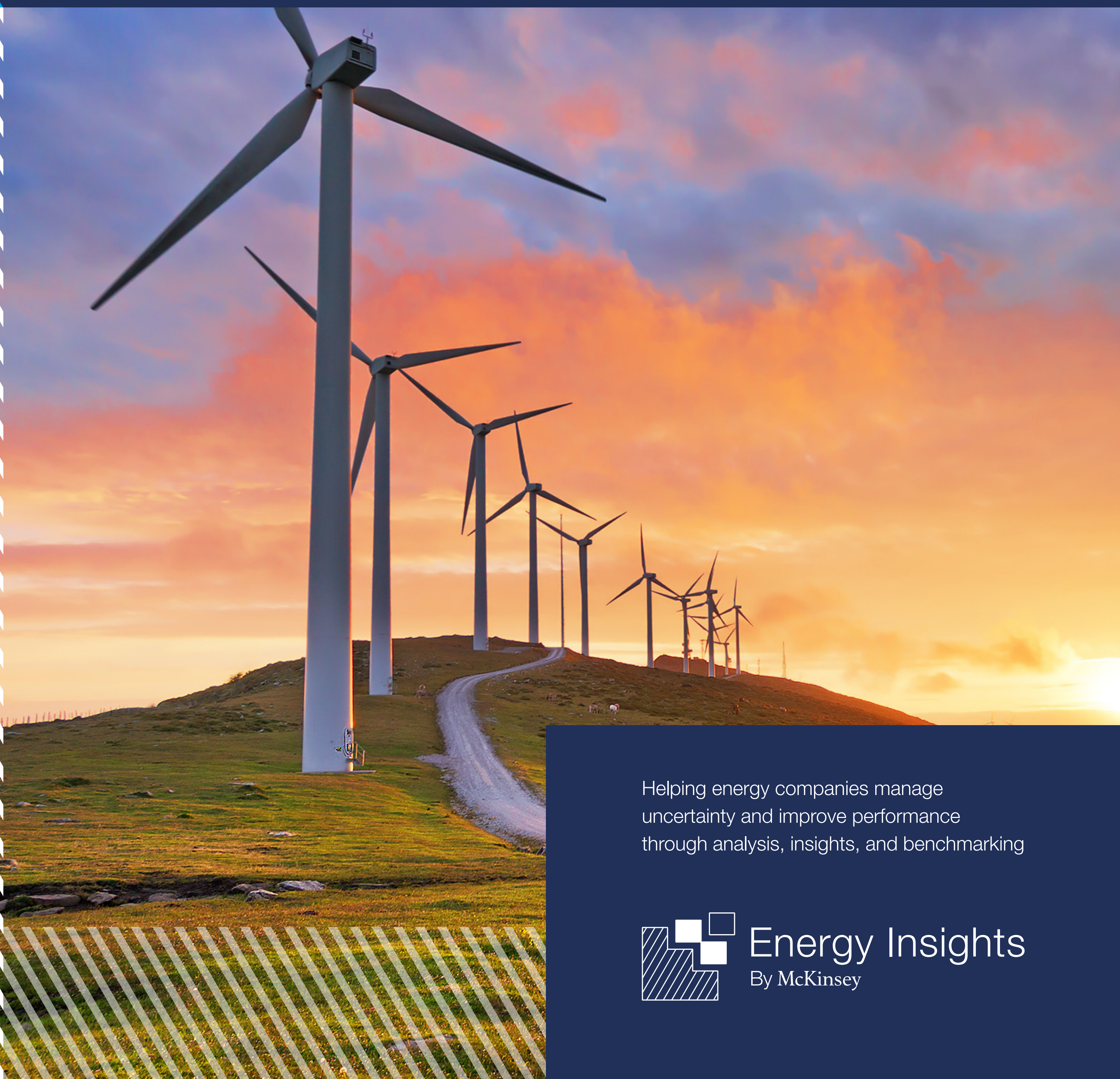
Global Energy Perspective: Accelerated Transition

The eight shifts that lead to a more rapid energy transition

November 2018



Helping energy companies manage uncertainty and improve performance through analysis, insights, and benchmarking

Energy Insights
By McKinsey

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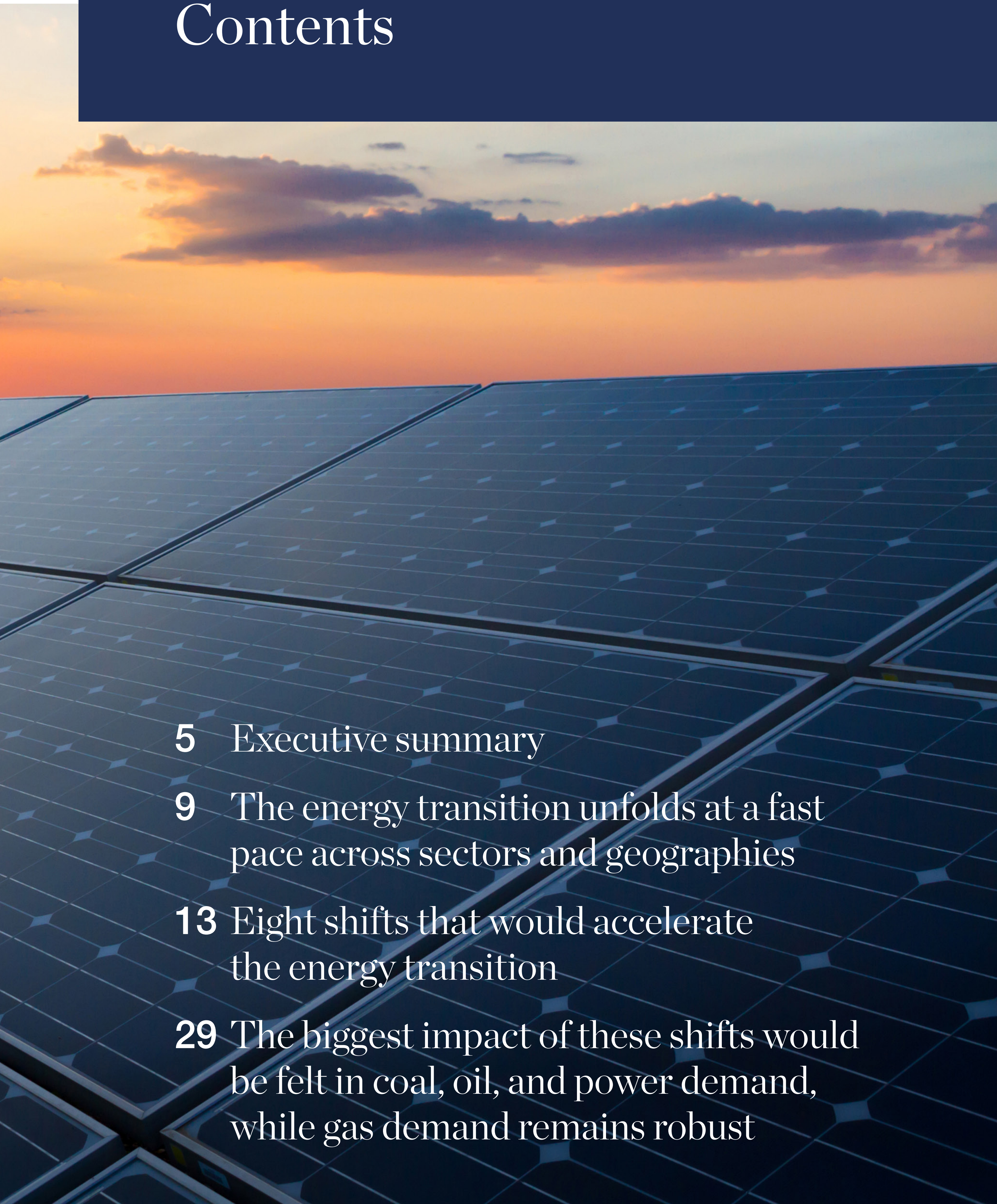


Executive summary

The economy is in the midst of a fundamental energy transition that affects how we fuel our vehicles, heat our homes, and power our industries. Many of the changes that make up this transition are changes away from inefficient technologies, such as internal combustion engine (ICE) cars and oil/gas boilers, toward electrified and higher efficiency alternatives. There is also a trend toward cleaner power generation from renewables. For companies, governments, and individuals alike, these developments require significant adaption. Whether one is searching for new value pools in clean or renewable technologies or preparing for challenges to their existing business models, the implications are widespread.

Every year, we publish our Global Energy Perspective Reference Case, which captures the McKinsey view of how energy demand will evolve in the future, to help our clients understand the implications of the energy transition. Yet, the speed and magnitude of many of the current shifts in our energy systems are challenging to project; they are inherently complex to understand fully, and different trends often affect or reinforce others. Therefore, we have developed this outlook, which reviews the impact of eight potential shifts that many of our clients ask about and that would further accelerate the energy transition. Although these eight shifts may not represent the most probable future, they should be considered conceivable based on the developments that can be observed today:

Shift 1 Faster uptake of electric vehicles (EVs) Accelerated EV uptake to 100% of the vehicle fleet in China, Europe, and North America and 50% in the rest of the world by 2050 minimizes demand from road transport, today's biggest oil demand sector

Shift 2 Improved efficiency gains and increased uptake of low-emission fuels for aviation and marine Meeting the aviation and marine transport sectors' 50% emission reduction targets adversely affects oil demand growth

Shift 3 Accelerated electrification of residential heat Heating 50% of homes in Europe and North America with electric heat pumps by 2050 slows down global gas demand growth

Shift 4 More rapid electrification of cooking in non-Organization for Economic Co-operation and Development (OECD) Africa and Asia Accelerated electrification of cooking strongly increases power demand growth

Shift 5 Increased demand reduction and recycling of plastics Plastic bans, more efficient use of plastics, the replacement of plastic with alternative materials, and recycling affect demand for petrochemicals, the largest driver of global oil demand growth

Shift 6 More efficiency gains, recycling, and low-emission feedstock in iron and steel production Improvements in energy efficiency and the carbon intensity of iron and steel production decreases industrial coal demand globally

Shift 7 More extensive electrification of EU industry low- and medium-temperature heat Electrification of low- and medium-temperature heat in Europe reduces gas demand for the third largest sector in the region

Shift 8 Accelerated cost reduction for renewables and storage Renewables and battery storage become the cheapest power source at scale, outcompeting fossil fuels

For each of these shifts, this outlook presents the impact they could have on annual oil, gas, coal, and power demand. Overall, there are five potential implications for the global energy sector and its value chains:

1 **Oil demand (currently 32% of energy supply with 99 MMb/d) could peak before 2025** but would still represent 26% of energy supply in 2035 (80 MMb/d) and 18% in 2050 (55 MMb/d). If ICE vehicle efficiency improvements continue as expected, EVs see a faster uptake, plastic demand growth slows down, and more recycling reduces demand for new plastic feedstock, oil demand could peak as soon as the early 2020s and decrease rapidly thereafter

2 **Gas demand continues to grow as its role in the energy system remains stable** from its current 21% of energy supply (3,430 bcm) to 22% of energy supply in 2035 (3,700 bcm) and 23% in 2050 (3,800 bcm). Natural gas has a balancing role in the power system, and this makes it resilient despite the electrification of residential and industrial heat and a large-scale move in the power sector toward renewables and batteries

3 **Fossil fuel demand decrease is disproportionally large compared to power demand increase**, with the accelerated transition resulting in ~20% less fossil fuel demand compared to the Reference Case, but only ~10% more power demand in 2035 (31k TWh). For 2050, there is ~30% less fossil fuel demand and ~15% more power demand (46k TWh). This disproportionality is driven by strong efficiency gains from electrification

4 **Coal demand (currently 28% of energy supply with 5,320 Mtce) will decrease rapidly** toward 21% of energy supply in 2035 (4,100 Mtce) and 19% in 2050 (3,850 Mtce). In an accelerated energy transition, the power sector and iron and steel production would require much less coal in the future, and coal demand would not reach its 2014 high again

5 **Projected carbon emissions remain well above a 2-degree Celsius pathway** as all shifts combined would bring CO_2 emissions from current 32 $GtCO_2$ to 22 $GtCO_2$ in 2050. This closes only around half the gap between the Reference Case (32 $GtCO_2$) and the IEA's 2-degree Celsius pathway (13 $GtCO_2$)

Even in a world in which such fundamental changes in the transport, buildings, industrial, and power sectors reduce the use of fossil fuels drastically, additional measures would be needed to reach international climate goals. Further developments and cost declines of key technologies, an increased demand for 'clean' solutions, and innovations we might not see on the horizon today could disrupt the energy system even further.

The energy transition unfolds at a fast pace across sectors and geographies

The global economy is in the midst of a fundamental energy transition. Over the last two decades, an increasing share of total primary energy demand has shifted away from fossil fuels toward renewables such as solar and wind.

Particularly in electricity generation, where in 2016 the newly added power generation capacity from renewables was larger than the new capacity from coal, gas, and oil combined, this shift away from fossil fuels fundamentally changed the landscape in the power sector. Moreover, a growing share of the energy we consume directly is moving away from fossil fuels toward (renewable) electricity. Be it heating, lighting, cooking, or transportation, many applications today are powered by electricity rather than fossil fuels.

We are also seeing significant pressure on fossil fuels from improvements in energy efficiency. While energy demand is still growing strongly in most developing countries, we are seeing a decoupling of energy demand growth from economic growth in many developed countries. In addition to electrical energy services being more energy-efficient than their fossil fuel powered counterparts, internal combustion engines in cars, boilers for heating, and industrial processes have also become much more efficient. With this increasing energy efficiency, we are, in some cases, seeing energy intensity decrease despite continued economic growth, even in countries like the United States, one of the countries with the highest energy consumption per capita.

For companies, governments, and individuals alike, these developments mean notable change. Whether one is intrigued by new markets in clean technologies and the renewable energy sector, preparing for challenges to existing business models, or considering the purchase of an EV or electric heat pump, the implications are widespread.

Every year, we publish the Global Energy Perspective Reference Case to help our clients understand these implications, based on an outlook to 2050 that captures the McKinsey perspective of how energy demand will likely evolve.

Five key insights from the 2018 Global Energy Perspective, summarizing the fundamental energy demand outlook and projecting the most likely scenario for how the energy transition will unfold over the next decade

1 Global energy demand growth decelerates following a structural decline in energy intensity

2 Electricity demand grows four times faster than all other fuels

3 Renewables' cost decline accelerates further, outcompeting new-built fossil capacity today and existing capacity in 5-10 years

4 Coal demand peaks in the next decade, oil in the next two; in contrast, gas continues to grow modestly

5 CO_2 emissions plateau by 2030 and remain far from a 2-degree Celsius pathway

While the level of detail and the comprehensive view of the connections and interactions in our energy system have proven invaluable in discussions with our clients and in enhancing their understanding of the sensitivities of the global energy system, forecasting the energy transition has often proven challenging. The growth of renewable energies, for instance, has consistently been underestimated by most experts, and some developments in energy efficiency, electric transport, and storage that are part of everyday life today seemed unthinkable only a few years ago. In addition to renewables, EVs or modern power storage solutions are a good example for the faster-than-expected pace of the energy transition. Last year (2017) alone, over one million new EVs were sold, adding 50% to the 2016 operating fleet of EVs, and over the past five years battery packs have seen an average cost decrease of 15-20% per year, much faster than expected by most experts.

In discussions with our clients, we found that they were curious about the impact of specific developments that can broadly be clustered in two categories: the energy transition unfolding at a dramatically accelerated pace, and events and technological breakthroughs that create a tipping point for the adoption of a certain technology.

This outlook explores what the global energy future would look like if eight 'accelerating' developments or shifts happen. We consider each of these shifts to be conceivable, given current developments. Whether stand-alone or in combination with the other shifts, they have a disruptive impact on the energy system at a global level and even more so on local levels. We discuss the projected effects of this selective set of shifts on different fuels and consider the implications on the future state of the energy system relative to our Reference Case[1].

