BP Technology Outlook

A brief perspective

November 2015

The world of energy faces some tough challenges in the decades ahead, particularly in meeting increasing demand with less environmental impact. The *BP Technology Outlook* shows how technology can play a major role in meeting these challenges by widening energy resource choices, transforming the power sector, improving transport efficiency and helping to address climate concerns out to 2050.

The publication is intended to help decision makers as they make choices about policies, investments and priorities for the years ahead. This summary of the full publication focuses on some of the key findings and highlights ways in which technology can help energy evolve.

To access the full publication visit **www.bp.com/technologyoutlook**

Insights from the BP Technology Outlook

Since the 18th century, energy has helped to drive human and economic development, a process that continues today. This journey has been largely fuelled by fossil fuels – coal, oil and gas – providing heat, power and mobility for industry and consumers. The past three decades have seen a surge in these trends, driven by demand from emerging economies, led by China and India. However, consuming all of the available fossil fuel resources would create greenhouse gas (GHG) emissions well above the threshold recommended by scientists. For the future, we need energy that is affordable, sustainable and secure.

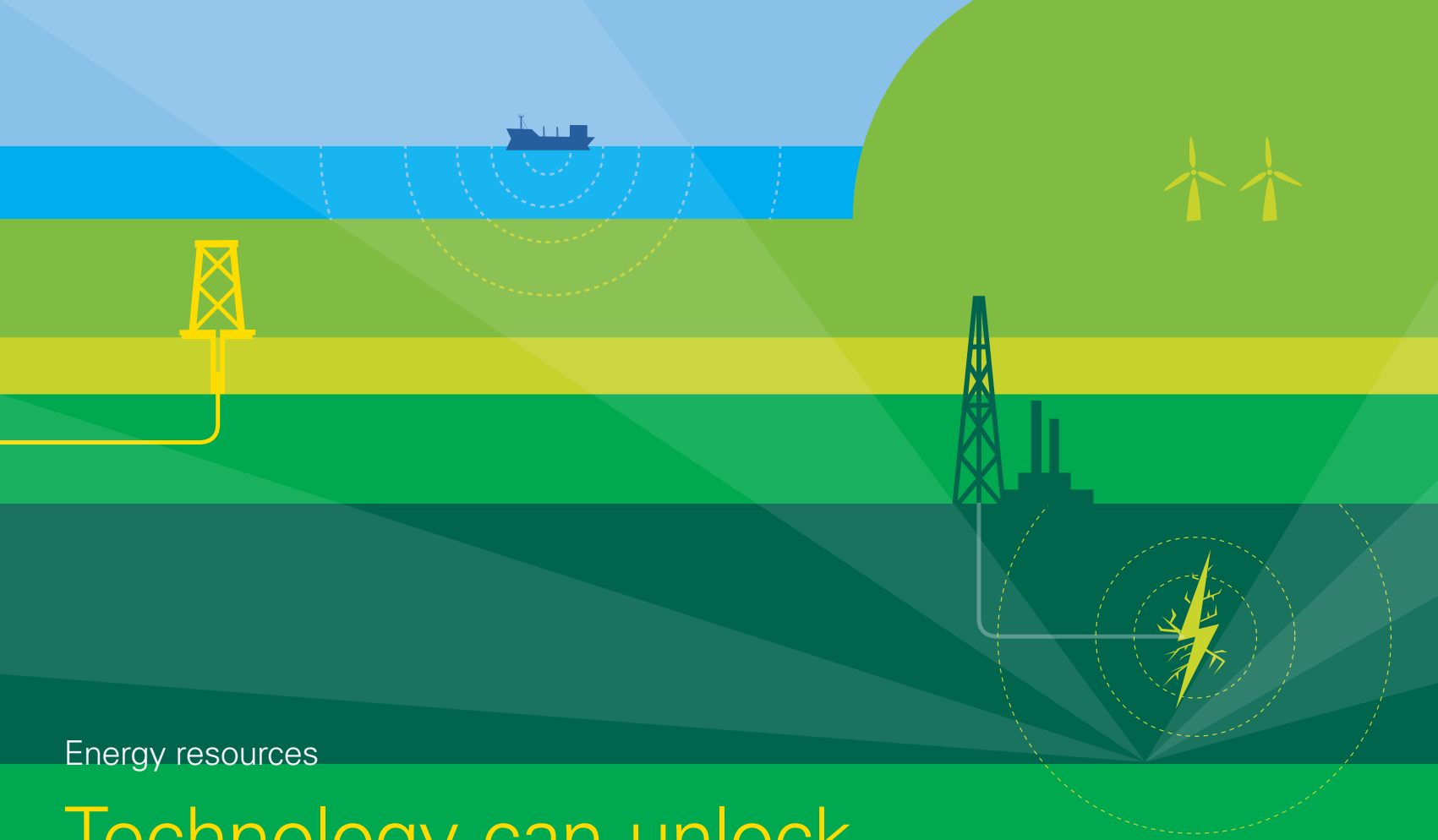
The *BP Technology Outlook* examines what technology can do in terms of access to primary energy resources and how it might change both the power and transport sectors, especially in the context of reducing carbon emissions. It also examines the impact of natural resource constraints on technological choices and emerging technologies that have the potential to accelerate or disrupt energy models in the future.

