NATURAL GAS
PROVIDING MORE AND CLEANER ENERGY
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreword from the CEO</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Introduction from Shell’s Integrated Gas and New Energies Director: The critical role of natural gas</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Chapter 1: An energy transition</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Powering progress</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Growing global demand for energy</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Urbanisation</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Providing more and cleaner energy</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>The challenge of climate change</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Improving air quality</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Energy transitions</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>The role of natural gas in the energy transition</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>An abundant, secure and flexible energy source</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Fulfilling the potential of natural gas</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>Chapter 2: Electricity generation</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>The energy transition in electricity generation</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>The role of natural gas in electricity generation</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>Reducing greenhouse gas emissions</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>Reducing air pollution</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Reducing use of water</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>Natural gas supports the integration of renewables</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Carbon capture, utilisation and storage in electricity generation</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>Chapter 3: Industry</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>The energy transition in industry</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Light industry</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Heavy industry</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>Chemicals</td>
<td>49</td>
<td></td>
</tr>
<tr>
<td>Carbon capture, utilisation and storage in industry</td>
<td>49</td>
<td></td>
</tr>
<tr>
<td>Chapter 4: The built environment</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td>The energy transition in the built environment</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>The role of gas in homes</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>Distributed energy systems</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>District heating</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>Combining heat and power</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>Increasing city resilience</td>
<td>59</td>
<td></td>
</tr>
<tr>
<td>Power to gas: the promise of hydrogen</td>
<td>59</td>
<td></td>
</tr>
<tr>
<td>Chapter 5: Transport</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>The energy transition in transport</td>
<td>61</td>
<td></td>
</tr>
<tr>
<td>LNG for transport</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>LNG for trucking</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>LNG for shipping</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>Gas-to-liquids fuels</td>
<td>67</td>
<td></td>
</tr>
<tr>
<td>Compressed natural gas</td>
<td>67</td>
<td></td>
</tr>
<tr>
<td>The future of natural gas</td>
<td>69</td>
<td></td>
</tr>
</tbody>
</table>
Meeting growing global demand for energy, while tackling climate change and pollution, is a fundamental challenge facing society. It was the focus of two historic meetings convened by the United Nations in 2015. In New York, world leaders agreed on 17 Sustainable Development Goals. They range from eradicating hunger to ensuring clean water is available for everyone. The UN identified energy as a “crucial” common link for achieving these ambitious goals.

Later that year, in Paris, world leaders agreed to work towards limiting the global rise in temperature to well below 2°C above pre-industrial levels, to avoid the more serious effects of climate change.

Both the Sustainable Development Goals and the Paris Agreement have galvanised countries, companies and individuals to strengthen efforts to cut greenhouse gas emissions and improve air quality, while providing the energy that powers our lives. Even today, one in every six people in the world does not have access to electricity.

A transformation of the global energy system is needed. This will take place at different paces depending on a range of factors, from national policies to the technologies and products consumers choose.

Shell is playing its part in the energy transition – from reducing the carbon intensity of our oil and gas operations, to investing in low-carbon technologies, including carbon capture and storage, hydrogen, solar and wind power.

That is why I announced a net carbon footprint ambition, covering not just emissions from our own operations but also our customers’ emissions from the products that we sell. We aim to cut the net carbon footprint of our energy products by around half by 2050, on a grams of CO₂ equivalent per megajoule consumed basis. As an interim step, by 2035, we aim to reduce it by around 20%. We will do this in step with society’s drive to align with the Paris goals.

A major contribution we can make right now is to continue to expand the role of natural gas, which makes up half of our total production.

This publication explains why Shell believes gas is needed across the global economy – now and in the future.
Natural gas helps provide more and cleaner energy around the world.

With the number of people on the planet expected to increase by a billion by 2030, gas is one of the few energy sources that can meet growing demand while reducing emissions from electricity generation, industry, the built environment and transport.

Using natural gas is already helping to reduce carbon dioxide and improve air quality where it replaces coal or diesel. This has been seen in electricity generation from the UK to the USA, as well as in countries like China, where increased use of natural gas is helping to reduce air pollution in power and industry.

Gas also supports an increasing role for renewables. It provides critical support for wind, solar and hydroelectricity, helping to match the supply and demand of cleaner electricity. This will be important as the use of electricity expands.

Gas will also continue to play a critical role in sectors where demand is anticipated to grow, but which are more difficult to electrify, such as the production of steel, cement and chemicals, as well as long-distance transportation of people and goods.
Energy benefits most people throughout their lives. Today, more than ever, our livelihoods, wellbeing and communities depend on reliable sources of energy. Energy lights, heats and cools homes and businesses. It transports and connects people and goods all over the world. It enables better water and sanitation systems and improvements in healthcare and education. It is used to make steel, cement, chemicals and other building blocks for the world’s growing cities.

The United Nations (UN) has described energy as “central to nearly every major challenge and opportunity the world faces today. Be it for jobs, security, climate change, food production or increasing incomes, access to energy for all is essential.”

Yet, even today, little or no access to energy deprives part of the world’s population of the opportunity to improve their quality of life. Around 1.1 billion people continue to live without electricity, more than three times the population of the USA. A further billion people struggle with unreliable supplies of electricity.

The world will need more energy as populations grow. By 2070, the global population could reach 10 billion. That is 2.5 billion more people than today, which is equivalent to the combined populations of China and India, the two most populous countries in the world.

An increase in energy demand will also be driven by economic growth, and as people seek to improve their quality of life. That could mean lighting a home at night, running a refrigerator to store food or medicines, growing a business, or fuelling a car. Even assuming significant future energy efficiency gains, global energy demand is expected to grow by 30% between 2015 and 2040, according to the International Energy Agency (IEA) New Policies Scenario.

Reflecting economic growth, increases in future energy demand are likely to be concentrated in China, India, Africa, the Middle East and South-East Asia. In Asia, energy demand is expected to increase by 50% by the middle of the century, as the number of people in the region grows by 900 million. Demand for energy will also increase significantly in Africa.
How large could the energy system grow?

As we consider the future development of economies, and assume significant energy improvements, we estimate that an average of about 100 gigajoules of primary energy per person is approximately what is required to fuel the energy-based services that support the decent quality of life to which people naturally aspire.

Average current primary energy use*
Gigajoules per person per year

300
150
100

* Source: Shell analysis

Urbanisation

Today, cities consume about three-quarters of global primary energy and emit more than half of the world’s total greenhouse gases, according to the UN. Around two thirds of the world’s population are expected to live in cities by 2050, up from around half today. This reflects population growth and migration trends. It will require building the equivalent of a new city of more than 1 million people every week for the next three decades.

The greatest growth is expected in China, India, the USA and Sub-Saharan Africa. In China, around 1 billion people are expected to live in cities by the middle of the century – 350 million more than today and the equivalent of 40 new cities, each the size of Greater London. In India alone, more than 300 million people are expected to move to cities over the next 25 years. The use of energy and other resources such as water will increase considerably, as increased productivity, economic development and rising incomes drive up demand.

Providing more and cleaner energy

Providing access to energy, while minimising negative impacts on the planet and the air we breathe, is one of the greatest challenges of the 21st century. In 2015, the UN adopted 17 Sustainable Development Goals. These goals seek to tackle some of the world’s greatest challenges by 2030. Goal 7 aims to “ensure access to affordable, reliable, sustainable and modern energy for all”. This is an ambition that implies changes in the way energy is produced, accessed and used.

The challenge of climate change

Since the start of the Industrial Revolution, human activities have significantly raised the concentration of greenhouse gases in the atmosphere; mainly carbon dioxide (CO2), methane and nitrous oxide. In 2014, the 5th Assessment Report of the UN Intergovernmental Panel on Climate Change (IPCC) concluded that it is “extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century”.

At a landmark UN climate conference in Paris in 2015, world leaders agreed to work towards limiting the global rise in temperature to well below 2°C above pre-industrial levels to avoid the more serious effects of climate change, including floods, droughts and sea-level rises. The world is already around halfway to that 2°C limit.
Today, energy is responsible for two-thirds of global greenhouse gas emissions. Oil (32%), natural gas (21%) and coal (29%) together make up 82% of the world’s energy mix, according to the IEA.

The remaining fifth comes from biomass (including wood, peat and dung), waste, nuclear, hydropower, and other renewables (such as solar and wind). More energy from the current mix means more greenhouse gases, which leads to further climate change.

