The world's energy system is at a crossroads. Current global trends in energy supply and consumption are patently unsustainable — environmentally, economically, socially. But that can — and must — be altered; *there's still time to change the road we're on*. It is not an exaggeration to claim that the future of human prosperity depends on how successfully we tackle the two central energy challenges facing us today: securing the supply of reliable and affordable energy; and effecting a rapid transformation to a low-carbon, efficient and environmentally benign system of energy supply. What is needed is nothing short of an energy revolution. This *World Energy Outlook* demonstrates how that might be achieved through decisive policy action and at what cost. It also describes the consequences of failure.

Oil is the world's vital source of energy and will remain so for many years to come, even under the most optimistic of assumptions about the pace of development and deployment of alternative technology. But the sources of oil to meet rising demand, the cost of producing it and the prices that consumers will need to pay for it are extremely uncertain, perhaps more than ever. The surge in prices in recent years culminating in the price spike of 2008, coupled with much greater short-term price volatility, have highlighted just how sensitive prices are to short-term market imbalances. They have also alerted people to the ultimately finite nature of oil (and natural gas) resources. In fact, the immediate risk to supply is not one of a lack of global resources, but rather a lack of investment where it is needed. Upstream investment has been rising rapidly in nominal terms, but much of the increase is due to surging costs and the need to combat rising decline rates — especially in higher-cost provinces outside of OPEC. Today, most capital goes to exploring for and developing high-cost reserves, partly because of limitations on international oil company access to the cheapest resources. Expanding production in the lowest-cost countries will be central to meeting the world's needs at reasonable cost in the face of dwindling resources in most parts of the world and accelerating decline rates everywhere.

Preventing catastrophic and irreversible damage to the global climate ultimately requires a major decarbonisation of the world energy sources. On current trends, energy-related emissions of carbon-dioxide (CO_2) and other greenhouse gases will rise inexorably, pushing up average global temperature by as much as 6°C in the long term. Strong, urgent action is needed to curb these trends. The 15th Conference of the Parties, to be held in Copenhagen in November 2009, provides a vital opportunity to negotiate a new global climate-change policy regime for beyond 2012 (the final year of coverage of the first commitment period of the Kyoto Protocol). The conference will need to put in place a framework for long-term co-operative action to bring the world onto a well-defined policy path towards a clear, quantified global goal for the stabilisation of greenhouse gases in the atmosphere. It will also need to ensure broad participation and put in place robust policy mechanisms to achieve the agreed objective.

e energy sector will have to play the central role in curbing emissions – thro… major improvements in efficiency and rapid switching to renewables and other lo… carbon technologies, such as carbon capture and storage (CCS).

Securing energy supplies and speeding up the transition to a low-carbon energy system both call for radical action by governments – at national and local levels, and through participation in co-ordinated international mechanisms. Households, businesses and motorists will have to change the way they use energy, while energy suppliers will need to invest in developing and commercialising low-carbon technologies. To make this happen, governments have to put in place appropriate financial incentives and regulatory frameworks that support both energy-security and climate-policy goals in an integrated way. Removing subsidies on energy consumption, which amounted to a staggering $310 billion in the 20 largest non-OECD countries in 2007, could make a major contribution to curbing demand and emissions growth. High international oil prices, by deterring consumption and encouraging more efficient demand-side technologies, push in the same direction, but only at the expense of economic growth and of living standards in consuming countries, both rich and poor. And some of the alternatives to conventional oil that high prices encourage are even more carbon-intensive. Many countries have made progress in crafting national responses, but much more needs to be done. A new international climate agreement is but a first essential step on the road towards a sustainable energy system; effective implementation is just as crucial. Delay in doing either would increase the eventual cost of meeting any given global climate target.

More of the same: a vision of a *laisser-faire* fossil-energy future

In our Reference Scenario, world primary energy demand grows by 1.6% per year on average in 2006-2030, from 11 730 Mtoe to just over 17 010 Mtoe – an increase of 45%. To illustrate the course on which we are set, this scenario embodies the effects of those government policies and measures that were enacted or adopted up to mid-2008, but not new ones. This provides a baseline against which we can quantify the extent to which we need to change course. Demand grows at a slower rate than projected in *WEO-2007*, mainly due to higher energy prices and slower economic growth, especially in OECD countries. Fossil fuels account for 80% of the world's primary energy mix in 2030 – down slightly on today. Oil remains the dominant fuel, though demand for coal rises more than demand for any other fuel in absolute terms. The share of the world's energy consumed in cities – an estimated 7 900 Mtoe in 2006 – grows from two-thirds to almost three-quarters in 2030.