Our analysis highlights three striking themes

1. **Technology has extraordinary potential to increase accessible primary energy resources, both fossil and non-fossil, while reducing their costs.** Projected global energy demand at 2050 could be met many times over. The key question for policy makers and businesses becomes one of choice – which resources make sense to pursue given their relative costs and characteristics?

2. **Digital technologies have more widespread potential than any other technology area to transform energy production, supply and end-use.** They offer a real opportunity to improve safety and reliability, reduce costs and contribute to more efficient operations.

3. **Introducing a carbon price would open up a range of potential pathways for energy, with the power sector offering the most compelling options for decarbonization at comparatively low cost.** For the transport sector, vehicles are set to become more energy efficient, with liquid fuels likely to continue to dominate the market whilst batteries become more cost competitive.



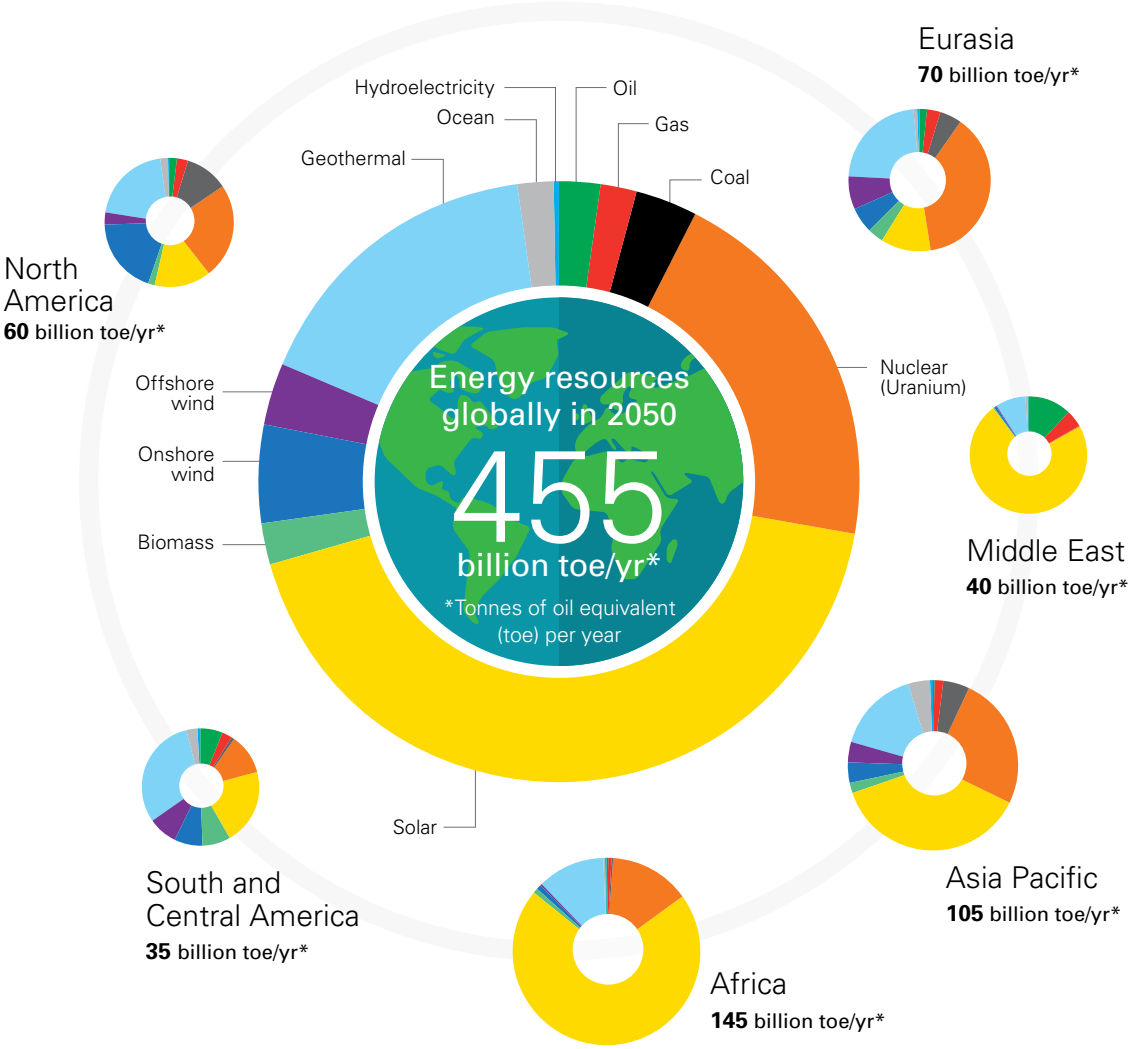
Energy resources

Technology can unlock plentiful supplies of energy

Advances in technology will keep energy supplies plentiful and affordable. We estimate that the energy theoretically accessible in 2050 could be 455 billion tonnes of oil equivalent per year. **That's more than 20 times the amount needed to meet expected demand.** Technology can unlock supplies of almost all forms of energy, from fossil fuels to sunlight and wind. In fact, several of these resources could theoretically meet all primary energy demand on their own.

