grounding accidents are recurring events that cause considerable material damages, and even fatalities and harmful oil spills.

The Electronic Chart Display and Information System (ECDIS), using Electronic Navigation Charts (ENC), reduces grounding probability by about 30%. New IMO regulations require that ECDIS is implemented throughout most of the fleet by 2020. ECDIS will function as a platform for other support systems, such as advanced weather routing.

ADVANCED WEATHER ROUTING

Traditionally, weather routing has mainly focussed on safe navigation, avoiding bad weather. However, weather routing could also optimise fuel consumption (about 10% savings), time of arrival, crew and passenger comfort, or hull fatigue. The preferred route will be provided by a risk-based approach and will depend on the selected optimisation objective, ship characteristics, and variations in wind, waves, and currents. Warning criteria for extreme weather events, including rogue waves, are needed, and also consideration of the effects of climate change.

Towards 2020, the accuracy and spatial-temporal resolution of met-ocean real-time and forecast data is expected to have improved, along with data collection from remote and onboard sensors. Response models for sea-keeping and resistance in waves will be customised to individual ships and routes. This will be achieved by utilizing real-time and historical data with self-learning algorithms.
PIRACY DETECTION AND DETERRENCE

High insurance premiums reflect the likelihood of armed robbery, piracy, and terrorism to seafarers and ships. These threats are not expected to subside over the next decade.

Successful threat mitigation requires early detection and effective, remotely-controlled deterrents (e.g. water, sound, electric shock).

Commercial, high performance radars already have 4 times the range of standard navigational radars. They can detect dingy-sized objects over a distance of up to 4 nm (nautical miles), and this will have increased to 10 nm by 2020. Real-time data from radars, sonars, and cameras, together with long-range satellite data, will be processed by an onboard warning system. During the next decade, it is expected that private service providers will offer piracy warnings via satellite, which are integrated with the onboard system.

In response, pirates will try to adapt their attack strategy.

SHIP-PORT SYNCHRONISATION TECHNOLOGY

Shipping contracts typically require vessels to steam at “utmost despatch”, i.e. at top speed, between ports, regardless of the availability of berths at the destination port. This leads to unnecessarily high fuel consumption and emissions, and contributes to port congestion, as vessels rush to their destination only to have to lie at anchor for days.

By 2020, berth planning algorithms, using satellite tracking and weather routing, will be integrated into ship-port communication systems. This will facilitate synchronisation and generate berthing schedules that maximise the terminals’ throughput at minimal transhipment cost, while minimising vessels’ dwelling and fuel consumption.

As ships tend to be more vulnerable in waiting situations close to shore, reduced time in port will also enhance ship safety and security.
the arctic ship – exploiting new opportunities in the north

OVER THE NEXT decade, shrinking amounts of summer sea ice, along with higher prices of hydrocarbons and greater exploitation of raw materials, will result in an increase in Arctic ship traffic. This will lead to faster development of Arctic-related technologies, such as ice route optimisation software, hull load monitoring systems, and introduction of new icebreaking concepts. Inexperienced crews will be prepared for ice navigation by using ice training simulators. As conventional lifeboats or liferafts are not designed for safe evacuation in Arctic ice conditions, new amphibious types of evacuation vessels will be brought into service.

INTRODUCTION
Climate models predict a significant decrease in Arctic summer ice cover over the next ten years. Less ice provides new opportunities for shipping, leading to more intense and rapid development of Arctic-related technologies. Increased demand for seaborne trade in the Arctic will lead to the introduction of larger vessels that require novel icebreaking services.

Many technologies that are commonly used in more temperate areas, such as conventional lifeboats may not work in the Arctic environment.

Crews with little experience in Arctic navigation need support systems for decision making, and require training to be able to navigate safely and effectively in Arctic waters. Increased demand for seaborne trade in the Arctic will lead to the introduction of larger vessels that require novel icebreaking services.

NOVEL ICEBREAKERS
The bow shoulder areas of an escorted vessel that is wider than the icebreaker, are exposed to unbroken ice, leading to increased ice resistance.

Wider channels can be broken by icebreakers with an oblique hull form that is especially designed for sideways icebreaking. Sideways operation is achieved by using several 360° rotating azimuthing propulsors. Such an icebreaker would operate bow first when escorting smaller vessels, and sideways for wider vessels. This design would allow an icebreaker with a 20 m beam to open a channel up to 40 m wide. This would enable a single icebreaker to escort wider vessels, which to date require two traditional icebreakers. Tests indicate that when in oblique operation mode, the speed is less than half the normal speed. Over the next decade, this novel icebreaking concept is expected to be widely adopted for Arctic operations.

ICE LOAD MONITORING
When navigating in ice-covered waters, the captain must be able to judge when the ice load has reached a level that exceeds the local strength of the ship’s hull.

The ice load monitoring system on the bridge should indicate when extreme loading occurs. Ice loading is continuously measured by a couple of 100s of strain gauges that are affixed to selected frames in the bow region of the vessel. The signals measured will then be benchmarked against the known safety limits of the frames. The safety limits have been calculated, based on the vessel-specific, finite-element model. This system relies on correct sensor positioning, calibration and detection of malfunctioning sensors, and the quality of the benchmarking.

It is expected that over the next decade, such systems will be deployed on many Arctic vessels providing advice on when to slow down or when to select another route in order to avoid ship damage.

The Arctic ocean could be largely ice free in summer within a decade.
ARCTIC EVACUATION VESSELS

Conventional lifeboats or liferafts are not designed for safe evacuation under Arctic ice conditions. Ice strengthened and winterized lifeboats are needed to travel over ice formations, like ice ridges, and to transit in open water. By 2020, such vessels will use the Archimedes’ screw concept for movement. Two large, screw-like, floating pontoons will be located along either side of the vessel. Design challenges include the material of the pontoons and their connections, as they will have to tolerate high impact loads at extreme temperatures.

Evacuation vessels on board Arctic ships will have to be included in the general winterization of the ship, e.g. protected from icing and with preheating of their engines.

ICE ROUTING SOFTWARE

Ships without icebreaker escort will have to find their own routes through the ice that will keep their fuel consumption and travel time to a minimum.

By 2020, ice routing software will take into account information on prevailing ice conditions, based on satellite images, weather observations, ice charts, and weather and ice model forecasts.

Ice conditions, such as level ice, brash ice channel, floe ice field, and ice ridge field, will be simulated stochastically for the area of the route selected initially. The model will then compute the resulting ice resistance, speed, and transit time, also taking into account the ship characteristics. The navigator will set the preferred optimization criteria, such as speed, transit time, fuel economy, or emissions, for best route selection.

Ice routing may also suggest the safer routes through ice.

ICE NAVIGATION TRAINING SIMULATOR

A growing number of ships in Arctic areas will have navigators with little or no ice experience. Effective training methods for mastering navigation in ice are needed.

Training simulators offer an environment in which the navigator can train for ship operations in varying conditions of simulated ice, darkness, snow, fog, and icing. The ship response to navigator’s actions is computed in real-time, based on the ship–ice interaction and propulsion models, together with the effects from chosen weather conditions.

The navigators will learn to recognize different ice types and to avoid heavy ice features, such as ice ridges and multi-year ice. Training for specific ship operations, such as station keeping in ice or ice management, can be performed in the simulator. The challenge will be to model ship behaviour realistically for all different types of ice conditions.

480 container transit voyages across the Arctic around 2030?
Source: DNV, Position Paper 04-2010
the virtual ship
– new ways of designing ships

MODERN SHIP DESIGN requires careful consideration of technical uncertainties, market specificities, future energy prices, existing and upcoming regulations, and anticipated climate change. These factors pose greater challenges for handling uncertainty and for managing risk.

Advanced modelling methods and tools for the development and assessment of new hull designs, propulsors, and complex machinery systems are an enabling technology for addressing these risks.

INTEGRATED SHIP DESIGN TOOLS
The complexity of future designs and the risks involved will accelerate the adoption of advanced modelling methods and tools, thereby enabling the development and assessment of new hull designs, propulsors, and machinery systems. This design approach will be based on versatile software environments, including multi-objective optimisation algorithms.

Mathematical methods, objectives, constraints, and analysis suites will be entirely controlled by the designer on a case-specific basis. The calculations involved will utilise module-based tools for each subsystem of the ship, e.g. for the machinery components or the hull shape. The different modules will be linked through an integrated design platform. In order to ensure timely evaluations, the software will devise multi-scale, multi-physics, and multi-resolution models of the pertinent physics.

The definition of performance will be multi-dimensional. The integrated design tools in place by 2020 will support the distributed, parallelised, and coordinated execution of the various design tasks by taking full advantage of multi-processor architectures and the internet infrastructure. The uptake in the design and optimisation of more complex, specialised, and costly ships, such as passenger and service vessels, will be higher.

The major risks that will be faced in the use of integrated design tools towards 2020 will be their considerable complexity and the need for expert users. Additional risks, related to software integration, data management, and communication, can also be expected.

One crucial factor is access to reliable data on design, performance, and cost of the different technology options. Most of these data may be collected from end-user applications, model-based approaches, and large-scale testing. Tighter interactions between ship-owners, yards, component manufacturers, and classification societies will be essential.

COST BENEFIT OF ABATEMENT MEASURES
Average marginal abatement cost and CO₂ reduction potential for the world fleet in 2030. Baseline: 1.53 bill tons/year. Source: DNV

The right design may save up to 20% fuel expenses - at zero cost.
Source: DNV, Position Paper 05-2010
MODEL-BASED HULL DESIGN

Traditional hull design optimisation is usually limited to still-water conditions, design cargo loads, and design speed conditions. This approach can result in ships being built that have poor performance under off-design conditions.

In 2020, hull design tools will seamlessly integrate computer-aided engineering components, i.e. CAD, CFD, & FEM, with multi-objective optimisation. The definition of performance will be generalised to include resistance, efficiency, sea-keeping, manoeuvrability, strength, etc. The inclusion of drag reducing or propulsive efficiency enhancing devices increases the need for computational tools of high predictive power. In 2020, ships will be designed with realistic operation profiles to produce robust hulls that perform adequately under a wide range of external conditions.

The major challenge is to implement these tools in a way that is both flexible and computationally efficient.

LARGE-SCALE DEMONSTRATORS

In order to remain abreast of the complexities and risks in shipping in 2020, a faster and safer path from idea creation to the actual launch of novel products is required. The use of advanced modelling tools will be the first step. To gain confidence and bring innovative technologies forwards to commercialisation, laboratory tests and large-scale demonstration projects are necessary.

Showcase projects have the ability to validate theoretical models, identify and address safety challenges, qualify technologies, and eliminate perception biases. Modelling tools and experimental projects will complement each other by defining the specifications for testing and scale-up with greater accuracy. Large-scale demonstrators can only be established jointly, between developing organisations and end-user shipping companies.

Sharing the investment and risks among the major stakeholders will accelerate innovation and technology adoption.

CAD: Computer Aided Design
CFD: Computational Fluid Dynamics
FEM: Finite Element Method

VIRTUAL ENGINE ROOM

Model based ship machinery design.

LARGE SCALE DEMONSTRATORS

Ongoing large scale demonstration for marine fuel cells (Viking Lady).
Oil, gas, and coal will continue to dominate the energy mix, covering 79% of global energy supply by 2020. Global energy consumption increases by 19% over the next decade, driven primarily by non-OECD countries.

New technologies will therefore be concentrated on improving efficiency and reducing environmental impact, in relation both to extraction and to power generation.
Offshore drilling technology

Could drilling speed increase by 50% towards 2020 through real-time monitoring and better algorithms, and through hardware and process improvements?

Subsea production

The next generation subsea processing will require a step change in both technology and power consumption. What are the solutions that will enable the development of new complicated fields as well as boost production of existing fields?

Arctic offshore development

Offshore Arctic activity is expected to increase, and will be strictly regulated to minimise environmental impact. Will remote operations and extreme distance tie-ins become part of the solution?

Unconventional oil and gas

The age of cheap oil is over, forcing the oil majors to exploit unconventional resources such as oil sands and shale gas. Could the use of renewables for steam and power production and new water treatment technologies reduce the environmental footprint?

Future refineries

Future refineries will process unconventional fuels and crudes containing varying concentrations of corrosive components, therefore demanding new systems and materials. Will ways of utilizing CO₂ also be developed?

Gas-fired power plants

Gas is increasingly viewed as more than just a transition solution towards a low carbon economy. Will new technologies enable higher efficiencies and lower emissions in these plants?

Coal-fired power plants

Could more efficient, supercritical and ultra-supercritical power plants significantly reduce emissions and become the predominant technology for new plants in 2020?