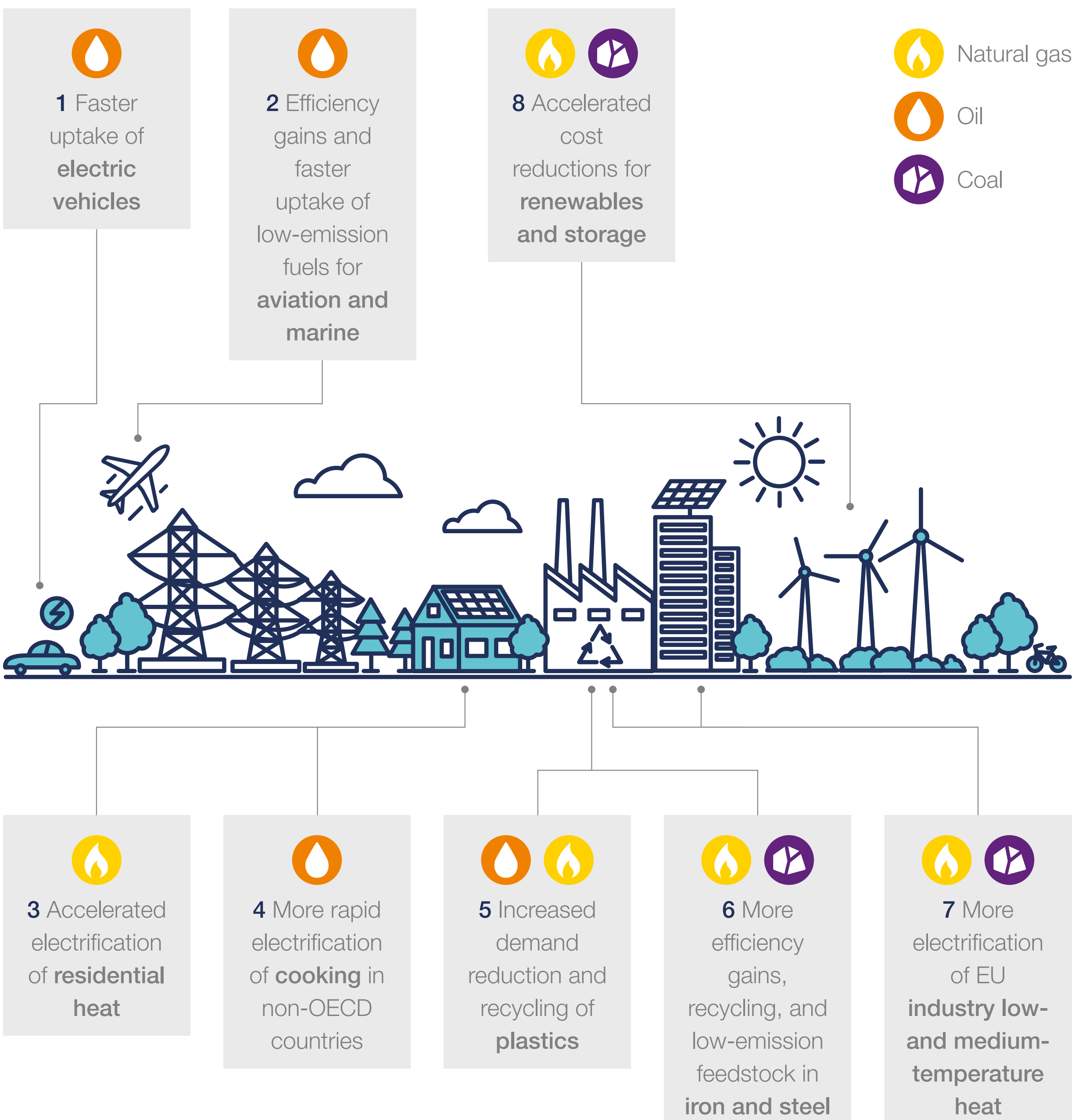
1 This outlook uses the August 2018 version of the Global Energy Perspective Reference Case.

Eight shifts that would accelerate the energy transition

Our accelerated transition scenario addresses a selection of the most commonly asked questions from our clients about shifts across sectors and fuels. Together with a broad global network of sector experts, we defined these eight shifts in certain regions and sectors in a conceivable manner.

For many of these shifts, this is based on developments that can already be observed today, such as the accelerating drop in battery storage costs or strong EV market growth. This chapter introduces the eight shifts, reflects on developments to date, and explores ways in which these shifts could materialize in the future.

The eight shifts of the accelerated energy transition scenario across different sectors and fuels



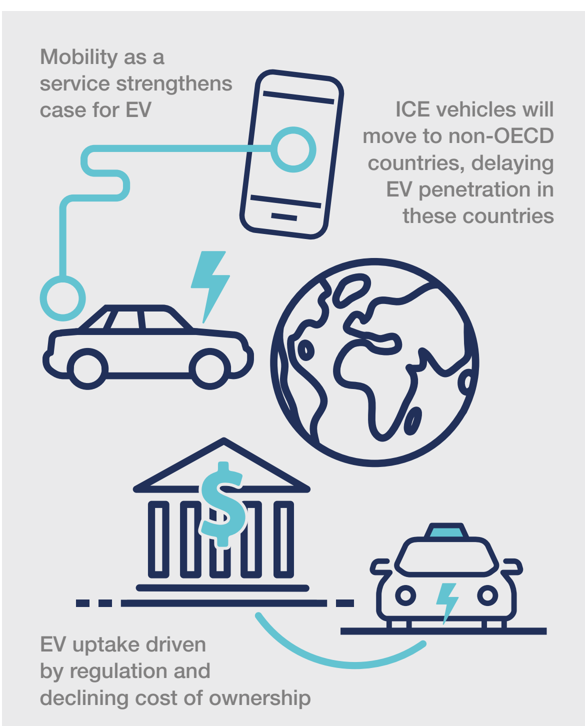
Shift 1 Faster uptake of electric vehicles (EVs)

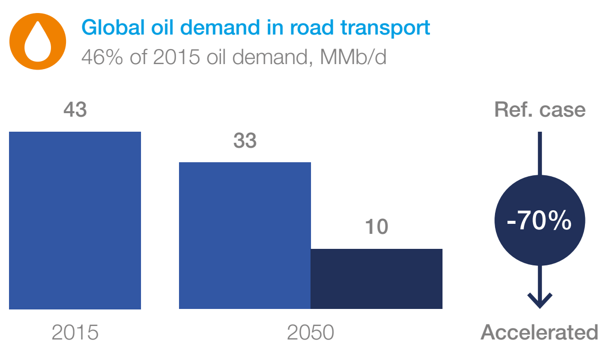
Accelerated EV uptake to 100% of the vehicle fleet in China, Europe, and North America and 50% in the rest of the world minimizes demand from road transport, today's biggest oil demand sector

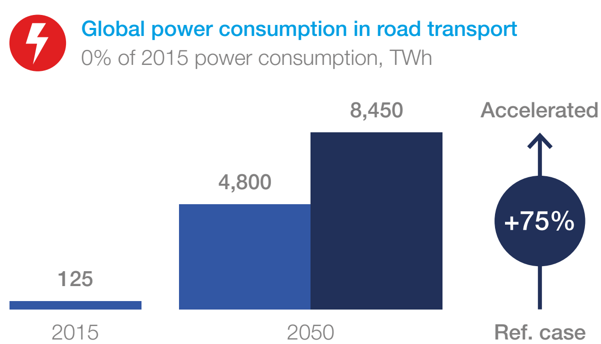
In recent years, sales of EVs have seen exponential growth. Unexpected for many observers, the number of electric passenger cars sold surpassed the 1 million mark for the first time in 2017, representing more than 50% of the then 2 million EVs already on the street. Overall, the market has seen strong growth rates of 40-50% p.a. in recent years, and, in certain countries like Norway, EVs now account for almost 50% of new car sales. The majority of EVs on the road are currently in China, followed by Europe and the US. Much of this strong demand growth has been driven by regulatory incentives, often via tax breaks and other financial benefits. In some countries, like Norway and China, these incentives can compensate for up to 45% of the EV purchase price.

With battery costs rapidly dropping (on average 15-20% p.a. over the last 10 years), at some point in the early 2020s the total cost to own an EV, including the fuel cost savings, will be lower than the total cost to own an ICE car, even though the initial purchase price might still be higher. This applies not only to passenger cars and two-wheelers but also to other vehicle segments like commercial vehicles, including vans, buses, and even trucks. After this 'tipping point', economic considerations alone would be sufficient to accelerate the growth of EV sales, leading to further learning effects and driving the cost down even more. Developments such as 'transport-as-a-service', including on-demand, shared mobility, and autonomous driving

1 Accelerated EV uptake to 100% of the vehicle fleet in OECD countries and 50% in non-OECD countries minimizes today's biggest oil demand sector







would accelerate this process further as economic considerations become a much more important factor for the purchase (or replacement) decision in shared-ownership or service models.

Cities are also increasingly limiting access for ICE cars in their city centers or thinking about banning them altogether. Today, over 200 European cities have already installed low emission zones or access regulation, and major cities like Mexico City, London, and Paris have announced diesel bans by 2025. In the US, eight states have currently set out goals for EVs, and even some emerging economies—often markets with strong growth rates for car sales—have announced plans to target certain shares of EV sales (e.g., India aims to have EVs account for 30% of new car sales in 2030) or completely phase out fuel-powered vehicles (e.g., China). Many European governments have announced ICE sales bans in the coming decades.

On the supply side, different original equipment manufacturers (OEMs) have publicly announced EV targets that would allow a quick ramp-up of EVs—cumulatively over 10 million electric car sales by 2020 (equivalent to ~10% of global passenger car sales).

Overall, these developments make it conceivable that the EV market will continue to grow with rates between 15-20% per year and that, by 2035, EVs across different vehicle segments will account for 65% of total global sales (70 million electric passenger cars per year). For China, Europe, and North America, this would lead to virtually all vehicles on the road being electric by 2050. In other countries, which often import used vehicles, a similar development would take place, just delayed by several years once ICE vehicles are worn out. This would lead to a third of the global fleet being electric in 2035 and over 80% in 2050.

Such developments would have a significant impact on global oil demand, as road transport accounted for 46% of total oil demand in 2015. The impact on regional supply chains, including refinery utilization rates, distribution networks, and car workshops, would be disruptive. Finally, with a road transport transition of that scale, significant investments in infrastructure would also be needed. With more than 400 million battery electric passenger cars on the street in OECD countries and China in 2035, a widely available charging infrastructure would be needed, as many urban users won't have access to home charging. At least 40 million public charging stations would be needed, which implies, on average, 2.4 million of these installed per year between now and 2035.

Shift 2 Improved efficiency gains and increased uptake in low-emission fuels for aviation and marine

Meeting the aviation and marine transport sectors' 50% emission reduction targets for 2050, without compensation or off-setting, adversely affects oil demand growth

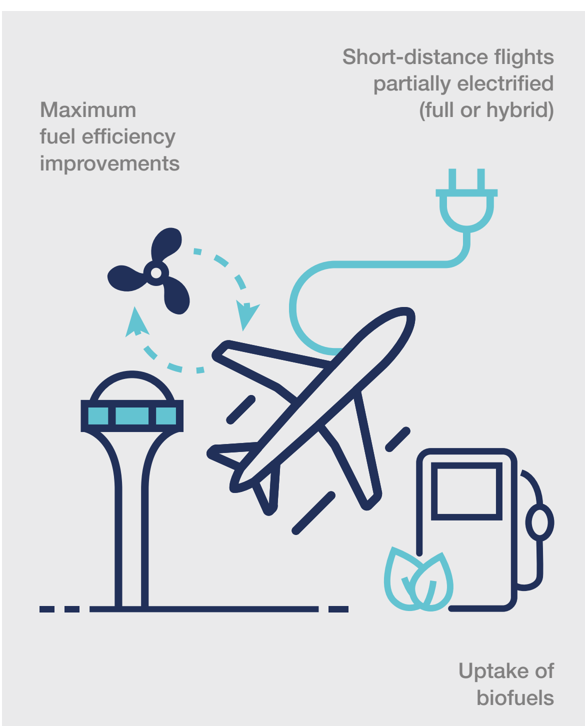
In recent years, the aviation sector has experienced strong growth with passenger numbers growing 5-6% per year over the last decade. Consequently, the sector was an important driver for global oil demand with growth of 1.7% p.a. between 2005 and 2015.

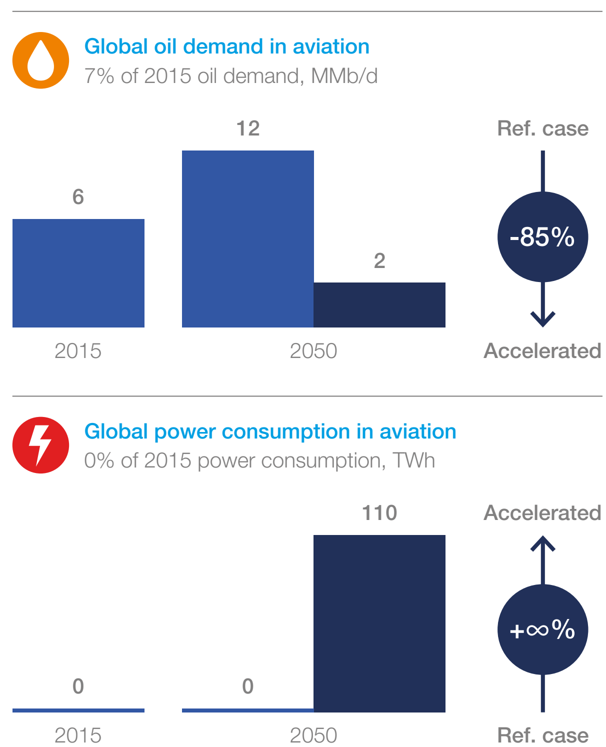
According to our sector experts, this trend will continue with the growth of the global middle class, and the aviation sector's demand for oil will nearly double to 12 MMb/d by 2050. By 2035, the sector expects 7.2 billion passengers per year, up from 3.8 billion today, and oil demand of 9 MMb/d—50% higher than today.

Growth is also expected in the marine sector. With a continued increase in global maritime trade, energy demand is expected to grow by 1.5-2.0% per year through 2050. In 2015, marine consumed 5 MMb/d (5% of total global oil demand) and is expected to reach about 6 MMb/d in 2050, taking into account expected improvements in efficiency and changes in the fuel mix with LNG.

Due to environmental concerns and increased regulatory efforts, however, both sectors' umbrella organizations have set themselves ambitious targets for the reduction of CO_2 emissions and other pollutants.

2a Meeting aviation industry's 50% emission reduction target negates oil demand growth in the sector





Aviation

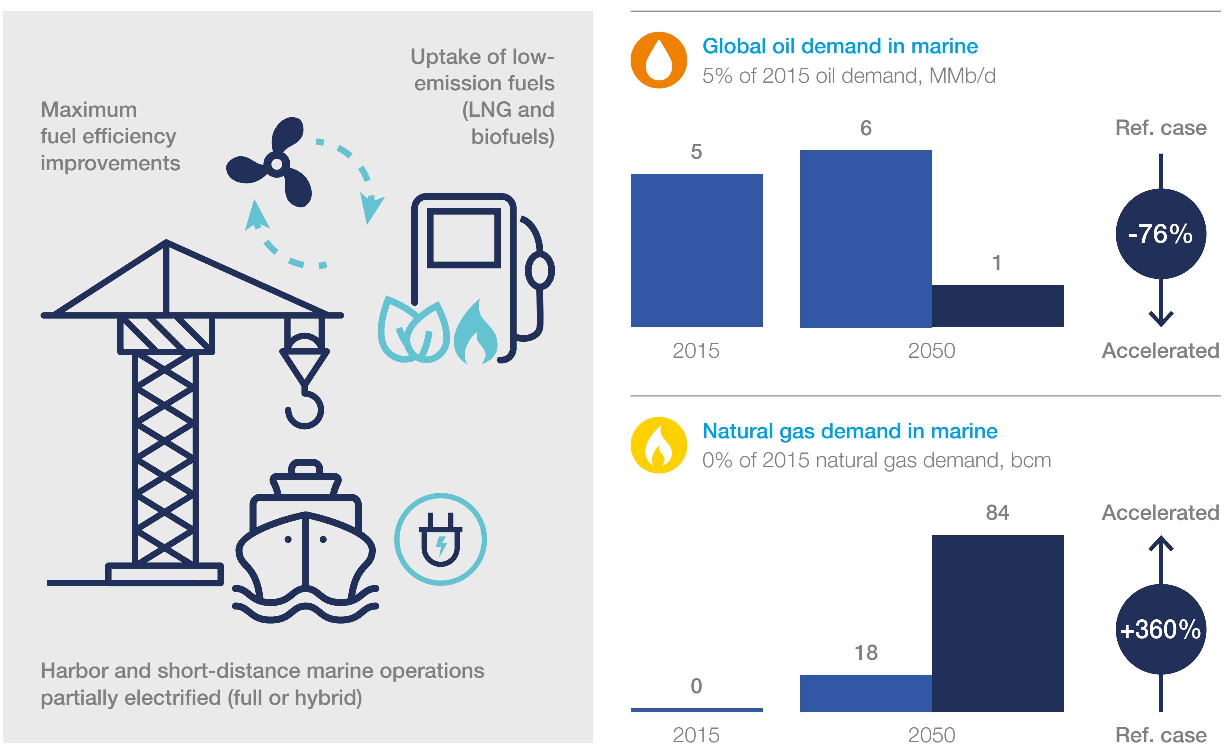
IATA and ICAO, the global aviation organizations, are aiming at carbon neutral growth from 2020 onwards (i.e., at least flat emissions), and emissions should be reduced to 50% of 2005 levels by 2050. To achieve this, the aviation sector is aiming for efficiency improvements between 1.5-2.0% p.a. and plans to introduce advanced biofuels with low emissions to the fuel mix to offset excess emissions. Should carbon offsets at the required scale not be an option, much higher efficiency improvements (~3% p.a.), accelerated biofuel uptake, and even electrification of short-haul flights (hybrid or full electric) will be required to reach these ambitious targets.