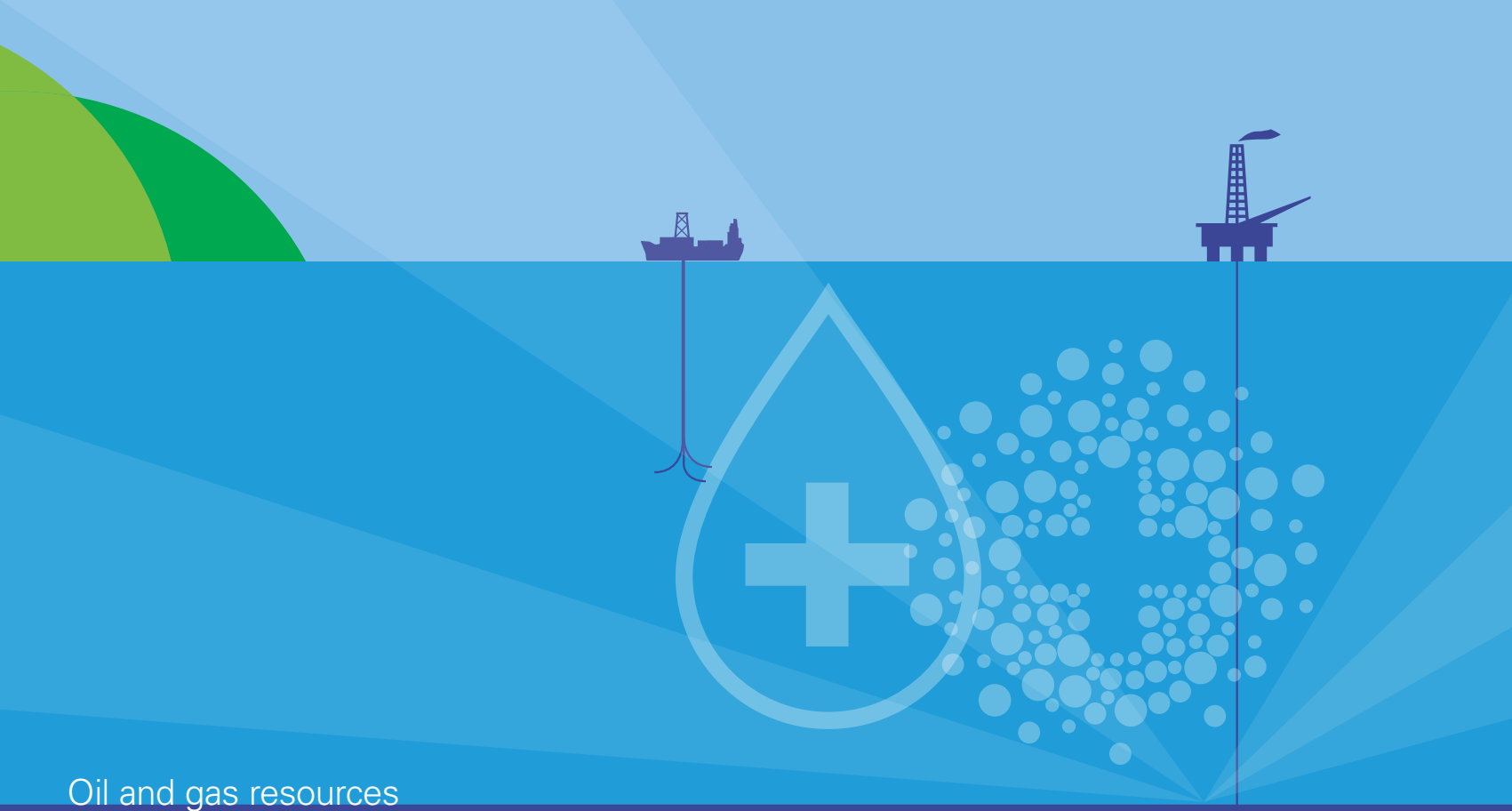
The absolute volumes of resources assessed are less important than their relative proportions. In addition, other factors such as cost of supply, energy density, remoteness from centres of demand, supply chain constraints and intermittency must be considered. Taken together these mean that only a limited portion of the full potential needs to be or will be accessed by 2050. **The question becomes less about "will we have enough energy?" and more about "what kind of energy do we want?"**

The world has abundant technically-accessible energy resources



NOTE: The chart represents the energy resource potential per year based on the availability of the underlying source of energy, without reference to economic viability. Fossil and uranium (for nuclear) resources have been annualized over a 50-year period for comparison with renewables which are available each year.