Carbon capture and storage

Well-known solutions will largely be applied in the first demonstration plants by 2020, but what are the technological improvements that will be needed, not least to ensure the long-term commercial viability of CCS?
INTRODUCTION

Production rates from mature fields are declining rapidly. In the Gulf of Mexico, production from mature fields is falling by 20% per year. This downward trend is forcing the oil and gas industry to drill ever deeper and to explore more complex reservoirs. However, this is a costly exercise. A deepwater well typically costs between US$100m and US$120m, while a comparable figure for shallow water wells in the Arabian Gulf is US$ 16m (2010 values). Simultaneously, production from existing reservoirs must also be increased.

Where will we be in 2020?

A key word for development towards 2020 is diversity. Heavy deepwater units will drill in even deeper waters and explore more complex reservoirs. At the same time, lighter units will be used for intervention and enhanced oil recovery (EOR) activities in mature deep and shallow water. Yet another type of vessels will be used for decommissioning. All these solutions will be powered by real-time monitoring and advanced control systems, significantly reducing drilling time. Innovative concepts, such as complete subsea drilling, are expected to be at prototype stage and not commercially available before 2020.

DIVERSE DRILLING AND INTERVENTION SOLUTIONS

A key word for the development towards 2020 is diversity. Rather than “one-size-fits-all” advanced deepwater rigs, capable of taking on a range of assignments, the development of a series of specialised units seems more probable.

Heavy deepwater units, reaching reservoirs 15,000 – 30,000 feet below sea level, will be part of the equation. This type of unit will be needed for developing, for example, the pre-salt discoveries in Brazil at reservoir depths from 17,749 to 21,325 feet.

Within the next decade a market for decommissioning of subsea wells should also be expected. This activity will start in the UK in 2015 followed by Norway in 2020, and we expect this market will be taken by specialised decommissioning units, rather than by traditional deepwater rigs.

A third trend is towards specialised rigs for completion and work-over activities, targeting the need for well maintenance activities in mature oil and gas fields. Higher maintenance and intervention activities are needed in order to squeeze more oil and gas out of existing reservoirs, so called EOR.

EXTREME MATERIALS FOR EXTREME WELLS

Towards 2020, operation is anticipated at pressures above 20,000 psi and at temperatures above 200°C. These extremes of pressure and temperature, in combination with high levels of H₂S and CO₂, will drive the use of Corrosion Resistant Alloys (CRAs).

The various systems involved in oil and gas exploration and production are often examined in isolation and not from an integrated, holistic perspective. Hence it is unclear which risks may be posed by these interactions in the long-term. This is further compounded by difficulties in inspecting and determining the relevant conditions and status.

Recent deepwater discoveries in Brazil could match the reserves of Russia or Kuwait.
there is explosive growth in the volume of well data being produced. Integration of real-time drilling information with down hole logging tools will enhance logging of down hole pressures, geological data, and drilling performance. This will assist in the early detection of drilling problems, accurate wellbore placement, and improvements in production performance.

Data from nearby wells, in combination with reservoir models, will contribute to effective well-planning and accurate well-core placement, reducing uncertainty and improving operations. More accurate operational load history could also improve maintenance and reduce non-productive time. Systems for integrated operation will allow more onshore involvement in drilling and well operations, and support the offshore crew in handling challenging operations and situations.

The explosive growth in real-time information, backed up by rapid development of better algorithms and improved control and management systems, will result in drilling speeds increasing significantly towards 2020.

Several concepts are under development, and the proposed solutions appear promising and elegant. However, considerable work remains to be done. We expect that subsea drilling will be at a prototype stage by 2020, but that floaters will still be the dominant platform for deepwater exploration.

Drilling speed will increase by 50% towards 2020.

Moving into ultra-deepwater will oil price climbs above US$ 70 – 100 per barrel. Source: Business Insights

The Badger Explorer, which drills and buries itself beneath the ground carrying a full package of logging sensors. Source: www.bxpl.com
subsea production – the ruling concept for future offshore fields

**BUSINESS FORECASTS** indicate that more subsea wellheads than ever will be installed in the years ahead. A step change will occur with respect to subsea processing and subsea electric power supply. Standardised, building block-based field development will become the backbone of small, fast-track developments. In addition, passive data gathering is expected to move to automated decision-making, and it is expected that industry leaders will take full advantage of automated decision tools by 2020.

**INTRODUCTION**

There are three routes into the subsea future. The first is the development of novel technologies to cope with future demand for difficult reservoirs. The second is standardised, building block-based field development. The third important route is extending the production life of existing fields.

The drivers for the first route include difficult oils and long-distance transport, and here the requirement for subsea processing will be clearly recognised.

The drivers for the second route are small, new developments and tail-end production for which time to first oil is critical, together with low investment costs in order to reach requirements to net present value, NPV.

Thirdly, towards 2020 many existing subsea fields will reach the end of their design life and face declining reservoir pressure. In order for production to continue from these fields, significant efforts will be required in assessing the integrity of the system, as well as introducing subsea processing.

**SUBSEA PROCESSING**

New subsea developments, located at a distance from existing infrastructure or shore and requiring long tiebacks, along with fields with more complex reservoirs with heavy oil or high water cut, will require processing of the hydrocarbons subsea.

Subsea processing (separation and boosting) will require a step change in both technology and power consumption. Large subsea gas compression stations do not exist in 2010, but will have been developed by 2020.

From the power perspective, moving from kW to MW will require a new generation of subsea power systems. In addition to needing a new class of cables, penetrators, and power connectors, it will also be necessary to develop transformers, motors, and variable speed drives that are suitable for subsea use. Providing large watertight and pressure-proof housing, and disposing of the megawatts of generated heat adds to the complexity.

Subsea developments are relatively young in comparison with conventional platforms. Several systems will reach the end of their design life by 2020. In order for this to be extended, operators will need to demonstrate the integrity of the production system, and also address issues such as obsolescence of the control system and declining reservoir pressure. Subsea separation and boosting will be necessary in order to handle drops in reservoir pressure, and new methods will be essential for extending the life of subsea installations.
THE ALL ELECTRIC SUBSEA STATION

With the introduction of the large electric power consumers required by subsea processes, it will ultimately be possible for the Christmas tree itself to be electrified. This will replace the hydraulic actuators currently used for most functions on the trees. An all electric subsea station will result in simpler umbilicals, as all the hydraulic lines will no longer be necessary.

One challenge is the length of power cables required. AC cables can transmit power for distances up to 100 km, depending on cable type and voltage level. For distances over 100 km, High Voltage Direct Current (HVDC) systems and cables are needed. The HVDC systems available in 2010 are suitable for subsea use.

A handful of highly advanced all electrical subsea systems are anticipated to be online towards 2020, with Åsgard and Ormen Lange leading the way, but extensive uptake will be further into the future.

FROM PASSIVE DATA TO AUTOMATED DECISIONS

Today’s subsea systems contain instrumentation whose primary purpose is reporting on the status of critical components, and for controlling production. These data are today not used for investigating trends or for predicting future conditions. The amount of data available is increasing exponentially, and already there is so much data that a human operator is overwhelmed.

The industry needs higher availability and reductions in the time and costs needed for maintenance and intervention. For this to be possible, improved knowledge on the state of corrosion, erosion, and other degradation mechanisms is essential. Additionally, information on the condition of valves, actuators, and other key components is necessary. Finally, a key issue is smart use of all the collated data and information.

>> These developments will be enabled by greater capacity in communication lines, more sophisticated, cheaper sensors, and more intelligent software systems that can recognize trends and patterns, and that can predict future states through real-time simulation. In other words, a sort of artificial intelligence is necessary to assume the data-handling role currently filled by human operators. Industry leaders will take full advantage of automated decision tools in 2020.

STANDARDISED SUBSEA EQUIPMENT

Many new fields will be smaller and marginal, thus demanding cheaper equipment with shorter delivery times. One solution is standardisation. Pre-designed, standard, approved subsea components will replace the tailor-made solutions of today. In order to decrease delivery times, less reliance must be placed on an extensive design process. Subsea equipment providers will be expected to keep the main building blocks of subsea systems in stock, enabling delivery of a complete system within less than one year, rather than after several years. Delivery of a complete subsea tree would be expected within a few months from ordering.

One challenge is to find the optimum balance between using standard products and meeting field-specific requirements. Another risk lies in the change in business processes, as equipment suppliers would need to produce equipment on speculation, rather than based on a firm contract. This business model will shift some of the financial risk from operators to the suppliers. We expect that by 2020 the majority of the components for marginal fast-track developments will be based on standardised modules.
arctic offshore development – oil and gas activity going north

SEVERAL ASSESSMENTS indicate a large potential for oil and gas production in the Arctic. Although Arctic production today represents only a small fraction of the total and is mainly concentrated onshore, it is expected that offshore Arctic activity will increase, particularly where reserves are located in areas with seasonal or year-round sea ice. The activity will most likely be strictly regulated, with considerable focus on zero environmental impact and reducing the footprint.

INTRODUCTION
The growing focus on Arctic oil and gas exploration has raised the need for adequate standards and industry practices. Equipment and personnel functionality in a cold, remote, and dark situation will present significant challenges that will necessitate the development of appropriate and reliable solutions.

Additionally, the continued focus on environmental protection will mean that regulatory regimes will be tightened, such as shifting from a limited impact towards no impact. Similarly, the functional or performance-based requirements will be maintained and constricted by regulators and class societies, with an expected increase in demand for documentation to prove that demands are being met. It will also be necessary to demonstrate an adequate and increased level of redundancy, escalating the complexity and scope of Arctic operations and production.

WORKING CONDITIONS
Knowledge on working safely in the Arctic is critical for personnel, the environment, and assets. To ensure that people and equipment are able to operate and function as required, focus on winterization will increase. For example, the ventilation challenges for production and drilling facilities may be solved by 2020 by incorporating operational experience.

Maintenance, repair, and operation will be increasingly conducted by remotely operated robots, replacing integrated operations (IO) with remote operations (RO).

MATERIALS FOR THE ARCTIC
Material for the use in the cold climate need acceptable toughness properties, in particular, new high strength steels to prevent brittle fracture. These requirements will be governed by installation operating conditions in arctic areas. Hydrophobic paintings and coatings with insulation, corrosion protection, anti-icing or de-icing properties will be developed for cold climate and that are also tolerant to large temperatures variations.

Light weight structures made of glass fibre reinforced plastic composites, aluminium and other light weight materials may be an option in cold climates. Common is the need for reliable specification and qualification criteria for welding procedures, safe and cost-effective application of materials for hydrocarbon exploration and production in Arctic regions.

11% of the Arctic is now classified under some degree of protection, compared to 6% in 1980 and close to nothing in 1950.

Source: CAFF
**ALL-YEAR ARCTIC DRILLING**

Exploration drilling will continue to be performed during the ice-free, light summer season, but new, submerged, almost autonomous drilling solutions have become attractive, changing the way resources are found, proven and possibly tested. These innovations will not solve mobilisation and intervention of the drilling operation by 2020, but the solutions will require less surface presence, and remote surveillance and control of drilling operations will become possible.

Arctic production drilling requires new solutions that enable year-round operation, pushing for larger rigs that minimise logistical support requirements. Ice management will be incorporated into the overall system reliability by 2020, and use of available rig space will be optimised, whilst maintaining the requirements for material handling and safety. Stricter regulations are expected with respect to regular emissions to air and to sea, and to reduce the possibility of large-scale oil spills.

**EXTREME DISTANCE TIE-INS**

Subsea production from Arctic oil fields will become a reality, even for fields located far offshore, thanks to developments in flow assurance. This has been possible due to advances in control and monitoring of long-distance, multiphase-flow pipelines and improvements in our understanding of the association between pressure drops and a wide range of fluid properties.

Although the challenges of intervention, repair, and maintenance of subsea production facilities, for which surface vessels are still needed, have not been solved, the need has been reduced as subsea and pipeline systems have become more reliable.

Subsea separation and compression will be widely used in more benign waters and have been shown to be reliable solutions that will also be considered for Arctic conditions, especially for deeper waters with heavy ice conditions.

**OFFSHORE PRODUCTION**

Despite the expected advances in long distance tie-ins and subsea production, the need for Arctic surface production facilities offshore will continue as large-scale burial of facilities has not been feasible. This is particularly expected to be true for the shallow, ice-covered waters in the Pechora, Kara, Chukchi, and Beaufort Seas, which will be developed ahead of deeper waters. The foundations for surface facilities will differ from conventional ones by being unique solutions, thus adding to the field development costs, which are expected to be high.

Areas with milder sea ice conditions, such as the Barents Sea and West of Greenland, will see more conventional field development solutions utilising ice management. After 2020, the next step in offshore production could be the burial of the whole production facility below the sea-bed, completely avoiding surface installation in shallow waters.