The world currently emits 32 billion tonnes of energy-related CO₂ each year. To limit the rise in global temperature to 2°C, the IEA has calculated that energy related CO₂ emissions need to fall to around 18 billion tonnes a year by 2040. This poses a significant challenge. To put it in context, removing around 200 million cars from the road (equal to every car in Europe) would save just 1 billion tonnes each year.

Today’s energy mix also has a significant impact on air quality, particularly in densely populated urban areas. In the energy system, most air emissions occur as a result of the combustion of fuels such as coal and diesel. There is broad consensus that air pollution affects millions of people around the world. It leads to early deaths and productivity loss due to lung and heart diseases.

Although developed countries have seen improvements, many developing countries with rapidly growing economies are experiencing worse air quality. The World Bank estimates that more than half of the burden falls on China, India and other economies in Asia.

Improving air quality

Air pollution in Asia

<table>
<thead>
<tr>
<th>Country</th>
<th>PM2.5</th>
<th>PM10</th>
</tr>
</thead>
<tbody>
<tr>
<td>S. Korea</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Philippines</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indonesia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vietnam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Myanmar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td></td>
<td></td>
</tr>
<tr>
<td>India</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: World Health Organization

Particulate Matter air pollutants that have adverse impacts on human health.
In China, air pollution associated with burning coal results in costs estimated at around $73 billion, or about 6.6% of gross domestic product, according to a study by the consultancy PwC Strategy&, which specialises in tax, audits and assurance. It represents one-third of China’s annual public spending and 300% of public spending on pollution and health. This study shows that, in line with the government’s target, increasing the share of natural gas in the energy mix from 6% today to 10% in 2020 could reduce costs related to air pollution by around $12.5 billion – $3 billion for every additional percentage increase in gas’ share.

**The cost of air pollution from coal in China**

<table>
<thead>
<tr>
<th>Cost of coal</th>
<th>Cost of air pollution from coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>~$81</td>
<td>~$172</td>
</tr>
</tbody>
</table>

**Total cost**

~$254 per tonne

**Source:** IMF “Getting energy price right”, “Externalities of coal 2012” State Statistics Bureau, PwC Strategy & analysis.

The Cost of Coal in China 2015 (US$ Per Tonne).

Data does not include Taiwan

### Energy transitions

To meet rising global demand for energy while avoiding serious consequences of climate change and air pollution, a transformation of the global energy system is required. This will take place across electricity generation, industry, transport, and the heating and cooling of buildings. These are the four sectors of the economy in which most energy is consumed and greenhouse gas emissions and air pollution are produced.

This transition is already under way. It is proceeding at different paces and producing different outcomes in different countries. The speed of the transition will continue to depend on factors such as the availability of natural resources, national policies to address climate change and local air quality, as well as energy security and affordability. It will also be influenced by the pace of economic growth, technological innovation, and choices made by companies and consumers.

This transformation will span decades and feature an evolution of established energy sources, such as oil, gas and renewables, as well as new and emerging energy technologies. This could require investment of up to $3.5 trillion each year to 2050, to be in line with the objectives of the Paris Agreement, according to the IEA. This is double the current level of investment.
The role of natural gas in the energy transition

Natural gas is a critical component of the energy transition – helping to meet increasing demand while lowering greenhouse gas emissions and improving air quality. It is one of the few energy sources that can be used across all sectors of the global economy. It is used to generate electricity, provide heat for essential industrial processes, heat homes and fuel the transport of people and goods.

Natural gas emits between 45% and 55% lower greenhouse gas emissions than coal when used to generate electricity, according to IEA data. Today, coal-fired power stations produce around 40% of the world’s electricity, which represents more than two-thirds of global CO₂ emissions from electricity generation. Using natural gas instead of coal to generate electricity can significantly reduce air pollution. Compared to coal-fired power plants, modern natural gas-fired power plants emit less than one-tenth of the pollutants.

Despite the significant role of renewables, they cannot provide all the world’s energy needs today. Renewables chiefly power electricity, which only meets around a fifth of global energy demand. For renewables to have a bigger impact, electricity must play a larger part in other key sectors of the economy. The role of electricity grows, the world will increasingly rely on the electricity supply being reliable and affordable, as well as sustainable.

Natural gas will have a central role in the energy transition in the industrial sector. In light industry, such as textiles, switching from coal to gas boilers can make a significant contribution to cost reductions, lower greenhouse gas emissions and improved air quality. Likewise, in heavy industries such as iron, steel, cement and chemicals, switching from coal to gas to produce the intense heat required in furnaces can significantly reduce emissions. Natural gas will continue to be a central component to produce everyday products such as plastics and fertilisers. (See Industry).

Natural gas will have a central role in the energy transition in the built environment. In developing economies, it will replace traditional biomass in heating and cooking, helping to reduce the health impacts of localised emissions from other fuels. In developed countries, planning that incorporates infrastructure to accommodate an increasing share of highly efficient, distributed gas-fired combined heat and power (CHP) systems will help to reduce emissions of greenhouse gases and air pollution, particularly where they replace electricity and heat generated from coal or diesel. (See The built environment).

Natural gas is playing an important role in the energy transition in the transport sector, as part of a mosaic of fuel and engine solutions. Liquefied natural gas (LNG) is helping diversify the fuel mix and reduce air pollution as a fuel for heavy-duty road transport and shipping. Natural gas is also converted into high-quality cleaner burning gas-to-liquids (GTL) fuels for heavy-duty vehicles, inland and seagoing marine vessels. (See Transport).

The use of natural gas-fired CHPs can also support the integration of low-emissions sources of energy, including geothermal heat and power, solar, wind and batteries. (See The built environment).

Data are for 2015: Mt = million tonnes, Gt = gigatonnes

Source: IEA analysis
These advantages suggest a central role for natural gas in the energy transition. In its New Policies Scenario, the IEA expects that use of natural gas could increase by 45% over the next 25 years. Developing countries are expected to account for more than three-quarters of that growth.

Use of natural gas also has the potential to support economic development in developing countries, for instance through employment during the construction and operation of gas-related infrastructure, or through fiscal revenues from gas trade. Gas provides energy to fuel manufacturing and industrial development. It can also help improve the reliability of electricity supply, supporting productivity in countries where there is limited electricity or outages are frequent.

**An abundant, secure and flexible energy source**

Natural gas is an abundant, secure and flexible source of energy and the high levels of anticipated demand can easily be met by known levels of recoverable natural gas resources. As technology advances, so does our ability to unlock the world’s natural gas resources.

Today, global proven gas resources stand at 769 trillion cubic metres, enough to supply global gas demand for 219 years at current levels of demand, according to the IEA. Conventional gas currently accounts for more than three-quarters of the world’s gas supply. Hydraulic fracturing has the potential to unlock large additional volumes of unconventional gas. For countries with large domestic natural gas resources, the impact of developing substantial additional volumes of natural gas can transform economies.

**What is unconventional gas?**

Until recently, most natural gas has come from rock formations that, once drilled, allow the gas to flow freely. Unconventional gas resources lie trapped in dense rock, inside pores up to 20,000 times narrower than a human hair. A technique known as hydraulic fracturing is used to break open rock and release natural gas. This involves pumping fluids into the well bore at high pressure. The fluids comprise around 99% sand and water, with 1% chemicals added to help the gas flow more freely. Hydraulic fracturing typically takes place a kilometre or more (thousands of feet) below drinking water supplies. Concrete and steel barriers are inserted into the wells as standard practice to prevent any drilling or fracturing fluids from entering local water supplies.

It is important that the industry continues to focus on safety, environmental safeguards, and engagement with local communities to address concerns and help develop economies. This means considering each project – from the geology to the surrounding environment and communities – and designing activities using technology and approaches suited to local conditions.

An abundant, secure and flexible energy source

Natural gas is an abundant, secure and flexible source of energy and the high levels of anticipated demand can easily be met by known levels of recoverable natural gas resources. As technology advances, so does our ability to unlock the world’s natural gas resources.

Today, global proven gas resources stand at 769 trillion cubic metres, enough to supply global gas demand for 219 years at current levels of demand, according to the IEA. Conventional gas currently accounts for more than three-quarters of the world’s gas supply. Hydraulic fracturing has the potential to unlock large additional volumes of unconventional gas. For countries with large domestic natural gas resources, the impact of developing substantial additional volumes of natural gas can transform economies.
Natural gas can be transported by pipeline or ship to where it is needed, whether for electricity generation, powering industry, heating buildings or transport.