The sector is investigating ways to achieve these targets in the most cost-effective way. Over the past 40 years, the fuel economy in the aviation sector has improved by 50%, and each new airplane design is projected to provide ~15% additional efficiency gains. For instance, the Boeing 787 was designed to be 20% more fuel-efficient than the Boeing 767, which it is intended to replace. In addition, in 2017, 100,000 flights were operated partially on biofuels, and in 2020 the sector is aiming for 1 million biofueled flights. Finally, the dawn of electric aviation is expected in late 2030 in OECD countries, with major breakthroughs in battery and electric propulsion on the horizon and several prototypes under development today. Regulators are also starting to investigate potential decarbonization routes for this sector. The Norwegian government, for instance, aspires for 100% of all domestic routes to be electrified by 2040.

Marine

Similarly, the International Maritime Organization (IMO) has announced a target to reduce marine's greenhouse gas (GHG) emissions to 50% of 2008 levels by 2050 and address the emissions of other pollutants as well. While LNG and biofuels play an

2b Meeting marine industry's 50% emission reduction target negates oil demand growth in the sector



important role in the achievement of these targets, efficiency improvements and the electrification of short-distance trips and port-side technologies will also play a role.

Historically, maritime efficiency gains have ranged between 1.0-1.5% p.a., but larger gains are likely to be achieved in the future due to increasing competitive pressure, regulatory push, and improved practices of route optimization and arrival planning. To achieve its ambitious emission targets, the maritime fuel mix must also change. Biofuels, natural gas, and electricity will all play a role in this effort. For instance, the emergence of dual fuel engines that can run on both oil and natural gas and an increasing number of LNG fuel stations in important harbors will accelerate the uptake of LNG in marine. In addition to emissions savings, natural gas is increasingly cost-competitive with oil, delivers better fuel economy, and could soon become the preferred fuel for new vessels or retrofit old vessels. Biofuels are not yet abundantly consumed in the maritime sector but it is possible, based on current biofuel technologies, to be used in existing vessels as a fuel addition. Finally, electric vessels are showing promise in the small-to-medium size category. China, for instance, is showing rapid progress with a new all-electric cargo ship (2.4 MWh battery pack) which was operated for the first time in 2018. Although it has a limited range of only 80 km per charge, this achievement marks a significant milestone in electrification in the maritime industry.

Together, these developments would significantly reduce global oil demand in aviation and marine from 12% of global demand (11 MMb/d) in 2015 to 6% (3 MMb/d) in 2050 in the accelerated scenario, vs. 17% of global oil demand (19 MMb/d) in the Reference Case.

Shift 3 Accelerated electrification of residential heat

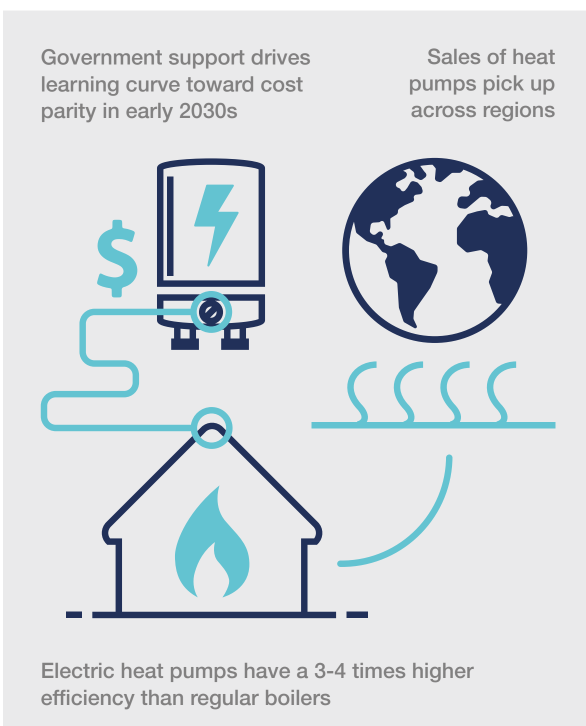
Heating 50% of homes with electric heat pumps in Europe and North America by 2050 slows down global gas demand growth

Electric heat pumps have seen a strong uptake in recent years, particularly in the European market, where the annual growth rate of heat pump sales was 12% in 2016. Much of this has been driven by favorable regulation and financial incentives, such as subsidies or tax benefits. The initial purchase and installation of such pumps is, unless subsidized, more expensive than for their fossil fuel counterparts. Over their lifetime, however, they have much lower operating costs due to their higher efficiency—often more than 3-4 times higher efficiency than a gas or oil boiler. Depending on the difference between oil and gas costs and the electricity price, this increased efficiency can recoup the higher upfront investment via lower operating cost.

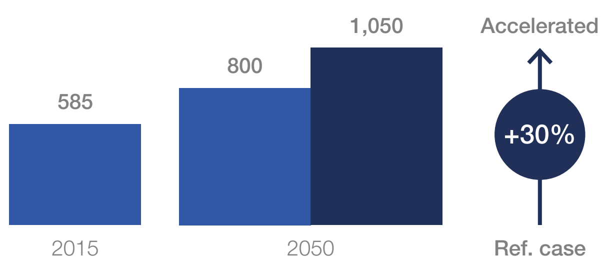
With declining electricity costs and decreasing investment cost driven by an increasing stock and learning curve effects (with the current market growth, heat pump technology will see over 30% cost reduction by 2030 at the latest), heat pumps reach total cost of ownership (TCO) parity post-2030 and then see an explosive uptake in the residential (and commercial) heating sector.

In the meantime, continued favorable regulation, such as the announced phase-out of gas for residential heating in the Netherlands, will ensure that the production of such heat pumps continues on the learning curve.

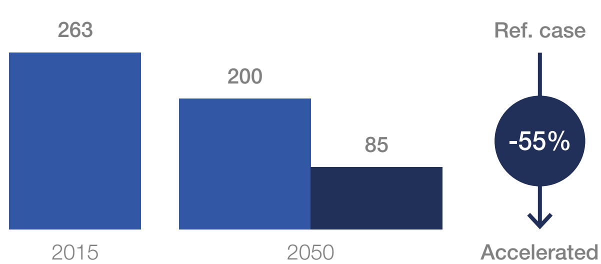
3 Heating 50% of homes with electric heat pumps in Europe and North America slows down global gas demand growth



Power consumption in residential heating (in EU & NA)
2% of 2015 power consumption, TWh



Natural gas demand in residential heating (in EU & NA)
10% of 2015 natural gas demand, bcm



Shift 4 More rapid electrification of cooking in non-OECD Africa and Asia

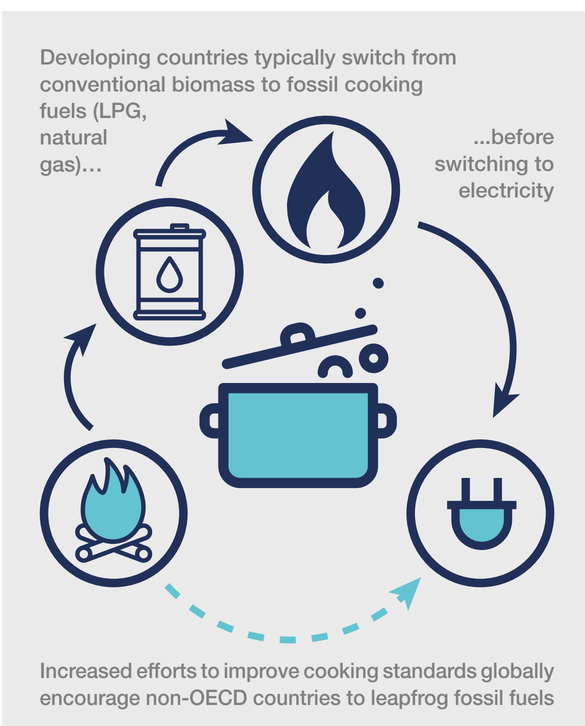
Accelerated electrification of cooking in non-OECD countries strongly increases power demand growth

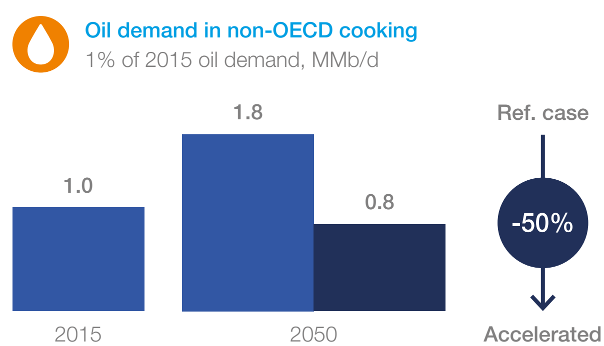
Currently, more than 90% of the population in Sub-Saharan Africa and more than 60% of the population in Southeast Asia lack access to affordable, reliable, sustainable, and modern energy for cooking. These households often rely on biomass or heavily subsidized liquid oil products like kerosene for cooking, which has detrimental effects on people's health and on the environment due to deforestation and air pollution.

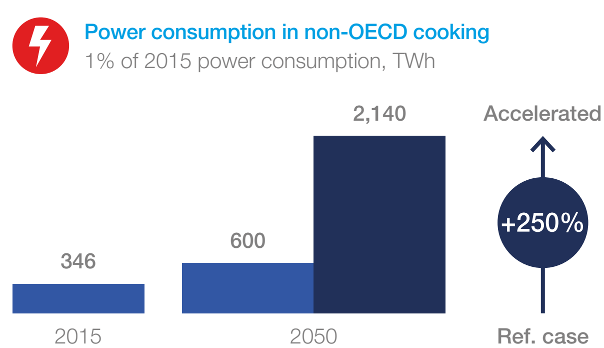
One of the alternatives to heavily polluting fuels has been liquefied petroleum gas (LPG), which, thanks to widely introduced subsidies, has been increasingly adopted in recent years. In our Reference Case, 3% of the growth in global oil demand (0.35 MMb/d) can be attributed to this development, in particular due to a switch in cooking technologies used in non-OECD Africa and Asia. The popularity of LPG is primarily driven by limited availability of local alternatives, such as natural gas and electricity, which require considerable investments in infrastructure to ensure structural access, especially in remote, rural locations in low-income countries.

With the decreasing cost of decentralized technologies, such as solar cells, batteries, and other electric cooker components, alternatives for fossil fuel-based cooking could become reality. In this shift, we conceive that it's possible that

4 Accelerated electrification of cooking in non-OECD countries strongly increases power demand growth







photovoltaic-based electric cooking solutions reach cost parity in 2035. This is driven by learning curves in electric cooking technologies, as well as governments and NGOs who decide to shift fossil fuel subsidies to instead support electrical access and electrified cooking, resulting in a leapfrog development from conventional biomass to electric cooking, skipping fossil fuel-based cooking. This results in a ~1-MMb/d reduction in oil use through 2050, while adding 1,550 TWh of electricity use for cooking (the equivalent of adding India's power demand today) in non-OECD Africa and Asia.

Shift 5 Increased demand reduction and recycling of plastics

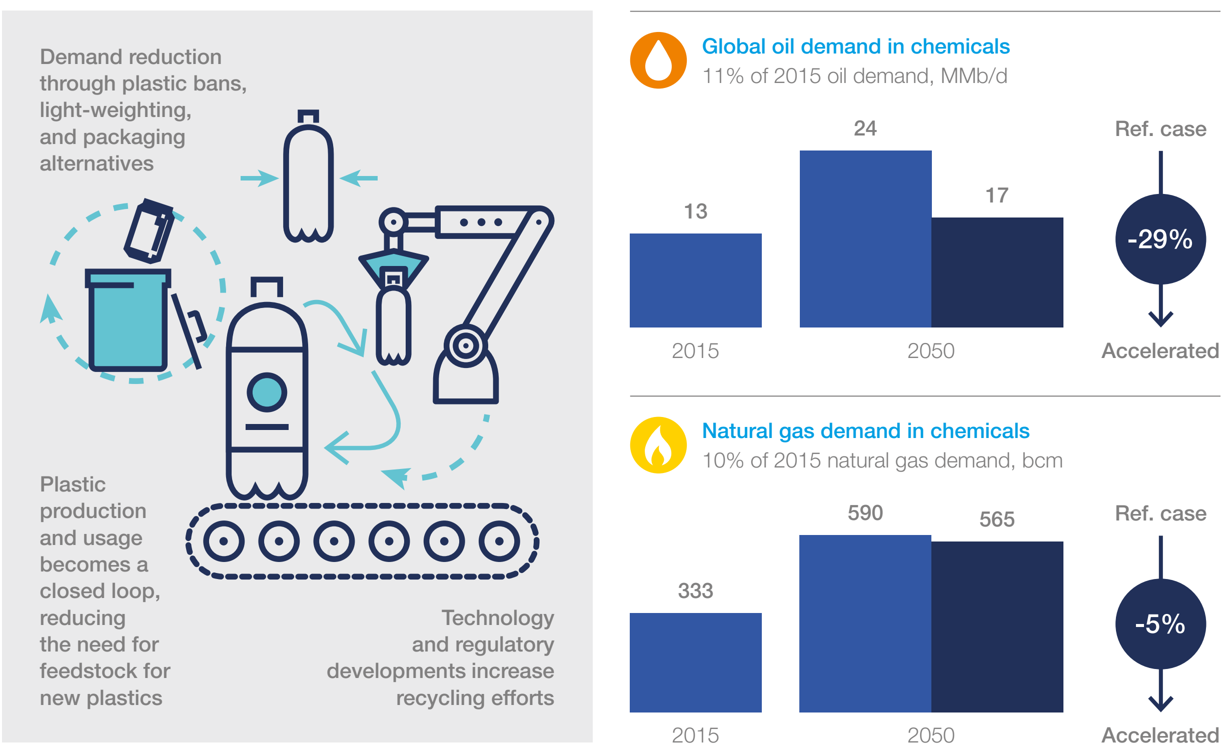
Plastic bans, more efficient use of plastics, the replacement of plastic with alternative materials, and recycling affect demand for petrochemicals, the largest driver of global oil demand growth

The chemicals sector has historically witnessed robust growth (over 2% p.a. from 1980-2015) and is the biggest driver of global oil demand for decades to come in our Reference Case. In the Reference Case, the chemicals sector will need an additional ~12 MMb/d of oil by 2050, much of which will be used as feedstock to produce plastics.

However, a combination of shifting consumer demand, policy, economics, and technology can reduce this growth figure substantially. In recent years, more and more countries are discussing or have already taken measures to tackle plastic pollution, and consumer perception is changing in response to plastics accumulating in the oceans and environment. To date, over 70 countries have introduced national regulations for single-use plastics of which more than 50% were implemented in the last three years. Other measures to reduce the use of plastics include encouraging alternatives to plastic packaging, bans on new landfills like in Western Europe, or taxes on the incineration of plastic as is currently proposed in different European countries. Efficiency improvements and cost reduction efforts have started to reduce the amount of plastics used for certain packaging.

At the same time, recycling technologies are improving rapidly. In Germany, for instance, the cost of plastics recycling has decreased on average by 15% p.a. over the past few years. Recycling is

5 **Recycling and more efficient use of plastics cuts the largest growth driver of global oil demand**



further enabled by an increasing trend to 'design-to-recycle', allowing for more recycling efforts in the entire value chain.

If we conceive that the reduction in plastics demand, compared to the continuation of historic trends, accelerates from 10% in the Reference Case to 20% by 2050 and that recycling rates increase from less than 20% to 40% in 2050, these trends together will slow down the demand for new ('virgin') plastic and therefore reduce oil demand by ~30% (7 MMb/d) compared to the 2050 Reference Case.

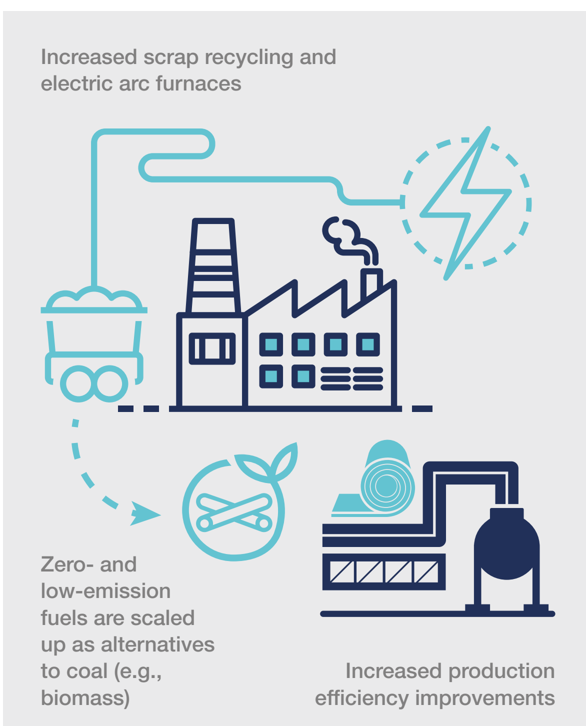
Shift 6 More efficiency gains, recycling, and low-emission feedstock in iron and steel production

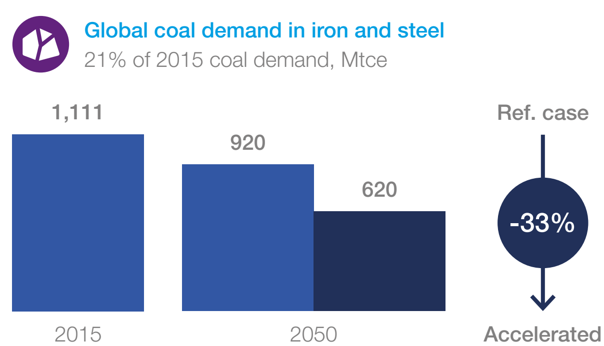
Improvements in energy efficiency and the carbon intensity of iron and steel production decreases industrial coal demand globally

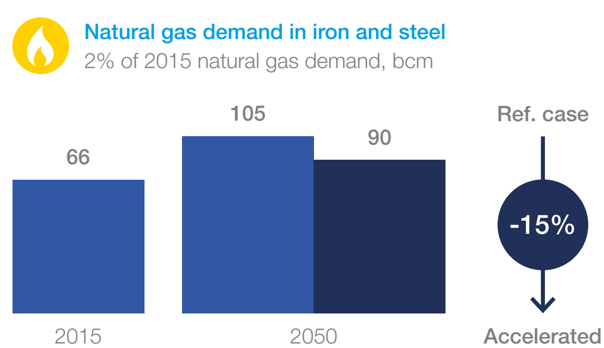
With fuel (and electricity) as one of the main cost drivers in iron and steel production and significant overcapacities in the global supply chain, efficiency improvements are crucial for the industry to remain competitive. Since 1980, energy intensity has already come down by 20%. More recently, many new efficiency-improving technologies have appeared, such as HIsarna, which improves energy efficiency by up to 20%. Part of this trend includes the shift toward producing with more efficient electric arc furnaces (EAF) instead of blast furnaces (BF)—which currently accounts for 67% of steel capacity in US. Using electricity not only reduces demand for coal in heat generation, but it also has the potential to eliminate coal as a feedstock. If EAF uses recycled scrap steel instead of direct reduced iron, energy intensity can come down to ~3 GJ/t steel (cf. BF = ~19 GJ/t steel).