Source BP.



Oil and gas resources

Technology can increase oil and gas recovery rates and reduce costs

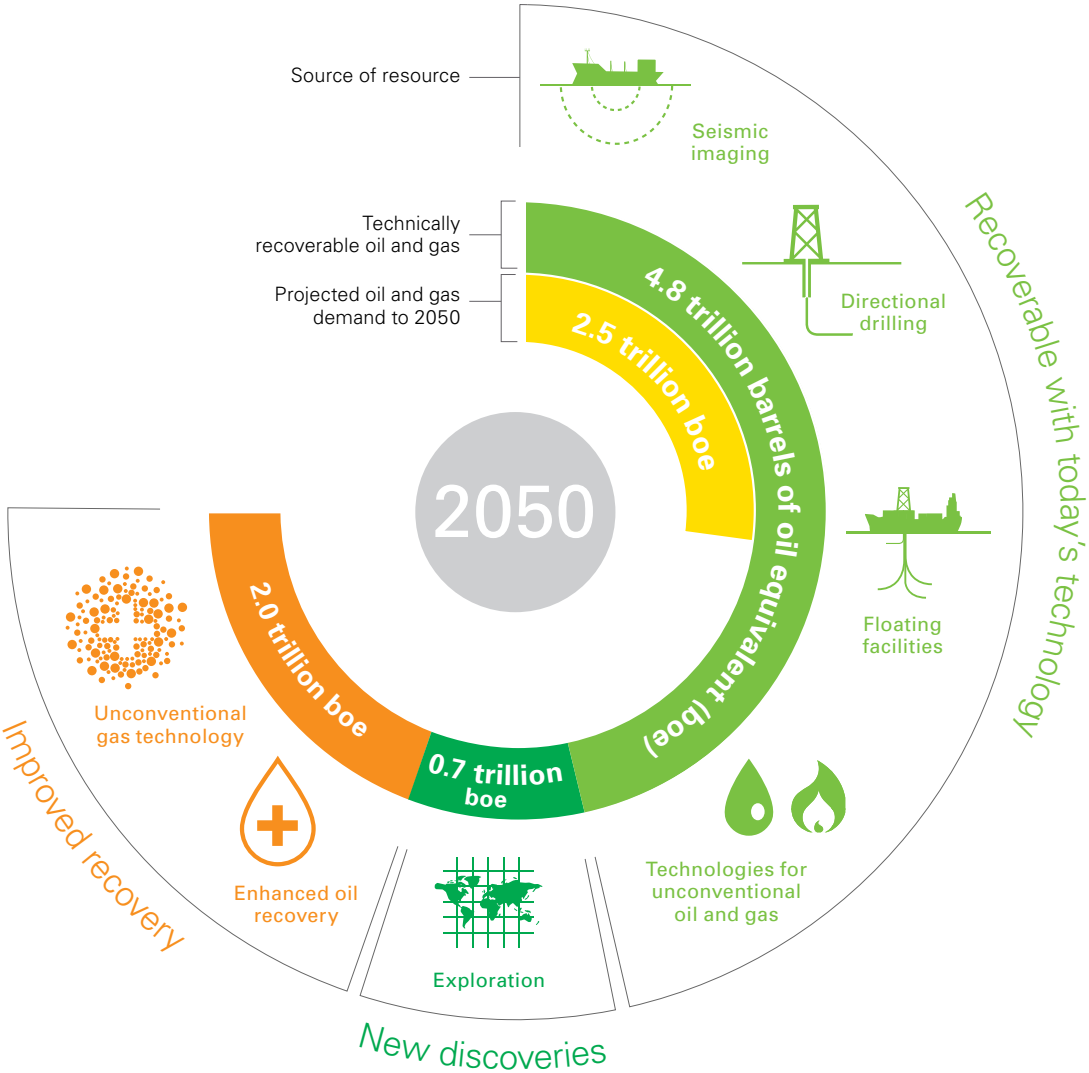
Technology will play a major role in providing oil and gas to meet demand over the coming decades as the world transitions to a lower-carbon economy.

Our estimates suggest that cumulative oil and gas demand out to 2050 could be around 2.5 trillion barrels of oil equivalent. No major technology breakthroughs are needed to meet this demand. Our analysis shows that **applying today's best available technologies to discovered oil and gas resources could significantly increase 'reserves'** from 2.9 trillion barrels of oil equivalent to 4.8 trillion barrels.

The most significant change to resource opportunities over the past 10 years has been the advent of production from shale and tight rock – this has more than doubled total potentially accessible oil and gas in discovered reservoirs. Other key technology levers include enhanced oil recovery – the biggest contributor to increasing recoverable oil volumes – subsurface imaging, and operational improvement through the use of digital technologies, such as sensors, robotics and supercomputers for data analysis.

Future technology advances and new discoveries could add a further 2.7 trillion technically recoverable barrels of oil equivalent through to 2050. Given that nations are increasingly seeking to limit carbon emissions by using less energy and shifting towards lower carbon fuels, it is unlikely that all these resources will be required.