Pumped through pipelines, gas can be cost-effectively transported over long distances and as part of an integrated gas transport network. The total length of the world’s natural gas pipelines would stretch to the Moon and back eight times.

When pipelines cannot cost-effectively reach consumers, natural gas can be cooled to make a liquid, shrinking its volume for shipping to where it is needed or to the start of a pipeline. New and existing pipelines and the rapid growth of LNG, in combination with new sources of natural gas from both conventional and unconventional sources, are increasing energy supply, security, diversity and flexibility.

There has been rapid growth in the number of countries supplying LNG, almost doubling between the start of the century and 2017. This has significantly increased the flexibility and security of gas supply options for importing countries. For example, in 2017 China imported natural gas from more than 20 countries, via a combination of both pipelines and as LNG.

The number of countries importing LNG has quadrupled, with LNG trade increasing from 100 million tonnes in 2000 to 300 million tonnes in 2017, according to IHS Markit. Floating storage and regasification units (FSRUs) present a fast, flexible and economically competitive option for countries looking to import LNG. These vessels can be docked in a port to regasify LNG and feed gas into a transmission or distribution network.

FSRUs are scalable, quick to deploy and require less capital than an onshore terminal or pipeline project. This makes them particularly attractive to developing countries seeking gas supply for an identified source of demand, such as a power plant or industrial area, and as the starting point for a wider expansion of gas infrastructure. They can also help reduce risk for investors and lower the hurdles for access to finance.

FSRUs also offer benefits to countries looking to replace or complement existing gas supplies, or to balance seasonal variations in hydropower. Currently, there are over 20 FSRU terminals in operation worldwide and many more under construction, according to the International Gas Union.

In 2015, a Golar FSRU was moored off the Red Sea port of Aqaba in Jordan. It provided relief to Jordan’s power producers, which had experienced major cross-border gas pipeline supply disruptions.

Prior to the disruptions, 92% of thermal electricity generation had been from natural gas. This was reduced to as little as 8% in 2014, but recovered to 90% once the FSRU was running at full capacity.
Fulfilling the potential of natural gas

A combination of natural gas and renewables offers countries a predictable, reliable, flexible and cost-effective pathway to a lower emissions energy system.

Fulfilling the potential of natural gas in the global energy supply system depends largely on economics, policy and the environmental benefits of natural gas.

Gas becomes increasingly competitive with other fossil fuels when all costs are considered. These include the costs associated with purchasing and using the fuel, as well as the anticipated costs associated with the resulting greenhouse gas emissions and negative impacts of air pollution on the environment and human health.

Cleaner and more affordable energy

In the USA and UK, a combination of economics, technical developments and policy has increased demand for natural gas in the electricity sector. In the USA, the shale gas revolution saw the share of gas-fired electricity generation increase from 18% to 32% between 2002 and 2016, corresponding with a decline in the share of coal-fired electricity generation from 49% to 29%, according to the US Energy Information Administration (EIA). Over the same period, the share of renewable electricity increased from 9% to 14%, driven mainly by state-level renewable portfolio standards. Meanwhile, CO₂ emissions from the electricity sector decreased by 20%.

What is carbon pricing?

Governments acting to put a price on carbon emissions (often referred to as “carbon pricing”) can help reduce emissions and encourage greater investment in energy sources that produce little or no carbon.

The World Bank has described how a “price on carbon helps shift the burden for the damage back to those who are responsible for it, and who can reduce it. Instead of dictating who should reduce emissions where and how, a carbon price gives an economic signal and polluters decide for themselves whether to discontinue their polluting activity, reduce emissions, or continue polluting and pay for it. In this way, the overall environmental goal is achieved in the most flexible and least-cost way to society. The carbon price also stimulates clean technology and market innovation, fuelling new, low carbon drivers of economic growth.”

One option is for governments to tax emissions, which directly establishes a cost for emitting CO₂. An alternative is to cap emissions and allow a price to develop through the trading of emissions allowances.

In the UK, a government-led “carbon price” floor of £18 per tonne introduced in April 2015, contributed to a 56% increase in demand for natural gas in the power sector and a 73% decrease in demand for coal-fired electricity generation in the first half of 2016, according to Aurora Energy Research. As a result, CO₂ emissions from the UK power sector decreased by 24%. In April 2017, the UK went a day without using any coal to generate electricity for the first time since 1882.
In addition to carbon pricing, government policymakers have applied regulatory approaches including performance standards and emissions limits to accelerate reductions across the power sector, industry, modes of transport and the built environment. In China, the government has introduced policies to support a shift from coal to gas. This is part of a comprehensive plan to reduce carbon intensity by 18% from 2016 to 2020, and tackle higher levels of air pollution. This could see gas demand increase by 90% by 2025, according to the IEA’s New Policies Scenario. Demand could increase by 8.7% each year to 2022.

Regulatory, economic or technical barriers can also impact gas demand, sometimes to the advantage of more carbon intensive options, including coal. Here, coal-to-gas switching can be supported by changes to policy frameworks that support, for example, a government-led change in tariff structure, the re-allocation of electricity generation slots, or alternative dispatch schedules.

Financing gas and electricity transmission infrastructure can also present challenges, particularly in developing countries. In these countries, loans, guarantees and other forms of financial risk mitigation are often important in initiating development of the necessary infrastructure. Given the relative complexity of gas markets, training and capacity building are often also important to ensure that countries realise the full benefit of natural gas resources.

The case for natural gas on environmental grounds requires high standards throughout the gas supply chain. Realising the full potential of natural gas in the energy system will also require the gas industry to demonstrate progress in further improving its environmental footprint. This includes reducing emissions of methane from the natural gas supply chain, which can diminish the relative CO₂ emissions benefits of natural gas.

Managing methane emissions from the natural gas value chain

Methane is a potent greenhouse gas. When it is released into the atmosphere it has a much higher global warming impact than CO₂.

Around 60% of the world’s total methane emissions occur naturally—including from wetlands, oceans and vegetation decay. The remaining 40% of methane emissions are the result of human activities, such as livestock farming and energy production.

About 13% of total global methane emissions come from oil and gas related activities. The IEA estimates that there were 76 million tonnes of methane emissions from oil and gas operations in 2015, split roughly equally between the two.

Natural gas consists mainly of methane. Efforts to address climate change therefore require the industry to reduce both deliberate and unintended methane emissions from the gas value chain, from production to the final consumer. These emissions usually occur in three ways: emissions of unburnt methane from fuel combustion; venting, for example, from equipment for safety reasons; and unintended emissions, such as small leaks.

It is important that the gas industry continues to monitor and reduce methane emissions. This includes wider implementation of methane leak detection and repair programmes. It also includes deployment of advanced technologies, such as optical imaging and pro-active maintenance and modernisation of pipeline systems.

High levels of methane emissions reduce the greenhouse gas benefits of gas compared to other fuels. However, the lifecycle emissions of gas remain significantly lower than those of coal in both electricity generation and industry.
The energy transition in electricity generation

A reliable, affordable and sustainable supply of electricity is vital for social and economic development. It is used to light rooms, refrigerate food and medicine, power computers, and charge mobile phones. Apart from during the global economic crisis in 2008-2009, electricity generation has increased every year since 1971, reaching 23,816 terawatt hours (TWh) in 2014. Yet, even today, 1.1 billion people – one in every six people on the planet – continue to live without access to electricity, according to the IEA. A further billion people only have access to unreliable or unsafe electricity supplies.

Electricity generation differs from other energy sectors by being ‘intermediate’. This means it converts primary energy into electricity for use in other sectors. Electricity does not create emissions at the point of use. However, the source of the electricity has a significant impact on lifecycle emissions. When electricity is generated from cleaner energy sources it can play a key role in reducing greenhouse gas emissions and air pollution in transport, the built environment and industry.