**OIL SPILL RECOVERY**

The development of several Arctic oil fields has pushed the development of reliable detection, mapping, mitigation and recovery of possible oil spills in ice covered waters. Although there is a continued focus on oil spill prevention, effective spill recovery technologies have been developed. Biological dispersants for cold water will be available and replace chemicals by 2020. A large scale mechanical recovery technology is now available after a collective development by the major oil companies. Both the use of biological dispersants and mechanical recovery has shown to be successful and have been benchmarked in controlled field experiments.

Even though the recovery technology will be available in 2020, prevention of oil spills will still receive much attention from the public, authorities, operators and NGO’s.
unconventional oil and gas – adding price competitive reserves

**INTRODUCTION**

The age of cheap oil is over. Over the last 25 years, for every four barrels of oil consumed, only one has been discovered, and this ratio will probably worsen. Daily world oil consumption is about 85 million barrels (mbd), and oil production is expected to never exceed 95 mbd. Companies are tapping into more costly, lower quality, and more unconventional oil sources. Unconventional oil, e.g. oil sands, comes with severe environmental challenges and is more expensive to extract.

While oil is primarily used for transport, natural gas is dominantly used for power generation. And while unconventional oil will continue to represent only a small part of oil production also in the next decade, unconventional gas is set to change the entire gas market due to its competitive price.

Unconventional gas sources are shale gas, coalbed methane, and tight gas. As natural gas is cleaner both in production and in use, and also more abundant, the demand for gas is expected to grow almost twice as much as for oil and be in the range of 4 trill m³/yr by 2020.

**SOLAR STEAM FOR EOR**

In 2009, 25 % of California’s total natural gas consumption was used for steam production for Enhanced Oil Recovery (EOR). By using EOR, 40 % more oil can be extracted. The same method can also be applied to produce steam for production of oil from oil sands.

Using solar energy instead of gas could provide substantial cost and CO₂ savings. In sunny regions, concentrated solar parabolic trough systems could produce large quantities of steam at a constant price of US$3/MBtu, well below US$5-20/MBtu costs based on natural gas. These systems consist of long parabolic mirrors that focus the solar energy onto a heat transfer fluid. Solar-gas hybrid steam could reduce current annual fuel costs by about 20 %. By 2020 this percentage is expected to increase.

Larger replacements will require efficient thermal energy storage solutions, such as molten salt. Areas for solar steam production might have to compete with solar electricity generation.

**HORIZONTAL DRILLING IN SHALES**

3-dimensional, drilling-bit positioning and mud motors are standard tools that enable directional drilling for up to 10 km. Directional drilling is needed to penetrate and follow geological gas formations effectively, in order to exploit gas from unconventional reservoirs.

In shale gas formations, where horizontal drilling is used the productivity of horizontal wells can be as much as 400 % higher than for vertical wells, but their costs are only 80 % higher.

The Marcellus shale gas formation is, the 2nd largest natural gas field in the world, extends from New York to West Virginia, and holds 14 trillion m³ of gas. (In comparison, the Shitokman gas field in the Barents Sea holds about 3 trillion m³ of natural gas). It is expected that horizontal drilling will be central in the development of this gas formation by 2020.

1000 bar
265 litres/s
are the conditions at which water, sand and chemicals are injected into the rock formation.

---

**Steam from concentrated solar power. Source: Grist.org**

**Horizontal drilling bit for shale gas. Source: Baker Hughes**
HYDRAULIC FRACTURING

Unconventional gas is usually tightly trapped in rock formations, thereby preventing high production rates. In order to achieve commercially viable flow rates, hydraulic fracturing (or fracing) can be used. This method creates fractures in the bedrock from the injection of a highly pressurized fluid (1000 bars). Fracing requires large volumes of water, typically in the range of 21,000 m³ for a single shale gas well. In addition, chemicals to reduce viscosity are injected, and sand to hold the fractures open. Although the industry has used fracing on tens of thousands of wells for the last 40 years, there is concern regarding contamination of groundwater in new shale gas developments. It is therefore expected that public opinion could emerge as the biggest risk.

MOBILE WATER TREATMENT

As the fracing process consumes considerable volumes of water, water recycling and disposal are essential for further unconventional gas production. Many of the production sites are remote and lack water infrastructures. Fresh and waste water are sometimes trucked. Mobile, truck-mounted systems for water treatment are currently being developed and use a combination of electro-coagulation and electro-flotation separation techniques. Water with up to 0.3 kg/l of total dissolved solids, and with particle sizes of less than 1 micron can be treated. The cleaned brine is reused in the fracing process, reducing the amount of water that needs to be trucked by 10-40%.

By 2020, fracing will occur increasingly in more densely populated areas, leading to greater use of this mobile water treatment technology. The adoption of this technology in other water intensive industries is anticipated.

OIL SAND EXTRACTION

Canada’s oil sands are an important source of secure and reliable energy, but there are environmental impacts that demand responsible mitigation. Viscosity of oil sands is about 10 times higher than peanut butter at room temperature. The oil in oil sands is really called bitumen and oil sands gets its name because the bitumen is trapped in a matrix of about 83% sand, 10% bitumen, and a remainder of clay and water. Oil produced from oil sands currently release 2.2 times more GHG emissions per barrel than conventional oil.

The energy and water demand in oil sands extraction is not sustainable—water is a limiting resource in Alberta and conventional energy consumption continues to increase greenhouse gas emissions.

New, lower impact technologies are being explored but need to be proven, demonstrated and applied. Oil sands will become cleaner towards 2020 but will not reach the same environmental footprint as conventional oil extraction.

The Canadian oil sands represent 1.7 trillion barrels of oil equivalent, making it the world’s second largest reserve.
future refineries – pointing to a sustainable future

FUTURE REFINERIES will face a number of challenges including: (1) complying with stricter emissions requirements, (2) maintaining system integrity while processing opportunistic crudes with varying concentrations of corrosive components, (3) processing unconventional fuels, and (4) meeting fuel chemistry targets based on product mix changes. This will lead to the implementation of new processes to utilize CO₂, advanced materials for corrosion resistance, intelligent operations, and secure IT systems to extract the data necessary for making timely decisions. Refineries will also include integrated biorefineries.

INTRODUCTION

In 2009 there were 661 refineries worldwide, with a combined capacity of 87 million bbl/d. These refineries contribute almost 6% of the annual global stationary CO₂ emissions. By 2020, 47% of refinery capacity additions will be in the non-OECD Asia-Pacific region and 22% in the Middle East. In Europe and North America, there will be consolidation and plant improvement, with debottlenecking, improved efficiency, and reductions in emissions. In Europe, demands for middle distillates, such as diesel and jet fuel, has increased, with a concomitant decrease in the share of gasoline.

This trend is expected to extend to other parts of the world. South America will need additional refinery capacity to process new heavy oil discoveries and additional downstream petrochemical facilities to add value to the crude oil. These changes in supply and demand, combined with stricter emission requirements, increase the need for refineries that are able to operate dynamically.

UTILISATION OF CO₂

Utilisation of CO₂ in refineries will take three basic forms: 1) direct implementation of CO₂ in processes, 2) use of CO₂ as a feedstock for production of fuels and chemicals, and 3) use of CO₂ in producing biomass, which is then converted to fuels and chemicals in various ways.

Insertion of CO₂ into organic molecules, such as epoxides, to produce polymers is being developed by several companies. Dry reforming of methane, using CO₂ instead of water to produce a variety of hydrocarbon fuels, was developed almost three decades ago, but is being revitalised through new catalysts and process improvements.

CO₂ has also been used in the production of methanol, syngas, ethylene, and formic acid through thermochemical and electrochemical processes. These processes will be combined in a variety of ways that are tailored towards the needs of specific refineries.

INTEGRATED BIOREFINERIES

Integrated biorefineries that produce both fuels and chemicals, replacing petrochemicals, will become increasingly attractive as a way to utilize CO₂ and to avoid using fossil fuels as feedstocks. The biorefineries currently processing ethanol or biodiesel are simple, single-product systems.

However, it is now apparent that biomass can be used not only to make fuels, but also other chemicals. Furthermore, biomass can be thermally converted to syngas or formic acid, which are then feedstock for drop-in hydrocarbons (also called renewable hydrocarbons), which are indistinguishable from those made in conventional refineries.

Finally, biorefineries will incorporate a number of processes that will use wastewater and CO₂ to manufacture unique chemicals that are not accessible to conventional refineries. For example, bio-char, a residue from thermal processing, is nutrient-rich and can be used as fertilizer.

Increasing refining capacity will come in developing countries.
INTELLIGENT OPERATIONS

Refining companies use several simulation, analyses, control, and optimization technologies for operating and maintaining their plants. These include process simulation and modelling software, linear programming models, advanced process control and real-time optimization tools, and plant historians that are used to capture and store large amounts of continuous real-time data streams from plant sensors into a database for real-time and future analysis.

The current stand-alone auto-mated forecasting and control approaches in refinery operations will be increasingly integrated in the future. Plant-wide process modelling tools will be joined with other information systems, such as plant historians. Such plant-wide process modelling tools will enable the plants to:

- Be highly flexible, producing “greener” products demanded by the marketplace from more variable-quality feedstock.
- Help operate the refinery more reliably, safely and cost-effectively and to remain compliant with increasingly stringent environmental mandates and legislation.

ADVANCED MATERIALS

Maintaining plant integrity under varying crude chemistry conditions will require more corrosion resistant materials. New process chemistries that utilize non-crude feedstock will necessitate development of materials that are resistant to corrosion in a different range of environments to those encountered in current refineries. Advanced Ni-base alloys and high temperature coatings will be further developed to improve their high temperature oxidation resistance and their corrosion resistance to various acids in alkylation processes. Chromium and aluminium-containing Ni-base alloys and coatings that resist metal dusting will be introduced.

Composite materials are often problematic in refineries due to concerns related to their lack of resistance to hydrocarbons, their potential for contaminating the product stream, their poor fire safety, and their electrostatic charge build-up. Research in nano-composite materials to improve fire resistance, reduce hydrocarbon permeability, and improve electrical conductivity will yield another class of materials for the designers of future refineries.

Composites embedded with sensors, such as optical Bragg grating fibre sensors for detecting mechanical strains, will enable real-time monitoring of piping systems throughout the plant. Self-repairing materials, for example embedded with hollow microspheres containing epoxy pre-cursors, will enable components to withstand local damage temporarily, while permanent repair or replacement of parts is organised. Specialised, oxide and nitride coatings will be available for increased resistance to wear and corrosion in various refinery units.

LIQUID PRODUCTION IN 2020

Change in projected world liquid production in 2020. Source: EIA 2010

SENSORING

Wireless sensors placed in a refinery terminal storing fuel grade ethanol.
Gas-fired power plants – from transition to ultimate solution?

THE DISCOVERY and exploitation of unconventional gas sources, such as shale gas and coalbed methane, have resulted in revitalisation of gas as fuel for electricity generation. Gas used to be described as a transition towards a low carbon economy. Nowadays, gas is mentioned as the ultimate solution by many oil and energy companies. The continuous development and improvement of gas-fired power plants towards 2020 will result in plants with higher efficiencies and lower emissions, but radically new designs are not expected.

INTRODUCTION

Gas-fired power plants mainly consist of either of two configurations; combined cycle (gas turbine (GT) – steam turbine) and simple cycle gas turbine plants.

Gas-fired power plants currently provide about 20 % of the world’s electricity production, corresponding to 4 trillion kWh. Global energy consumption will increase towards 2020, and gas is at the least expected to maintain its relative share. The result will be an annual increase in power generation from natural gas of 2.1 %, corresponding to 15 GW of added capacity per year over the next decade. Changes in policy and market conditions could increase this figure further.

Power generation from coal releases 60 % more CO₂ than gas per kWh. Tougher regulations regarding CO₂ emissions towards 2020, combined with abundant gas reserves due to shale gas and coalbed methane, and new gas pricing regimes may result in gas increasing its relative share.

40-50 new gas-fired power plants will be added every year in the next decade.

GAS TURBINE TECHNOLOGY

The combined cycle (CC) power plant ((GT) and steam turbine) is today’s predominant gas-fuelled power plant configuration. It is expected that, on a 10 year horizon, the majority of new power plants will use this conventional technology. The latest technology shows net power efficiencies of up to 60 % for CC plants and 45 % for simple cycle plants at steady state conditions.

Both these efficiencies are expected to increase slowly in the coming 10 years, due to additional improvements and optimisation of clearance, higher turbine inlet temperature, and improved part load efficiency. It is also expected that government regulations will further drive NOx and CO₂ emission reductions from simple cycle and CC power plants. This will require optimised emission control combustion systems in addition to these improvements to the actual turbine.

NEW MATERIALS

In order to achieve higher efficiency, a higher turbine inlet temperature is desired. But to improve the temperature capabilities, new materials are needed. High temperature, low conductivity ceramic coatings are being developed by several manufacturers to meet this challenge. Temperatures over 1600 °C are well above the melting point of the metallic substrate and require highly reliable coatings. New ceramic materials also reduce the need for cooling.