Technology helps keep oil and gas resources plentiful



Source BP.

Power generation

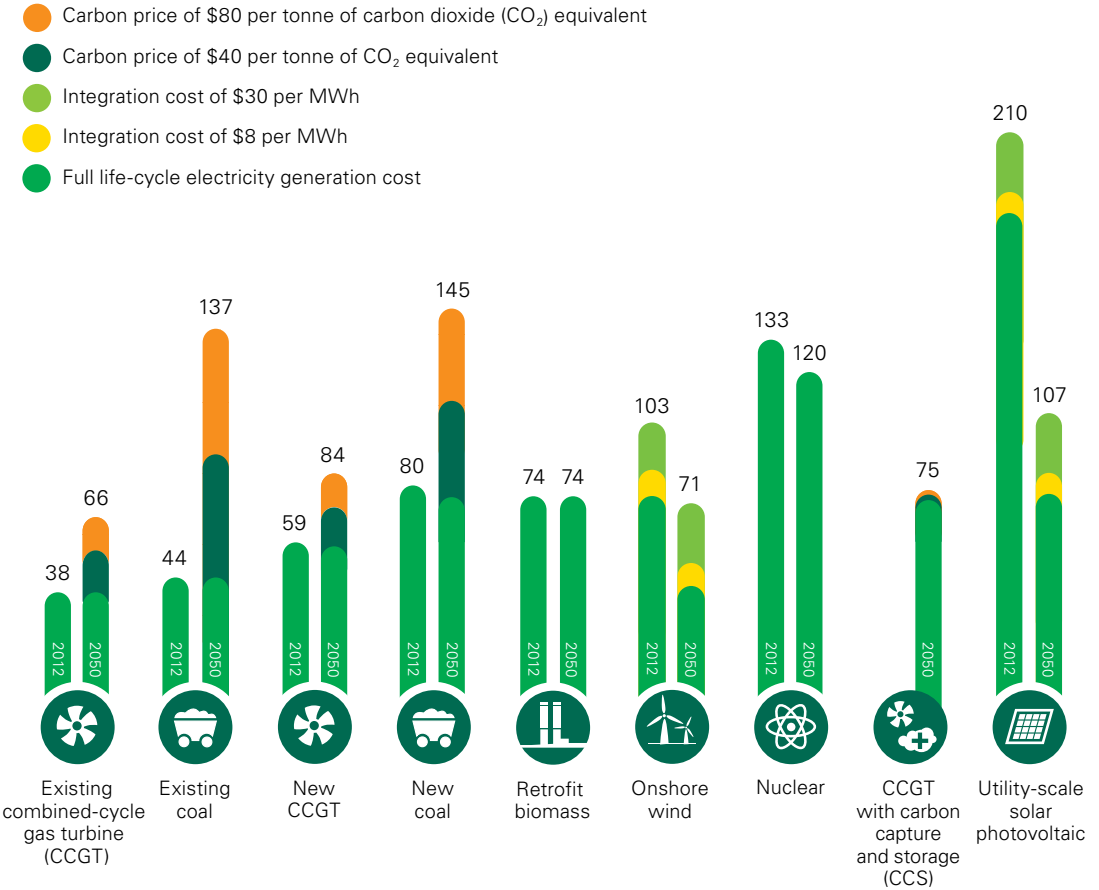
Technology can create cheaper, cleaner energy

The chart shows the costs of generating electricity in North America from different fuel feedstocks – ignoring all taxes and other duties. Technology advances are expected to bring down the costs of most forms of electricity generation by 2050 while a carbon price would increase costs of the higher carbon options.

The chart includes the cost of providing back-up to wind and solar using gas-fired power when the wind is not blowing or the sun is not shining. It also shows that gas-fired power plants fitted with carbon capture and storage to sequester the carbon emissions below the ground can become competitive with an $80 per tonne carbon price by 2050.

The power sector offers greater scope than the transport sector for reducing carbon emissions, at a comparatively low cost of carbon. It currently accounts for 38% of world primary energy demand, with gas and coal-fired power generally most competitive, but we expect wind and solar to continue reducing costs at around 14% and 24% respectively per doubling of installed capacity, consistent with past performance. Without a carbon price, gas and coal will remain the cheapest sources of electricity. However, with even a relatively modest carbon price of $40 per tonne of CO_2, gas gains an advantage over coal. At higher carbon prices, wind and solar power become more competitive, providing there is sufficient back-up capability.

Levelized cost of electricity[1] in North America to 2050



Note: No commercial scale carbon capture and storage (CCS) power plants existed in 2012. Assumptions: Coal at $80/tonne, gas at $5/mmBtu and pelletized biomass at $80/tonne.

[1]$ 2012 per megawatt hour.

Source BP.