Today, electricity provides around a fifth of final energy consumed globally and is responsible for 40% of energy-related greenhouse gas emissions, according to the IEA. When generated from lower carbon energy sources, increased use of electricity will support emissions reductions in the power sector, as well as across end-use sectors in industry, transport and the built environment. By mid-century, electricity could account for as much as 50% of energy use and up to 40% by 2040. Much of this demand growth will come from developing countries, particularly Sub-Saharan Africa and South Asia, where 95% of those with no electricity live.
1.1 billion people still do not have access to electricity

Source: IEA World Energy Outlook 2017

The role of natural gas in electricity generation

Natural gas-fired electricity generation has an important role to play in the energy transition. It can help to reduce greenhouse gas emissions and air pollution by displacing coal and oil-fired generation and supporting the integration of variable renewables into the energy mix. Natural gas also has the potential to significantly contribute to economic development in developing countries. Secure supplies of natural gas can help improve the reliability of power supply, supporting productivity where there is limited existing electricity supply or power outages are commonplace.

Historically, the scale-up in the availability of gas has dramatically changed the energy landscape and provided countries with an important opportunity to power growth. According to the IEA’s New Policies Scenario, more than 380 gigawatts (GW) of new gas-fired power plants could be needed in developing countries in Asia over the next 25 years to support energy needs and economic development.

Reducing greenhouse gas emissions

Despite the promise of renewable electricity, it cannot provide all the world’s energy needs. After a period of rapid growth, renewables account for around one-quarter of global electricity generation, with wind and solar energy sources accounting for around 5% of global electricity generation today. Renewables, such as solar and wind power, are also intermittent, requiring sufficient backup to ensure reliable electricity supply when there is limited sun or wind. Today, coal accounts for around 40% of global power generation and contributes more than two-thirds of CO2 emissions from electricity generation. While generation growth has slowed, CO2 emissions from coal-fired electricity generation would need to decline by an average of 3% each year to 2025 to be on track with the goals of the Paris Agreement, according to the IEA.

Natural Gas emits between 45% and 55% lower greenhouse gas emissions than coal when used to generate electricity, according to IEA data. Switching from coal to gas turbines and combined-cycle plants will be critical to reducing greenhouse gas emissions. In distributed energy systems, gas-fired combined heat and power units also produce significantly fewer greenhouse gas emissions than coal-fired units. (See The built environment).

Displacing coal-fired power plants and diesel generators with a combination of gas-fired electricity generation and renewables is a fast and cost-effective way to reduce greenhouse gas emissions from the power sector, while maintaining reliable supplies of electricity.

Coal-fired electricity generation is on a steep downward trajectory in many countries and global coal generation growth has slowed. However, many countries are still increasing their use of coal for electricity generation. In 2015, new coal capacity additions stood at more than 80 GW, representing more than a quarter of new electricity generation capacity globally. Of this, around 30% was from subcritical plants with lower efficiency and higher emissions, according to the IEA. In China alone, 52 GW were added and around 150 GW are under construction. In India, where three-quarters of electricity is generated from coal, generation use of coal rose by 3.3% in 2015.
In countries, such as India, where diesel generators are common, usually due to unreliable power supply, a greater role for gas can bring economic and environmental benefits. For example, if one 100-MW gas turbine replaces 200 diesel generators with a capacity of 500 kW each, around $30 million could be saved in fuel cost each year, while significantly reducing greenhouse gas emissions and air pollution, according to the IEA.

In developing countries, financing the necessary gas and electricity infrastructure can be challenging. Commercial entities, as well as independent financial institutions, such as international development banks, have an important role to play in supporting access to the required loans, guarantees and other forms of financial risk mitigation. Training and capacity building can also help develop the necessary regulatory and market structures.

The Organisation for Economic Co-operation and Development (OECD) countries electricity generation by energy source

In many economies, huge structural shifts are taking place in electricity generation, including switching from coal to gas, a rapid ramp-up of renewables and a decline in nuclear.

Source: OECD

“GAS PLAYED AN IMPORTANT PART IN RECENT POSITIVE CO₂ EMISSIONS TRENDS IN MANY COUNTRIES AND IN THE OVERALL FLATTENING OF GLOBAL ENERGY RELATED EMISSIONS” – IEA 2017
Reducing air pollution

Across the world, the rapid growth of cities is focusing attention on the environment and health impacts associated with air pollution from electricity generation, particularly when power plants are located close to urban centres.

Air pollution is the world’s largest environmental health risk. Emissions of pollutants, including particulate matter, sulphur dioxide and nitrogen oxide have major adverse impacts on human health. According to the IEA, coal use is the largest source of global emissions of sulphur dioxide. This is a cause of respiratory illness and a precursor of acid rain, which has a major negative impact on forests, lakes and agricultural yields.

The use of natural gas instead of coal in electricity generation significantly reduces pollution. Compared to coal-fired power plants, modern natural gas-fired power plants emit less than one-tenth of the sulphur oxides, nitrogen oxides, particulates and heavy metals.

Fitting coal-fired power plants with technologies that reduce the amount of pollutants emitted can help. However, this does not mean they will always be deployed and their effectiveness depends on regulatory and operator enforcement.

Even if sulphur and nitrous oxides and other pollutants are removed, coal ash still needs to be disposed of and can lead to local water contamination. Coal-fired power plants are also a major source of mercury emissions that can harm the brain, heart, kidneys, lungs and immune system. In the USA, coal plants account for around 40% of all mercury emissions resulting from human activity. Between 2002 and 2011, a switch from coal to other fuels, as well as the installation of control technologies at coal power plants, contributed to a 50% decrease in mercury emissions.

CASE STUDY: THE TOTAL COST OF ELECTRICITY GENERATION FROM COAL AND GAS IN THE PHILIPPINES

GAS-FIRED ELECTRICITY BECOMES EVEN MORE COMPETITIVE WHEN THE ANTICIPATED COSTS ASSOCIATED WITH CLIMATE CHANGE, THE IMPACT OF POLLUTION AND OTHER FACTORS ARE INCLUDED
Reducing use of water

Many parts of the world are experiencing ‘water stress’, where the supply of water is not meeting demand. Natural gas-fired power plants consume less than 50% of the water needed for coal-fired electricity generation. Coal requires substantial water volumes at every stage – from mining and washing the coal to burning it in power plants and treating the combusted waste. It accounts for around 7% of all water use globally.

The World Health Organization estimates that every person requires between 50 and 100 litres of water each day for the most basic needs. Annually, the world’s installed coal-fired power plant units consume enough water to meet the needs of more than 1 billion people, according to a Witteveen+Bos report for Greenpeace International. If the water that the coal industry uses to mine hard coal and lignite is included, it equates to 1.2 billion people. Water saved by switching from coal to natural gas can be used in households, industry and agriculture.

Today, around 40% of coal-fired power plants are in areas with high levels of water stress. Building more coal-fired power plants in these regions threatens to intensify competition with other water users. Even plants that use sea water or dry-cooling technologies require significant amounts of fresh water for scrubbing air pollutants.

By 2050, India may be the most populous country with 17% of the global population, while only having 4% of the world’s fresh water resources.

This is already having an impact on farmers in Maharashtra state, where there is tension between the use of water for agriculture and energy. Several coal-fired power plants have reduced operations, sometimes for months, because of a lack of water.
Natural gas supports the integration of renewables

Renewable electricity generation, such as wind and solar, will be critical to meeting growing global energy demand while reducing emissions and improving air quality. Electricity generation from renewables expanded by more than 30% between 2010 and 2015 and could reach 40% of total global electricity generation by 2040, according to the IEA.

Demand is being driven by cost reductions and policies aimed at enhancing energy security and sustainability as well as reducing CO₂ emissions and improving air quality. Today, renewables represent around a quarter of electricity generation.

Despite rapid growth, renewables such as wind and solar are variable energy sources, which means they only produce electricity when there is sufficient sun or wind. Natural gas-fired power plants provide a competitive and flexible back-up to variable renewables today. They can reach full output in minutes, providing electricity almost instantaneously and rapidly responding to lulls in solar or wind power supply and to surges in demand. By contrast, in addition to producing higher levels of CO₂ and air emissions, coal-fired power stations often require long and costly start-up periods to pre-heat their boiler and steam systems before they can start supplying power to the grid.

Gas-fired power plants can often also be built closer to where electricity is needed, such as towns and cities, because they require less land, produce much lower localised air pollution than coal, and have a different risk profile to nuclear power plants. This helps to increase the speed and efficiency at which electricity can be delivered.

