EXECUTIVE SUMMARY

Fossil fuels currently meet 80% of global energy demand. Even if current policy commitments and pledges made by countries to tackle climate change and other energy-related challenges were to be put in place, global energy demand in 2035 is projected to rise by 40% – with fossil fuels still contributing 75%. Demand over the coming decades will stem mainly from energy needs of emerging markets such as China and India. The use of coal, gas and oil to fuel the power, industry, buildings and transport sectors is set to rise. Although environmental concerns have led to a significant increase in lower-carbon options, these are not yet deployed widely enough to meet current or future demand for energy. Over the past two decades, the global share of power generation from non-fossil sources has decreased from 37% (in 1990) to 33% (in 2010); in contrast, the share of coal-fired power generation has risen from 37% to 42%. Fossil fuels will continue to provide the majority of global energy needs for the foreseeable future, but are there sufficient resources to meet the demand?

Given the major fluctuations witnessed in energy markets in the past seven years – notably the global economic crisis – *Resources to Reserves 2013* assesses the availability of fossil fuels and surveys the cutting-edge technologies needed to find, produce and bring them to the market, while avoiding adverse impacts on the environment to the greatest extent possible. This new edition also highlights the need for strategic approaches specific to each fuel type.

Availability of fossil fuels

Fossil fuels are abundant in many regions of the world and they are in sufficient quantities to meet expected increasing demands. However, most of them are still classified as **resources** and not yet as **reserves**. This distinction is important as it reflects the likelihood that the fossil fuels will be brought to the market. Resources are those volumes that have yet to be fully characterised, or that present technical difficulties or are costly to extract, for example where technologies that permit their extraction in an environmentally sound and cost-effective manner are still to be developed. Reserves are those volumes that are expected to be produced economically using today's technology; they are often associated with a project that is already well-defined or ongoing. As the more accessible, conventional supplies are exhausted, so more technically demanding resources will need to be exploited.

A key role for the industry is to convert resources into reserves. This reclassification relies heavily on the application of advanced technological solutions, which is strongly linked to fuel prices. High fuel prices stimulate the development and testing of more sophisticated solutions, and result in a growth of reserves. Exploring and extracting these reserves economically, and in an environmentally responsible manner, will require investment in new innovative solutions.

Fossil fuels, also collectively known as hydrocarbons, include oil, gas and coal. Any source of oil and gas that requires production technologies significantly different from those used to produce from conventional reservoirs is described as unconventional. A quick summary of known hydrocarbon reserves and resources demonstrates the potential supply:

- Proven reserves of **conventional oil** are estimated to be around 1.3 trillion barrels, with remaining recoverable oil resources representing about 2.7 trillion barrels. Globally, proven reserves have increased modestly since 1990, despite the growth in consumption. The global reserves-to-production ratio, based on current consumption levels, is in the range of 40 to 45 years. As resources are successfully converted into reserves, this period will be extended.
- Proven reserves of **unconventional oil** are around 400 billion barrels (bb), with estimated recoverable resources of 3.2 trillion barrels.
- Proven reserves of **conventional gas** are estimated at around 220 trillion cubic metres (tcm) – the equivalent of around 1.4 trillion barrels of oil – with remaining recoverable resources of 460 tcm.
- Proven reserves of **unconventional gas**, because of the heterogeneity of the rock formations, are very difficult to assess. Remaining recoverable resources (excluding methane hydrates) are estimated at 330 tcm.
- Reserves of **coal** are high, with proven reserves of hard coal estimated at 730 gigatonnes (Gt) (approximately 3.6 trillion barrels of oil equivalent [boe]) and proven reserves of lignite estimated at 280 Gt (approximately 0.7 trillion boe). Remaining recoverable resources of hard coal and lignite are estimated at around 18 and 4 trillion tonnes, respectively.

Developing various fossil fuel reserves is highly complex. As a means of assessing potential profitability, producers start by estimating the relative cost of development and the carbon intensity (the amount of carbon dioxide [CO_2] emitted for each unit of energy produced) of the fuel to be produced. Conventional natural gas typically has the lowest cost per energy unit and the lowest carbon intensity. All unconventional gas developments generally have low carbon intensity and diverge mainly in the cost of development. By contrast, unconventional oil developments (such as from bitumen, coal gasification and oil shales) are more expensive to produce and have higher carbon intensities. Coal has the highest carbon intensity of the fossil fuels.