Transport

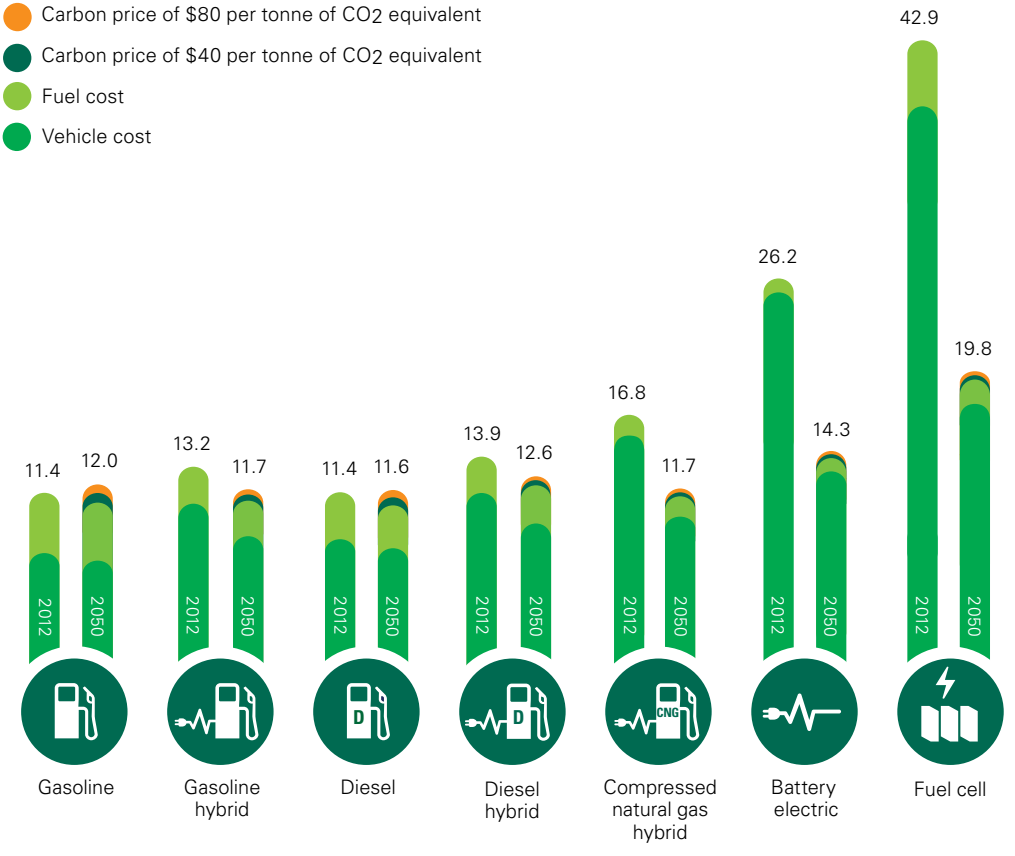
Technology can enable energy to be used more efficiently

The chart shows the total cost of travel in a passenger vehicle in North America using different types of engine. The overall running costs of vehicles per kilometre travelled are projected to remain broadly flat to 2050, with the costs and benefits of fuel efficiency broadly offsetting one another.

The fuel economy of vehicles is improving fast, largely driven by emissions standards set by governments. Looking ahead to 2035 we expect the **average efficiency of new light-duty vehicles to improve 2-3% per year** as a result of increased hybridization and improved powertrains, combined with advanced fuels and lubricants. Hence, vehicles powered by liquid fuels are likely to continue dominating global transportation through to 2035 and beyond. By 2050, with advances in battery technology, electric vehicles are likely to be competitive, while fuel cell vehicle costs still have further to go. However there are other benefits of zero emissions vehicles, especially in an urban environment, and regulations have been introduced and could be reinforced to reflect this trend.

Other technology options that can contribute to reduced emissions include natural gas and biomass, with the cost of supplying biofuels expected to fall, particularly for second generation biofuels made from grasses, wastes and other non-edible agricultural matter.

Passenger vehicle running costs[2] in 2012 and 2050



Assumptions: Vehicle cost per kilometre is based on North America average distance travelled of ~194,000 kilometres over the vehicle life. Fuel cost assumes nominal oil and gas prices of $80/bbl and $5/mmbtu. Costs exclude all taxes and other duties.

[2] US cents 2012 per km for medium sized car.

Source BP.