Gas-fired power plants ramp up to provide flexible backup to variable renewables

CASE STUDY: FLEXIBLE GAS GENERATION INCREASES TO SUPPORT VARIABLE SOLAR GENERATION IN CALIFORNIA

Gas generation ramps up when wind is low

Wind generation Gas generation

Source: Red Electrica de Espana 2015

Solar power generation ramps up during sunlight

low night time electricity demand met by conventional electricity supply

Natural gas-fired power generation ramps up to meet evening demand

Hour of day

Natural gas supports variable hydropower in Brazil

AN INCREASING SHARE OF ELECTRICITY SUPPLIED BY VARIABLE RENEWABLE ENERGY SOURCES IS MAKING IT INCREASINGLY CHALLENGING FOR GOVERNMENTS AND UTILITIES TO DEVELOP ELECTRICITY SYSTEMS THAT MATCH SUPPLY AND DEMAND EFFICIENTLY.

In Brazil, hydropower provides around 90% of electricity when there is sufficient rainfall. In years when there is not enough rain, gas-fired power plants make up the shortfall. Many of the gas-fired power plants in Brazil today were built in response to severe water shortages in 2001 and 2002. In 2015, a severe drought saw hydropower’s share of electricity supply drop to around 70%.

Source: IHS Markit, Aneel
Energy storage technologies, including batteries, will increase the flexibility of the grid and facilitate integration of renewable electricity sources. In addition to batteries, other energy storage systems include pumped hydropower or conversion of surplus electricity into storable thermal energy or hydrogen. These options are maturing rapidly. Technological innovations have lowered costs, however cost-competitive large-scale battery storage and delivery of electricity, equivalent to that provided by an average power station, is not expected for at least a decade, according to a study by IHS Markit. While batteries can store energy for the short term, technologies are also needed to match seasonal variations in demand for heat or cooling in many parts of the world.

The ability to build and operate gas-fired power plants quickly, at lower cost and in a range of sizes, offers important benefits. As the share of renewable electricity generation increases, the requirement for electricity generated from traditional coal, gas and nuclear power plants is anticipated to decline, often with utilisation rates of less than 60% of their full capacity. As this occurs, the economic advantage of gas-fired power plants increases, relative to coal and nuclear plants. This is because, on average, gas-fired power plants can be built twice as fast as coal and nuclear plants, cost less to build and are cheaper to maintain. They are therefore able to recover their investment costs and operate at a profit sooner than coal and nuclear plants. Nuclear plants often also have technical constraints to operating at lower utilisation rates. In addition, the shorter construction and development time of gas-fired power plants reduces the time between initial investment and generation of electricity and can help reduce investment uncertainty.

### Comparative construction and operating costs of power generation technologies

<table>
<thead>
<tr>
<th>Construction cost $/MW</th>
<th>USA</th>
<th>Total Generation cost $/MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>1,000,000</td>
<td>0.05</td>
</tr>
<tr>
<td>Gas</td>
<td>7,000,000</td>
<td>0.15</td>
</tr>
<tr>
<td>Nuclear</td>
<td>5,000,000</td>
<td>0.20</td>
</tr>
<tr>
<td>Wind</td>
<td>4,000,000</td>
<td>0.25</td>
</tr>
<tr>
<td>Rooftop Solar</td>
<td>3,000,000</td>
<td>0.30</td>
</tr>
<tr>
<td>Utility Solar</td>
<td>2,000,000</td>
<td>0.35</td>
</tr>
<tr>
<td>Solar Thermal with Storage</td>
<td>1,000,000</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Source: Levelised cost of energy 2017 Lazard

### New gas-fired power plants become increasingly competitive with new coal-fired power plants as utilisation levels decrease

**Anticipated cost of power generation vs. power plant utilisation, Texas 2030**

<table>
<thead>
<tr>
<th>Power plant utilisation rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
</tr>
<tr>
<td>25%</td>
</tr>
<tr>
<td>50%</td>
</tr>
<tr>
<td>75%</td>
</tr>
</tbody>
</table>

Source: IHS Markit
Carbon capture, utilisation and storage in electricity generation

Longer term, natural gas-fired power plants could use carbon capture, utilisation and storage (CCUS) to capture up to 90% of their CO2 emissions.

The Intergovernmental Panel on Climate Change (IPCC) suggests that CCUS will be required on a major scale, across both electricity generation and industry, to meet long-term climate change ambitions. According to the IEA, CCUS will need to account for 14% of CO2 reduction by 2060 to be on track with the goals of the Paris Agreement. To do so, CCUS would need to remove around 1 billion tonnes of CO2 a year by 2030 and almost 7 billion tonnes by 2060.

The Energy Transition Commission states that more than 100 new CCUS plants need to be built each year from 2020 to 2040 to meet the Paris goals. Reducing emissions will be more difficult, disruptive and expensive unless the use of CCUS becomes widespread. (See CCUS in Industry).

What is carbon capture utilisation and storage?

Carbon capture and storage (CCS) is the name given to a set of technologies that capture and store CO2 deep underground, preventing its release into the atmosphere. The three core elements of capture, transport and storage have been demonstrated for many years in the oil and gas industry.

It can be used to reduce CO2 emissions from both the power and industrial sectors. There are 21 large-scale CCS projects in operation or under construction globally, with a combined capacity to capture around 40 million tonnes of CO2 each year. That is equivalent to taking 10 million cars off the road.

Carbon capture, utilisation and storage (CCUS) includes the use of CO2 for enhanced oil recovery, agriculture and the production of building materials.

How CCS works

1. Capture
   CO2 capture separates CO2 from gas, before it is emitted, using a chemical solvent. The captured CO2 is separated from the solvent and compressed into a liquid form for transport.

2. Transport
   CO2 is generally pumped through a pipeline, taking the CO2 from the industrial site where it has been produced, to its storage site which may be onshore or offshore.

3. Storage
   CO2 is injected deep underground into the microscopic spaces in porous rocks. A layer of impermeable rock, called a cap rock, lies directly above the porous rocks ensuring that the CO2 remains there permanently.

4. Measuring, monitoring and verification
   Monitoring of storage sites takes place within the storage reservoir, as well as at the injection well, where sensors can detect small changes in pressure or CO2 levels. In addition, a number of monitoring technologies can be incorporated within the geosphere, biosphere and atmosphere surrounding the storage site to make sure the CO2 is stored permanently.
The energy transition in industry

The industrial sector is made up of a variety of sub-sectors that produce the building blocks of modern economies, including iron, steel, cement and the chemicals used to support longer, healthier lives and produce many everyday products.

Even assuming significant improvements in the efficiency with which economies produce, consume and recycle, demand for these and other materials will increase significantly to meet the needs of a growing global population and economy. In 2015, industry accounted for 38% of global energy use and 24% of all global CO2 emissions, according to the IEA. Reducing energy demand and emissions from the industrial sector over the long term, without compromising economic and social development goals will require effective implementation of energy efficiency strategies, switching to lower-carbon fuels and raw materials, and the best available technologies such as carbon capture, utilisation and storage.

Increasing use of cleaner-burning natural gas in industry, where it displaces coal and oil, offers the potential to significantly reduce greenhouse gas emissions and air pollution today. These benefits are being recognised by policymakers, particularly in rapidly growing economies such as China. In Northeast China, industrial coal to gas switching is estimated to have added around 17 billion cubic metres to overall gas consumption in 2017, driven largely by policies to reduce air emissions. That is enough gas to supply Belgium for a year. According to the consultancy Wood Mackenzie, global industrial gas demand is likely to increase by 45.5% between 2015 and 2035, with growth of 107% in China and 108% in India. Demand is expected to rise significantly in the chemicals sector, with growth in the need for everything from food packaging to car parts.
CASE STUDY: CR SNOWFLAKE BEER SICHUAN COMPANY BREWERY, CHINA

CR SNOWFLAKE BEER SICHUAN COMPANY BREWERY IS THE LARGEST MODERN BREWERY IN SOUTHWEST CHINA. TO LOWER COSTS, IMPROVE EFFICIENCY AND REDUCE EMISSIONS, THE COMPANY HAS DEVELOPED A DISTRIBUTED ENERGY SYSTEM BASED ON GAS-FIRED COMBINED HEAT, COOLING AND POWER GENERATION.

Compared to the equivalent coal system, it is expected to improve efficiency by 22%, reduce CO₂ emissions by 43% and reduce sulphur oxide and nitrogen oxide emissions by 165 and 48 tonnes a year respectively. Any surplus electricity can also be sold back to the local grid.

Coal-to-gas switching in Lanzhou, China

Lanzhou is the capital of Gansu, a province in Northwest China. Until 2013, Lanzhou was one of the country’s most polluted cities, largely because of emissions from industry. Residents referred to it as a ‘city which could not be seen on a satellite’.