Due to continuing strong economic growth, China and India account for just over half of the increase in world primary energy demand between 2006 and 2030. Middle East countries strengthen their position as an important demand centre, contributing a further 11% to incremental world demand. Collectively, non-OECD countries account for 87% of the increase. As a result, their share of world primary energy demand rises from 51% to 62%. Their energy consumption overtook that of the OECD in 2005.

Global primary demand for oil (excluding biofuels) rises by 1% per year on average, from 85 million barrels per day in 2007 to 106 mb/d in 2030. However, its share

world energy use drops, from 34% to 30%. Oil demand in 2030 has been revi… downwards by 10 mb/d since last year's *Outlook*, reflecting mainly the impact o… much higher prices and slightly slower GDP growth, as well as new government policies introduced in the past year. All of the projected increase in world oil demand comes from non-OECD countries (over four-fifths from China, India and the Middle East); OECD oil demand falls slightly, due largely to declining non-transport oil demand. Global demand for natural gas grows more quickly, by 1.8% per year, its share in total energy demand rising marginally, to 22%. Most of the growth in gas use comes from the power-generation sector. World demand for coal advances by 2% a year on average, its share in global energy demand climbing from 26% in 2006 to 29% in 2030. Some 85% of the increase in global coal consumption comes from the power sector in China and India. The share of nuclear power in primary energy demand edges down over the *Outlook* period, from 6% today to 5% in 2030 (its share of electricity output drops from 15% to 10%), reflecting the consistency of our rule not to anticipate changes in national policies — notwithstanding a recent revival of interest in nuclear power. Nuclear output nonetheless increases in absolute terms in all major regions except OECD Europe.

Modern renewable technologies grow most rapidly, overtaking gas to become the second-largest source of electricity, behind coal, soon after 2010. Falling costs as renewable technologies mature, assumed higher fossil-fuel prices and strong policy support provide an opportunity for the renewable industry to eliminate its reliance on subsidies and to bring emerging technologies into the mainstream. Excluding biomass, non-hydro renewable energy sources — wind, solar, geothermal, tide and wave energy — together grow faster than any other source worldwide, at an average rate of 7.2% per year over the projection period. Most of the increase occurs in the power sector. The share of non-hydro renewables in total power generation grows from 1% in 2006 to 4% in 2030. Hydropower output increases, though its share of electricity drops two percentage points to 14%. In the OECD, the increase in renewables-based power generation exceeds that in fossil-based and nuclear power generation combined.

Massive investments in energy infrastructure will be needed

The Reference Scenario projections call for cumulative investment of over $26 trillion (in year-2007 dollars) in 2007-2030, over $4 trillion more than posited in *WEO-2007*. The power sector accounts for $13.6 trillion, or 52% of the total. Most of the rest goes to oil and gas, mainly for exploration and development and mostly in non-OECD regions. Unit capital costs, especially in the oil and gas industry, have continued to surge in the last year, leading to an upward revision in our assumed costs for the projection period. That increase outweighs the slower projected expansion of the world energy system. The current financial crisis is not expected to affect long-term investment, but could lead to delays in bringing current projects to completion, particularly in the power sector. Just over half of projected global energy investment in 2007-2030 goes simply to maintain the current level of supply capacity: much of the world's current infrastructure for supplying oil, gas, coal and electricity will need to be replaced by 2030. To provide adequate assurances about the circumstances that

govern future investment in energy-supply infrastructure, negotiations need to
concluded urgently on an international agreement on combating climate change a
the implications for national policies quickly assessed.

These projections are based on the assumption that the IEA crude oil import price averages $100 per barrel (in real year-2007 dollars) over the period 2008-2015, rising to over $120 in 2030. This represents a major upward adjustment from last year's *Outlook*, reflecting the higher prices for near-term physical delivery and for futures contracts, as well as a reassessment of the prospects for the cost of oil supply and the outlook for demand. In nominal terms, prices double to just over $200 per barrel in 2030. However, pronounced short-term swings in prices are likely to remain the norm and temporary price spikes or sharp falls cannot be ruled out. Prices are likely to remain highly volatile, especially in the next year or two. A worsening of the current financial crisis would most likely depress economic activity and, therefore, oil demand, exerting downward pressure on prices. Beyond 2015, we assume that rising marginal costs of supply exert upward pressure on prices through to the end of the projection period.