As this edition of *Resources to Reserves* illustrates, the current increase in fossil fuel supply over recent years has been made possible thanks to impressive advances in technology. Future supply will require even more demanding technological innovations that can increase production in existing and new sources while also responding appropriately to relevant environmental challenges.

Using advanced technology to move from resources to reserves

Resources to Reserves 2013 provides an overview of the new technological developments and discusses the potential next steps for each fuel type.

Conventional oil and gas

There are various examples where technological developments have made it possible to extend oil production from a field over a much longer time than was initially foreseen. Securing future oil production will require greater output from brown fields (fields already in production) by employing improved and enhanced oil recovery (EOR) techniques. At the end of their anticipated lifecycle, most fields still contain significant volumes of oil. Technological advancements mean that a larger fraction of these volumes could be brought to the surface. For example, on average about 50% of the original oil-in-place volumes in reservoirs could be recovered by using the latest cutting-edge technology.

Even a 1% increase in the average recovery factor could add more than 80 bb, or 6%, to global proven oil reserves. Over the last 20 years, the average recovery factor from the Norwegian Continental Shelf has seen a significant shift – from 34% to around 46% today. This has largely been driven by technology with contributions from horizontal/multilateral drilling, improved seismic acquisition, four-dimensional seismic techniques and improved subsea facilities. With the recent accelerated developments in smart fields (fields that use a whole range of technological solutions), even higher recovery rates could be achieved. If the shift seen in Norway were to be achieved in all the basins of the world, it would double current proven reserves. A similar additional shift could be achieved by adopting EOR techniques on a much wider scale. Currently, there is a significant increase in the number of EOR pilot tests, especially those using chemical methods and CO_2 injection. Examples may be found around the world, from China, Russia, the Middle East and North America to Argentina. In spite of these efforts, the maturing of existing projects and the complexity of implementing EOR technologies will lead to decreased production levels in non-Organization of the Petroleum Exporting countries (OPEC) countries, with a corresponding increase in production of conventional oil from OPEC countries.

Natural gas is set to play an increasing role in meeting the global demand for energy, especially in power generation and heating. Whereas a few decades ago gas was often stranded (too remote to be financially viable to transport to market) and an unwanted by-product of oil production, many such gas projects are now being actively pursued. More often than not, the principal challenge in the past was in bringing the gas to market. However, today, liquefied natural gas (LNG) provides a cost-effective solution in many cases. Liquefying natural gas, shipping it in ever larger carriers and using regasification at an increasing number of locations close to the end-user is making it more financially viable to transport gas to market. Qatar and Iran in the Middle East, in particular, have seen a significant increase in capacity. Recent new technological developments are towards offshore floating LNG options (liquefaction on a boat), with the first to be built in the sea north-west of Australia. In Qatar, the first large-scale gas-to-liquids plant is already under construction.

The frontier locations for conventional hydrocarbons are now in ultra-deepwater and in the Arctic. Adding to the complexity of exploration and production in these locations is the imperative to do no harm to the pristine and sensitive environments. In these often remote locations, operations such as subsea processing and compression are required to allow transfer by pipeline to distant facilities. Important growth regions in deepwater exploration and production are Brazil and West Africa. Many of the technologies developed for deep water could eventually be used in Arctic regions. Additional challenges in the Arctic include protecting facilities from ice-related dangers and extending the drilling season. In future, technologies that enable very long tie-backs from field to coastal collection points could make it more viable for other developments to proceed. Technology is continuing to evolve at a rapid pace. Current developments, concentrated around the Barents Sea and the North Slope of Alaska, are outlined in this edition.

Unconventional oil and gas

The global potential for unconventional oil is high. Though the resources and reserves base is similar to that for conventional oil, there are potentially more resources awaiting technological solutions. The world's extra-heavy and oil-sands resources are largely concentrated in Canada and Venezuela. Mining operations to develop the shallow reserves are seeing a significant increase. Many of the deeper deposits are developed by using steam to reduce viscosity. Because of the energy intensity of these projects and the associated carbon footprint, many such developments now have to contain solutions for carbon capture and storage (CCS), *i.e.* processes by which CO_2 is captured at the emission source and then, usually, injected into underground sites for long-term, geological storage.