The main disadvantages are the high costs and the brittle material properties. New types of superalloys can also be used to improve temperature handling capabilities. However, significant manufacturing challenges must be solved in order for these to be commercially viable. Modular components can be used, such that expensive materials are only used in those areas where they are absolutely essential.

MARKET OUTLOOK

Combined plant efficiency in %

2007 2015 2020

Renewables Natural gas Nuclear Coal Liquids

25 20 15 10 5 0

Combined plant efficiency in %

65 60 55 50 45 40

Gas turbine combined cycle Super-high temperature gas turbine

Turbine inlet temperature in °C

1100 1300 1500 1700

Gas fired plants produce about 20 % of the World’s electricity. Source: UEA 2010

A continuous drive towards higher efficiencies. Source: mhi.co.jp
ALTERNATIVE FUELS

Fluidized bed combustion and Integrated Gasification Combined Cycle (IGCC) are two interesting future technology options that allow the use of alternative fuels, such as biomass. They also permit wider use of poor quality coal or heavy oil with higher sulphur content, allowing for reduced emissions. For fluidized bed combustion, the conventional GT combustor is replaced by a fluidized bed combustor.

Challenges in development are related to corrosion and erosion.

The IGCC gasification process removes impurities that would otherwise cause corrosion in the turbine and also removes sulphur, which would produce polluting oxides in the flue gases. IGCC has been under development for several decades, and it has been predicted that its efficiency could be increased up to 48%.

The IGCC is more complicated and has more components than conventional gas turbines, and therefore reliability is a key challenge.

COMPRESSED AIR ENERGY STORAGE (CAES)

CAES will emerge as a viable alternative to pumped hydro for bulk energy storage. CAES is, essentially, a gas turbine in which the compression and expansion train have been decoupled. The compressor is driven by an electric motor during periods of low electricity cost, and the compressed air is stored in an underground cavern.

During high price periods, the air, together with fuel, is released to a combustion chamber, which then drives the expansion turbine. CAES uses less than half the fuel of an open cycle gas turbine, and has a much higher part load efficiency. However, only two CAES plants have been built to date.

Further development of turbo-machinery and plant design is necessary to improve efficiency and lower capital costs. Ultimately, the storage of waste heat from the compression cycle could remove the need to burn fuel, thereby reducing CO2 emissions to zero.

CO2 CAPTURE

The application of CO2 capture and storage (CCS) to Gas Turbine Combined Cycle (GTCC) will probably not occur on a commercial scale before 2020. The indisputable challenge of this technology is the lower energy efficiency due to unfavourable thermodynamics. Adding CCS to a CC plant also considerably increases cycle complexity. The most likely technology option is capture of CO2 after combustion, whereas pre-combustion with hydrogen turbines or oxy-combustion need more research and are anticipated as being longer-term options. Some R&D on these two latter alternatives is in progress and will continue in the period up to 2020. Although the most promising option up to 2020 and beyond is post-combustion CCS, there are several integration uncertainties that must be addressed, such as flexibility and how it might affect ability to cycle might be affected.

Uptake of CO2 capture technologies is policy-driven.
coal-fired power plants – still the largest electricity producer in 2020

COAL-FIRED POWER PLANTS will continue to hold the most important share in the global power mix. The main challenges with this power source are efficiency and emissions, especially of CO$_2$. More efficient, supercritical and ultra-supercritical power plants will reduce emissions by up to 17%, and will be the predominant technology for new plants. In climate conscious scenarios, biomass co-firing will be used in those regions with high availability of biomass. Integrated Gasification Combined Cycle offers the possibility of reducing other emissions, but will not take-off before 2020.

INTRODUCTION

By 2020, global energy use will increase by 19%. For the electricity sector, coal will maintain its share of almost 40%.

For decades, the coal-fired power industry has been working at improving efficiency; the main driver has been reducing fuel costs, but in more recent years, CO$_2$ emissions have also been a major concern. However, the influence of this driver is highly dependent on the scenario.

Another challenge associated with thermal power production is water consumption, mainly for cooling, especially in areas with water scarcity.

40% of electricity will come from coal - also in 2020.

SUPERCRITICAL AND ULTRA-SUPERCRITICAL PLANTS

Pulverised coal combustion (PCC) is the predominant technology for generating electricity from coal and accounts for more than 97% of capacity. Most existing plants operate at subcritical conditions, with the best examples reaching 39% electrical efficiency.

For more than 50 years, it has been known that operation at much higher steam temperatures and pressures (in the range of 600°C and 240-300 bar), called ultra-supercritical conditions, can increase efficiency by at least 8%. This increase in efficiency can reduce CO$_2$ emissions by 17%.

However, the challenges are limitations in material strength and corrosion resistance. In the last two decades progress has been made, and plants use a variety of materials for different sections: ferritic stainless steels, containing 9-12% chromium along with small concentrations of niobium, tungsten, vanadium, and molybdenum, are used for thick section piping due to their high creep strength; austenitic stainless steels and nickel-base alloys containing high chromium are used where steam-side and fire-side corrosion are expected.

Components with solid Ni-base alloy containing over 30% chromium are difficult to manufacture due to brittleness. Increased use of chromium and aluminium coatings, which promote the formation of chromium and aluminium oxide films as coatings or claddings, will be explored in the future.

Comparison of emissions of SO$_2$, NO$_x$, and PM between IGCC and super critical coal-fired power plants. Source: NETL.
INTEGRATED GASIFICATION COMBINED CYCLE

A different way of producing electricity from coal is via the integrated gasification combined cycle (IGCC). This process has been developed to increase efficiency and reduce emissions.

In this process, a syngas, comprised mainly of CO and H₂, is generated by partial combustion. The syngas is cleaned before being burned in the combustion chamber of a gas turbine. Thus, compared with PCC plants, IGCC has lower emissions of many pollutants, including particulates, SO₂, and NOₓ.

Electricity is produced by a combined cycle of gas and steam turbines. The capacity of existing plants lies in the 250-300 MW range, and their net efficiencies are between 40-43 %. Challenges related to IGCC include concerns about capital costs, as well as availability and reliability.

BIOMASS CO-FIRING

One relatively rapid way of reducing CO₂ emissions from coal-fired power plants is using biomass. Co-firing in existing pulsed fuel boilers can be more profitable than building a new plant that is designed to use 100 % biomass.

Co-firing is not without problems, as there are large variations between different types of biomass regarding particle size and content of fibre and oversized particles.

A decrease in power output is also associated with co-firing, and the proportion of biofuel that can be used in fuel blend is limited. However, it is clear that although the reduction potential is limited, this can be an attractive option in certain regions, compared with many of the alternatives.

ADVANCED COOLING

A subcritical PCC plant consumes 2-3 m³ water per MWhe, with the exact amount dependent on the type of cooling system and the efficiency of the turbine. Adding CCS will result in the volume of water required being doubled. Of the coal-fired power plants in US, India, China, and Europe, 60-70 % are located inland, where water scarcity will be an increasing problem.

One approach to reducing water consumption is replacing the common evaporative cooling towers with dry cooling towers, which are cooled only by air. However, as dry cooling only can cool down towards air temperature, rather than to the dew point for evaporative cooling, plant efficiency is decreased. In addition, dry cooling systems must be larger, which increases the cost.

A breakthrough in cooling is needed to ensure the long-term viability of coal-fired power plants.
carbon capture and storage — an opportunity for reducing emissions

**INTRODUCTION**

The technologies needed for capturing CO₂ from combustion gases are commercially available today. However, they require substantial energy inputs for operation (25-30% of the energy produced by the power plant) and still need to demonstrate their feasibility at larger, commercial-scale for CCS deployment. It is therefore anticipated that there will be intense activity up to 2020, aimed at analysing and optimising CO₂ capture solutions. This will be based on experience gained from 15-25 demonstration projects that are under development at locations on all continents, with the main focus on amine absorption technologies, chilled ammonia absorption, and oxy-fuel combustion.

New and emerging CO₂ capture technologies will require longer development and demonstration programmes, and these will progress for multi-functional membranes, chemical looping combustion, and fuel cells integrated into power plants with CO₂ capture.

**AMINE SCRUBBING**

This strategy targets removal of CO₂ from exhaust gases, and is fundamentally limited by the fact that the concentrations of CO₂ in exhaust are low, and large volumes of other gases must be separated in order to achieve overall efficiency.

After 50 years of commercial application in natural gas streams, CO₂ capture by amine absorption and stripping with aqueous monoethanolamine (MEA) are the leading technologies for separating CO₂ from combustion gases.

**GAS SEPARATION BY MEMBRANE**

The CO₂ capture energy penalty can be lowered by reducing the amount of associated gases in the system. One strategy for this is to remove nitrogen from the air before combustion.

The cryogenic air distillation process has been commercially available for decades, but its high cost is a limiting factor. An alternative option is to separate gases using specialized membranes. This can be applied either before or after combustion or in other innovative ways, e.g. to produce and separate hydrogen. The combustion products are water vapour and CO₂, requiring simple dehydration to produce a relatively pure CO₂ stream.

Many technological developments have addressed the challenge of multi-functional membranes, and the common challenge is scaling up the membranes to produce noteworthy separation rates. Qualification and verification will be essential to bring these up to the scale required.

A semi-permeable membrane simplifies the CO₂ capture.

CCF plants produce more CO₂ but dispose up to 90%.

Captured CO₂ and O₂ require simple dehydration to produce a relatively pure CO₂ stream.

AMINE SCRUBBING — some at prototype scale — in the period to 2020. Captured CO₂ will require new infrastructures for transport and permanent storage. For some regions, Enhanced Oil Recovery may provide a viable business model to justify these investments.

Amine scrubbing will be a fully matured technology by 2020.

**NET EMISSIONS BENEFIT**

**MEMBRANE GAS SEPARATION**
CO₂ pipelines are a mature industry in North America, currently spanning more than 2500 km in sparsely populated areas, where about 50 megatonnes of CO₂ are transported annually from natural sources to EOR projects.

Likewise, cold, slightly pressurized, ship transport of gases has been a commercial industry for decades. However, both these industries need to scale up their activity globally by a factor of 100-1000 if a significant fraction of the stationary, large CO₂ emission sources are to be upgraded to implement CCS. This presents new challenges in terms of cost-effective risk management of high-pressure CO₂ pipelines, some of which will be sited near populated areas.

Radically scaled-up CO₂ shipping concepts are under development and these will stretch current methods of risk management.

STORAGE SITE QUALIFICATION AND MONITORING

Over the next 10 years, CCS project developers will strive to identify appropriate storage sites that provide confidence in storage permanence.

Many sites will be in saline formations, where data coverage is relatively sparse. Thus, there will be a growing need for specialist services related to mapping, modelling, and characterizing storage site performance, including uncertainty and risk management of the whole site qualification process.

When storage sites have been qualified and injection has begun, the sites will be monitored in various ways to ensure that they perform as expected and required.

An emerging monitoring technique is surface displacement mapping. This technique can identify net changes in the order of 1 mm movement per year, which is the order of magnitude of surface movement caused by sub-surface CO₂ storage.

We expect that CCS will be part of the Clean Development Mechanism in 2020.
Although fossil fuels will continue to dominate, the next decade will constitute the start of a transition towards a low carbon economy. In the greenest scenarios, a host of new technological solutions related to existing renewable energies and nuclear power will come into play.

Some of these could dramatically boost performance and efficiency, making cleaner energies economically viable.
Wind energy 62
Onshore wind turbines will not increase in size, but they will be smarter. Offshore turbines, however, may increase from 3MW to 10MW, but what are the new solutions that will be necessary for managing access and maintenance?

Solar heat and power 64
New developments, e.g. in thin-film photovoltaics or in solar arrays, will offer cheaper solar power. Will efficiency improvements and reduced production costs mean a break-through for solar energy?

Biofuels for the future 66
Gasification of biofuels offers flexibility regarding feedstock product, but suffers from high capital costs. What are the technical solutions and how will the challenges regarding pipelines and storage of biofuels be met?

Geothermal energy 68
Enhanced Geothermal Systems have the potential to deliver low-emission energy at a manageable price, but depend on complex and deep drilling to access the heat of the Earth. Which technologies will make this possible?

Nuclear energy 70
Life extension, safe operation, advanced reactor designs, and solutions to nuclear waste disposal are all key issues. Will small modular reactors result in expansion in the use of nuclear power for remote or mobile applications?
wind energy
– onshore and offshore in different directions

WIND ENERGY started onshore, and the turbines currently used offshore are modifications of the onshore versions. In the next decade, the technology trends onshore and offshore are expected to become significantly different. Whilst the size of onshore turbines will remain in the 3 MW range, offshore turbines will increase to 10 MW. Onshore turbines will probably be tailored for each specific location/terrain, while offshore turbines will be installed further from shore, requiring new solutions with respect to access and maintenance.