Combined with our oil-demand projections, these assumptions point to persistently high levels of consumer spending on oil in both OECD and non-OECD countries. As a share of world GDP at market exchange rates, spending soared from 1% in 1998 to around 4% in 2007, with serious adverse implications for the economies of consuming countries. That share is projected to stabilise at more than 5% over much of the *Outlook* period. For non-OECD countries, the share averages 6% to 7%. The only time the world has ever spent so much of its income on oil was in the early 1980s, when it exceeded 6%. On the other hand, OPEC oil and gas export revenues jump from under $700 billion in 2006 to over $2 trillion in 2030, with their share of world GDP rising from 1.2% to 2%.

Most incremental oil and gas will come from OPEC – *if they invest enough*

World oil supply is projected to rise from 84 mb/d in 2007 to 106 mb/d in 2030 in the Reference Scenario. Netting out processing gains in refining, global production reaches 104 mb/d. Although global oil production in total is not expected to peak before 2030, production of conventional oil — crude oil, natural gas liquids (NGLs) and enhanced oil recovery (EOR) — is projected to level off towards the end of the projection period. Conventional crude oil production alone increases only modestly over 2007-2030 — by 5 mb/d — as almost all the additional capacity from new oilfields is offset by declines in output at existing fields. The bulk of the net increase in total oil production comes from NGLs (driven by the relatively rapid expansion in gas supply) and from non-conventional resources and technologies, including Canadian oil sands.

The bulk of the increase in world oil output is expected to come from OPEC countries, their collective share rising from 44% in 2007 to 51% in 2030. Their reserves are, in principle, large enough (and development costs low enough) for output to grow faster than this. But investment by these countries is assumed to be constrained by several factors, including conservative depletion policies and geopolitics. Saudi Arabia remains the world's largest producer throughout the projection period, its output climbing

m 10.2 mb/d in 2007 to 15.6 mb/d in 2030. Non-OPEC conventional oil productio
eady at plateau and is projected to start to decline by around the middle of the ne
decade, accelerating through to the end of the projection period. Production has already peaked in most non-OPEC countries and will peak in most others before 2030. Falling crude oil and NGLs production is largely offset by rising non-conventional output, which keeps total non-OPEC output broadly flat over the second half of the projection period. Conventional capacity, net of natural production declines at existing fields, is set to grow in the near term, but dwindling new discoveries and a fall in the size of new fields are expected to drive up marginal development costs, leading to a drop in output.

The projected increase in global oil output hinges on adequate and timely investment. Some 64 mb/d of additional gross capacity — the equivalent of almost six times that of Saudi Arabia today — needs to be brought on stream between 2007 and 2030. Some 30 mb/d of new capacity is needed by 2015. There remains a real risk that under-investment will cause an oil-supply crunch in that timeframe. The current wave of upstream investment looks set to boost net oil-production capacity in the next two to three years, pushing up spare capacity modestly. However, capacity additions from current projects tail off after 2010. This largely reflects the upstream development cycle: many new projects will undoubtedly be sanctioned in the near term as oil companies complete existing projects and move on to new ones. But the gap now evident between what is currently being built and what will be needed to keep pace with demand is set to widen sharply after 2010. Around 7 mb/d of additional capacity (over and above that from all current projects) needs to be brought on stream by 2015, most of which will need to be sanctioned within the next two years, to avoid a fall in spare capacity towards the middle of the next decade.

Production of natural gas is also set to become more concentrated in the most resource-rich regions. Some 46% of the projected growth in world gas production in 2006-2030 comes from the Middle East, its output tripling to around 1 trillion cubic metres (tcm) by 2030. About 60% of the region's incremental output is consumed locally, mainly in power stations. Most of the remaining increase in world output is provided by Africa and Russia. If investments in these countries falter, lower gas supply could lead to greater reliance on coal and higher CO_2 emissions.