Unconventional gas – tight gas, shale gas and coal-bed methane – has seen substantial growth in the United States and Canada, driven mainly by the need to minimise reliance on imported fuel. Technology has been central to this growth. Driving vertical and horizontal wells, and creating hydraulically generated fractures to maximise and steer the flow of gas, has brought dividends. However, the financial viability of these developments remains very sensitive to the local gas price. Further cost reductions are possible through improved drilling and completion techniques, as well as enhanced understanding of the basic flow phenomena in stress-sensitive reservoirs. There is an enormous opportunity to export the experience and learning gained to other parts of the world where the exploration of such resources is still in its infancy.

With the increasing demand for natural gas, prospects are being explored for sour gas (gas contaminated with CO_2 or hydrogen sulphide). Key to such developments is the ability to separate out the contaminants and dispose of them in an environmentally friendly manner. The Middle East, Kazakhstan and South-East Asia have substantial volumes of such resources under consideration for development.

Methane hydrates offer a potentially enormous source of methane gas and are thought to be the most abundant source of hydrocarbon gas on earth. However, the technical challenges in accessing this resource in a cost-effective and environmentally acceptable manner are still being addressed. Significant production in the short to medium term is not anticipated and therefore global forecasts do not generally include production of methane from this source.

Coal

Coal production has seen a steep increase in the last decade, with projections pointing to a continued rise for the next decade. These increases are driven mainly by economic growth in emerging economies, particularly in China and India. Environmental imperatives demand that, in the longer term, CO_2 emissions from the use of fossil fuels must decline; this is particularly the case for coal, the most carbon-intensive of the fossil fuels. If the environmental issues can be resolved, there are sufficient coal resources to satisfy expected demand for many more decades. Reducing emissions from coal could be achieved by:

- developing technologies to improve the efficiency of coal use;
- using CCS.

The greater the effectiveness of these two options, the less will be the emphasis on switching to lower-carbon alternatives.

Moving towards ever thinner, deeper and less uniform coal seams poses a number of challenges for mining, all of which are likely to lead to an increase in the cost of production. Alternatively, it may trigger a move to exploit the abundant reserves of shallower but lower-quality coal. Technology is constantly being improved, offering opportunities for those with state-of-the-art mining techniques to export them to regions where such techniques have yet to be deployed.

Future improvements, for example, may come from the further development of underground coal gasification, in which coal is gasified in situ to generate power, or from generation using advanced technologies. Advanced ultra-supercritical steam cycles and integrated gasification combined cycle (IGCC) technology with state-of-the-art gas turbines are currently being developed. Further development of more cost-effective, energy-efficient CCS technologies will be essential to the future use of coal.

Mitigating the environmental impact

The future use of all fossil fuels is increasingly determined by political debates and governmental regulations reflecting concerns about local environments and greenhouse gas (GHG) emissions, particularly CO_2. The year-on-year rise in anthropogenic GHG emissions is a matter of global concern. Reducing them can only be achieved by switching to lower-carbon fuels, better management of GHG emissions, and more efficient production and consumption of fossil fuels – all of which become more effective with the development and application of improved technology.

While much emphasis is placed on switching from fossil fuels to non-fossil or renewable energy sources, as this edition of *Resources to Reserves* highlights, both technological improvements and fuel switching among fossil fuels also has significant potential to reduce GHG emissions. For example, while power generated from coal globally releases more than 1 000 grams of CO_2 per kilowatt hour (gCO_2/kWh), a state-of-the-art coal-fired generation plant releases around

740 gCO_2/kWh. So, there is much potential to reduce emissions simply by deploying more efficient technology. If a coal-fired generation unit were to be replaced by a state-of-the-art unit firing natural gas, emissions could be reduced even further, to 370 gCO_2/kWh. This potential to substantially reduce CO_2 emissions reflects both the higher heat content of gas and the higher efficiency of the gas-fired power generation process. Though the choice of fuel is largely determined by resource availability and cost, environmental factors now play an increasingly important role.