Following a three-year programme to reduce air pollution, focused on switching from coal to natural gas, emissions were significantly reduced. This resulted in a 40% decrease in hospital admissions related to respiratory conditions, a 68% decrease in associated medical costs and an 18% increase in GDP. Visitor numbers have also increased and, in 2015, Lanzhou won the ‘Today’s Revolution and Advancement Award’ at the UN Paris Climate Conference in recognition of this achievement.

The use of natural gas in industry has other significant benefits. Gas almost completely combusts, while coal produces large volumes of ash and slag, which require expensive handling and disposal. Gas boilers supplied by pipelines do not require on-site fuel storage, loading, or waste disposal. This saves valuable space and associated costs. The study shows that by converting from coal to natural gas, a textile company in Jiangsu on China’s east coast has saved more than 100 square metres of space.

In some industries, the reliable and steady temperatures provided by gas boilers can improve product yield and quality. These benefits are accruing to businesses across the paper, textile, food, chemical and pharmaceutical industries in China. For example, in China’s Xinjiang Province, a chemical company has increased product revenue by 33% by switching from a coal boiler to a gas boiler. In industries such as ceramic and glass production cleaner fuel combustion in furnaces can also result in higher quality products.
Heavy industry

In heavy industry, such as iron, steel, cement, and chemical production, hydrocarbons are required to produce high temperatures or chemical reactions. In these sectors, displacing coal with natural gas can make a significant contribution to lowering greenhouse gas emissions and improving air quality.

Today, half of all iron and steel continues to be produced by reducing iron ore in emission-intensive coal-fired furnaces. In cement production, more than 90% of the energy used is fuel combustion.

According to the IEA Energy Technology Perspectives, to support the goals of the Paris Agreement, the share of coal in cement production would be required to decrease from 63% in 2014 to 25% by 2060.

Overall, the share of fossil fuels is anticipated to drop from 83% to 59%, with natural gas making up 48%, compared with 11% in 2014.

Chemicals

Natural gas can be used as a feedstock in the manufacture of certain base chemicals. The petrochemicals industry converts methane into ammonia, which is used in agricultural fertilizer, and into methanol, which is used in energy and construction.

Chemicals companies use ethane, the second-largest component of natural gas after methane, to make ethylene. This is first converted into performance chemicals such as polyester, higher olefins and polyethylene. In turn, they are used for a wide variety of consumer and packaging end products, including clothing, detergents, furniture, bottles and containers.

The chemicals industry is growing rapidly to support increasing standards of living. Today, oil and natural gas account for 75% of the global total final energy mix in the chemicals and petrochemicals subsector, including use as a feedstock and for production, according to the IEA. Coal contributes 10% worldwide, but a much higher share in China, where it makes up 32% and is used widely for ammonia and methanol production.

Natural gas, as a feedstock and for the production of chemicals and petrochemicals, has a lower carbon intensity than both oil and coal.

Carbon capture, utilisation and storage in industry

CCUS is one of the few options for reducing CO₂ emissions from energy-intensive industries, including the production of steel, cement and chemicals. These industries rely on hydrocarbon fuels to generate high temperatures essential to their industrial processes. As a result, they emit CO₂. Meeting long-term climate change ambitions will require a large and rapid increase in the number of CCUS projects. It will require significant collaboration and knowledge sharing to accelerate CCUS development. (See Electricity generation).

This chart presents an analysis from Shell’s Scenarios team of the likely growth across different sub-sectors of industry and agriculture, from 2013 until the early part of the second half of the century, and the potential to decarbonise each sub-sector. The analysis is based on both challenging and optimistic assumptions for the deployment of new technologies and efficiency improvements. The middle, blue circle represents the 2013 breakdown of total final energy consumption by light industry, agriculture (including the relatively minor roles of forestry and fishing) and the five sub-sectors of heavy industry: pulp and paper, iron and steel, nonferrous metals, chemicals and petrochemicals, and nonmetallic minerals, including cement. The production growth of each sector is indicated by the size of the coloured circles, and their colours indicate our qualitative assessment of the difficulty of decarbonising them.

Source: Shell Scenarios (Shell Scenarios are neither predictions nor forecasts of future events, rather they are designed to present plausible potential visions of the long-term future).
CASE STUDY: CARBON CAPTURE AND STORAGE ON THE NORWEGIAN CONTINENTAL SHELF

STATOIL, SHELL AND TOTAL ARE DEVELOPING A PROJECT THAT WILL CAPTURE AND STORE CO₂ FROM A CEMENT FACTORY, AN AMMONIA PLANT AND A WASTE-MANAGEMENT SITE IN EASTERN NORWAY.

The captured CO₂ will be transported by ship from the carbon capture facilities to a receiving terminal located on the west coast of Norway. At the receiving terminal, it will be transferred from the ship to intermediate storage tanks, before being sent through a pipeline on the seabed to injection wells east of the Troll gas field on the Norwegian continental shelf. The first phase of the project could store up to 1.5 million tonnes of CO₂ each year.
**The energy transition in the built environment**

The main uses of energy in buildings are heating, cooling, lighting and cooking. These uses account for around 30% of the energy used globally and 55% of demand for electricity. Depending on the steps taken to improve the energy performance of buildings, demand could increase by up to 28% between 2014 and 2060. Most of this demand is expected to come from developing countries, where the total floor area of buildings is expected to double by 2060. Including emissions from the generation of electricity that they use, buildings are responsible for more than one-quarter of global energy-related CO₂ emissions today.

**The role of gas in homes**

In many developed countries, it is emerging practice for heating (water, space and cooking) to be powered by electricity. However, the extent of electrification will depend on how quickly existing buildings can be retrofitted. Retrofitting existing buildings across such countries could take decades. It will also require significant investment in power generation and transmission infrastructure to meet the increasing demand for electricity.

Where gas infrastructure is in place, replacing conventional natural gas-fired boilers with highly efficient natural gas-fired condensing boilers today represents a fast and cost-effective way to improve energy efficiency and reduce emissions from the use of energy in buildings. In the EU, for example, heating accounts for 27% of total energy consumption (including in houses, offices and public spaces), with gas accounting for 46% of supply.

According to a Burgeap Report for trade association Eurogas in 2014, if all existing conventional gas boilers were replaced with high-efficiency condensing boilers, the EU member states could reduce CO₂ emissions from heating by as much as 7%. In countries with existing gas infrastructure, gas can also be a cheaper source of heating than electricity. For example, in the UK gas costs up to three times less per kilowatt hour than electricity.

Highly efficient gas boilers can also support the integration of renewable energy sources, such as heat pumps, by meeting any shortfalls in demand for heat on very cold days. Such hybrid systems allow consumers to access the lowest-cost energy available. Longer term, these systems will also allow the integration of decarbonised gas, such as biogas or hydrogen.

**Case Study: Freedom Project, Wales**

The Flexible Residential Energy Efficiency, Demand Optimisation & Management Project (Freedom Project) is a collaboration between an electricity distribution network operator (Western Power Distribution) and a gas distribution network operator (Wales & West Utilities).

It involves the installation of 75 hybrid heating systems in residential properties in Bridgend, Wales. The project’s hybrid heating system includes an exterior air source heat pump and high-efficiency gas boiler in homes, and a control which enables switching between the two heat sources. Wales & West Utilities estimates that, if implemented across the UK, such a system could reduce the CO₂ intensity of heating by up to 50%, or more if biogas is used.
In developing countries, traditional biomass such as wood, dung and peat still meets 43% of energy demand in homes. Replacing these fuel sources with cleaner-burning natural gas eliminates the impact of high levels of indoor air pollution. In India alone, where around 700 million people still rely on solid fuels for domestic cooking, exposure to household solid fuels is estimated to cause 500,000 premature deaths and 5 million illnesses each year.

**Distributed energy systems**

Distributed energy is generated at or near the point of use. Relative to traditional centralised electricity generation, distribution and transmission, distributed energy systems can improve efficiency and reduce emissions of greenhouse gases and air pollutants. An increase in distributed electricity generation is being driven by the need to overcome technical planning and financial challenges associated with centralised power and the transmission and distribution of electricity. This is particularly true in developed countries where there are often complicated planning processes and local resistance to overhead transmission lines. In countries with less developed infrastructure, such as China and India, distributed power provides fast and simplified access to energy.