By 2050, we assume, for the shift, an increase of ~25% in energy efficiency in overall steel production (all routes) and that ~60% of global steel production will come from EAF. Moreover, increasing carbon prices, currently observed or expected in countries around the world, will incentivize the switch away from remaining coal toward biomass in heat generation (~4% of global steel). Overall, this development decreases coal demand in the iron- and steel-producing industry significantly.

6 Iron and steel energy and carbon intensity reduction strongly reduces global industrial coal demand







Shift 7 More extensive electrification of EU industry low- and medium-temperature heat

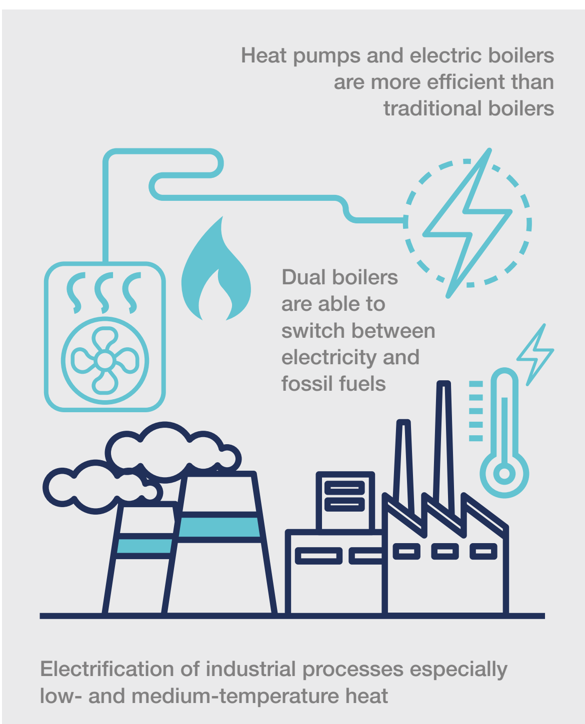
Electrification of low- and medium-temperature heat in Europe reduces gas demand for the third largest sector in the region

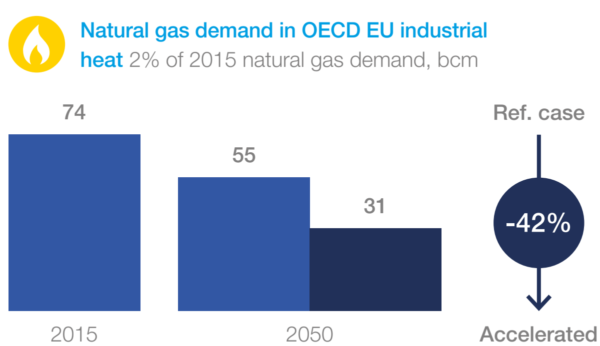
Depending on the type of industry, ~50% of energy is used for the generation of heat for industrial processes. Heating processes are split into three categories—low-, medium-, and high-temperature heat—where the breakdown is very industry-dependent.

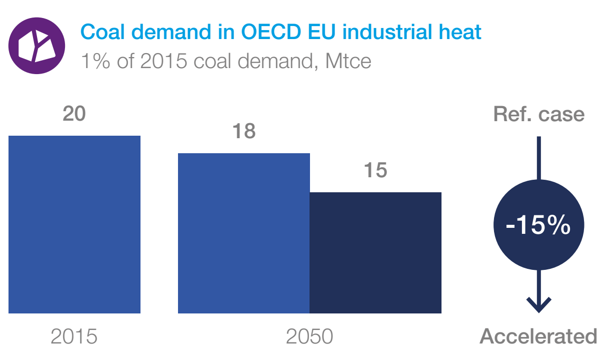
High-temperature heat is mainly used in heavy industries: iron and steel, non-metallic minerals (e.g., cement), and non-ferrous metals (e.g., aluminum, copper). These require fuels with a high energy density (currently natural gas and coal) and are, with current technologies and cost projections, difficult to replace by electricity. Other industries—predominantly manufacturing, food and tobacco, construction, pulp and paper, and wood and wood products—have higher shares of low- and medium-temperature heat.

Currently, fuel cost is the biggest cost component of heat production, of which much is generated by burning gas and some is generated by burning coal. Electric heat pumps, however, operate at an efficiency that is 3-4 times higher for low-temperature heat generation and, with the cost of this technology coming down, will even be 'in the money' for some additional applications (e.g., residential heating, see Shift 3). For medium-temperature heat, hybrid (or dual) boilers that use varying shares of electricity and gas are becoming

7 Electrification of low- and medium-temperature heat in Europe reduces gas demand of the third largest sector in the region







increasingly attractive as they enable producers to quickly adapt to varying price differentials between gas and electricity (and carbon prices). Such producers can even benefit from demand-side response (DSR) compensation by reducing their power demand in peak times (more gas) and increasing it in low-demand times (e.g., nights). Currently, this only applies to regions with a relatively large price differential between gas and power.

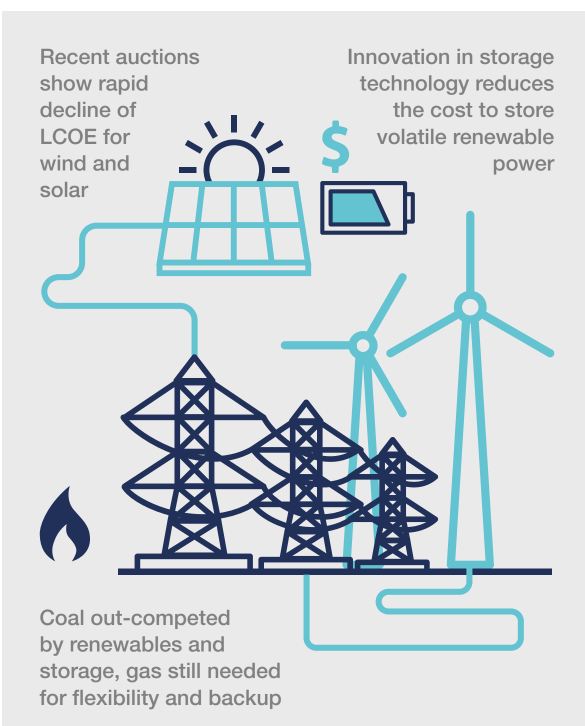
This shift assumes that stronger regulation on carbon abatement and accelerated technological developments—similar to those described in Shift 3—will lead to increased electrification of low- and medium temperature heat in OECD Europe. With up to 80% of low- and medium-temperature heat in OECD Europe electrified by 2050, gas and coal demand in the sector would go down (gas by 23 bcm and coal by 4 Mtce), but the impact would remain modest vs. the Reference Case, given the high consumption of energy by high-temperature heat and other non-heat related processes.

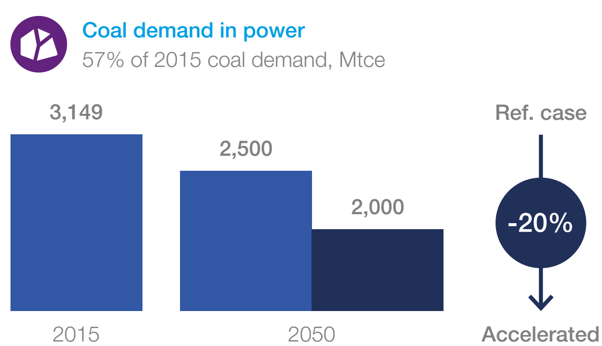
Shift 8 Accelerated cost reduction for renewables and storage

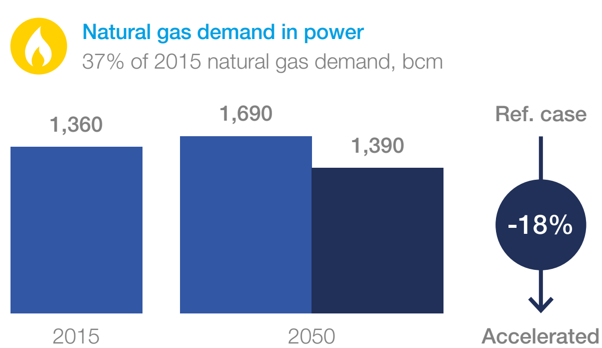
Renewables and battery storage become the cheapest power source at scale, outcompeting fossil fuels

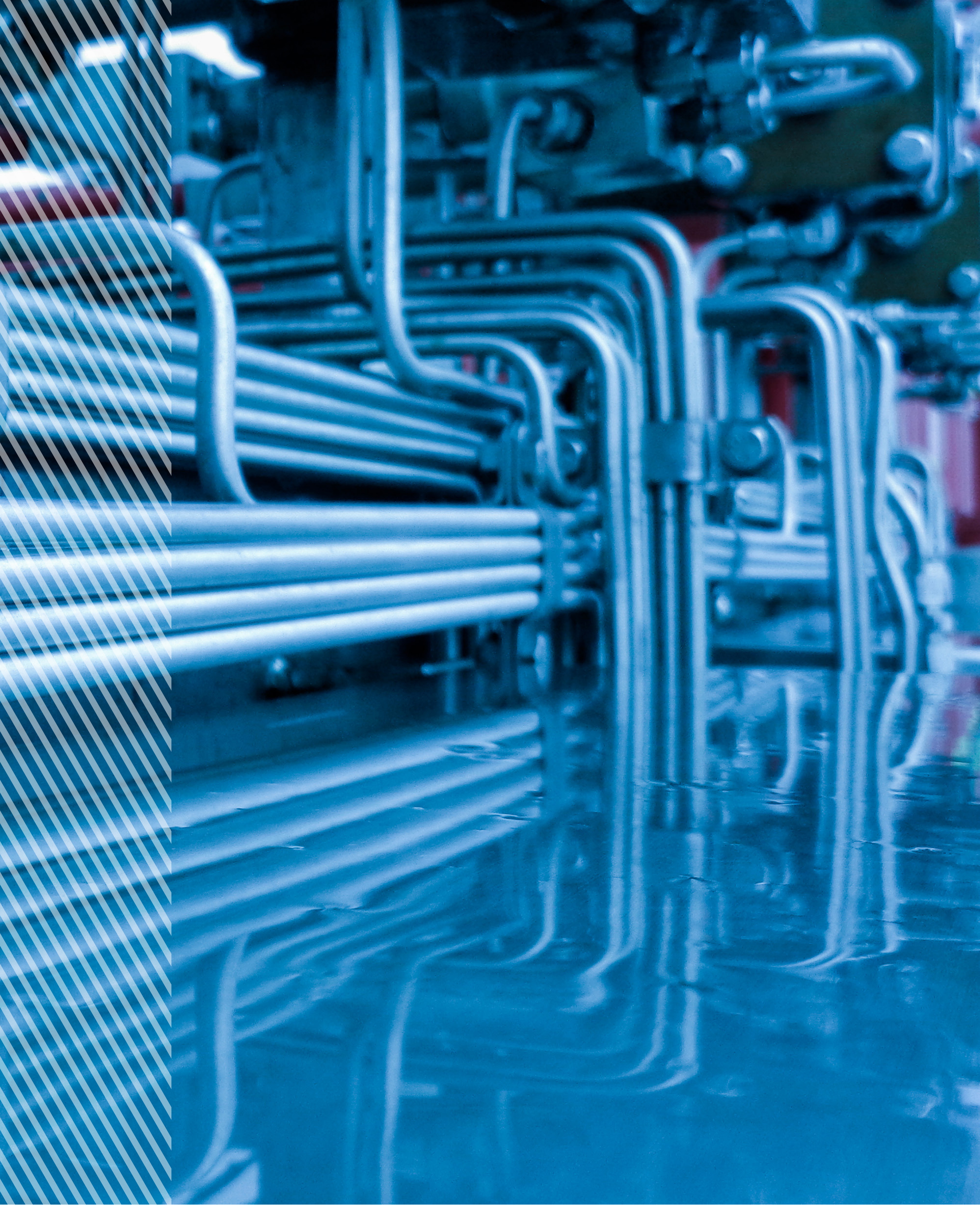
Renewable energy technologies such as wind and solar have seen an astonishing cost decline in recent years. Many different factors have led to this cost decline. Besides rapid technological improvements and innovation, regulation has also played an important role and led to a rapid increase in installed capacity, either in the form of public subsidies for R&D and commercialization, via feed-in tariffs, or via mandatory generation mix shares. This rapid growth, in turn, has led to significant learning effects and the development of supply chains. Furthermore, over the past several years, power auctions have become a popular tool to enhance cost transparency and increase competition, especially in contrast to predefined feed-in tariffs, thereby driving down margins in the value chain. Auction results have frequently undercut prevailing price assumptions and, thereby, accelerated the ongoing transition. With ever lower auction results being reported, renewables are in many regions already cost-competitive to new fuel-powered generation and will soon be competitive in most of the remaining regions. Moreover, the cost for storage has come down by more than 3.5 times over the past five years alone. With these developments continuing, large-scale renewables along with storage to address daily intermittency will soon be the lowest cost alternative for power generation and outcompete new fossil fuel generation.

8 Renewables and battery storage become cheapest power source at scale, outcompeting fossil fuels









The biggest impact of these shifts would be felt in coal, oil, and power demand, while gas demand remains robust

Developments in recent years suggest that it does not take many unexpected developments to fundamentally change the trajectory of the global energy system or specific industries.

Just a decade ago, most experts did not expect renewables to play a significant role any time soon. Technological development, partially driven by R&D, subsidies, and feed-in tariffs, helped to massively reduce costs for new solar and wind capacity, and new renewable power capacity surpassed new fossil fuel capacity for the first time in history two years ago. Up until recently, EVs did not seem like even a distant threat to traditional car manufacturers or oil & gas (O&G) companies. Now, advances in battery technology, at-scale factories, grid developments, and beneficial regulation have caused these same companies to re-think their product strategies. Our analysis shows that a small number of accelerated developments that we're starting to see today can have a large impact on the value chain in global energy markets.