The world is not running short of oil or gas just yet

The world's total endowment of oil is large enough to support the projected rise in production beyond 2030 in the Reference Scenario. Estimates of remaining proven reserves of oil and NGLs range from about 1.2 to 1.3 trillion barrels (including about 0.2 trillion barrels of non-conventional oil). They have almost doubled since 1980. This is enough to supply the world with oil for over 40 years at current rates of consumption. Though most of the increase in reserves has come from revisions made in the 1980s in OPEC countries rather than from new discoveries, modest increases have continued since 1990, despite rising consumption. The volume of oil discovered each year on average has been higher since 2000 than in the 1990s, thanks to increased exploration activity and improvements in technology, though production continues to outstrip discoveries (despite some big recent finds, such as in deepwater offshore Brazil).

…imately recoverable conventional oil resources, which include initial proven a… …obable reserves from discovered fields, reserves growth and oil that has yet t… be found, are estimated at 3.5 trillion barrels. Only a third of this total, or 1.1 trillion barrels, has been produced up to now. Undiscovered resources account for about a third of the *remaining* recoverable oil, the largest volumes of which are thought to lie in the Middle East, Russia and the Caspian region. Non-conventional oil resources, which have been barely developed to date, are also very large. Between 1 and 2 trillion barrels of oil sands and extra-heavy oil may be ultimately recoverable economically. These resources are largely concentrated in Canada (mainly in Alberta province) and Venezuela (in the Orinoco Belt). The total long-term potentially recoverable oil-resource base, including extra-heavy oil, oil sands and oil shales (another largely undeveloped, though costly resource), is estimated at around 6.5 trillion barrels. Adding coal-to-liquids and gas-to-liquids increases this potential to about 9 trillion barrels.

Globally, natural gas resources are large, but, like oil, are highly concentrated in a small number of countries and fields. Remaining proven reserves amount to 180 tcm — equal to around 60 years of current production. Three countries — Russia, Iran and Qatar — hold 56% of the world's reserves, while just 25 fields worldwide hold almost half. OPEC countries also hold about half. Remaining reserves have more than doubled since 1980, with the biggest increases coming from the Middle East. Although the size of gas discoveries has been steadily declining in recent decades in the same way as for oil, discoveries continue to exceed production. Ultimately recoverable remaining resources of conventional natural gas, including remaining proven reserves, reserves growth and undiscovered resources, could amount to well over 400 tcm. Cumulative production to 2007 amounts to less than one-sixth of total initial resources. Non-conventional gas resources — including coalbed methane, tight gas sands and gas shales — are much larger, amounting perhaps to over 900 tcm, with 25% in the United States and Canada combined.

But field-by-field declines in oil production are accelerating…

Globally, oil resources might be plentiful, but there can be no guarantee that they will be exploited quickly enough to meet the level of demand projected in our Reference Scenario. One major uncertainty concerns the rate at which output from producing oilfields declines as they mature. This is a critical determinant of the amount of new capacity and investment that will be needed globally to meet projected demand. The findings of a detailed field-by-field analysis of the historical production trends of 800 fields, set out in Part B of this *Outlook*, indicate that *observed* decline rates (the observable fall in production) are likely to accelerate in the long term in each major world region. This results from a fall in the average size of field and, in some regions, an increase in the share of production that is expected to come from offshore fields. Our analysis demonstrates that, in general, the larger a field's reserves, the lower the peak relative to reserves and the slower the decline once the field has passed its peak. Rates are also lower for onshore than offshore (especially deepwater) fields. Investment and production policies also affect decline rates.

We estimate that the average production-weighted observed decline rate worldw[illegible] currently 6.7% for fields that have passed their production peak. In our Referenc[illegible] Scenario, this rate increases to 8.6% in 2030. The current figure is derived from our analysis of production at 800 fields, including all 54 super-giants (holding more than 5 billion barrels) in production today. For this sample, the observed post-peak decline rate averaged across all fields, weighted by their production over their whole lives, was found to be 5.1%. Decline rates are lowest for the biggest fields: they average 3.4% for super-giant fields, 6.5% for giant fields and 10.4% for large fields. Observed decline rates vary markedly by region; they are lowest in the Middle East and highest in the North Sea. This reflects, to a large extent, differences in the average size of fields, which in turn is related to the extent to which overall reserves are depleted and whether they are located onshore or offshore. Adjusting for the higher decline rates of smaller fields explains the higher estimated decline rate for the world, compared with that based on our dataset.