While the continued use of fossil fuels will inevitably produce CO_2 emissions, new technologies make it possible to limit their release into the atmosphere. CCS is now being piloted and demonstrated in various parts of the world. At present, saline aquifers, which are abundant in many parts of the world and potentially offer large storage volumes, are considered as the storage sites likely to dominate in the long term. Current technologies for storage in saline aquifers need further improvement, especially for long-term monitoring, understanding gas flow in aquifers and for evaluating the potential for leakage through overlying rock and fault systems.

In the long term, incentives for emissions reduction, such as carbon pricing schemes, could provide an essential stimulus to encourage CO_2 storage. Further efforts to resolve remaining issues associated with monitoring and long-term liability will also be needed. Carbon pricing will, of course, drive up the cost of producing fossil fuels. Some implications of carbon pricing assumptions are addressed in this edition.

In the Weyburn oilfield (Canada), CO_2 is being injected to enhance oil recovery while, at the same time, the oilfield is being monitored to assess the amount of CO_2 stored. In oilfield operations, the more energy-intensive oil recovery methods, *e.g.* steam injection for recovery of heavy oil and bitumen, may in future need to incorporate CCS. Another option is to store CO_2 in coal beds to prompt the release of methane. Some scientists suggest that such a process could eventually be used to release methane from methane hydrates, with some initial, small-scale trials having been successfully completed.

As releasing methane into the atmosphere is potentially much more harmful than releasing CO_2, methane released during exploration and production is often flared (methane is burnt on site to convert it to CO_2), particularly at oil drilling sites. However, priority should be given during exploration and production to using the gas rather than flaring it. For example, the gas may be reinjected back into an oil reservoir to maintain pressure for subsequent oil recovery, used to supplement local heat or power requirements, or transported for use elsewhere (if commercially viable). Such initiatives are under way in many parts of the world.

Key conclusions and recommendations

Fossil fuels dominate world primary energy supply. Resources are in place for this to continue well into the 21st century. Societal implications, particularly the demand for an environmentally sustainable, low-carbon future, will be pivotal to their continued use. Advances in technology will be absolutely essential to ensure that the use of fossil fuels remains affordable and clean.

In some regions, innovative technological solutions have led to a sizable increase in reserves. There is a significant opportunity to pursue a wider application of these state-of-the-art solutions by teaching others, learning from others and demonstrating rigour in their deployment. Innovation can often be found by applying existing technology to a new environment.

Flexibility in the use of fossil fuels can offset some of the environmental challenges. For example, switching from coal to gas for power generation or using high-carbon fuels for situations in which decarbonisation and integration with renewable fuels is possible without losing efficiency.

Resources of fossil fuels are available to meet the increasing energy demand; that much is clear. The emphasis now is on the technology, prices and policies that will ensure it is financially viable to develop the world's resources into proven reserves. Technology has developed by leaps and bounds since the last edition of Resources to Reserves was published, but a concerted effort in research and development (R&D) is still needed to go forward. Large-scale investment over the coming decades will be vital to this effort. Public policy will play a key role in providing the measures and incentives for industry to make the necessary investments.

Recommendations

Radical and co-ordinated policy action across all regions will be needed to support ongoing exploitation of fossil fuels, while addressing successfully the environmental, economic and technical challenges that arise. In particular, the carbon intensity of supply chains and subsequent use of oil, gas and coal must decrease.

Strong governance, with policies and legislation directed at reducing GHG emissions from the exploration, production and transport of fossil fuels, will be essential to guide the development of more complex technologies. This will be particularly important to ensure that operations in pristine and sensitive environments are completed without long-term environmental damage.

Continued use of fossil fuels will, of course, lead to emissions of GHGs. In this regard, governments must take steps to stimulate improvements in equipment in the power and end-use sectors. Efforts can be directed, for example, to increasing the fuel efficiency of vehicles, developing less carbon-intensive industrial processes, and improving the efficiency of power generation technologies. Policy also plays an important role in supporting the spread of best practice.

For deep cuts in emissions from the industry and power sectors, CCS is essential (particularly at large point sources). Policy measures to accelerate the development of CCS, to reduce its capital and operating costs, and to create an enabling regulatory environment are all necessary. Desirable, predictable incentives must be provided if the widespread deployment of CCS is to become a long-term reality.