This chapter describes the implications for the global energy sector and its value chains if the eight shifts described in the previous chapter materialize. We have identified five key insights:

1 **Oil demand (currently 32% of energy supply with 99 MMb/d) could peak before 2025** but would still represent 26% of energy supply in 2035 (80 MMb/d) and 18% in 2050 (55 MMb/d)

2 **Gas demand continues to grow as its role in the energy system remains stable** from its current 21% of energy supply (3,430 bcm) to 22% of energy supply in 2035 (3,700 bcm) and 23% in 2050 (3,800 bcm)

3 **Fossil fuel demand decrease is disproportionally large compared to power demand increase**, with the accelerated transition resulting in ~20% less fossil fuel demand compared to the Reference Case, but only ~10% more power demand in 2035 (31k TWh). For 2050, there is ~30% less fossil fuel demand and ~15% more power demand (46k TWh)

4 **Coal demand (currently 28% of energy supply with 5,320 Mtce) will decrease rapidly** toward 21% of energy supply in 2035 (4,100 Mtce) and 19% in 2050 (3,850 Mtce)

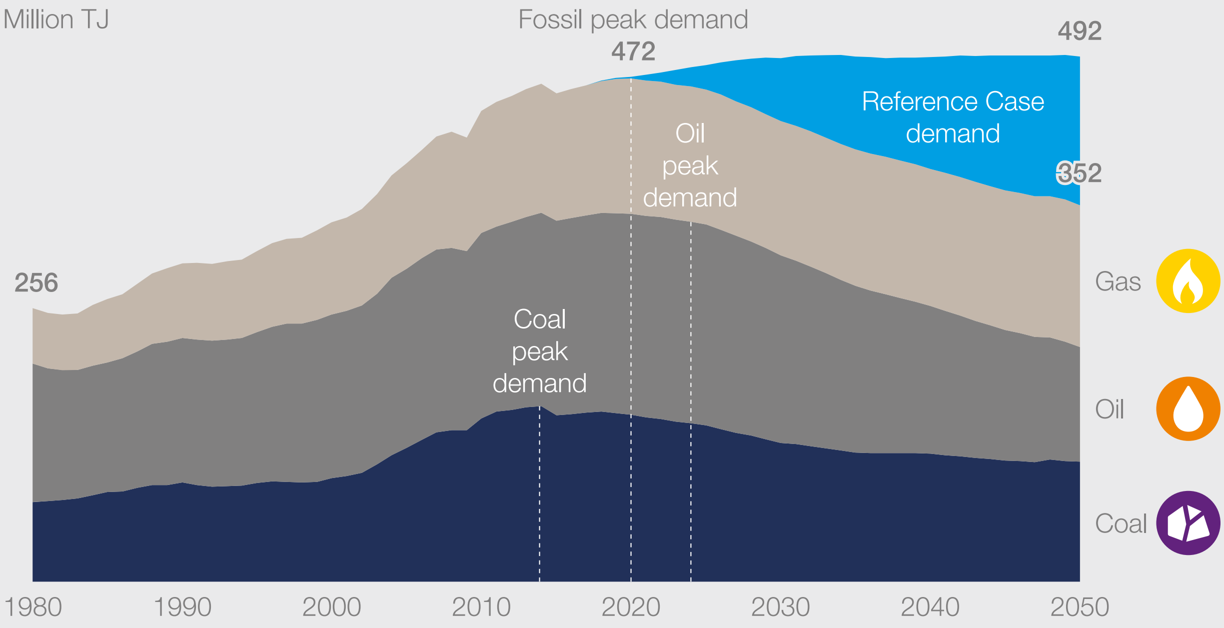
5 **Projected carbon emissions remain well above a 2-degree Celsius pathway** as all shifts combined would bring CO_2 emissions from current 32 $GtCO_2$ to 22 $GtCO_2$ in 2050. This closes only around half the gap between the Reference Case (32 $GtCO_2$) and the IEA's 2-degree Celsius pathway (13 $GtCO_2$)

Box 1 The combined impact of the accelerated transition scenario

If all the shifts described in the previous chapter fully materialize, fossil fuel demand by 2050 would be significantly affected but would still be ~55 MMb/d oil, ~3,800 bcm gas, and even ~3,850 Mtce coal. Overall, fossil fuels in 2050 would account for 58% of total primary energy demand (as compared to 70% in the Reference Case).

With the combined impact of the eight shifts, total fossil fuel demand decreases in the 2020s with oil and coal in decline, while the share of gas remains stable

Global fossil fuel demand



Effect of the shifts on fossil fuel and power demand varies strongly; all the shifts together reduce 2050 fossil fuel demand by ~200 bcm of gas, ~49 MMb/d of oil, and ~900 Mtce of coal

Effect of the shifts on 2035 fuel demand compared to the Reference Case

	Power TWh	Natural gas bcm	Oil MMb/d	Coal Mtce
1 Faster uptake of electric vehicles	+2,192	-35	-15	N/A
2 Efficiency gains and faster uptake of low-emission fuels for aviation and marine	+18	+41	-7	N/A
3 Accelerated electrification of residential heat	+15	-93	~0	-3
4 More rapid electrification of cooking in non-OECD countries	+546	-11	~0	+6
5 Increased demand reduction and recycling of plastics	-41	+3	-3	-52
6 More efficiency gains, recycling, and low-emission feedstock in iron and steel	-16	-6	~0	-164
7 More electrification of EU industry low- and medium-temperature heat	+164	-25	~0	-3
8 Accelerated cost reductions for renewables and storage		-419	~0	-696
Effect of increased power demand on generation mix	→	+134	~0	+213
Sum of combined effects	+2,877	-412	-24	-699
Percentage change in 2035 fuel demand compared to the Reference Case	+11%	-11%	-24%	-15%

Effect of the shifts on 2050 fuel demand compared to the Reference Case

	Power TWh	Natural gas bcm	Oil MMb/d	Coal Mtce
1 Faster uptake of electric vehicles	+3,646	-24	-24	N/A
2 Efficiency gains and faster uptake of low-emission fuels for aviation and marine	+238	+66	-15	N/A
3 Accelerated electrification of residential heat	+242	-101	-1	-5
4 More rapid electrification of cooking in non-OECD countries	+1,545	-13	-1	+1
5 Increased demand reduction and recycling of plastics	-114	-20	-7	-88
6 More efficiency gains, recycling, and low-emission feedstock in iron and steel	-43	-13	0	-300
7 More electrification of EU industry low- and medium-temperature heat	+273	-23	0	-4
8 Accelerated cost reductions for renewables and storage		-295	0	-717
Effect of increased power demand on generation mix	→	+226	0	+205
Sum of combined effects	+5,787	-197	-49	-906
Percentage change in 2050 fuel demand compared to the Reference Case	+11%	-11%	-24%	-15%

1 Oil demand could peak before 2025 and although it remains a significant share in total global energy supply, it would force oil companies to adjust their project portfolios

Today, oil demand makes up more than 30% of the global energy supply with 99 MMb/d. In recent years, annual oil demand grew by 1-1.5 MMb/d p.a. However, in an accelerated transition scenario, that trend would quickly change, and oil demand would peak before 2025, roughly 15 years earlier than in our Reference Case. Despite peaking early and declining afterwards, oil demand would still make up 26% of energy supply in 2035 (80 MMb/d) and 18% in 2050 (55 MMb/d). With the declining productivity of existing fields, this would mean that new fields would still need to continue to be developed.

Three shifts shape future oil demand in this scenario: faster uptake of EVs in road transport (Shift 1), changes in marine and aviation (Shift 2), and plastics demand reduction and recycling (Shift 5).

In the short term, the slowing of plastic demand growth, increased plastics recycling, and accelerated electrification of road transport—on top of continued ICE fuel efficiency improvements in the Reference Case—in particular cause global oil demand to peak (see Box 3).

Upstream oil producers would soon be faced, for the first time, with a sustainable decline in demand that would also be felt in oil prices. In an environment in which oil prices decline due to underlying fundamentals rather than day-to-day politics, operators who sit on the unprofitable side of the oil cost curve will either structurally improve profitability, diversify their portfolio, or fold. In some areas, this trend can already be observed, such as the abandonment of some tar sand projects in Alberta or deep-sea and Arctic oil drilling. With low oil prices, however, many more projects could become unprofitable and would be abandoned. Low capex spend will directly hit the services industry, especially the providers who are not in the top quartile or are not well-placed geographically.

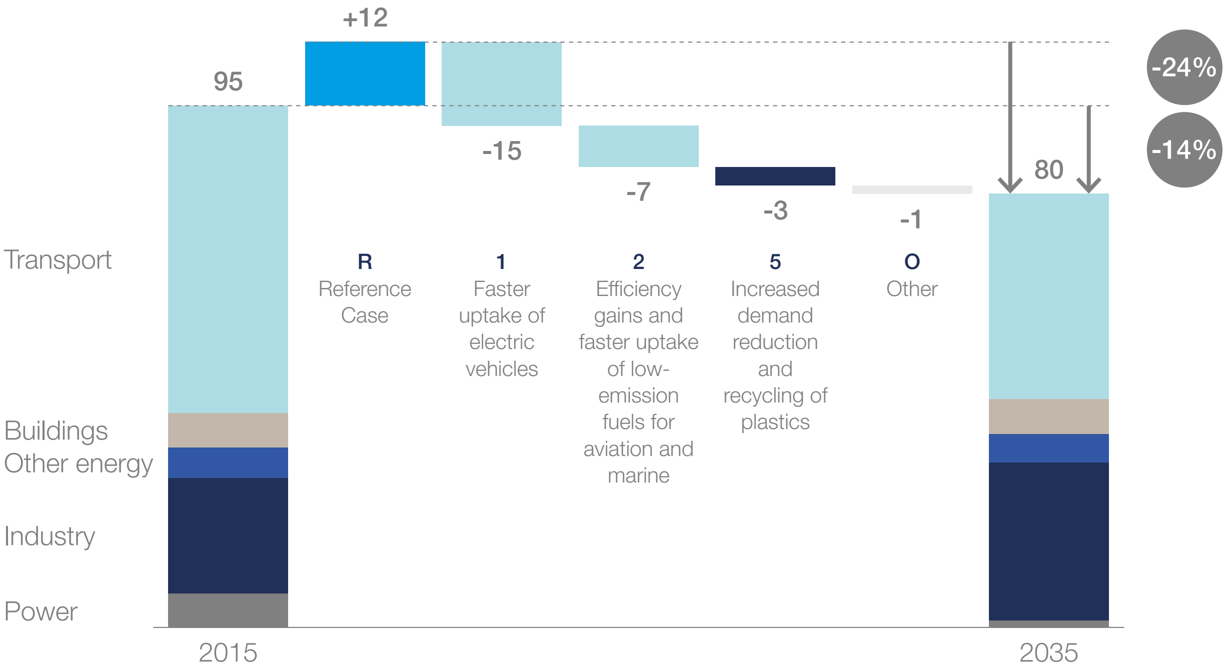
In such an accelerated transition, there are, naturally, alternative business opportunities for large O&G players that are worth considering. Large-scale offshore renewable wind projects, for instance, play to many of the traditional strengths of O&G producers and have already proved popular. Solar, batteries, and recharging infrastructure are other promising areas, especially if the world approaches 100% of cars on the road in China, Europe, and North America and 50% in other countries being EVs. The decrease in plastics primary demand and the increase in recycling will limit future activity in the petrochemicals industry, and the industry will need to re-focus its sources of feedstock as the supply hub landscape also changes. Refiners might need to consider alternative markets for naphtha or plan to reduce their output. Plastics manufacturers may wish to consider opportunities in recycling or could position their plastics as a 'sustainable' alternative to steel.

Downstream operators in the distribution, storage, and transport sectors could also see demand for their capacity fall sharply. The refining sector could be at risk for structural underutilization given fixed capacity, leading into further capacity rationalization especially in Europe. Yet, there could be opportunities to capitalize on changed market conditions by investing in facilities for biofuel or hydrogen instead. Transport operators may want to explore how to capture these value pools created by biofuels and hydrogen and how to retrofit their fleets. The same goes for companies involved in retail and distribution, which will see demand switch to alternatives—first in OECD countries and then eventually in non-OECD countries. *Continued on page 40*

Effects of accelerated transition scenario shifts on oil: Displacement of oil originates from fuel shifts in the transport sector (road, aviation, and marine) and changes in feedstock demand for plastics

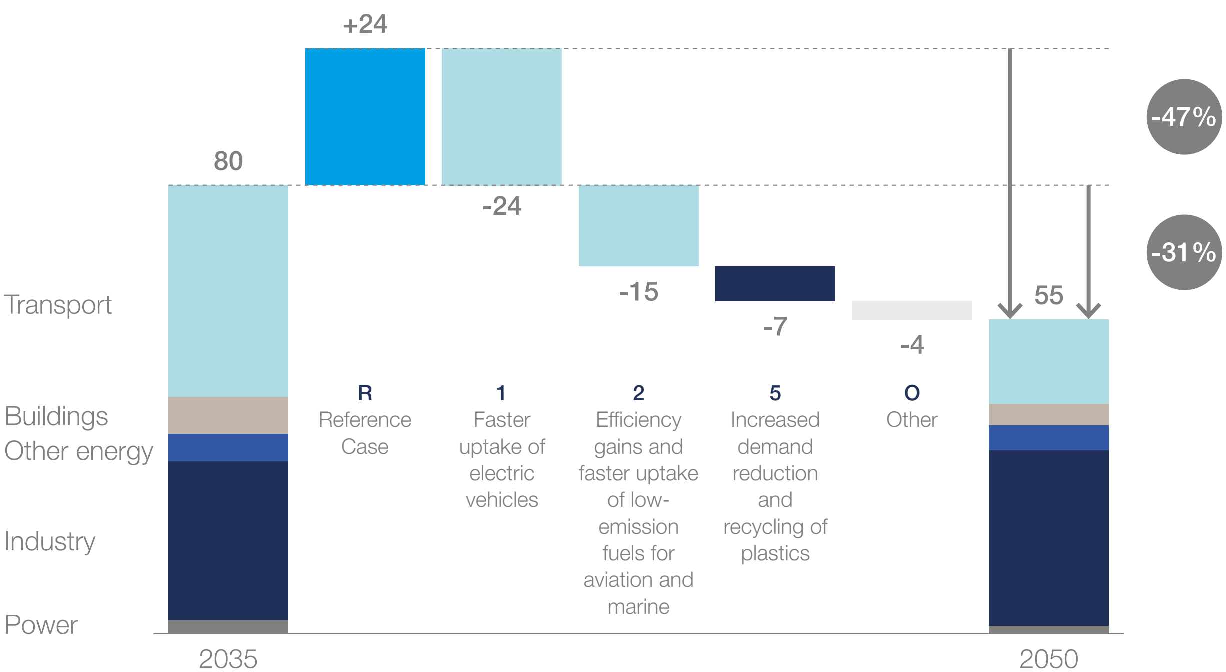
Effect of individual shifts on global demand for oil toward 2035

MMb/d



Effect of individual shifts on global demand for oil toward 2050

MMb/d



Box 2 Short-term oil demand peak: Signposts to watch

Although most forecasts agree that peak oil demand will happen in the upcoming decades, our accelerated transition sees oil demand peak before 2025—much earlier than most expect and seemingly at odds with the stable oil demand growth we've seen in recent years. If we look at the main signposts, can we already observe some trends today that suggest that the accelerated transition may happen?

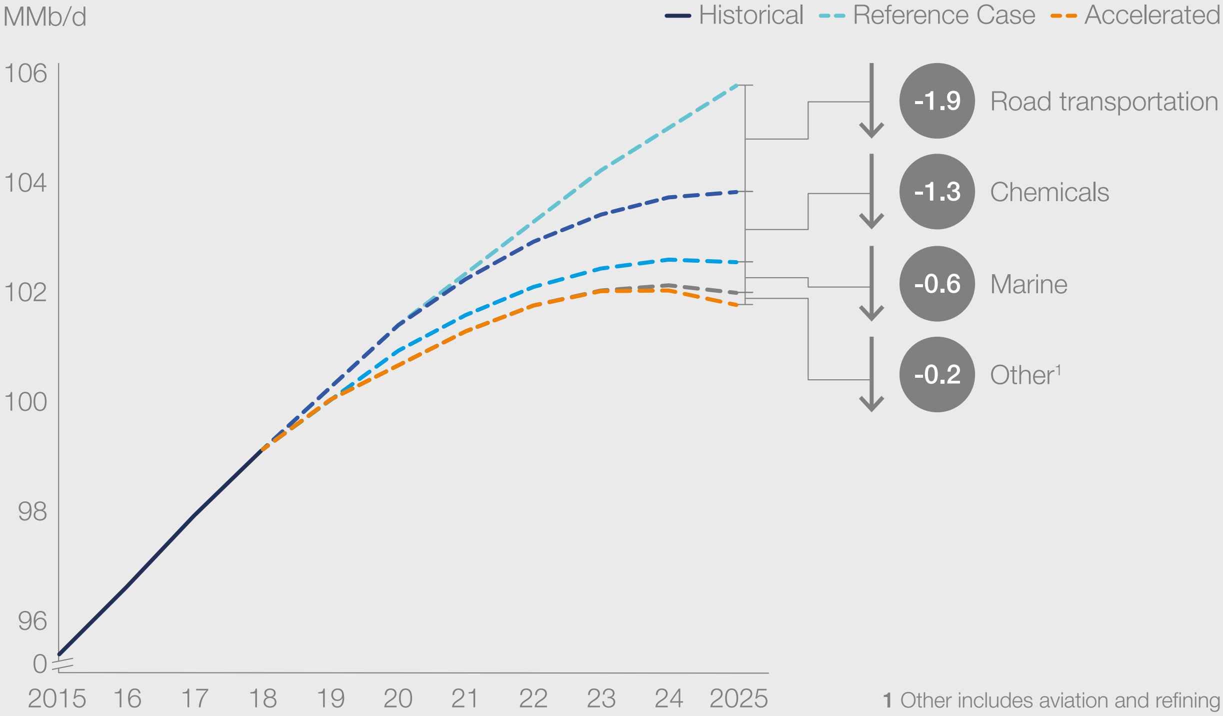
In our accelerated transition, two shifts lead oil demand to reach its peak before 2025: accelerated electrification of road transport, which leads to a 1.9-MMb/d demand reduction in 2025 compared to our Reference Case, and slowing plastic demand growth and increased plastics recycling, which lead to a 1.3-MMb/d reduction in 2025. A third shift—the fuel switch in the marine sector—is less obvious but could lead to an additional 0.6 MMb/d reduction in 2025.

Accelerated EV uptake

Early signposts show that the accelerated EV uptake—30 million additional electric passenger cars on the road by 2025—is faster than national policy targets, but in line with OEMs' capacity commitments. The development of EV charging infrastructure is expected to keep up sufficiently in the short term to allow for faster EV uptake than in our Reference Case.