***Natural*, or underlying, decline rates are about a third higher on average than observed decline rates, though the difference varies across regions reflecting differences in investment.** (The natural decline rate strips out the effects of ongoing and periodic investment.) For the world as a whole, it is estimated at 9% for post-peak fields. In other words, the decline in production from existing fields would have been around one-third faster had there been no capital spending on those fields once they had passed their peak. Our Reference Scenario projections imply an increase in the global average natural decline rate to around 10.5% per year by 2030 (almost two percentage points higher than the observed rate), as all regions experience a drop in average field size and most see a shift in production to offshore fields over the projection period. This means that total upstream investment in some countries will need to rise, in some cases significantly, just to offset this faster decline. The implications are far-reaching: investment in 1 mb/d of *additional* capacity — equal to the entire capacity of Algeria today — is needed each year by the end of the projection period just to offset the projected acceleration in the natural decline rate.

…and barriers to upstream investment could constrain global oil supply

Faster natural decline rates will mean a need for more upstream investment, both in existing fields (to combat natural decline) and in new fields (to offset falling production from existing fields and to meet rising demand). In fact, total upstream investment (in oil and gas fields) has been rising rapidly in recent years, more than tripling between 2000 and 2007 to $390 billion in nominal terms. Most of this increase was to meet higher unit costs: in cost-inflation adjusted terms, investment in 2007 was 70% higher than in 2000. Worldwide, upstream costs rose on average by an estimated 90% between 2000 and 2007 and by a further 5% in the first half of 2008, according to the IEA Index of Upstream Capital Costs. Most of the increase occurred in 2004-2007. Based on the plans of 50 of the world's largest companies surveyed for this *Outlook* (accounting for more than three-quarters of world oil and gas production), global upstream oil and gas investment is expected to continue to rise, to just over $600 billion in nominal terms by 2012 — an increase of more than half over 2007. If costs level off, as assumed, real spending in the five years to 2012 would grow by 9% per year — about the same rate as in the previous seven years.

The Reference Scenario projections imply a need for cumulative investment in the upstream oil and gas sector of around $8.4 trillion (in year-2007 dollars) over 2007-2030, or $350 billion per year on average. That is significantly less than is currently being spent. This is due to a major shift in where that investment is needed. Much more capital needs to go to the resource-rich regions, notably the Middle East, where unit costs are lowest. In short, the opportunities for international companies to invest in non-OPEC regions will diminish as the resource base contracts, eventually leaving the countries holding the bulk of the world's remaining oil and gas reserves to take on a larger burden of investment, either directly through their national companies or indirectly, in partnership with foreign investors. It cannot be taken for granted that these countries will be willing to make this investment themselves or to attract sufficient foreign capital to keep up the necessary pace of investment.

Stronger oil company partnerships could bring mutual benefits

Major structural changes are underway in the upstream oil and gas industry, with the national companies playing an increasingly dominant role. In the Reference Scenario, they account for about 80% of total incremental production of both oil and gas between 2007 and 2030. In most of the countries with the largest oil and gas reserves, national companies dominate the upstream industry and foreign companies are either not allowed to own and develop reserves or are subject to tight restrictions. Higher oil prices and a growing conviction among political leaders that national companies serve the nation's interests better than private and foreign oil companies have boosted the confidence and aspirations of national companies, some of them rivalling the international companies for technical capability and efficiency. The international oil companies, which have traditionally dominated the global oil and gas industry, are increasingly being squeezed by the growing power of the national companies and by dwindling reserves and production in accessible mature basins outside OPEC countries. The super-majors have been struggling to replace their proven reserves and expand production, while the share of their cash earnings that is returned to shareholders has been growing.

How the structure of the global oil and gas industry evolves in the coming decades will have important implications for investment, production capacity and prices. The increasing dominance of national companies may make it less certain that the investment projected in this *Outlook* will actually be made. The long-term policies of some major resource-rich countries in support of national goals may lead to slower depletion of their resources. Although some national companies, like Saudi Aramco, perform strongly in most areas, others may be less well placed to address the financing, technical and managerial challenges of bringing new upstream capacity on stream. Partnerships between the national and international companies could help address these challenges. The mutual benefits that could accrue are compelling: the national companies control most of the world's remaining reserves, but some lack the technology and skilled personnel to do much more than simply maintain existing producing assets; the international companies are opportunity-constrained, but have the management skills and technology to help national companies develop their reserves.