Emerging technologies

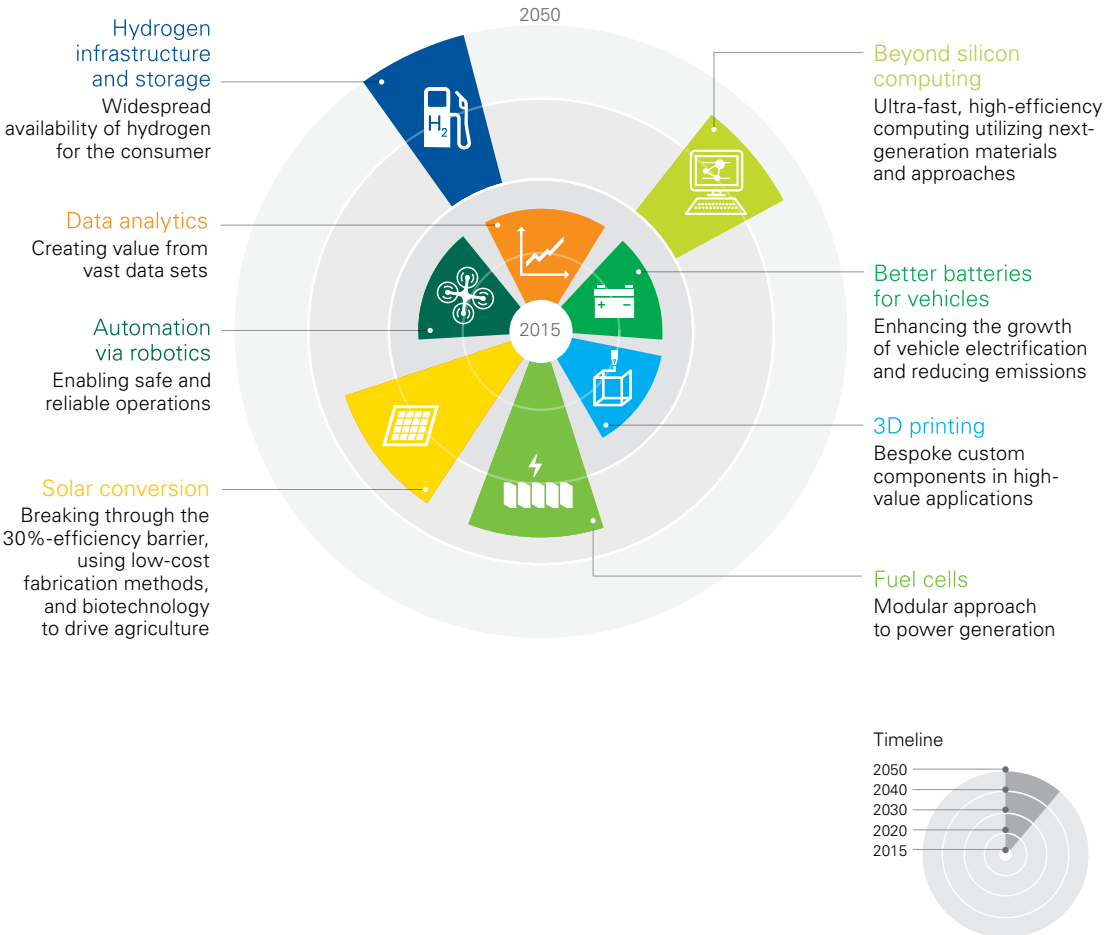
A range of emerging technologies could transform the energy landscape

Major energy technology advances have been rare, but when they have occurred they have driven transformation and disrupted markets and business models. The clearest recent example in the oil and gas sector is the development of directional drilling and hydraulic fracturing technologies for producing shale gas and oil. The pace of innovation and therefore potential for such breakthroughs is increasing, facilitated by businesses, universities, governments, specialist research centres and consultancies combining their capabilities.

The nature of certain technologies in areas such as digital systems, bioscience and nanoscience confers on them great disruptive potential. In the shorter term, **digital technologies – such as data analytics and automation enabled by supercomputing – have the greatest potential to drive far-reaching change,** offering multiple opportunities to make energy supply and consumption safer, more reliable, and more cost-effective. It is perhaps difficult for us to imagine their potential in the longer term, when, for example, some expect machines to overtake humans in intelligence.

Developments in advanced materials could lead to extraordinary improvements in the performance of batteries, solar conversion and the use of hydrogen as a fuel. However, these developments could still take decades to be applied globally due to the huge amounts of capital required.