SMART BLADE DESIGN

Wind turbines use blades that can be twisted (pitched) to suit the wind speed and to maintain the desired output. The pitch action requires feedback from a controller and activation by actuators. Faster responses could be obtained if the blade itself were to twist when the loads on it increase. By designing the turbine blades with some degree of sweep (like a curved sword), this can be possible.

Another solution is to orient the carbon fibres in the blade so that it twists slightly whenever it is bent. It is also possible to design “smart blades” with active controls, i.e. blades that change their aerodynamic properties according to the measured loads.

More sophisticated blade designs are anticipated within the next ten years. The challenge will be to prove that new designs, with limited field history, function satisfactorily over the operating life of the installation. Key aspects will be robustness and fatigue strength.

ADVANCED CONTROL SYSTEMS

Optimum control is key to smooth and safe running of a wind turbine. The control system has to know when to start, to stop, and to yaw, and how much to pitch the blades to maximise energy output and to minimize loads.

The latest control systems can measure the loads in each of the blades, and are used to smooth out loads due to turbulent winds. The same measurements can be used to calculate fatigue effects and can shut down the turbine if damage is critical. The data can also allow the operating strategy to alter to maximize energy capture.

Operating individual wind turbines in wind farms with different operating rules requires smart sensor technology and complex control algorithms. Improved data transfer capabilities and decision support systems will enable centrally located control centres to optimise the operations of the wind farms.

INTRODUCTION

Wind energy, as it is known today, started onshore. Turbine capacity is typically in the range of 2.3–3 MW, limited by the size (width, height, and length) that can be transported by truck. Onshore applications have probably reached their maximum size, and future turbines will not be significantly larger. They will, however, be smarter, and may be tailored for each specific location. Today’s offshore turbines are basically slightly modified onshore versions.

Towards 2020, two different trends will emerge in offshore wind power. Turbines will increase in size, with 10 MW turbines probably in operation by 2020, and they will be installed further from shore. For example, the average distance from shore for wind farms installed in Europe in 2009 was 12.8 km, while the Dogger Bank wind farm is located 125–195 km from shore. In USA and China, wind farms located far from shore will probably be in operation by 2020.

Chinese offshore wind capacity may reach 22.8 GW by 2020.

Source: Bloomberg Businessweek

Most studies underestimated the growth of the wind industry.

Source: DNV

Offshore turbines are expected to grow in size.

Source: EWEA and DNV
NEW FIXED AND FLOATING OFFSHORE FOUNDATIONS

At present, offshore wind turbines are limited to shallow water (20-30 m water depth), and most use a single, tubular, monopile foundation. For deeper waters, various “jacket” structures that comprise several footings and are similar to (but smaller than) offshore oil and gas installations, will be developed. Optimised platform types and better understanding of loads and foundation design, will increase the viable water depths to about 50 m.

Towards the end of the next decade, floating platforms will be used for wind turbines, enabling them to operate in almost unlimited water depths and where winds are best. Prototypes are being tested and several concepts are on the drawing board. One challenge of moving onto floaters is the need for complex dynamic cables to enable connection to the grid.

Offshore wind could supply 25% of the UK’s electricity demand by 2020.  

Source: Carbon Trust

DIRECT DRIVE

Most turbines use a gearbox to increase the rotor speed of the electric generator. Gearboxes are prone to failure and increase the weight of the turbine.

A number of manufacturers have replaced the gearbox with a single, large-diameter generator which, combined with a converter, can be connected to the grid. This approach is not without its own challenges, and both the cost and weight of this option currently exceed the more conventional design with a gearbox. However, this approach is very promising, particularly if permanent magnets become cheaper and more powerful, lighter materials are introduced, and converters become more versatile.

Direct drive options will become cost-competitive towards 2020, and are likely to become the dominant drive type for all sizes of wind turbines.

As floating wind turbines require deep waters for the connecting /mating of the nacelle to the support structure, using floaters will require new installation methods.

However, several areas with high potential for floating offshore wind, i.e. US and Asia, only have shallow water close to shore, and therefore either the mating operation will have to occur at site, requiring complex and costly offshore operations, or a completely different way of installing the turbines must be developed.

One new concept is to transport fully assembled turbines horizontally, on a barge, from the fabrication yard to the offshore site. Once at site, the barge tilts 90 degrees through a ballasting operation, to release the turbine in a vertical position. Provided that challenges related to up-ending and release of turbines are resolved, horizontal installation of complete turbines will be commercially available by 2020.

Developments like Dogger Bank will require new solutions to operation and maintenance. Source: EWEA, DNV
solar heat and power – solar in “the wind”

SOLAR POWER has been relatively expensive, but the development of thin-film photovoltaics (TFPV) means that production costs will drop to US$0.2/W by 2020. This will drive solar roof installation from 10 million in 2009, to 100 million rooftops by 2020. Also, crystalline PV, currently enjoying 80-90 % market share, will increase its efficiency to an estimated 32 %. Solar variations, e.g. day and night, can be bridged by concentrated solar power systems. Passive solar building design can decrease energy costs for heating, cooling, or lighting by 20-50 %.

INTRODUCTION

Solar systems are mainly applied to electricity supply and, to a lesser extent, warm water production. Solar power has been traditionally labelled as too expensive to scale up to have an impact on the overall energy economy.

New developments, e.g. in thin-film photovoltaics (TFPV), or in solar arrays will offer cheaper solar power. Currently, the best solar PV installations in sunny environments produce enough energy to “pay back” the energy required to make them in less than a single year. It is expected that the solar energy industry will show the same exponential growth pattern in the next decade, as the wind industry has demonstrated during this decade.

Future developments will mainly focus on efficiency improvements of photovoltaics (PV) and reducing production costs. By 2020, the market share of solar energy will have a significant impact on regional energy production.

THIN-FILM PHOTOVOLTAICS

TFPV are considered a disruptive technology for traditional PV. The production costs of TFPV are falling and will reach grid-parity in selected markets before 2015. TFPV production costs are predicted fall from their current level of US$0.7/W, to US$0.2/W over the next decade.

TFPV technology involves depositing thin films of either CdTe, CIGS, or Si on a substrate, using chemical vapour deposition or printing methods. Many of these PV materials are subject to shortages. In the sunniest areas the levelized cost of electricity from TFPV systems is about US$0.15/kWh, before subsidies. This is far below spot electricity prices and comparable with the electricity from nuclear power. TFPV panel production is projected to grow by 24 % annually, reaching 22 GW/yr by 2020. Long-term reliability, initial degradation, and seasonal variation are some of the TFPV challenges.

CRYSTALLINE SILICON PV – CHEAPER AND MORE EFFICIENT

Cr-PV, the workhorse of the solar industry, has approximately twice the efficiency per unit area than TFPV (i.e. 19 % vs. up to 11 %), but at a higher cost of about US$1/W compared with US$0.75/W.

The main technological challenge is increasing PV efficiency while reducing production costs. Whereas laboratory PV already shows an efficiency of more than 40 %, an increase in commercially available PV efficiency of up to 30 % may be expected by 2020. The one major technological obstacle for cr-Si, is the need to replace sawing of Si ingots in order to create wafers. This step is time-consuming and wasteful, with only about half the Si able to be used.

During the next decade, an increase in cr-PV solar-powered mobile devices (e.g. phones or self-powered sensors) is expected, and also greater use of concentrated PV, as they are more heat tolerant. Note that PV also produce electricity in conditions of diffuse sunlight.

PV efficiency of 30% may be expected by 2020.
Source: EPIA

$ / kWh

Further drop in production cost is expected.

Commercialisation lags 10-20 years behind research prototypes.
Source: NREL
CONCENTRATED SOLAR POWER

If energy is needed from a PV system at night or in other low-light situations, storage is required. By using thermal storage technologies, such as molten salts, CSP can produce energy when the sun is not shining. CSP uses mirrors in various configurations to concentrate direct sunlight (factor of 100-500) onto a small area, ultimately resulting in production of steam and driving of a steam turbine.

In 2010, about 800 MW of CSP power plants had been installed worldwide, with up to 13000 MW of capacity at some planning or permitting stage. Key issues for CSP are the requirement for as much cooling water as fossil fuel power needs, and the necessity for direct sunlight. This means that CSP is of limited relevance for Southeast Asia, where light is diffuse due to air pollution and weather patterns.

BUILDING INTEGRATED SOLAR

The permitting phase takes time and can be a limiting factor for building a power plant. Building Integrated Solar (BIS) power can reduce overall costs and help in meeting land-use limits or aesthetic objections. PV roof tiles are examples of such BIS. In 2011, solar shingles that integrate amorphous-silicon or CIGS TFPV into conventional materials and polymer roofing shingles will be available. As the solar system is installed during the initial shingle installation, or inevitable roof replacement, the installation costs are low. “A million solar roofs” in the 1990s became “10 million” in 2009, and may evolve to “100 million solar roofs” by 2020.

A market is emerging for 2nd party agreements between owners of large roofs and installers/owners of rooftop solar facilities. This may further accelerate BIS development. BIPV tend to have significantly higher operating temperatures, which means efficiency could be lower than in a free-standing system.

SOLAR WATER HEATING AND PASSIVE SOLAR

Solar PV and Concentrated Solar Power systems have high capital costs. Solar Water Heating (SWH) and passive solar heating in buildings are cheaper, simpler technologies. Passive solar heating concepts combine heat transfer, climatology, and architecture to minimise the energy use by a building, and can reduce the cost of heating by 20-50%.

The current global capacity of SWH is about 100 GW (thermal), which has been estimated to save about 748 million barrels of oil equivalents annually in heating. Indeed, in sunny regions where electricity is expensive and there is a medium-long heating season, SWH can have a payback time as short as 5 years. Global installations of SWH will probably grow to 600-1000 GW (thermal) by 2020.

Commercialisation lags 10-20 years behind research prototypes.

Source: NREL

SOLAR INTEGRATED INTO BUILDING

Solar shingles mounted onto rooftop.
Source: UNI-SOLAR®

SOLAR WATER HEATING

Rooftop mounted water heater.
Picture: Julian
biofuels for the future – a sustainable option for transport fuel

BIOFUELS are a sustainable option for transport fuel. First generation biofuels in use today will start to be replaced by second and third generation biofuels over the coming decade. For second generation biofuels, gasification offers flexibility with regard to feedstock product, but suffers from high capital costs. Lignocellulosic ethanol widens the spectrum of feedstock for ethanol production, though freeing the sugars for fermentation is difficult. Algae, a third generation biofuel, are affected by several challenges and therefore will not have entered the market widely by 2020.

INTRODUCTION
Biofuels are one option for sustainable transport fuels. First generation biofuels, based on fermentation of starch and sugars, are well-developed. However, further implementation is hindered by lifecycle carbon emissions, indirect land-use changes, and deforestation. Thus, technologies that can utilize other feedstocks, such as wood and agricultural wastes, have been developed. These are known as second generation biofuels.

Two main production routes exist for second generation biofuels: gasification and fermentation. Although the basic technology exists, profitable production of biofuels has not yet been proven feasible.

In order to commercialise biofuels, policies must be in place to improve their cost competitiveness compared with fossil fuels. Therefore, technology uptake is highly dependent on scenario.

GASIFICATION – LIQUID AND GASEOUS FUELS
Gasification is an established technology that uses heat to convert biomass to a syngas that consists mainly of carbon monoxide and hydrogen. Gasification allows for the use of a wide variety of feedstocks. The syngas produced can then be processed further into a large number of different products, both liquid and gaseous fuels. These fuels are essentially indistinguishable from the corresponding petroleum-based fuels.

In the production of liquid fuels, Fischer-Tropsch (FT) is the dominant process. The CO and H₂ react in the presence of a catalyst to form hydrocarbons, with the end product determined by the choice of catalyst. A key challenge is to produce a gas that is sufficiently clean for further synthesis.

The syngas can also be processed further to produce gaseous fuels. It can be methanised and used as Biosynthetic natural gas (SNG) in the current infrastructure. The process is strongly exothermic, so efficient recovery of the reaction heat is essential for any industrial production. Hydrogen can also be produced from the syngas using water-shift reactions and CO₂ removal. One advantage is the production of a carbon-free fuel, whilst a disadvantage is the need for a dedicated infrastructure.

The thermochemical route for biofuel production through gasification offers considerable flexibility regarding feedstock as well as products. The main drawback with gasification technology is the high capital costs, and thus the need for a large-scale plant in order for biofuel production to be economically feasible. However, the size is limited by inbound biomass logistics. An oil price of US$100-130/bbl is required for FT-diesel to be competitive by 2020.