-rich African countries have no excuse for their citizens' energy overty

A number of sub-Saharan African countries hold large oil and gas resources, which are expected to underpin strong growth in their production and exports in the coming two decades or so. Conventional oil production in the ten largest hydrocarbon-producing countries in sub-Saharan Africa reached 5.6 mb/d in 2007, of which 5.1 mb/d was exported. In the Reference Scenario, output rises to 7.4 mb/d and oil exports to 6.4 mb/d in 2030. Gas production in these countries increases more than four-fold, from 36 billion cubic metres in 2006 to 163 bcm in 2030, with most of the increase going to export. These projections hinge on a reduction in gas flaring, adequate investment and avoiding disruptions to supplies through civil unrest. Cumulative government revenues from oil and gas output (from royalties and taxes) in these ten countries are projected, in aggregate, to total $4 trillion over 2007-2030. Nigeria and Angola remain the largest exporters, with combined cumulative government revenues of about $3.5 trillion. Taxes on oil and gas production account for more than 50% of total government revenues in most of the oil- and gas-rich sub-Saharan African countries.

Despite the vast hydrocarbon wealth of these ten countries, most of their citizens remain poor. As a result, household use of modern energy services is very limited. Two-thirds of households do not have access to electricity and three-quarters do not have access to clean fuels for cooking, relying instead on fuelwood and charcoal. Unless there are major government initiatives to address this problem, the number of electricity-deprived people is projected to increase over the projection period, as the population grows. And more than half of the total population of these countries still relies on fuelwood and charcoal for cooking in 2030.

Tackling energy poverty is well within these countries' means, but major institutional reforms are needed. We estimate the capital cost of providing minimal energy services (electricity and liquefied petroleum gas stoves and cylinders) to these households over the *Outlook* period to be about $18 billion. This is equivalent to only 0.4% of cumulative government revenues from oil and gas. An improvement in the efficiency and transparency of revenue allocation and the accountability of governments in the use of public funds would improve the likelihood that oil and gas revenues are actually used to alleviate poverty generally and energy poverty specifically.

The consequences for the global climate of policy inaction are shocking

The projected rise in emissions of greenhouse gases in the Reference Scenario puts us on a course of doubling the concentration of those gases in the atmosphere by the end of this century, entailing an eventual global average temperature increase of up to 6 °C. The Reference Scenario trends point to continuing growth in emissions of CO_2 and other greenhouse gases. Global energy-related CO_2 emissions rise from 28 Gt in 2006 to 41 Gt in 2030 — an increase of 45%. The 2030 projection is only 1 Gt lower than that projected in last year's *Outlook*, even though we assume much higher prices and slightly lower world GDP growth. World greenhouse-gas emissions, including non-

ergy CO_2 and all other gases, are projected to grow from 44 Gt CO_2-equivalent 005 to 60 Gt CO_2-eq in 2030, an increase of 35% over 2005.

Three-quarters of the projected increase in energy-related CO_2 emissions in the Reference Scenario arises in China, India and the Middle East, and 97% in non-OECD countries as a whole. On average, however, non-OECD per-capita emissions remain far lower than those in the OECD. Emissions in the OECD reach a peak after 2020 and then decline. Only in Europe and Japan are emissions in 2030 lower than today. The bulk of the increase in global energy-related CO_2 emissions is expected to come from cities, their share rising from 71% in 2006 to 76% in 2030 as a result of urbanisation. City residents tend to consume more energy than rural residents, so they therefore emit more CO_2 per capita.

The road from Copenhagen must be paved with more than good intentions

Strong, co-ordinated action is needed urgently to curb the growth in greenhouse-gas emissions and the resulting rise in global temperatures. The post-2012 global climate-change policy regime that is expected to be established at the Copenhagen conference in 2009 will provide the international framework for that action. With energy-related CO_2 accounting for 61% of global greenhouse-gas emissions, the energy sector will have to be at the heart of discussions on what level of concentration to aim for and how to achieve it. The target that is set for the long-term stabilisation of greenhouse-gas concentration will determine the pace of the required transformation of the global energy system, as well as how stringent the policy responses will need to be. Successfully meeting that target will hinge on effective implementation.