Time range from technology commercialization to significant impact



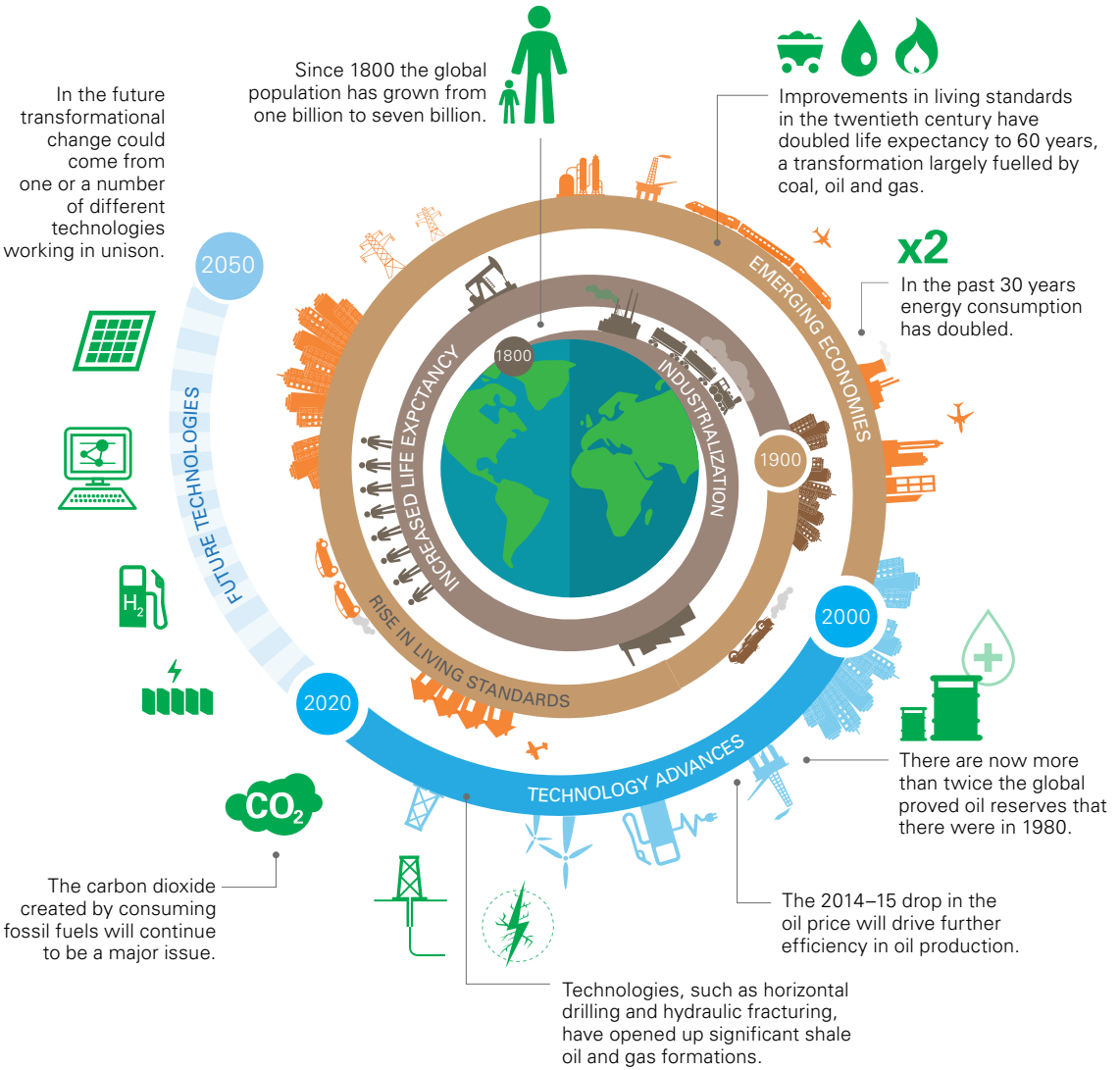
Source BP.

The age of energy technology

The *BP Technology Outlook* shows that primary energy resources are plentiful and fears about oil and gas running out before 2050 have all but disappeared. The major concern relating to energy is the impact of those greenhouse gas emissions that are caused by the use of fossil fuels and, to a considerably lesser extent, their production. Policymakers are seeking to find ways to limit and ultimately reduce emissions from all sources, even as total energy consumption continues to rise. Technology becomes increasingly critical as it offers ways to address this dilemma.

Our analysis confirms that putting an effective, meaningful price on carbon globally could accelerate the development of technologies and drive a decisive shift towards lower-carbon energy. The combination of policy-making by governments and innovation from business, working with partners in academia and elsewhere, has the potential to release the power of technology to deliver a future in which the supply, conversion and use of energy is affordable, sustainable and secure.

The energy journey



Source BP.

More information

BP Energy Outlook 2035
Projections for world energy markets, considering the potential evolution of the global economy, population, policy and technology. Published annually. *bp.com/energyoutlook*

BP Statistical Review of World Energy
An objective review of key global energy trends. Published annually. *bp.com/statisticalreview*

Energy Sustainability Challenge
BP-funded multidisciplinary research programme involving 15 leading universities worldwide examining the relationships between natural resources and the supply and use of energy. Key findings have been published in a suite of handbooks on biomass, water and materials available at *bp.com/energysustainabilitychallenge*

Information about technology at BP can be found at
bp.com/technology

Disclaimer
This document contains forward-looking statements, particularly those regarding technology development, global economic growth, population growth, energy consumption, policy support for renewable energies and sources of energy supply. Forward-looking statements involve risks and uncertainties because they relate to events, and depend on circumstances that will or may occur in the future. Actual outcomes may differ depending on a variety of factors, including product supply, demand and pricing, political stability, general economic conditions, legal and regulatory developments, availability of new technologies, natural disasters and adverse weather conditions, wars and acts of terrorism or sabotage and other factors discussed elsewhere in this document.

Paper
This publication is printed on Mohawk PC 100 made from 100% FSC® recycled certified fibre sourced from de-inked post-consumer waste. The printer and the manufacturing mill are both credited with ISO14001 Environmental Management Systems Standard and both are FSC® certified.

Design
thebigwindow.co.uk

BP p.l.c. 1 St James's Square
London SW1Y 4PD
bp.com