Biofuels can generate US$ 230 billion and create over 800,000 jobs by 2020.  
Source: World Economic Forum
**LIGNOCELLULOSIC ETHANOL**

The sugar molecules required for fermentation to produce ethanol are not readily available in lignocellulosic biomass. They need to be made available using pre-treatments including steam heating, acid hydrolysis, and enzymes.

One motivation for developing this technology is so that non-food biomass can be used as feedstocks. The main challenge in the process is the pre-treatment, i.e. freeing the sugars. Pre-treatment optimisation is necessary before the full potential of this technology can be realised. With sufficient investment, a breakthrough can be expected by 2020.

In this process, ethanol is only one of the products. The major by-product, lignin, can be used to produce heat and power. Efficient use of all the products is necessary in order for the process to be economically feasible.

**ALGAE-BASED FUEL**

Algae convert CO₂, wastewater, and sunlight into biomass. The potential exists for algae to utilise CO₂ from industrial sites and nutrients in wastewater, and convert these into biofuels. Algae can contain up to 50 % oil. The algae are cultivated in large, open ponds or photobioreactors.

Current technology developments focus on harvesting (water removal) and reducing capital investment costs. Investors recognize that algae have considerable potential, with biofuel as one potential product, along with special chemicals. Significant focus is being directed towards developing technology to enable utilization of the entire feedstock.

Challenges include energy and water consumption, capital costs, operational costs, and lead time to commercial rollout. The uptake of algae will increase gradually during the decade, but will not constitute a major part of the fuel mix by 2020.

**PIPLEINES AND STORAGE**

In order to deliver large volumes of biofuel to the end users, pipelines and storage infrastructure are needed for transportation, blending, and distribution. For ethanol, pipeline concerns include stress corrosion cracking of steel, swelling of seals, and reaction with other residues in the pipelines.

Research over the last five years has largely addressed these concerns. Chemical inhibitors have been shown to be effective in preventing stress corrosion cracking and non-swelling gaskets are available. Butanol has not shown any tendency to cause cracking of steel. Biodiesel is generally incompatible with transport of jet fuel along the same pipeline.

Biodiesel does not cause cracking of steel, but could cause corrosion. Renewable diesel, which is essentially indistinguishable from petrodiesel, may not cause corrosion.

**Algae could deliver 6 - 10 times more energy per hectare than conventional cropland biofuels.**

*Source: Carbon Trust UK*
geothermal energy – offering baseload power anywhere

GEOTHERMAL POWER generates already gigawatts of electric power at sites near “hotspots” in the Earth’s crust. Also, smaller geothermal installations use heat pumps to recover heat from shallow zones in most regions of the world. Expanding the number of viable geothermal sites by targeting deep, hot zones represents an enormous potential. These Enhanced Geothermal Systems (EGS) depend on more complex and deeper drilling. The energy potential for EGS however, is far beyond current energy consumption, and can, in contrast to other alternative energy sources, provide baseload power – potentially at a manageable price.

INTRODUCTION

Enhanced Geothermal Systems (EGS) promise to liberate the geothermal sector from its current dependency on the limited number of the Earth’s “hotspots” near existing electricity grids. The technology strategy is to create an artificial, sub-surface heat reservoir/exchanger by hydraulic fracturing (fracing) the hot dry rocks several kilometres below the surface, and injecting water through the sub-surface network of created fractures.

A production well will recover the heated injectate (usually water) and direct it to the surface facilities for generating steam to drive a turbine. EGS have the potential to become available in most areas, and to be cheaper than new nuclear power plants.

High initial costs and induction of earthquakes during the fracturing phase have been identified as the main risks.

Geothermal energy is principally available everywhere at 9 km depth.

SPALLATION DRILLING

Drilling and well construction represent 40% of the development costs for a typical geothermal plant. These costs rise up to 60% for an EGS plant. Spallation drilling technologies are being developed to decrease the costs of drilling in hard, igneous and metamorphic rock.

Spallation drilling starts by applying focused lames, lasers, or superheated fluid to a rock surface in order to expand the crystalline grains within the rock. When the grains expand, micro-failures are created in the rock. Small particles, known as “spalls”, are ejected, and hence the name of the technology. Spallation drilling is accelerated by various factors, such as inherent stress in the rock. Generally, spallation drilling requires that energy is transferred to the bit in forms other than by using hydraulic pumps at surface.

By 2020, spallation drilling could make EGS available at depths of 9 km, making the concept viable anywhere.

INTER-WELL CONNECTED EGS

The fear of earthquake induction during fracturing of the reservoir can jeopardise an EGS project. Inter-well connected EGS replaces the fracting process with a drilling solution that creates a set of interconnected wellbores from at least two surface locations that intersect at the level of the thermal reservoir. This forms a full tubular heat exchanger at the level of the thermal reservoir, and has the added benefit of minimizing water losses in the reservoir.

The capital costs are higher than for traditional EGS, but the risks related to induction of earthquakes and water losses are controlled. A Norwegian company has received public funding for a demonstration project in the Oslo area for 2011. The intensity of drilling and the complexity of downhole operations, and therefore subsequent failures from this concept, are major risks.
KALINA POWER CONVERSION CYCLE

As more lower-temperature geothermal sites are considered for development, the use of efficient low temperature thermodynamic cycles becomes necessary. The Kalina cycle, invented in the 1980s, uses a 2-3 component working fluid mixture to convert heat energy into mechanical power that can be used to drive an electric generator. Since the phase change, from liquid to steam, is not at a constant temperature due to being a mixture, the temperature profiles of the hot and cold fluids in a heat exchanger can be made closer, increasing the global efficiency up to 50% at lower temperatures (down to 80-100 °C) compared with steam cycles or organic Rankine cycles. Therefore, this approach is also being used to recover waste heat at larger industrial plants.

The use of ammonia or organic chemicals in the mixture will be an operational risk requiring careful management.

LOW TEMPERATURE GEOTHERMAL

In those parts of the world that have a season for indoor heating lasting 3-6 months, low-temperature geothermal resources (25-60 °C) have real value. “Low-enthalpy” geothermal resources exist at 1500-3000 meter depths, and can be more easily drilled and developed.

Geothermal fluids at 25-60 °C can typically be used in district heating, greenhouses, fisheries, mineral recovery, and for industrial process heating. In cold climates, where surface water is near freezing, any pre-heating can be commercially useful, even if the geothermal fluids do not reach the “ideal temperature” level. Around the globe, district heating systems alone deliver the heat equivalent of almost 2 billion oil barrels annually. The major risk here is that the subsurface thermal resource is depleted more rapidly than it regenerates from the Earth’s internal heat.

In 2020, 1.6 trillion Btu/year could be saved by the recovery of industrial heat waste. (Source: DOE)

THERMOELECTRIC DEVICES

Transforming geothermal heat into electricity without moving parts is an attractive concept. Thermoelectric generators (TEG), which leverage the phenomenon that a temperature difference creates electricity, could solve this.

TEG today use semiconductors such as Bi2Te3. As they have an energy efficiency of less than 10% their use is not widespread. The first commercial TEG were introduced to power watches in the 1990s. However, the German car manufacturers, Volkswagen and BMW, have now developed TEG that can recover waste heat from a combustion engine.

A standard TEG module will cost around US$300 and produce 24 watts at 250 °C. In theory, TEG can target any system with a high temperature gradient, including geothermal sources. The long-term reliability of semiconductors exposed to heat is a recognised risk.

TECHNOLOGY UPTAKE IN EACH SCENARIO
nuclear energy – a reliable hydrocarbon free future?

NUCLEAR ENERGY is a means for centralised, stable, power generation, without using hydrocarbons. Fusion, promising a limitless energy supply without harmful wastes, is still far off in the future. Life extension of current reactors, safe operation of new reactors, successful implementation of advanced reactor designs, and viable solutions to nuclear waste disposal are all key for continued expansion of nuclear power. Small, modular nuclear reactors will expand the use of nuclear power in remote or mobile applications, but security issues must first be addressed for successful implementation of this power source.

INTRODUCTION

According to statistics from the International Atomic Energy Agency, there are currently 441 nuclear power plants worldwide, with a total installed capacity of 375 GWe, 5 power plants that have been shut down, and 60 more are under construction. In France, nuclear power already has a major share of the energy mix. China has plans for nuclear power on a massive scale, aiming to develop over 100 power plants in the next two decades. A resurgence of interest in nuclear power is also being experienced in the US, including license renewals for 80 reactors and new license applications.

To date, no country, with the exceptions of Sweden and Finland, has managed to find a technically and politically acceptable solution for permanent waste disposal. Temporary storage of spent fuel near reactor sites postpones the need to find a permanent solution, and also increases safety and security risks at each site. Reprocessing of spent fuel and use of breeder reactors may create, in addition to waste, material that could be used in weapons.

A typical reactor generates about 27 tons of spent fuel. Source: OECD

LIFE EXTENSION AND RISK MANAGEMENT

In the next decade, almost all the reactors in the US will have exceeded their original design life of 40 years. By 2030, the nuclear electricity generation is expected to decline unless additional life extension or new constructions takes place.

Several major issues are involved: (1) safety of operating reactors, especially from hitherto un-known failure modes; (2) fuel reliability and performance, (3) obsolete instrumentation and controls, (4) design and risk analysis tools based on legacy knowledge and computational tools, and (5) loss of trained work force.

Reactor pressure vessel material degradation through continued radiation damage is an issue for any life extension process. Since some of the current failure modes had not been anticipated in the past, there is concern regarding the occurrence of new failure modes over time. Efforts are underway to develop multi-scale models that link fundamental materials’ properties at an atomic level to failure modes, and attempt to predict future failure modes.

Improved understanding of materials degradation mechanisms will prompt the development of suitable monitoring systems. For example, monitoring reactor components for temperature, radiation, and corrosion using networked wireless sensors will improve the safety of systems through redundancy. But the reliability of wireless systems and their proper function in a radiation environment are key uncertainties.

In addition to improved technologies, human factor designs will be enhanced and a safety culture implemented. The loss of experienced workforce due to retirement will be addressed through expanded educational, training, and research programmes.
ADVANCED REACTOR DESIGNS

Advanced nuclear reactors with standardized designs and passive safety features are being developed to ensure reduced construction time, increased safety, and improved operating efficiencies. Over the next 10 years, it is likely that new reactor designs will be incremental improvements over existing water-cooled reactor designs. Beyond 2030, radically new designs, called Gen IV reactors, may come on stream. These will be either small, modular reactors (SMR) with 10 MWe to 311 MWe (Mega Watt electric power) capacity that can be used in a much more flexible manner or high temperature reactors (HTR) that use helium as a heat transfer medium. The SMR may be returned, completely sealed, to its original factory for dismantling and disposal following usage. Small reactors may be employed in remote locations for power production or other applications such as desalination.

MONITORED STORAGE SYSTEM

The spent fuel from nuclear reactors contain some of the original U-235 depending on the burn-up of the fuel. In total these account for about 96% of the original uranium and over half of the original energy content. This fuel is reprocessed in Europe and Russia to separate the uranium and plutonium from other high level radioactive wastes which are recycled as mixed oxide (MOX) fuel. A new reprocessing plant is being commissioned in Japan, which has been shipping its spent fuel to Europe for reprocessing.

In the U.S. reprocessing was prohibited due to concerns about proliferation of plutonium. There are currently about 270,000 tons of fuel in temporary storage with annual contributions of about 12,000 tons. With a 20 percent increase in capacity, this would rise to 14,000 tons per year.

NUCLEAR FUSION

Nuclear fusion, which could potentially provide a limitless supply of energy without significant waste production, has been the dream of scientists for decades. Two approaches to fusion energy are being pursued: the ITER programme uses a toroidal Tokomak reactor to confine plasma by a magnetic field to obtain the high temperatures needed for fusion.

The NIF (US) and HiPER (Europe) programmes use intense lasers to compress pellets of deuterium and tritium to generate fusion. The heat from the fusion is then used to generate steam to power turbines. Recent progress by NIF has been encouraging, but commercial application is still at least two decades away.

By 2020, the world´s nuclear energy capacity will grow by 19% while the contribution of nuclear energy to total energy will remain approximately the same.
While traditional sources, like coal, gas, hydro, and nuclear, produce stable power generation, future power systems will have to manage the variability and uncertainty in output from renewable energy sources like wind and solar.

New grid solutions and energy storage will be essential elements in future power systems.
CONTENTS

Integration of renewables 74
Renewable energy sources produce variable and uncertain power output. Could bulk energy storage and distributed energy storage, such as battery packs in distribution grids, be parts of the solution?

Super grids 76
Super grids connect large geographical areas into a single, unified system. Which solutions will enable trading of electricity over long distances and leverage the variable output from renewables?

Offshore transmission grids 78
Interconnecting multiple offshore wind power plants over long distances using offshore transmission grids poses new challenges. Will regulatory issues outweigh technological challenges?