In recent years, the cost of distributed energy has come down significantly and smaller, modular energy systems require less upfront investment than centralised power. This allows cities to plan smaller-scale investments instead of more complex and expensive infrastructure projects. In addition, distributed energy systems allow cities to increase power supply incrementally to meet demand. Policies designed to support an increasing role for distributed power are also creating more demand for natural gas. These policies recognise the role that natural gas can play in reducing emissions of greenhouse gases and air pollution, compared to coal.

**District heating**

District heating (also known as district heat networks) is a system for distributing heat generated in a centralised location for residential and commercial heating needs, such as space heating and water heating in buildings. The heat is distributed to where it is needed through a network of insulated pipes. Gas-fired district heating offers efficiency and environmental benefits, particularly when coal-fired boilers are converted to gas.

In China, the Ministry of Environmental Protection has implemented a plan to reduce air pollution in Beijing, Tianjin and 26 smaller cities in the north of China. Hundreds of thousands of homes have already been connected to new gas heating systems. Across China, coal to gas switching in the residential and commercial sector could add around 32 billion cubic metres (bcm) to China’s gas use between 2016 and 2020, compared to total demand of around 206 bcm in 2016.
Combining heat and power

Combined heat and power (CHP) systems (also known as cogeneration) are efficient, integrated energy technologies that generate electricity and heat close to where there are major centres of demand, such as towns and cities. A large share of energy is lost during conventional power generation. CHP units running on natural gas integrate the production of heat and power in a single, highly-efficient process.

The waste heat can be used to generate additional power, or be directed to nearby consumers in the form of steam or hot water via a short pipeline network. Waste heat can also be used in air conditioning units to meet the cooling requirements of buildings. This is also referred to as trigeneration. City planning that incorporates infrastructure to accommodate distributed gas-fired CHP generation helps to reduce emissions of greenhouse gases and air pollution, particularly when compared with the use of coal or diesel.

A combination of gas-fired district heating with gas-fired CHP is a highly efficient and cost-effective way to reduce CO2 emissions and air pollution. For example, a combination of CHP and centralised heat pumps used in Stockholm, the capital of Sweden, allows the production of heat using surplus electricity from renewables, with gas-fired power generation and district heating being used when renewable power is insufficient.

The use of natural gas-fired CHP can also support the integration of low-emissions sources of energy, including geothermal heat and power, solar, wind and batteries.

CASE STUDY: COMBINED HEAT AND POWER, ROPPONGI HILLS, TOKYO

ROPPONGI HILLS IS ONE OF JAPAN’S LARGEST INTEGRATED PROPERTY DEVELOPMENTS, LOCATED IN THE ROPPONGI DISTRICT OF MINATO, TOKYO.

The large complex incorporates office space, apartments, shops, restaurants, cafés and movie theatres, along with a museum, hotel, major TV studio, outdoor amphitheatre, and several parks. The Mori Building Tower has a natural gas CHP unit, which supplies electricity, heating and cooling to the whole area. The highly efficient system reduces energy consumption by 20% compared to centralised power generation. In turn, this cuts CO2 and nitrogen oxides by around 20% and 40% respectively.
CASE STUDY: K.I.E.L. COASTAL POWER PLANT, GERMANY

THE MUNICIPAL UTILITY STADTWERKE KIEL IS DEVELOPING A LARGE-SCALE GAS-POWERED COGENERATION PLANT IN GERMANY THAT WILL PROVIDE HIGH-EFFICIENCY HEAT AND POWER.

Compared to the coal-fired power plant that it will replace, CO₂ emissions are expected to be reduced by more than 70%.

Increasing city resilience

An increasing dependence on the infrastructure networks that deliver the energy people need leaves communities increasingly vulnerable to supply disruptions, such as those caused by natural disasters. In the USA, for example, where the electricity grid is 99.97% reliable, disruptions caused by bad weather, human error, animal interference or mechanical failure cost at least $150 billion in economic losses each year, according to the US Department of Energy. Resilient energy systems are critical to prepare for and reduce the impact of these disruptions, particularly in cities.

Gas-fired CHP systems strengthen the resilience of cities, providing backup power when the main grid is down. This was demonstrated when Hurricane Sandy hit the East Coast of the USA in 2012. Power disruptions affected 8.5 million people and left more than 1.3 million without electricity for a week. However, a gas-fired microgrid system at Long Island, New York, continued to generate electricity for 15 days, providing power to the North Shore Health System facility and 400 homes.

Power to gas: the promise of hydrogen

In countries with existing gas infrastructure, hydrogen (produced by steam methane reforming of natural gas, or through electrolysis using solar or wind power) can be combined with natural gas and used in power generation, or injected into a distribution network for use in buildings. This is sometimes referred to as ‘power to gas’. Today, most hydrogen is produced from natural gas. In the long term, hydrogen produced from renewables offers a storage solution for excess energy produced by variable renewables.

A report by KPMG, an audit, tax and advisory company, which explores the role of UK gas networks up to 2050, has shown that making use of the UK’s existing gas network could provide a practical and affordable way to reduce emissions from heating. The report shows that a combination of natural gas, biogas and hydrogen offers the lowest-cost emissions reduction pathway for the UK’s heating needs, saving the country up to $280 billion and consumers up to $12,350 each between 2015 and 2050. It is also shown to be the most technically feasible and socially acceptable option.
The energy transition in transport

Transport is essential to modern living. It drives economic growth, allowing countries to trade goods and communities to connect with one another. A growing and more prosperous global population will significantly increase demand for transport, for both personal mobility and the transport of goods. Meeting this demand while reducing emissions will require continued innovation.

Today, transport accounts for 28% of global final energy demand. Even with significant energy efficiency improvements and a greater proportion of the world’s population living in more compact cities, transport demand could increase by 46% by 2060, according to the IEA.

Satisfying increasing demand must be balanced with efforts to reduce greenhouse gas emissions, which contribute to climate change. Between 2010 and 2015, greenhouse gas emissions from transport increased by an average of 2.5% each year. Today, it is responsible for 23% of total global greenhouse gas emissions. Transport can also contribute to poor air quality, resulting in negative effects on the environment and human health.

Today, the transport sector is almost entirely powered by internal combustion engines fuelled with liquid hydrocarbons. This includes petrol and diesel in cars and fuel oil in ships. Improvements in the efficiency of these engines, in combination with lower sulphur fuels, have delivered considerable fuel savings and contributed to reductions in air pollution.

To meet increasing demand for transport with even fewer emissions, a mosaic of transport solutions will be required, including new lower-emissions fuels. This will include lower-emissions liquid fuels, biofuels and natural gas. It will also include new drivetrains and an increasing role for electric vehicles powered by both batteries and hydrogen fuel cells.

Natural gas will also have a significant role to play. Energy use in transport is expected to increase most in long-distance transport modes between 2015 and 2060, according to the IEA. In ships and trucks – where the size, weight and range of batteries currently limit their potential, natural gas could be an effective way to reduce air pollution and greenhouse gas emissions. The IEA estimates that use of natural gas for transportation could grow by as much as 14% between 2016 and 2022.

An effective transition in the transport sector will require a coordinated approach and policies that recognize the relationship between vehicles, fuels, refuelling infrastructure and consumer choice.
LNG for transport

LNG is emerging as a cost-competitive and cleaner-burning fuel for shipping and heavy-duty road transport. In the future, it could also be used for freight rail.

Realising the environmental benefits of LNG as a fuel will require collaboration across government and industry – growing infrastructure, supporting standards for emissions controls, and providing incentives that encourage demand growth for lower emissions fuels. This will be particularly important in the marine sector, which is subject to a complex regulatory environment with overlapping regional jurisdictions.

LNG for trucking

The IEA estimates that by 2060, 36% of additional energy demand for transport will come from road freight vehicles, particularly in East and South-East Asia. In 2015, China, India and countries in South-East Asia accounted for 30% of tonne kilometres (a measure of freight carried by a mode of transport) by road. This could increase to 46% by 2060.

In Africa, the share of trucking activity is expected to double by the end of the century.

Switching heavy-duty vehicles to LNG diversifies the fuel mix and can help reduce harmful air pollution. These benefits are helping to support demand in countries such as China, where there are already more than 200,000 heavy-duty trucks and buses on the road, refuelling at more than 2,000 LNG filling stations according to Sublime China Information. The number of LNG trucks is growing quickly, with sales of LNG heavy-duty trucks accounting for around 5% of total sales.