Government policies Signs of a more rapid electrification in road transport can already be observed, with some national governments adopting —and additional governments considering— policies that are in line with those necessary for an accelerated transition in the short and medium term. For example, China's target of 2 million EV sales by 2020 constitutes 85% of the projected 2.3 million EV sales in the accelerated

Global total oil demand in accelerated transition scenario

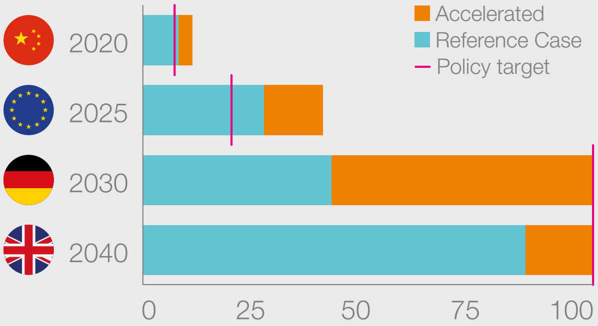


1 Other includes aviation and refining

Publicly committed EV production capacity in 2020 already surpasses the projected EV demand in the accelerated scenario

Policy targets and projected EV sales per scenario[1]

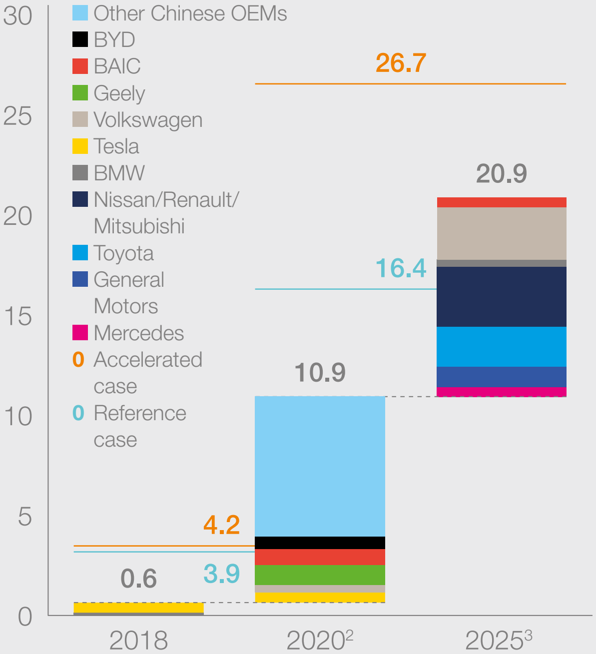
Non-ICE sales as % of total new car sales



1 Chinese target of 2 million EVs corresponds to ~8% market share. European Union is putting a 20% EV target into place for 2025. Germany and UK consider or have a total ICE sales ban by 2030 and 2040. **2** Not exhaustive: based on OEMs that make up ~30% of today's car market. No ramp-up assumed for Tesla and VW in '19 and '20. **3** Not exhaustive: based on OEMs that make up ~60% of today's car market. Nissan-Renault-Mitsubishi (2022) BAIC, Volkswagen, BMW (additional in 2025), Toyota, General Motors and Mercedes (2025). Source: IEA EV outlook (2017,2018) IHS Automotive (2018), McKinsey Energy Insights, ICCT. European Parliament Legislative Observatory.

Publicly announced EV targets of OEMs

Millions of passenger cars



scenario. The Chinese target is supported by existing policies, such as an EV credit system and purchase subsidies for EVs. In addition, China is considering banning ICE sales by 2040. Although we assume a higher European Union target for EV sales than currently announced (40% vs 20% respectively by 2025), multiple individual European governments have already announced bans on ICE sales by 2025 (e.g., Norway), 2030 (e.g., Denmark, The Netherlands, and Ireland, with Germany considering), and 2040 (e.g., the UK and France). Today, over 200 European cities already have installed low-emission zones or access regulation, and major cities like London, Paris, Rome, and Madrid have announced diesel bans by 2025.

Supply of EVs On the supply side, OEMs have publicly committed to an electric passenger car production capacity of over 10 million by 2020 (the majority in China), far exceeding the 4.2 million in EV sales assumed in the accelerated scenario. Looking further ahead, OEMs have already committed to at least another 10 million in capacity by 2025.

Charging infrastructure A key enabler for EV uptake is the availability of sufficient charging infrastructure and—although similarly challenging to ramping up EV supply—there is no fundamental reason to believe EV charging infrastructure would hold back the accelerated uptake in the next few years, given historic growth rates and current grid capacity. Over the last decade, growth rates of charging infrastructure have been exceeding growth rates of EVs. For instance, in The Netherlands, charging points grew by more than 50% p.a. over the last five years. Expectations are that, in the next few years, the vast majority of charging (over 85%) will happen at home and—to a lesser extent—at the office (~10%). Public charging—typically considered more challenging to realize than home or office charging—will become increasingly important when urban users, who don't have access to home charging, make the shift to EVs. Our geospatial modeling confirms that first adopters of EVs are zip codes with higher-income households and commercial users—two groups that are likely to have private charging infrastructure at their home or company.

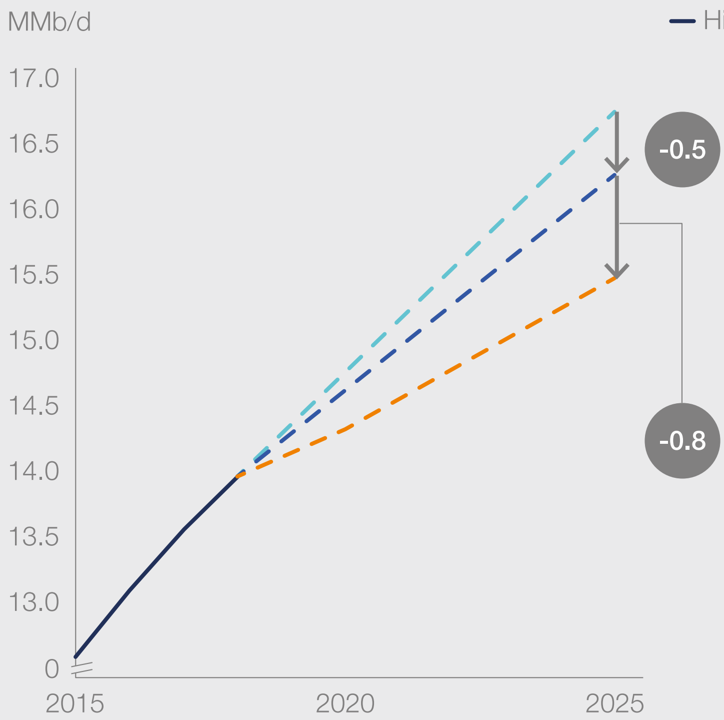
For the next few years, there seems to be sufficient capacity in power generation and current electricity grids, given the relatively small additional power demand of EVs compared to existing power demand from other sectors like buildings and industry. For instance, a 40% EV share in the German car fleet is expected to account for only 6% of total power demand. This should allow sufficient time for investments in the grid that are likely needed to enable significant penetration rates of EVs in the next decade. With developments in delayed- and smart-charging, peak load is also not expected to be significantly affected for the next few years and might even offer an opportunity for utilities to increase their capacity utilization rates.

Slowing plastic demand growth and increased plastics recycling

Early signposts show that plastic demand reduction (0.2-0.5 MMb/d) and increased recycling (0.6-0.9 MMb/d) together could contribute to reducing 2025 oil demand in the chemicals sector by 0.8-1.4 MMb/d compared to our Reference Case. This is in line with the accelerated scenario.

Plastic demand growth Slower economic growth projections, a trend toward more efficient

Global oil demand for chemicals in accelerated transition scenario



Short-term trends

Demand reduction 0.2-0.5 MMb/d

- Demand growth to slow down to 2.3-2.6% p.a. in 2015-2025 (vs. 2.8% in the Reference Case)
- This leads to plastic production reduction of 6-17 mtpa – equivalent of 0.2-0.5 MMb/d oil demand

Recycling growth rate 0.6-0.9 MMb/d

- Historically, the recycling rate has grown 8% p.a. (10% p.a. if recent low oil price effect is excluded)
- Assuming this historical trend is maintained, this leads to plastic production reduction of 17-27 mtpa – equivalent of 0.6-0.9 MMb/d oil demand

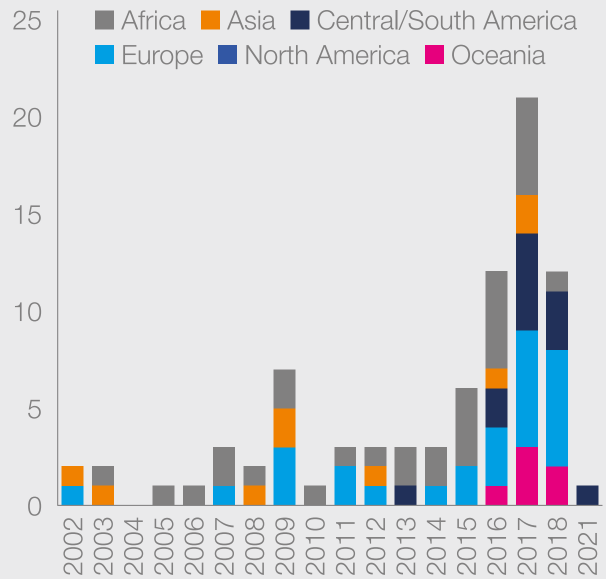
Chemicals demand reduction: Short-term trend

End market demand forecast 2025

Millions of tonnes per year, CAGR %

	Actual 2000-2015	Forecast 2015-2025
Construction	3.3	3.0
Packaging	4.2	2.2
Home/office consumables	3.8	3.0
Automotive	4.0	2.9
Agriculture	2.4	1.8
Home/office equipment	3.5	2.9
Industrial goods	3.9	1.4
Textiles	5.5	2.8
Electronics	3.8	3.9
Fuels	6.4	1.0

No. of new regulations on single-use plastics entering into force at national level worldwide[1]



1 North America is introducing local level regulation

Recycling rate: Short-term trend

Multiple regulations to divert plastics from waste stream worldwide

- New waste directive proposes recycling target for municipal waste of 65% by 2030
- Federal EPA establishes nationwide requirements for landfill, waste to energy, recycling (example California: goal of 75% recycling, composting/source-reduction of solid waste by 2020)
- Government aims to increase combined rate of recycling and incineration from 26% today to 50% by 2020
- Clean India Initiative about to invest USD10 billion until 2019, partly on waste management improvement

The CPG industry is beginning to lead using recycled plastic or adopting recyclable packing

Unilever	"100% of plastic packaging will be fully reusable, recyclable, or compostable by 2025"
Coca-Cola	"Aiming to make all its consumer packaging 100% recyclable by 2025"
P&G	"Double recycled resin in plastic packaging (2020 vs. 2010), ensure 90% of packaging is recyclable"

packaging, and an increase in government policies on plastic use suggests that demand for oil as a plastic feedstock might decrease by 0.2-0.5 MMb/d in 2025, in line with our accelerated scenario (0.5-MMb/d reduction in 2025). Our latest projections of plastics demand growth to 2025 suggest a slowdown to 2.3-2.6% p.a. compared to 2.8% p.a. in the Reference Case. This slowdown will be driven by a growing trend toward more efficient use of plastic—such as in packaging—and slowing growth across key economies and sectors, such as decelerating construction and demand for related plastics in key economies like China. Governments are increasingly implementing policies that affect demand for plastics. As of 2018, 73 national governments have regulations on single-use plastics, and 50% of those governments introduced those policies in the last three years.

Recycling rates Maintaining historic growth rates of recycling would result in another 0.6-0.9-MMb/d reduction in oil demand by 2025 compared to our Reference Case. Historically, recycling rates have increased by 8% per year over the last 15 years (including recent years with lower oil prices that have slowed recycling uptake growth). Additional recycling could be driven by technological developments (e.g., more sophisticated sorting and recycling technology) and current societal momentum toward plastics recycling (e.g., industries using recycled plastic or adopting recyclable packaging and various regulations on recycling, landfill waste, 'green' design, recycling targets that have been launched across the globe including in the EU, China, and the US).

Marine fuel mix changes and efficiency improvements

Signposts for the third shift are less obvious, with very few observations to confirm the assumptions on fuel mix changes and efficiency improvements in the accelerated scenario. This is not surprising as the marine shift assumes the fuel switch to biofuel and LNG in the marine sector to be driven by future regulation. If the changes in the marine sector materialize, this would lead to an additional 0.6-MMb/d reduction in 2025.

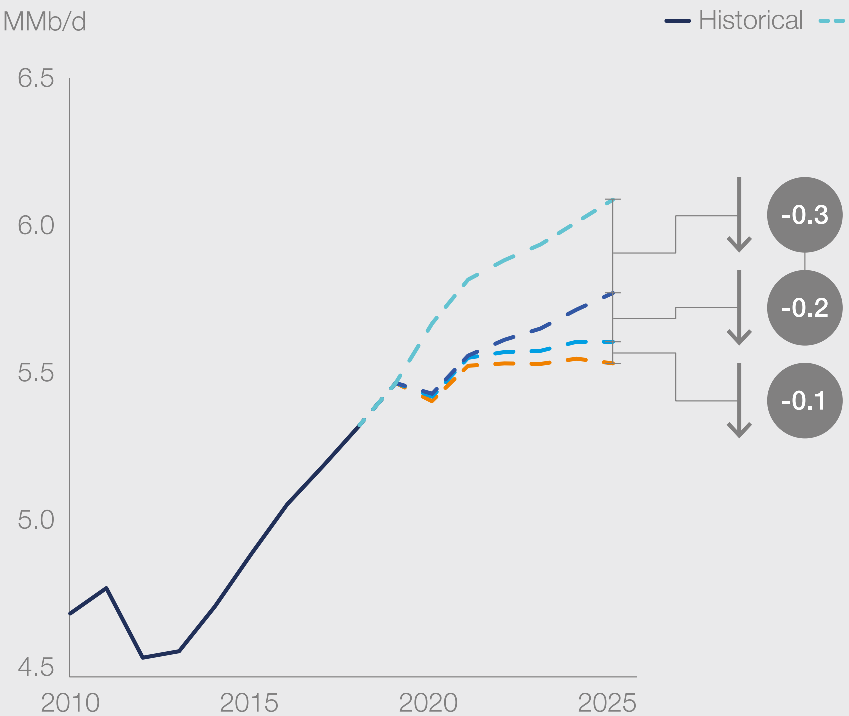
Fuel mix changes There is little consensus on how the marine fuel mix will change, and there are virtually no historic trends yet that suggest which way it will go. However, both the shipping and refining industry agree that fuel mix changes in the marine sector are pending with the MARPOL regulation coming into effect in 2020, which will lower the global marine fuel sulfur cap to 0.5%. Our accelerated transition scenario assumes that biofuels and LNG—which currently account for less than 0.1% of the fuel mix—will play an increasingly important role given their better emission performance compared to heavy fuel oil—the dominant fuel with 70% in the mix today—and anticipated improvements in their cost competitiveness.

Although global marine biofuel demand saw a strong decline in 2016, our accelerated case sees biofuels make up 4.5% of the marine fuel mix in 2020. Biofuels have little or no sulfur emissions, they don't require expensive vessel engines adaptations as drop-in fuel, and they have lower greenhouse gas emissions. With oil prices above USD70/bbl, biofuels become competitive. Biofuel bunkers are becoming more frequent (e.g., in Rotterdam and Singapore).

Uptake of LNG as a marine fuel depends heavily on expansion of bunkering infrastructure, which is currently concentrated in Northwestern Europe, and has limited coverage in other regions. An ongoing push from local regulators toward cleaner fuels is facilitating LNG bunkering infrastructure expansions along key shipping routes.

Fleet efficiency Other potential drivers for reduction in oil demand are improved new ship and total fleet efficiency, but there are no obvious signs that these will develop at an accelerated pace compared to our Reference Case. Current IMO regulations on EEDI (Energy Efficiency Design Index) require improvements in new ship energy efficiency of 10% every five years. The accelerated scenario assumes additional efficiency improvements will be needed to reach the IMO's 50% greenhouse gas reduction target by 2050. Additional improvements are currently being considered by the IMO and may come into play after a policy review in 2021 (effective in 2025). Arrival planning and speed reduction are potential ways to improve the efficiency of the existing fleet. However, there are no publicly announced plans for enforcing such measures via policy, and with the current economic growth, shipping experts actually observe increasing average speeds of the cargo fleets.

Global oil demand for marine in accelerated transition scenario



Biofuels and LNG have the potential to replace a significant amount of oil after MARPOL regulation comes into play in 2020

Improved **new ship efficiency** from higher EEDI standards will have a limited effect up to 2030. Additional **operational efficiency** (on top of what is assumed in the Reference Case) improvements are not expected to come into place before 2025.

Some companies are already installing charging facilities at their retail outlets, but retailers may want to consider how to position themselves for cleaner fuels in emerging markets like Africa, and which other alternative markets could absorb some of the lost oil demand.

For many governments in the world, especially those in oil-exporting nations, the implications of peak and decreasing oil demand and a lower oil price could prove problematic. Since these governments often own the reserves and resources, they will find it hard to diversify their revenues to prepare for lower demand and prices. Oil-producing nations with low-cost resources should focus on encouraging the industry to invest locally through policy incentives, but also on sufficiently diversifying their economies for a post-peak demand world.