Smart grids 80
The vision for a smart grid is that the behaviour and actions of all users connected to it are integrated in a cost-efficient manner. Which technologies will take us a step closer to that vision?
integration of renewables - managing variable power output

MORE THAN 80 countries have policies to promote renewable energy sources (RES). Many countries, especially within the EU, will experience significant challenges in managing the variable and uncertain power output from wind and solar plants in 2020.

The long-term sustainable solution calls for interregional transmission highways (Super Grids), intraday markets, demand response, harmonised grid codes for RES, and bulk and distributed energy storage.

Theoretical wind- and solar power resources in the U.S. Source: NREL GIS Group

>> Although excellent for balancing wind and solar power, hydro plants are limited by water availability and topography, whilst fast-starting gas turbines emit twice the amount of CO2 per kWh compared with a modern combined cycle gas turbine (CCGT) plant.

Among the key measures needed are new transmission capacity and intraday electricity markets. Transmission enables wide area balancing through cross-border power exchange, greater market pools, and a subsequent smoothing of RES output variability and prediction uncertainty (see chapter on “Super Grids”). However, transmission line projects can take up to 10–15 years to complete due to long concession times and public opposition. Electricity markets today are designed for dispatchable generation under relatively low load uncertainty. Going from the present ‘day-ahead’ to ‘2-hour ahead’ forecasting and subsequent market clearing could cut wind power forecast uncertainty by 50%. This market evolution is already ongoing in many countries.

Another important measure is the grid code requirements for variable-output RES. Conventional power plants of more than some 10s of MW are obliged to provide the full range of ancillary services, including frequency response, up/down regulation, voltage and reactive power regulation, and to stay online during faults. These services are essential for the stability of the power system. Today, smaller and often distributed power plants, such as wind and solar, are exempt from providing many of these services.

Among the new measures that could be needed, are bulk energy storage, such as compressed air energy storage (CAES) in areas where pumped hydro is unavailable, distributed energy storage such as battery packs in distribution grids, and demand response enabled through smart distribution grids (see chapter on Smart Grids on page 80).

variable wind power

- Managing Variability and Uncertainty

Renewable energy sources (RES), such as wind and solar, have variable and less certain power generation compared with coal, gas, nuclear, hydro (with reservoir), and biomass power plants. This increases the risk of being unable to match electricity supply to demand continuously.

To meet the EU 2020 target for RES, there will be more than 50 GW of wind power in and around the North Sea region. The winds here are highly correlated, meaning that a moving wind front hits a large area at the same time, which will lead to steep ramps of several GW per hour. This is challenging should the occurrence coincide with load ramping in the opposite direction. Coal and nuclear power plants take hours to come online. Fast-starting gas turbines and hydropower plants can come online within 3–15 minutes, and provide full ramping capabilities within a couple of minutes.

- Introduction

Many renewable energy sources are both variable, uncertain and have no inherent storage capability. Winds vary considerably even on low time scales. Radiation from the sun follows a diurnal pattern, but varying cloud covers can result in significant intraday variations. Waves are also governed by uncertain weather parameters.

Tidal power on the other hand is predictable, but the production will often not coincide with demand for electricity. Managing the variability and uncertainty of renewables will be a key issue in the future design and operation of power systems.

- Mapping of Renewable Resources

Down-ramping of wind power in West Denmark during storm, and subsequent balancing provided by Norwegian hydro power (8 Jan, 2005)
Grid codes for generators state their required performance during both normal and abnormal situations in the power system. Requirements include, among others, ancillary services and online operation during faults. Today, smaller and often distributed power plants are not required to deliver the same services as conventional generators. With an increasing amount of RES, this will challenge the power system stability. Many variable-output RES plants are now obliged to provide voltage and reactive power regulation. Down-regulation of wind power to avoid over-production is also being used. However, up-regulation of wind or solar will require continuous operation below available capacity (i.e. curtailment of power). This measure is not in use today, but might be implemented in systems with very high shares of wind and solar power by 2020.

A CAES plant uses electricity to compress air. The air is stored underground, and later released to a rebuilt gas turbine. CAES plants could have capital costs 2-3 times higher than those for fast-starting gas turbines, but they burn less than half the fuel (reducing CO₂ emissions equally) and have near flat efficiency at part load. Two CAES plants have been operated for more than 20 years; a 290 MW, 3 hour storage plant in Germany and a 110 MW, 26 hour storage plant in the US. For purposes of peak load shaving, reserve, and black start. The plant in Germany has started to provide balancing for the increasing amounts of wind power in northern Germany. Areas with suitable geological conditions for storing compressed air (e.g. salt deposits, limestone) include large parts of the US and northern Europe.

Managing variable power generation from renewables will be the key challenges for power systems in 2020.

Wind power reserved for frequency regulation.
super grids — the new bulk power transmission grids

SOCIETY IS INCREASINGLY dependent on a secure electricity supply. As large amounts of renewable energy sources (RES) will be connected to power grids in many parts of the world, a significant increase in power transmission capacity is essential. Super Grids can be defined as wide-area transmission networks, connecting large geographical areas into a single, unified system. This enables trading of high volumes of electricity over long distances and leverage on production variability from RES.

INTRODUCTION

In China, the vast majority of energy resources, mostly coal and hydro power, are located far from the load centres. In Europe, Super Grids could enable the transmission of offshore wind in the North Sea, along with solar energy in the Sahara, to load centres in central Europe. In US, the three non-synchronous areas can be more closely interconnected to improve security of supply and to facilitate integration of large amounts of RES.

The drivers for Super Grids are bulk transmission of power from production sites to load centres, large-scale integration of RES with variable power generation, and lower use of peak power plants. The Super Grid will include technologies such as High Voltage Direct Current (HVDC), Ultra High Voltage Alternating Current (UHVAC), High Temperature Low Sag Conductors (HTLS), and Flexible Alternating Current Transmission System units (FACTS).

OPERATING THE SUPER GRID

Operation of Super Grids will involve parties from different states and countries to a substantially greater extent than occurs today. Super Grids will call for an unprecedented need for coordination between multiple operators of the transmission system. One single operator should be responsible for the overlaying Super Grid. A single operator will ensure increased utilisation of generation assets on, for example, a US or European level. This can be achieved by interconnections enabling levelling of load on an overall level due to different consumption patterns and time zones. However, an overlaying Super Grid introduces potential dangers in terms of single outages that affect the power system at an unprecedented scale. This calls for the development of robust system controls, including increased use of load shedding, real time monitoring and self restoration provided by Smart Grid.

HIGH VOLTAGE DIRECT CURRENT (HVDC)

HVDC is preferred when transmitting large quantities of electricity over long distances (> 600 km), and is the only technically viable solution for long cables (> 40-100 km). HVDC overhead lines can carry 2-5 times the power of an AC line of similar voltage, significantly lowering the right-of-way (land requirement). Line Commutated Converters (LCC) have been in use since the 1950s while Voltage Source Converters (VSC) have been in operation since mid-1990.

At present, LCC have a capacity five times that of VSC, converter costs are lower, and losses are half that of VSC. VSC, on the other hand, provide operational benefits to the AC systems such as reactive power support and black start capabilities, as well as being the best option for meshed DC grids. VSC losses are comparable to those of LCC, and capacity will reach 3000 MW within 2020.

HIGH VOLTAGE DIRECT CURRENT (HVDC) TRANSMISSION CAPACITY

Comparison of transmission capacity of overhead lines using HVDC and HVAC.

<table>
<thead>
<tr>
<th>Voltage Source Converter capacity in 2020:</th>
<th>3 GW</th>
</tr>
</thead>
</table>

HVDC transmission projects in China. Source: Siemens Press Picture

800 kV DC

765 kV AC 500 kV DC 3 GW 3 GW 6 GW
ULTRA HIGH VOLTAGE AC (UHVAC)

UHVAC is basically a scale-up of existing transmission grid technology, moving from typically within the 300-500 kV range, to voltages in the range of 700-1000 kV or more. Thermal capacity of a 1000 kV UHVAC transmission line can be 6000 MW. UHVAC can be a viable competitor to HVDC for Super Grids. Its benefits include maturity and proven track record, ease of connection to existing AC systems, and the possibility of construction by voltage up-rating (raising the voltage by installing new isolators and increasing the distance to ground on existing transmission lines).

Among its drawbacks are challenges to utilising thermal capacity to the full extent and increased right-of-way compared with HVDC. UHVAC has, among others, been proposed for the North American Super Grid.

HIGH TEMPERATURE LOW SAG CONDUCTORS (HTLS)

HTLS provides an alternative approach to raising transmission capacity without increasing right-of-way. The power transmission capacity of traditional stranded aluminium conductors is limited by large sag at high temperatures and loss of tensile strength over time. HTLS conductors use composite cores and steel reinforcement to overcome these limitations. As a result, transmission capacity can be increased by 1.5-3 times compared with conventional aluminium conductors. Limited field experience and higher costs are presently the greatest obstacles for widespread implementation. HTLS conductor costs can be 1.5-10 times those for traditional stranded aluminium conductors. HTLS conductors can be established as the baseline for new transmission corridors in 2020 if costs are compatible with existing technologies.

ADVANCED FACTS DEVICES

Voltage, transient stability, and power oscillation damping are presently largely controlled by large power generators (50+ MW). In the future, these generators will be less online due to higher penetration of RES. FACTS devices, such as SVC (Static Var Compensator), STATCOM (Static Synchronous Compensator), and UPFC (Unified Power Flow Controller), are large power electronic devices that can control power system parameters at very high speed.

FACTS devices increase the available capacity of transmission lines. Present FACTS devices (SVC and STATCOM) can provide voltage control, and damp transients and power oscillations. In addition, advanced FACTS devices can provide control of power flow (UPFC), which subsequently lowers the risk of overloading lines. By 2020, advanced FACTS devices will be extensively used to increase transmission capacity and security of supply.

By 2020, advanced FACTS devices will be extensively used.
offshore transmission grids – bringing wind energy to shore

BY 2020, large offshore wind farm projects will be situated up to 100s of km from shore, and produce power in the range of several gigawatts. Power transmission to shore will require high voltage direct current (HVDC). The challenges of developing offshore HVDC grids towards 2020 are substantial, and related to AC/DC converter technology, development of meshed DC networks and DC circuit breakers, offshore substations, and subsea developments. Interconnection of countries with different regulatory regimes will be a major obstacle to overcome.

INTRODUCTION

In order to accommodate the EU 2020 renewable target, up to 40 GW of offshore wind power could be installed in the North Sea, requiring grid investments in the order of 11-28 billion Euros.

The US DOE estimates an offshore wind power potential of 54 GW within 2030. In the US, the Atlantic Wind Connection project is one of the first steps towards interconnecting multiple offshore wind power plants using an offshore transmission grid.

Alternating current (AC) cables are technically limited to distances of 40-100 km. Therefore, High Voltage Direct Current (HVDC) systems will be an integral part of offshore transmission grids.

In addition to technological challenges, regulatory issues such as operation of the offshore grid, cost coverage, and market coupling are major obstacles for interregional offshore grid developments.

VOLTAGE SOURCE CONVERTERS

Converters are used in HVDC systems, either to rectify or to invert the current. Voltage Source Converters (VSC) have been commercially available since 1997, but presently suffer from twice the energy losses and 1/5 the MW capacity of traditional Line Commutated Converters (LCC). On the other hand, their compact design means that use of VSC is feasible on an offshore platform. Unlike LCC, VSC can be connected to weak or passive AC networks (low short circuit capacity) such as wind power plants and offshore oil & gas installations (loads). In addition, VSC provide voltage control and black start capabilities. VSC technology will pave the way for multi-terminal DC networks, enabling interconnection of wind parks to shore and trading links between countries. Within 2020, VSC energy losses will be comparable to those of LCC (about 0.5 % at both terminals).

MESHED HVDC NETWORKS

Two-terminal (point-to-point) HVDC connections have been installed in many parts of the world, connecting asynchronous systems, systems with different frequency levels, and for bulk power transmission. An integrated offshore grid will require further development of Multi-Terminal HVDC (MTDC) technology. MTDC will reduce the necessary number of converter stations, and thus platform space offshore, and reduce subsequent energy losses.

However, a MTDC system is very sensitive to DC faults; without a DC circuit breaker, the entire MTDC system will be shut down to clear the fault. Towards 2020, some smaller offshore MTDC networks, without DC breakers, will arise on a national level. Interregional offshore MTDC networks will not emerge until after 2020 due to the lack of interregional frameworks and the long lead time.