The choice of global emissions trajectory will need to take into account technological requirements and costs in the energy sector. The normal cycle of capital replacement is a key constraint on the speed with which low-carbon technologies can enter into use without incurring disproportionate cost. The energy sector has a relatively slow rate of capital replacement in general, due to the long lifetime of much of its capital — for producing, supply and using energy. As a result, more efficient technologies normally take many years to spread through the energy sector. It will be necessary to face up to the reality of the cost of early capital retirement if radical measures are to be taken to speed up this process so as to deliver deep cuts in emissions. The rate of capital-stock turnover is particularly slow in the power sector, where large up-front costs and long operating lifetimes mean that plants that have already been built — and their associated emissions — are effectively "locked-in". In the Reference Scenario, three-quarters of the projected output of electricity worldwide in 2020 (and more than half in 2030) comes from power stations that are already operating today. As a result, even if all power plants built from now onwards were carbon-free, CO_2 emissions from the power sector would still be only 25%, or 4 Gt, lower in 2020 relative to the Reference Scenario.

Any agreement will need to take into account the importance of a handful of major emitters. The five largest emitters of energy-related CO_2 — China, the United States, the European Union, India and Russia — together account for almost two thirds of

bal CO_2 emissions; in the Reference Scenario, this proportion is expected to rem
milar in 2020. The contributions to emissions reduction made by China and the Unite
States will be critical to reaching a stabilisation goal. The scale of the reduction in energy-related emissions by country or region varies markedly with different levels of international participation.

The stabilisation goal will determine the scale of the energy challenge

This *Outlook* considers two climate-policy scenarios corresponding to long-term stabilisation of greenhouse-gas concentration at 550 and 450 parts per million of CO_2 equivalent. The 550 Policy Scenario equates to an increase in global temperature of approximately 3°C, the 450 Policy Scenario to a rise of around 2°C. The 550 Policy Scenario involves a plateauing of greenhouse-gas emissions by 2020 and reductions soon after. The 450 Policy Scenarios involves much more substantial reductions after 2020. Even then, emissions overshoot the trajectory needed to meet the 450 ppm CO_2-eq target, requiring greater emissions reductions after 2030. In both scenarios, total emissions are significantly lower in 2030 in all major emitting countries. To reach either of these outcomes, hundreds of millions of households and businesses around the world would need to be encouraged to change the way they use energy. This will require innovative policies, an appropriate regulatory framework, the rapid development of a global carbon market and increased investment in energy research, development and demonstration.

There is a wide range of international policy mechanisms that could be adopted to meet an agreed climate objective. However, as current political debate shows, and given practical issues in the energy sector, the reality is that nations adopt the approach or approaches that best reflect their varied interests and capabilities. This *Outlook* analyses the implications for the energy sector of a hybrid policy framework involving one particular combination of cap-and-trade systems, sectoral agreements (in the transport and industry sectors) and national policies and measures. Cap-and-trade systems are assumed to play an important role in the OECD regions. The carbon price there reaches $90/tonne of CO_2 in 2030 in the 550 Policy Scenario and $180/tonne in the 450 Policy Scenario.

In the 550 Policy Scenario, world primary energy demand expands by about 32% between 2006 and 2030 with the share of fossil fuels falling markedly. Demand grows on average by 1.2% per year, compared with 1.6% in the Reference Scenario. By 2030, demand is 9% lower than in the Reference Scenario, mainly as a result of efficiency gains. Global energy-related CO_2 emissions peak in 2025 and then decline slightly to 33 Gt in 2030, while greenhouse-gas emissions plateau by 2020 and are broadly flat through to 2030. Both total greenhouse-gas and energy-related CO_2 emissions are 19% lower in 2030 than in the Reference Scenario. The energy mix in this scenario is markedly different to that of the Reference Scenario, with fossil fuels losing market share to renewables and nuclear power. Oil demand rises to 98 mb/d in 2030 — almost 9 mb/d less than in the Reference Scenario. More than half of the oil savings occur in the transport sector in OECD countries and other major economies, as a result of

toral agreements to reduce emissions from light-duty vehicles and aviation. ices are around $100 per barrel (in year-2007 dollars) in 2030, 18% lower than in th Reference Scenario, due to lower demand. OPEC production still increases, to 49 mb/d in 2030, almost 13 mb/d higher than today (but 4 mb/d less than in the Reference Scenario). CCS is also deployed more quickly. In 2030, the installed capacity of CCS plants amounts to over 160 GW worldwide, of which about 70% is in OECD countries. CCS capacity is negligible in the Reference Scenario.