From extraction to use, LNG can reduce greenhouse gas emissions by up to 6% compared with diesel, according to a Thinkstep study for the Natural Gas Vehicle Association. Using the latest high pressure direct ignition engine, greenhouse gas reductions can be up to 15% lower, according to the study. LNG engines are also quieter than those using diesel. This is an advantage for urban areas, particularly for deliveries at night or areas subject to high traffic volumes.

LNG for transport

Once natural gas has been liquefied, the LNG is kept in insulated tanks until it is loaded into a specially designed ship or carrier. When it reaches its destination, LNG is offloaded into storage tanks at a facility known as a break-bulk terminal. This is used by supply barges, ferries, cruise liners, container ships and tankers in ports, rivers and coastal areas. Natural gas can also be liquefied on a small scale, which makes it even more accessible.

This approach uses liquefaction plants built in sections so they can be scaled up and down and moved to different locations. Trains and tankers carry LNG to storage tanks at fuelling stations for large trucks. Once there, the LNG is kept cool in insulated tanks. Customers fill up the vehicles in just the same way as they would with other liquid fuels.

LNG for trucks

Used in trucks delivering goods, LNG can reduce sulphur emissions, particulates and nitrogen oxides, and help reduce greenhouse gas emissions from production to use, compared to conventional diesel. It also has the potential to offer savings on fuel costs.

Vehicles that run on LNG can also be fuelled by biomethane, which is chemically and physically identical to the methane found in natural gas. When produced from organic waste, such as municipal waste, agricultural residues and manure, the use of biomethane can lead to lower greenhouse gas emissions, particularly when the methane used would otherwise be released into the atmosphere, such as at waste management or dairy sites.

Biomethane can be used directly in LNG fuel trucks, offering benefits to fleets with hub-and-spoke operations (a system of connections arranged like a wire wheel in which all traffic moves along spokes) and refuelling infrastructure close to biomethane production sites.
LNG for shipping

Around 80% of world trade in goods is by ship. This trade is expected to increase by nearly 50%, between 2017 and 2030. Today, there are limited alternatives to hydrocarbons to fuel ships, which still mainly run on heavy fuel oil and diesel.

The global shipping fleet produces air pollution, which impacts the environment and human health. Around 70% of these emissions occur within 400 kilometres of coastal communities – mainly in East Asia, South Asia and Europe.

The International Maritime Organization has made progress in agreeing to limit sulphur oxide and nitrogen oxide emissions from ships. LNG fuel can help ship operators meet these requirements. Compared to heavy fuel oil, natural gas combustion produces up to 80% less nitrogen oxides, which can help reduce smog formation.

Natural gas emits virtually no sulphur dioxide, so using more natural gas as fuel would emit less of the pollutants that cause acid rain. LNG also has a lower unit cost compared with low-sulphur heavy fuel oil or low-sulphur diesel fuel.

Shipping also produces greenhouse gas emissions. Although it is an efficient means to transport cargo over long distances, the scale of activity generates significant total emissions, with more than 50,000 merchant ships operating internationally. Switching from heavy fuel oil to LNG can reduce greenhouse emissions by up to 21% in a two-stroke engine with high-pressure injection and by 11% in a four-stroke engine, according to the Thinkstep study. This may become an increasingly important consideration for ship operators with the development of more stringent international emissions standards over the next decade.

Carnival Corporation, the world’s biggest cruise operator, has commissioned two cruise ships that will run on LNG in northern Europe and the western Mediterranean from 2019.

North American Emissions Control Area

The North American Emissions Control Area (ECA) came into effect in 2012. It includes the US Pacific, Atlantic and Gulf coasts, Hawaiian Islands, St. Lawrence Seaway, Great Lakes and those rivers accessible to international shipping. By 2030, emissions from ships operating in these areas are expected to be reduced each year by 1,300,000 tonnes for sulphur oxide, 1,200,000 tonnes for nitrogen oxide and 143,000 tonnes for particulate matter, according to the US Environmental Protection Agency (EPA). The EPA estimates that this could prevent 12,000 to 31,000 premature deaths, and relieve respiratory symptoms for nearly 5 million people each year in the USA and Canada. The health-related benefits to the USA are valued by the EPA at $110 to $270 billion by 2030.
CASE STUDY: BUSAN PORT, SOUTH KOREA

BUSAN PORT PROVIDES A LOGISTICS HUB FOR NORTHEAST ASIA, CONNECTING CONTAINER TRAFFIC FROM 500 PORTS IN 100 COUNTRIES.

The port is rapidly growing to support increasing demand. In response to concerns about local air pollution in the port area, with the support of the Korean government, the port authorities are converting their ground transport fleet from diesel to LNG.

Gas-to-liquids fuels

Natural gas is also converted into high-quality liquid transport fuels using a technology called the Fischer Tropsch process. Gas-to-liquids (GTL) fuel is a cleaner-burning alternative to diesel that can be used in existing heavy-duty and light-duty diesel engines as a drop-in fuel without the need for engine modifications, new infrastructure or vehicle investment. GTL fuel will play an increasingly important role in the fuel mix for heavy-duty vehicles, inland and seagoing marine vessels, rail and aviation ground fleets, particularly in regions seeking to improve local air emissions.

Compressed natural gas

Compressed natural gas (CNG) can be used in light- and heavy-duty vehicles and may emit fewer greenhouse gases and air pollutants than liquid fuels. For passenger cars, from the point where gas is extracted to when it is used in a car, CNG reduces greenhouse gas emissions by up to 23% compared with petrol and up to 7% compared with diesel, according to the Thinkstep study. For heavy-duty vehicles, CNG cuts greenhouse gas emissions by up to 16% compared to diesel. CNG also emits up to 58% less nitrogen oxide and up to 97% less particulate matter than diesel. Converting to CNG requires an upfront capital investment from vehicle owners. Where CNG costs less than liquid fuels, owners often recoup their investment over the lifetime of the vehicle.

GTL fuel, The Netherlands

Groningen chose to switch its municipal vehicles to GTL fuel to help improve the city’s local air quality. Vehicles include garbage trucks, street cleaners, vans, all-terrain vehicles and tractors.
CASE STUDY: CNG IN DELHI, INDIA

India is home to the world’s sixth-largest fleet of natural gas-fuelled vehicles, including CNG-powered taxis and buses.

In response to air pollution, Delhi was one of the first cities to mandate a shift from diesel to natural gas. This approach has significantly lowered emissions and improved air quality in many cities across India. Continued switching from diesel to CNG could contribute to a nine-fold increase in demand for gas to power India’s transport sector by 2040.

THE FUTURE OF NATURAL GAS

Energy powers progress. Meeting increasing global demand while minimising negative impacts on the planet and the air we breathe is one of the greatest challenges of the 21st century.

A transformation of the global energy system is needed. It will take place at different paces in different countries, depending on factors such as available natural resources and national policies designed to address climate change and local air quality.

Natural gas will be a critical component of this energy transition – to generate electricity, provide heat for essential industrial processes, heat or cool homes, and transport people and goods over long distances.

Switching from coal to cleaner-burning natural gas is significantly reducing greenhouse gas emissions and air pollution today.

The flexibility of natural gas will continue to support the integration of variable renewable electricity, cost-effectively responding to increases in demand and drops in supply from solar, wind and hydro.

An increasing share of electricity generated from renewables will drive greater use of electricity across industry, the built environment and transport.

Electricity generation is expected to increase from a fifth of energy use today to 50% by 2050. As the share of renewable electricity increases, the flexibility of natural gas will make it increasingly competitive with other thermal power generation, such as coal.

Natural gas will also be vital in parts of the economy that are more difficult to electrify, including industrial processes and freight transport.

Economics, government policies and relative environmental benefits will shape the future role of natural gas.

The economics will become more competitive when government policies consider not only the cost of purchasing and using fuel, but also the anticipated costs associated with the impacts on the environment and human health.

Government policies that put a price on carbon emissions can help reduce emissions and encourage investment in cleaner energy sources. Likewise, government-led emissions standards can drive investment and accelerate emissions reductions.

The natural gas industry must continue to prioritise safety, environmental safeguards and engagement with local communities.

A priority is to monitor and reduce methane emissions across the value chain, to realise the significant climate benefits compared to higher-carbon fuels.

Together, natural gas and renewables offer reliable, flexible and cost-effective access to more and cleaner energy.