2 Gas demand continues to grow as its role in the energy system remains stable

Today, global gas demand makes up 21% of the energy supply (3,430 bcm). In the accelerated transition scenario, that percentage would grow to 22% of energy supply in 2035 (3,700 bcm) and 23% in 2050 (3,800 bcm). Overall, that means continued growth and gas demand that's more than 10% higher than it is today.

For gas, the two main shifts are an accelerated electrification of residential heat and accelerated cost reduction for renewables and storage. The electrification of 50% of residential heat in Europe and North America would reduce 2035 gas demand by ~90 bcm (or ~3% of today's global gas demand) compared to the Reference Case. The availability of cheap renewables and storage at scale would cause gas demand to plateau after 2020 and reduce 2035 gas demand by another ~400 bcm (or ~11% of today's demand) compared to the Reference Case. This outweighs the effect from additional electricity demand that we see in the accelerated scenario (~130 bcm additional demand vs. the Reference Case by 2035 and even more thereafter). At a regional level, the OECD Americas and Europe, as well as the Middle East, would be most affected by this development. In North America, gas demand would decrease by 2035 instead of a strong increase as in the Reference Case, while the gas demand decrease in Europe would be accelerated—both mainly driven by the accelerated cost decrease of renewables. In non-OECD Asia and Africa, on the other hand, gas demand growth would accelerate, mainly because of increasing gas-fired power generation from accelerated electrification in transport and cooking.

After 2035, natural gas demand in the accelerated transition scenario continues to grow further. The reason for this is the role of gas as balancing capacity in the power system. Rapid power demand increase in high-economic-growth countries in Asia and Africa encounters storage and renewables supply constraints and requires balancing capacity in the system, in particular for seasonal balancing. Such seasonal balancing demand is often met by gas capacity.

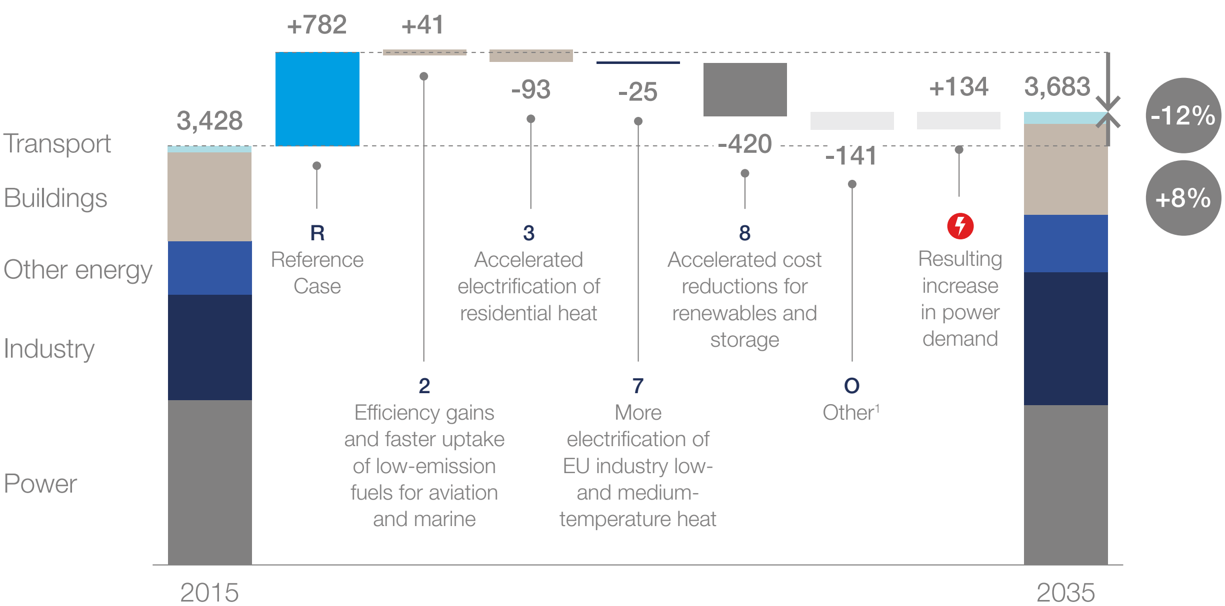
In our accelerated transition, gas demand growth is resilient. Gas will ensure seasonal energy balancing for renewables, thus growing from 3,430 bcm in 2015 to over 3,800 bcm by 2050. If there is a breakthrough in seasonal energy balancing technologies—like hydrogen, pumped hydro, or batteries—gas demand in 2050 will be roughly at today's level, eroding the growth.

Upstream oil and gas companies have in recent years increasingly focused on exploring and developing additional natural gas reserves. Much of this was driven by the expectation of a more important role for natural gas across all economic sectors, as gas is expected to serve as a replacement for coal and oil in heating, transport, industry, and even power. In the accelerated scenario, this

Effects of accelerated transition scenario shifts on gas: Gas demand continues to grow as its role in the energy system remains relatively stable

Effect of individual shifts on global demand for natural gas toward 2035

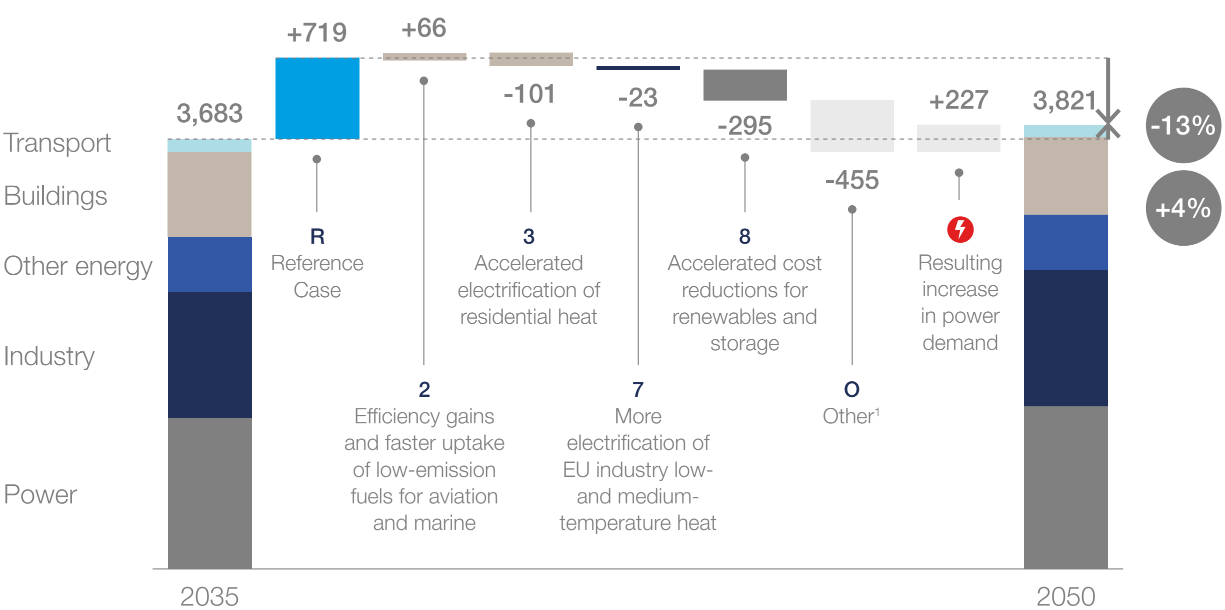
bcm



1 Includes declines in natural gas demand for oil refining, chemicals, and iron & steel

Effect of individual shifts on global demand for natural gas toward 2050

bcm



1 Includes declines in natural gas demand for oil refining, chemicals, and iron & steel

is a trend we would expect to continue; given declining field production, even just keeping output stable will require significant new upstream investments. The additional ~250 bcm by 2035 and the continued growth thereafter will also require improvements to the transport, trading, and distribution infrastructure along the entire value chain. This will, in particular, also include the further growth of LNG to enable trade across regions and the growth of demand in emerging markets. Moreover, the shift of demand from residential heat to power generation, and the demand on power generation to increasingly provide flexibility rather than just baseload, will require a different infrastructure use and different contracting schemes than in the past.

3 Fossil fuel demand decrease is disproportionally large compared to power demand increase

Much of the switch away from fossil fuels in transport, buildings, and industry is achieved by the electrification of energy services, like EVs and electrical heat pumps. Our analysis shows that the accelerated transition scenario would result in ~20% less fossil fuel demand compared to the Reference Case, but only ~10% more power demand in 2035 (31k TWh). For 2050, there is ~30% less fossil fuel demand and 15% more power demand (46k TWh).

That increase of 'only' 15% seems surprising at first in an accelerated transition in which fossil fuel consumption in 2050 is almost 30% lower than in the Reference Case. The answer to this counter-intuitive development can be found in the higher efficiency of many electric services compared to their fossil fuel counterparts. A full electric passenger car is on average over 3 times as efficient as an ICE car, and an electric heat pump is on average 3-4 times more efficient than a gas or oil boiler. Consequently, overall energy efficiency in the accelerated transition improves much faster than it does in the Reference Case. In the Reference Case, the energy intensity of global GDP improves by 28% from 4.7 MJ/USD in 2015 to 3.4 MJ/USD in 2035 (1.6% p.a.). In the accelerated transition, it improves by 34% to 3.1 MJ/USD in the same period (2.1% p.a.). The regions most impacted by this development are the OECD countries, while the sector most impacted is transport. In the accelerated transition, total final energy consumption in 2035 is 9% lower than in the Reference Case[2].

For several of these shifts, the extent to which they will materialize depends on whether they achieve a TCO advantage compared to conventional solutions or if they constitute the most cost-effective decarbonization option when decarbonization policies are in place. With increasing electrification, the cost of power replaces the cost for the original fuel and determines to a large extent if and when TCO parity will be reached. But (direct) economics are not the only factor of importance. For the industrial sector in particular, the reliability of power demand is critical for many processes. Short outages can have adverse effects on production processes, and longer outages at inopportune times—such as during cold periods in winter—can affect the consumer's decision to switch to electric heat pumps.

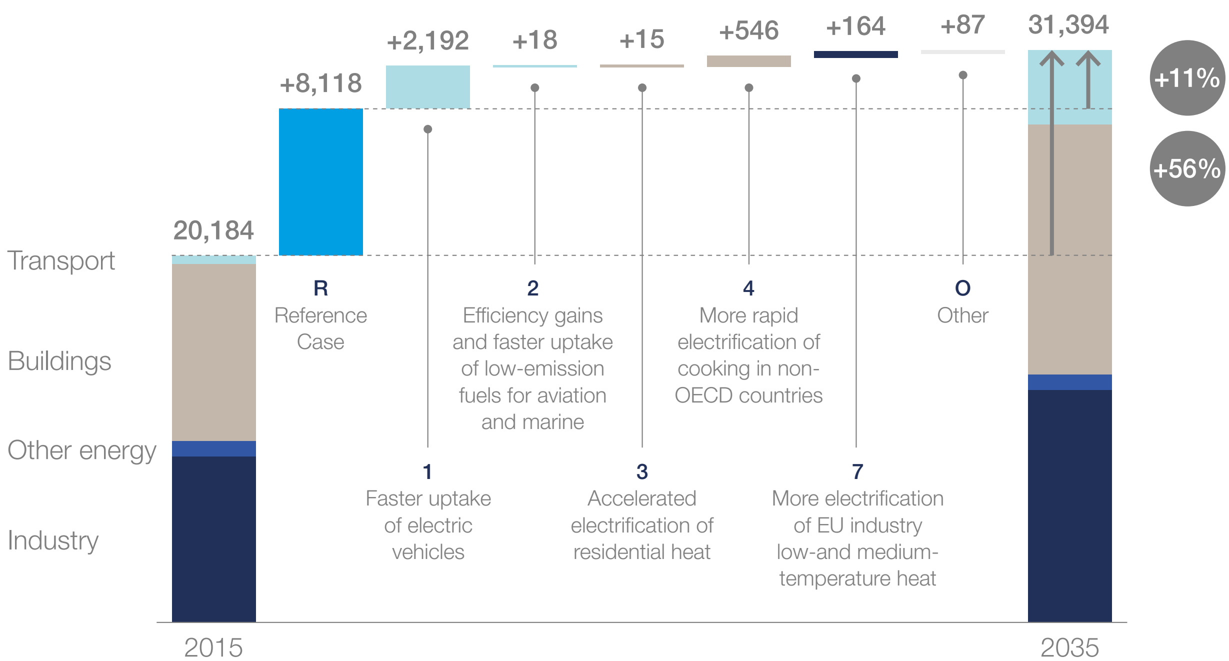
Utilities and grid operators must solve this trade-off if they want to benefit from an electrified economy. On the one hand, electrification will not happen at

2 Note that a large-scale electrification of the global energy system could lead to increased power demand from new supply chains, e.g., mining for metals and increased production of batteries, EVs and charging stations, etc., while power demand in incumbent supply chains, e.g., production of ICE vehicles, fuel stations, etc., would likely go down. Such secondary effects are not included in this analysis.

Effects of accelerated transition scenario shifts on power: Most of the increased power demand is driven by transport electrification and the non-OECD Africa and Asia cooking switch to power

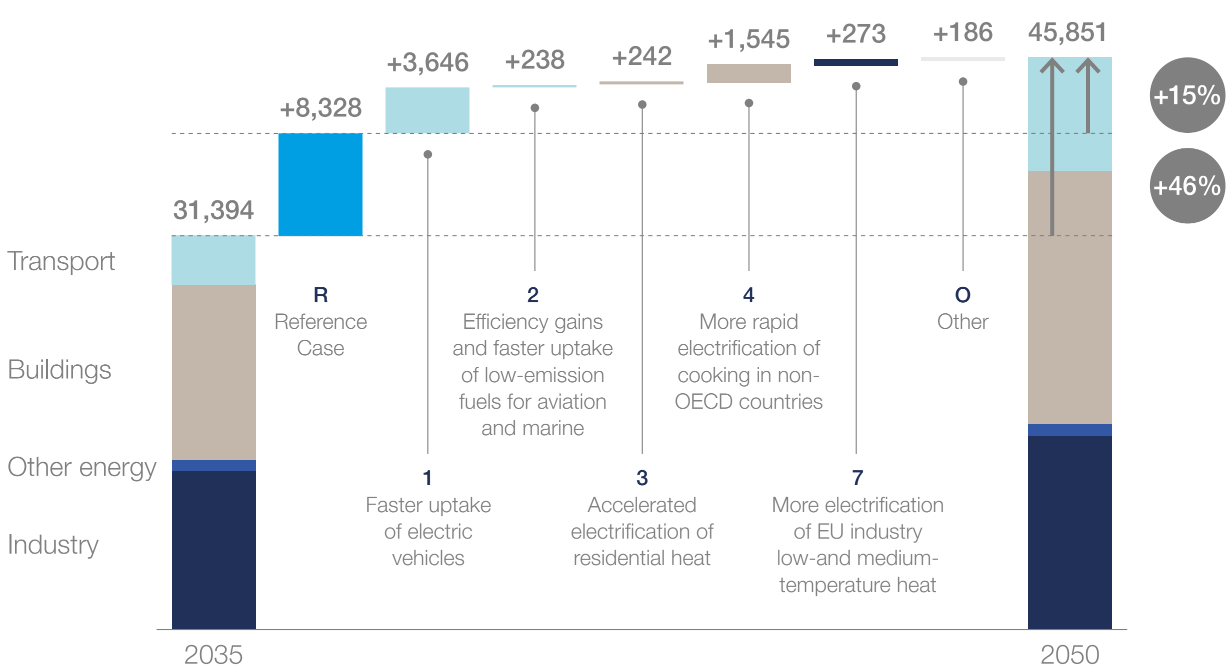
Effect of individual shifts on global consumption of power toward 2035

TWh



Effect of individual shifts on global consumption of power toward 2050

TWh



similar rates if power prices are high, power supply is unstable, or end users cannot access the required services. On the other hand, a strong growth of power demand in new sectors and with changing profiles will require large investments in generation capacity and transmission and distribution infrastructure. Finding an answer to this challenge should be high on the agenda of utilities around the world.

4 Coal demand will decrease rapidly by ~1.5% p.a. between now and 2035

After its all-time high in 2014, global coal demand has decreased for two consecutive years, but saw a modest increase in 2017. Our analysis suggests that, in an accelerated transition scenario, the uptick in 2017 can prove to be an outlier and that the downward trend would persist.

Coal today makes up 28% of energy supply with 5,320 Mtce. In the accelerated scenario, global coal demand would decrease rapidly toward 21% of energy supply in 2035 (~4,100 Mtce) and 19% in 2050 (~3,850 Mtce). This is mainly driven by a shift to cheaper renewables and a shift in the iron and steel sector that would reduce demand over the coming decades. At the same time, there is some additional coal demand compared to the Reference Case coming from the rapid increase in power demand, especially in high-economic-growth countries in Asia and Africa.