The 450 Policy Scenario assumes much stronger and broader policy action from 2020 onwards, inducing quicker development and deployment of low-carbon technologies. Global energy-related CO_2 emissions are assumed to follow broadly the same trajectory as in the 550 Policy Scenario until 2020, and then to fall more quickly. They peak in 2020 at 32.5 Gt and then decline to 25.7 Gt in 2030. This scenario requires emissions in OECD countries to be reduced by almost 40% in 2030, compared with 2006 levels. Other major economies are required to limit their emissions growth to 20%. Participation in an international cap-and-trade system is assumed to be broader than in the 550 Policy Scenario, covering all major emitting countries from 2020 onwards. Hydropower, biomass, wind and other renewables see faster deployment in power generation, accounting for 40% of total generation worldwide in 2030. An additional 190 GW of CCS is deployed in the last decade of the projection period compared with the 550 Policy Scenario.

The scale of the challenge in the 450 Policy Scenario is immense: the 2030 emissions level for the world as a whole in this scenario is less than the level of projected emissions for non-OECD countries alone in the Reference Scenario. In other words, the OECD countries alone cannot put the world onto the path to 450-ppm trajectory, even if they were to reduce their emissions to zero. Even leaving aside any debate about the political feasibility of the 450 Policy Scenario, it is uncertain whether the scale of the transformation envisaged is even technically achievable, as the scenario assumes broad deployment of technologies that have not yet been proven. The technology shift, if achievable, would certainly be unprecedented in scale and speed of deployment. Increased public and private spending on research and development in the near term would be essential to develop the advanced technologies needed to make the 450 Policy Scenario a reality.

Tackling climate change will require big shifts in spending

The profound shifts in energy demand and supply in the two climate-policy scenarios call for huge increases in spending on new capital stock, especially in power plants and in more energy-efficient equipment and appliances. The 550 Policy Scenario requires $4.1 trillion more investment in total between 2010 and 2030 than in the Reference Scenario – equal on average to 0.24% of annual world GDP. Most of this goes to deploying and improving existing technologies. Investment in power plants is $1.2 trillion higher, with close to three-quarters of this additional capital going to OECD countries. Additional expenditures on the demand side are even bigger. Most of the extra spending is by individuals, who have to pay more for more efficient cars, appliances and buildings. This extra cost amounts to $17 per person per year

average throughout the world. But these investments are accompanied by la[rge] savings on energy bills. Improved energy efficiency lowers fossil-fuel consumption b[y] a cumulative amount of 22 billion tonnes of oil equivalent over 2010-2030, yielding cumulative savings of over $7 trillion.

The additional up front expenditures on energy-related capital are, unsurprisingly, considerably larger in the 450 Policy Scenario. An additional $2.4 trillion needs to be invested in low- or zero-carbon power-generation capacity and an additional $2.7 trillion invested in more energy-efficient equipment, appliances and buildings than in the 550 Policy Scenario. Together, these costs equal on average 0.55% of annual world GDP. These expenditures are particularly great during the last decade of the projection period, when CO_2 emissions fall most rapidly and the marginal cost of abatement options rises sharply. Galvanising these investments would require clear price signals (including through a broad-based, efficient carbon market), appropriate fiscal incentives and well-targeted regulation. At $5.8 trillion, the cumulative savings on fuel bills are smaller than in the 550 Policy Scenario, because higher electricity prices offset the bigger energy savings.

The energy future will be very different

For all the uncertainties highlighted in this report, we can be certain that the energy world will look a lot different in 2030 than it does today. The world energy system will be transformed, but not necessarily in the way we would like to see. We can be confident of some of the trends highlighted in this report: the growing weight of China, India, the Middle East and other non-OECD regions in energy markets and in CO_2 emissions; the rapidly increasing dominance of national oil companies; and the emergence of low-carbon energy technologies. And while market imbalances could temporarily cause prices to fall back, it is becoming increasingly apparent that the era of cheap oil is over. But many of the key policy drivers (not to mention other, external factors) remain in doubt. It is within the power of all governments, of producing and consuming countries alike, acting alone or together, to steer the world towards a cleaner, cleverer and more competitive energy system. Time is running out and the time to act is now.