VSC technology will pave the way for multi-terminal DC networks.
DC CIRCUIT BREAKERS

In order to provide a comparable level of redundacy and reliability to today’s AC networks, MTDC networks will require DC breakers that are capable of clearing DC faults within milliseconds. The intrinsic nature of AC results in fairly simple circuit breakers, breaking the current when it is close to zero. In order to be able to clear a DC fault, a DC circuit breaker must be able to break full power as there is no natural zero current crossing. DC breakers for HVDC are currently not commercially available.

However, with existing capacity not exceeding 400 MW, they are far below the capacity necessary for large-scale wind integration (1000-2000 MW). Scaling up from today’s rather simple, seabed-fixed constructions, with 400 MW capacity, to large structures, both floating and seabed-fixed, with 2000 MW capacity requires further reductions in equipment size, whilst costs must also be kept at a reasonable level.

DC breaker prototypes for 2000A DC currents and 500kV DC voltage have been successfully tested on an existing MTDC scheme. Solid-State, Hybrid Circuit Breakers and Forced Commutation are possible solutions for DC breakers. For the DC breaker to add value, stringent requirements demonstrating high reliability of the breaker itself must be met.

SUBSEA POWER SYSTEMS

Exploration of deep and ultra-deep water, oil, and gas fields, as well as government requirements for lower emissions through power supply from shore, will result in more electric equipment being placed subsea. Voltage levels will typically increase from a couple of kV to 10s of kV, and power capacities in the range of 10s of MW. A major advantage of subsea power supply is reduction or elimination of topside equipment.

When locating land based equipment on seabed, one solution is air or gas filled modules with atmospheric pressure bringing along weight challenges, while another is modules filled with liquid challenging insulation and power electronics.

The wave and tidal energy industries, and possibly the wind energy industry, will benefit from subsea power developments, reducing the need for platform space, and potentially lowering the costs of installing these units offshore.

Key enabler for multi terminal DC networks: DC circuit breakers.
smart grids
– the future of power system operation

EXISTING POWER SYSTEMS are mainly designed for one-way power flows from large, centralised power plants to passive customers at the other end of the network. Although no truly “smart” power systems will be developed by 2020, many systems will have evolved to a level partially resembling the Smart Grid vision. Smart meters will be installed in most Western households and real-time pricing will provide customers with the incentive to flatten the diurnal load curve. The high voltage transmission system will be operated more safely and more efficiently using time-synchronized, millisecond measurements of voltage and current.

INTRODUCTION

A Smart Grid is an electric power network that utilises two-way communication and control-technologies to integrate the behaviour and actions of all users connected to it in a cost efficient manner. Smart Grids will evolve through the application of new technologies to grid infrastructure that already exists.

The fundamental drivers for the Smart Grid are the increasing number of variable and often distributed power generators (wind, solar, etc.), electric vehicles, a need to reduce peak loads, and a demand for higher reliability and quality of power supply.

Among the major risks are interoperability and cyber security. Interoperability is compromised by lack of protocols and standards. There are currently 62 approved IEEE standards and 36 more are under development. The Stuxnet worm warns that control systems in the power system are also targets for malicious attacks.

COMMUNICATION TECHNOLOGY

Smart Grids require high speed communication over large distances (up to 1000s of km) to enable millisecond measurements and ultrafast responses to system parameters, such as voltage magnitude and phase angle, frequency, and harmonics.

Broadband over power line (BPL) is only appropriate for medium and low voltage power lines, and can be a good option for rural areas due to low cost. Wireless communication through GSM (Global System for Mobile Communications) is another option, providing low cost and easy access. However, the use of a public network increases cyber security issues. Optical fibres, although more expensive, are more difficult to tap into than electrical wired or wireless communication, and are also immune to electromagnetic interference.

WIDE AREA CONTROL

A lack of grid infrastructure developments following the restructuring of the electricity supply sector has led to transmission grids being pushed further and further towards their limits.

Advanced energy management systems, known as WAMPACS (Wide Area Measurement Protection and Control Systems), use Phasor Measurement Units (PMU) in combination with GPS to measure voltage and current magnitude, and phase angle every 20–100 milliseconds at transmission substations and power lines.

The GPS time stamp ensures that measurements separated by large distances are synchronised to within 1 microsecond of accuracy. Advanced FACTS devices (see “Super Grid” chapter) will be used to control voltage and power flow. China had over 300 PMU installed by 2006, and US and Europe are following. WAMPACS will be in widespread use by 2020.
SMART METERS

A Smart Meter is a combination of a sensor that can measure electricity consumption in real-time, logic that enables communication with the operator, and an actuator that enables active control of consumer appliances. Real-time pricing of electricity consumption will give customers the incentive to load shift from peak to off-peak periods (demand response) and to promote energy efficiency measures.

Advanced Meter Management (AMM) is the ability to receive control signals from the operator and to switch off local electric appliances. Within 2020, direct control will predominantly be used in emergency situations to avoid blackouts.

Smart meters will automatically detect and report faults, which will enable distribution grid operators to perform necessary actions more quickly. Smart meters will also be needed to control fast charging of electric vehicles (EVs). To charge a single EV in less than 30 minutes, a single plug would need to draw more than 50 kW, or more than 50 times the average power consumption* of a Western household.

With millions of EVs on the roads in 2020, this could introduce significant risk to peak load management. By the end of 2006, 30 million smart meters had been installed in Italy, and the effect has been a significant flattening of the diurnal load curve. The European Union has a target of 80% penetration of smart meters into households by 2020.

*10000 kWh
8760 h

DISTRIBUTED CONTROL

Distribution systems will see an increasing share of distributed generation (DG), EV charging stations, and a general need for reducing peak loads and improving power quality. Distribution grid operators will rely heavily on monitoring and control using smart meters. Smart meters could be directed to switch off individual customers or smaller sections of the distribution grid during disturbances in order to avoid wide area blackouts.

On a longer timescale, smart meters could be used to switch on/off water heaters, refrigerators, freezers, or other appliances that can manage without electricity for shorter periods of time without lowering customer comfort. However, such direct control will meet significant public opposition and the necessary price incentives could outweigh the benefits.

Using smart meters for automatic fault detection, combined with advanced power line switching operations, will lower the risk of power outages to customers. Within 2020, distributed control will predominantly be used in emergency situations to avoid blackouts. SMART METERS will automatically detect and report faults, which will enable distribution grid operators to perform necessary actions more quickly. SMART METERS will also be needed to control fast charging of electric vehicles (EVs). To charge a single EV in less than 30 minutes, a single plug would need to draw more than 50 kW, or more than 50 times the average power consumption* of a Western household.

With millions of EVs on the roads in 2020, this could introduce significant risk to peak load management. By the end of 2006, 30 million smart meters had been installed in Italy, and the effect has been a significant flattening of the diurnal load curve. The European Union has a target of 80% penetration of smart meters into households by 2020.

*10000 kWh
8760 h

WAMPACS: Controlling power systems by 2020.

Impact on average load with introduction of real-time pricing in Italy

ADVANCED DISTRIBUTION MANAGEMENT

Managing distributed generation, load and storage using two-way communication.

HOURLY LOAD METERING

Impact on average load with introduction of real-time pricing in Italy
SUSTAINABLE COASTAL COMMUNITIES

“Sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future”

World Commission of Environment and Development, 1987
TECHNOLOGIES FOR A SUSTAINABLE FUTURE?

With the population continuing to rise and increasing strains being placed on natural resources and the global climate, will we have made any progress towards a sustainable future by 2020? Might the technology solutions available by the end of this decade be able to balance financial, societal, and environmental factors for current and future inhabitants of our Earth?

If the latest technologies were applied, how might a new, sustainable coastal society for millions of inhabitants appear in 2020? We have tried to imagine such a community, focussing primarily, but not solely, on new solutions developed and piloted in the maritime and energy industries.

INDEX

| Challenges for sustainable coastal communities | 84 |
| Floating districts | 86 |
| Energy systems | 88 |
| Future ports | 90 |
| Vision 2020 | 92 |
SUSTAINABLE COASTAL COMMUNITIES: CHALLENGES

CHALLENGES OF COASTAL COMMUNITIES will to some degree differ from that of inland urban areas as the vicinity to the ocean will have an effect on the way buildings are constructed, goods are transported or how ecosystems are managed.

Also, the impacts of a changing climate may be more imminent and intense in coastal zones with a rising water level, shifting precipitation patterns, more frequent intense weather events, floodings or storms. Any human urban developments will have to deal with coastal erosion, increased sedimentation of coastal...
Coastal erosion threatens homes.
Source: USGS

Many megacities are located by the coast and are increasingly exposed to severe weather.
Photo: NASA

Traffic problems due to flooding.
Source: ACE

Fairways, and pollution from industry, settlement or storm runoffs. Coastal ecosystems are among the most productive systems in the world, but also highly threatened. Salination of fresh water, destruction of marshes and wetlands have to be balanced with desired economic advance.

Developing societies and technologies that are resilient may minimize the risk of collapse when hit by climate or weather extremes. That is what we will visualise on the following pages.
Situation report:
Some parts of the old city district is flooded and the authorities are evacuating the residents.

Expansion of the floating district's new desalination module is needed. A tender is announced and discussed in a “twitter-like” media.

Floating district admin: Due to excess energy production we want to increase our fresh water export capabilities by installing a new desalination module (floating system). Please submit your bid for the contract by 2nd of May 12:00 GMT.

Mr. Lee: Isn’t the freshwater needs of the island more than covered already?
Community announcement: Temporary housing needed for evacuated people from flooded area in the old city. Please notify if you have available housing.

Mrs. Smith: We have room for a family of up to 5 people, happy to help in this terrible situation.

Supplier: What are the capacity requirements of the wanted system?

Floating district admin: Yes, but there is great demand in the city and we want to contribute to solve this problem by exporting water to the city.

Floating district admin: We need a system which can deliver 15,000 m³ pr day

Supplier: When should the system be installed?

Check out our new WC2000.

Floating district admin: We want a working system by the end of the year. For detailed information please refer to the documents posted on our community page. And please contact our drinking-water department if you have any questions.

Community announcement: We are pleased to announce that we have found housing for all the affected people. We want to thank all of you for the good help!
POSSIBLE FUTURE: ENERGY SYSTEMS

Situation report: Building Integrated Photovoltaics. Office requesting maintenance to replace a “solar window.”

Situation report: Transport adaptation to weather: more trams in winters, more subways in summer.

Mr. Lee: Let’s cool down a little and take the metro after this crazy day.

Ms Cooper: Meet you down at the beach! Will upload my coordinates.
Situation report:
Smartbuilding/city farming seasons Due to high dataservers activities before Christmas, heat and energy is cheap leading to low vegetable price grewed indoor.

Mr Smith: Need a new solar shingle for my roof. Need to replace a building window, and we need a new “thin film coated window”

Solar repairs R’ Us: Solar Repairs on their way! ETA 14.00 GMT

Mr Smith: Thanks! Will upload my billing info.

Grocery store: 50% off on cherry tomatoes due to server Christmas shopping season
POSSIBLE FUTURE: FUTURE PORT

Situation report:
Higher supply-chain integration between terminal and distribution channels enables personalized and dynamic logistical integration.

Situation report:
Ship to port integration enables possibilities of reduced fuel consumption and reduced congestion.

Ship: Now departing from Rotterdam. Please advice ETA and recommended speed.
**Ship:** Acknowledged, proceeding as recommended.

**Apple Store:** Critical. We are already sold out of our new iGadget. Close to social unrest. Please advice on arrival of next batch to ensure they are picked up at once.

**Terminal:** Based on the latest weather forecast the next shipment will arrive at our storage area on Thursday 15.00 GMT. A slot will be prepared for the immediate pick-up by truck. Please notify us if any changes occur.

**Terminal:** Two ships in line. Berth available on Monday 14.00 GMT. Given weather forecast, optimal route is uploaded to your system with recommendation of travelling speed of 13 knots.

**Ship:** Acknowledged, proceeding as recommended.
VISION 2020:
SUSTAINABLE COASTAL COMMUNITIES

- GEOThERMAL POWER PLANT
- BIOFUEL REFINERY
- OFFSHORE FLOATING WINDTURBINES
- MAGLEV COMMUTER
- DESALINATION PLANT OCEAN HEAT PUMP
- PIRACY DETECTION
- MOBILE FLOATING CITY MODULES
- NATURAL ON-SITE WASTE WATER TREATMENT
YOUR COMMENTS, PLEASE!

We want to hear your feedback and comments.


Looking at future technologies is a moving target. We have created a blog, where we discuss some of the subjects from Technology Outlook 2020. Follow the debate and/or share your comments.

OTHER RESOURCES
Go to www.dnv.com/foresight to order more copies, read electronic version, and watch videos about Technology Outlook 2020.
THIS IS DNV
DNV is a global provider of services for managing risk. Established in 1864, DNV is an independent foundation with the purpose of safeguarding life, property and the environment. DNV comprises 300 offices in 100 countries with more than 8,000 employees.