Upstream coal investors in such an accelerated transition might want to adjust their portfolios and investment decisions today to reflect the future demand drop and accommodate the long investment cycles that are so typical of the coal value chain. Coal mines typically take 5-10 years to become fully operational and much longer than that to amortize their investments. If demand and prices drop as implied by this analysis, competition among coal extractors for remaining demand would likely increase. Many extraction operations on the higher end of the cost curve or too far away from their customers could become unprofitable and might have to shut down. This also implies that some mines for which the investment decision is made today might never become operational. Mining companies may instead wish to position themselves in other extraction segments to take advantage of the anticipated increase in demand for certain metals associated with battery production. In coal distribution and transport, shipping firms may wish to retrofit part of their coal fleet to accommodate alternative cargos.

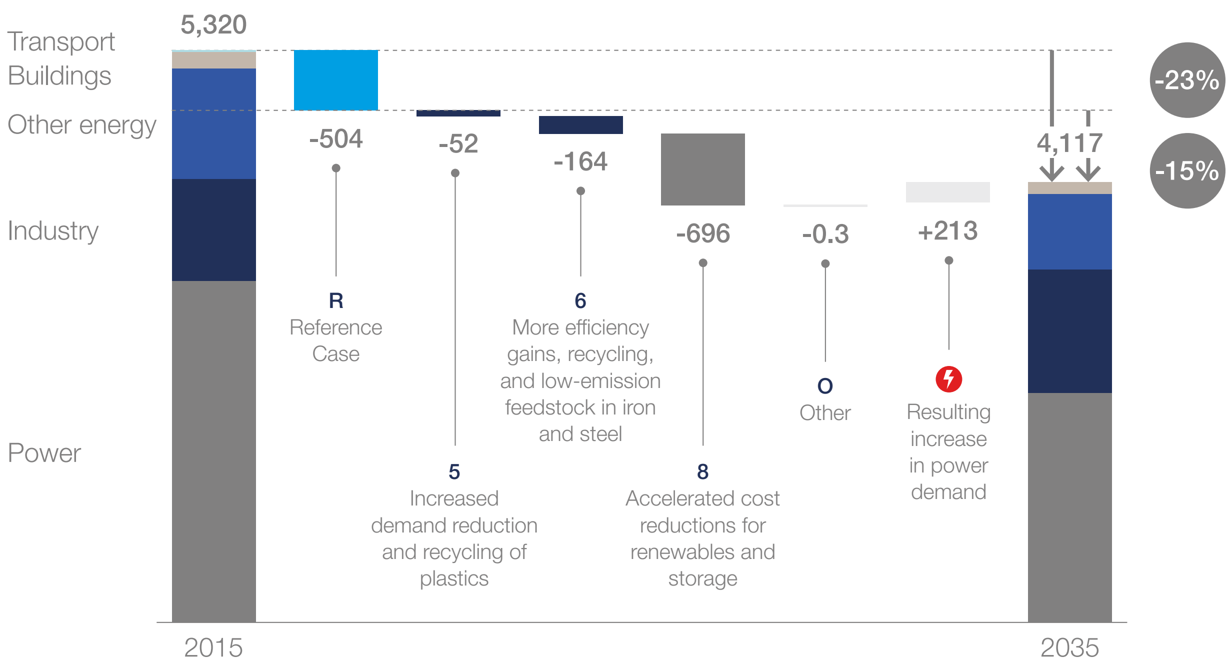
Coal power plants and industrial installations face a similar investment risk. Such assets typically take several years to go from investment decision to operation, and even longer until products can be sold at high enough margins to repay their investors. In an accelerated transition in which renewables and storage become the cheapest source for power and in which energy efficiency and recycling reduce coal demand in the industry, these assets could face the risk of becoming stranded. At first, this would mainly affect greenfield operations, but over time, the increased competitiveness of energy alternatives could make it harder and harder for existing power plants and industrial assets to compete and generate profits. Between 2010 and 2015, low wholesale power prices in Europe led to a revaluation of coal power plants and subsequent write-downs. Between 2010-12, annual write-downs (mostly on European coal assets) of European utilities reached USD8 billion per year and USD23 billion per year between 2013-15.

To avoid stranded assets, coal power plant operators may want to carefully observe developments in the renewables and storage sector and consider how much additional power a decarbonization of the economy could require as coal and other fossil fuels are phased out. In the accelerated transition, power demand in 2035 is ~11% higher than in the Reference

Effects of accelerated transition scenario shifts on coal: Shifts in the power and iron & steel sectors significantly reduce future coal demand

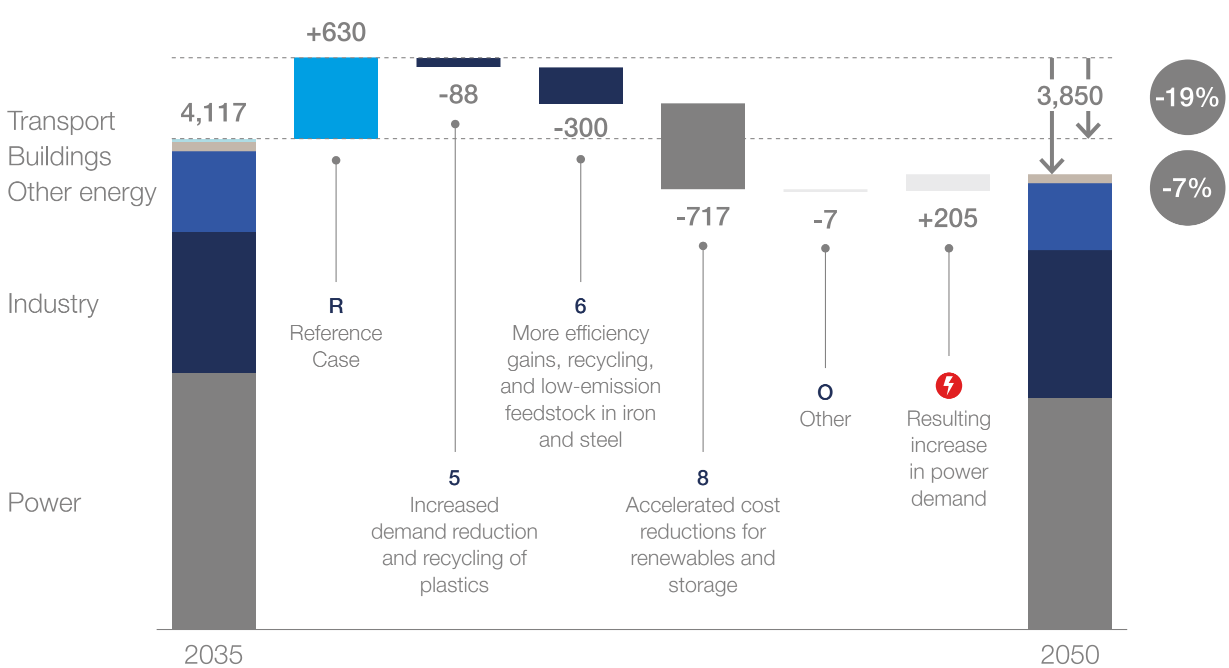
Effect of individual shifts on global demand for coal toward 2035

Mtce



Effect of individual shifts on global demand for coal toward 2050

Mtce



Case, mainly because many of the low-carbon alternatives switch from fossil fuels to power (e.g., EVs). Nevertheless, in 2035 coal demand drops by over 15% as most of this additional demand is met by cheaper renewables and storage. Instead of investing in additional coal plants, utilities might want to consider shifting investments to renewables, storage, and grid investments or even gas generators, which are much better suited to balance demand in a power system with high shares of renewables.

Governments may want to assess to which extent there is an energy security risk when intermittent renewables accelerate a coal phase-out. Many batteries have relatively short storage periods and are not suited to cover long, cloudy, and windless winter periods in which renewables, such as wind and solar, are less readily available. Energy systems with a high share of renewables may, therefore, require back-up procedures, which could involve keeping conventional plants as a reserve. For instance, the UK has introduced capacity market auctions to ensure sufficient supply at times of peak demand. Together with introducing floors for carbon prices, this has increased the cost of using coal while, at the same time, stimulating the adoption of alternative sources. Going forward, governments may want to assess this and similar policies to ensure a smooth energy transition even under an accelerated trajectory.

5 Projected carbon emissions remain well above a 2-degree Celsius pathway

With all shifts combined, CO_2 emissions would decline from the current 32 $GtCO_2$ to 22 $GtCO_2$ in 2050. This closes only around half the gap between the Reference Case (32 $GtCO_2$) and the IEA's 2-degree Celsius pathway (13 $GtCO_2$).

The early peaking of fossil fuel consumption and the rapid decline of coal and subsequently oil leads to a significant reduction in emissions from fossil fuel combustion in the accelerated transition. In 2050, energy-related CO_2 emissions are one third lower than in the Reference Case, implying an annual growth rate of –1.1% p.a., whereas emissions in the Reference Case remain roughly constant over that period.

The decline is mostly driven by lower emissions in the transport sector (–3.5% p.a.), power sector (–1.2% p.a.), and buildings sector (–0.8% p.a.), where the gas-rebound post 2035 prevents a steeper decline of emissions by 2050.

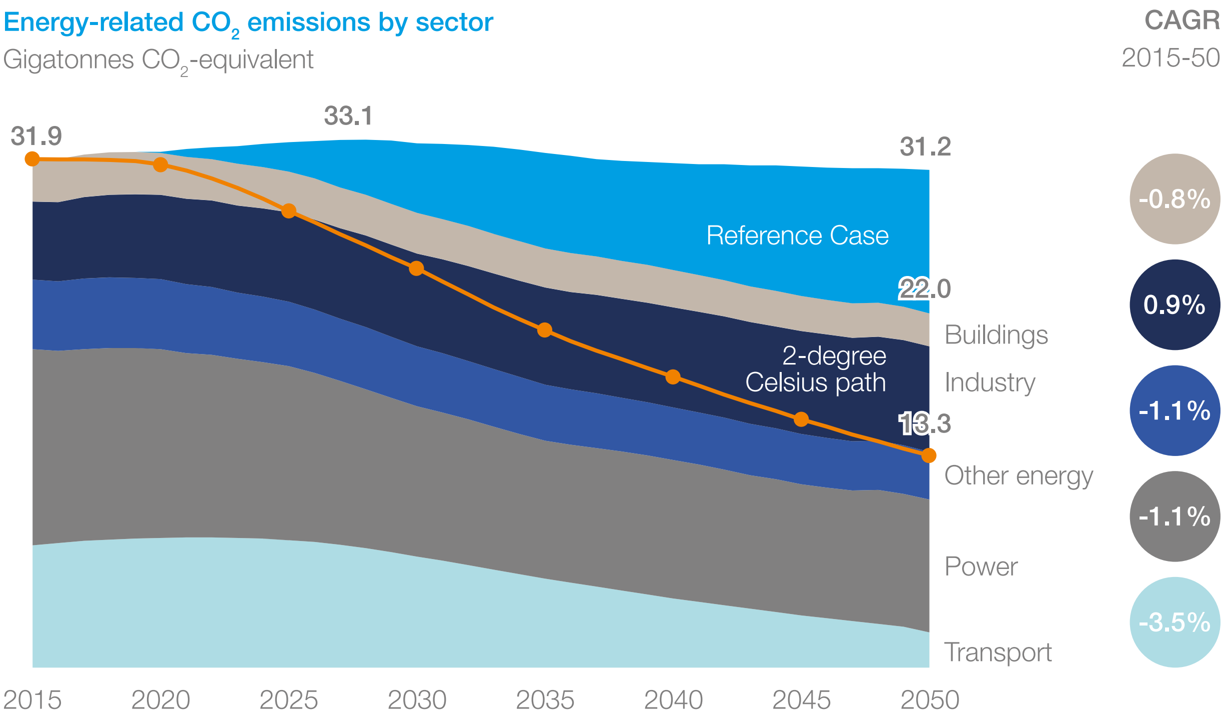
Overall, the full materialization of all eight shifts would close slightly more than half of the gap between the Reference Case and a 2-degree Celsius pathway[3].

To achieve international climate agreements, additional efforts would be needed, potentially driven by further development and cost declines of key technologies or innovations we might not even see on the horizon today. Many of the remaining 2050 CO_2 emissions in the accelerated transition stem from the power and the industry sectors. Within power, the question of storage (daily as well as seasonal) and the availability of enough renewables to satisfy growing power demand remains a topic to be solved. Within the industry sector, high-temperature processes and the consumption of fossil fuels as feedstocks are especially hard to decarbonize.

One of the potential disruptors that seems to be appearing on the horizon is the availability of

3 We compare the IEA's 2-degree Celsius pathway as a reference scenario. Whether a certain trajectory of energy-related CO_2 emissions is consistent with a 2-degree scenario also depends on non-energy related emissions (e.g., agriculture and land-use change), the cumulative amount of CO_2 emissions between now and the time emissions reach net-zero, the assumed amount of future negative emissions, the emissions of other climate pollutants, such as methane, and many more factors.

In the accelerated transition scenario, energy-related CO_2 emissions peak around 2020 but remain significantly above the level needed for a 2-degree Celsius pathway



relatively cheap hydrogen and the scale-up of applications that make use of it. With an ever-increasing share of renewables in the power mix, the operating cost of power generation and, therefore, wholesale electricity prices are decreasing and in some cases even negative (curtailed electricity). Moreover, in recent years, global electrolysis capacity has seen strong growth. With many new plants being built around the world, the capital cost to build such capacity is decreasing, bringing affordable hydrogen into the realm of possibilities. The potential of this disruptor is enormous. With its relatively high energy density, hydrogen can be used as an energy carrier in almost all sectors and a wide variety of applications. In transport, it could be used to decarbonize otherwise hard-to-decarbonize segments such as marine, aviation, and long-haul road transport. In buildings, it could be used leveraging existing gas infrastructure for heating purposes. In industrial sectors, it might find its application in the generation of high-temperature heat, or as feedstock for iron and steel or ammonia production. For short- or long-term seasonal storage in the power sector, it could also prove valuable, solving the intermittency challenge of renewables.

While the outlook for hydrogen is unclear and its large-scale availability uncertain, our analysis suggests that even in a world in which fundamental changes in the transport, buildings, industrial, and power sector reduce the use of fossil fuels dramatically, international climate goals would not be reached. It is, therefore, conceivable that future policies might not only aim to ensure that these shifts materialize but also set the stage for further acceleration to happen.

Box 3 Surprises in the accelerated transition toward 2050

Together, the eight shifts lead to strong growth in power demand, while reducing fossil fuel demand by ~20% in 2035 and by over ~30% in 2050. Individually, however, some of the effects these shifts could have on fossil fuel and power demand are rather surprising or seem counter-intuitive at first. Three things stand out:

The high increase in power demand resulting from the cooking shift in non-OECD Africa and Asia

Leap-frogging to power for cooking in many countries in which households currently depend on biomass has the second biggest impact on power demand (after the EV shift) and would increase power demand by almost 1,500 TWh in 2050, ~8% of today's global power consumption. Often, these countries switch from biomass to liquid fuels like LPG first and only then switch to power. The availability of affordable solar home systems (SHS) and increased grid access could enable such a shift and would have a significant impact on the power systems or SHS value chains in development countries.

The substantial efficiency gains that come from electrification across all shifts

Despite the large absolute power demand increase in road transport and non-OECD countries cooking, the overall power demand increase is disproportionally small compared to the fossil fuel demand decrease. Even a large-scale electrification of residential heat in OECD North America and Europe and the electrification of low- and medium-temperature industrial heat in Europe would not increase power demand by much.

The reason for this is that absolute power demand is already large today, accounting for almost 40% of primary energy demand, due to the much higher efficiencies of many electrical solutions compared to their fossil-fueled counter parts. An electric heat pump is 3-4 times more efficient than a gas or oil boiler, an electric passenger car up to 3-4 times more efficient than an ICE passenger car. Using more of such solutions will increase power demand but not to the same magnitude as it reduces fossil fuel demand.

The resilience of gas demand

In most shifts, even the ones that affect mostly gas demand, gas demand proves to be resilient. Shift 8, for instance, assumes that renewables and storage become the cheapest power source at scale. Consequently, renewables' penetration in the global power sector reaches almost 40% in 2035 and ~55% in 2050. Nevertheless, gas demand in the power sector in 2050 would only be ~20% lower than in the Reference Case (coal demand, on the other hand, would be ~30% lower). With the increased power demand from the other shifts (Shift 1–Shift 7), gas demand in 2050 is even 1% higher than in the Reference Case (coal demand would still be 45% lower). The reason for this is the role of gas as balancing capacity in the power system.

With renewables and storage making up most of the new capacity after 2020, gas demand growth slows down, mostly driven by the US and Europe. After 2035, however, high demand in high-economic-growth countries in Asia and Africa encounters storage and renewables supply constraints and requires balancing capacity in the system, in particular for seasonal balancing. Such seasonal balancing demand is often met by gas capacity.

Overall, this leads to a gas demand rebound post-2035 and, together with the higher power demand in an accelerated transition, to higher gas demand than in the Reference Case. Note that if other technologies—like hydrogen, pumped hydro, or batteries—play this seasonal balancing role, this additional gas demand would be much smaller or not materialize at all.

Global Energy Perspective

Our Global Energy Perspective is our fundamental outlook on energy demand until 2050, and it is developed by our dedicated sector teams, which are responsible for the primary research. We also collaborate with McKinsey experts around the world and across industries and engage with external industry experts to further refine our insights.

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