BP Technology Outlook 2018

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Thank you Lamar and welcome everyone. Thank you for coming along to this event.

BP's Technology Outlook summarises our analysis of technology trends carried out since the previous publication in 2015.

The previous version still receives over 500 downloads a month - despite being three years old!

We are providing you all with copies of the new, updated publication today.

Many things can impact the world of energy - including natural resources, national policies, and consumer or societal preferences.

In the Technology Outlook we try to adopt a strictly techno-economic perspective.

You will have heard it said that the optimist views the glass as half full, whereas the pessimist views the glass as half empty. We approach the Technology Outlook as engineers, who would probably view the glass as twice the size it needs to be.

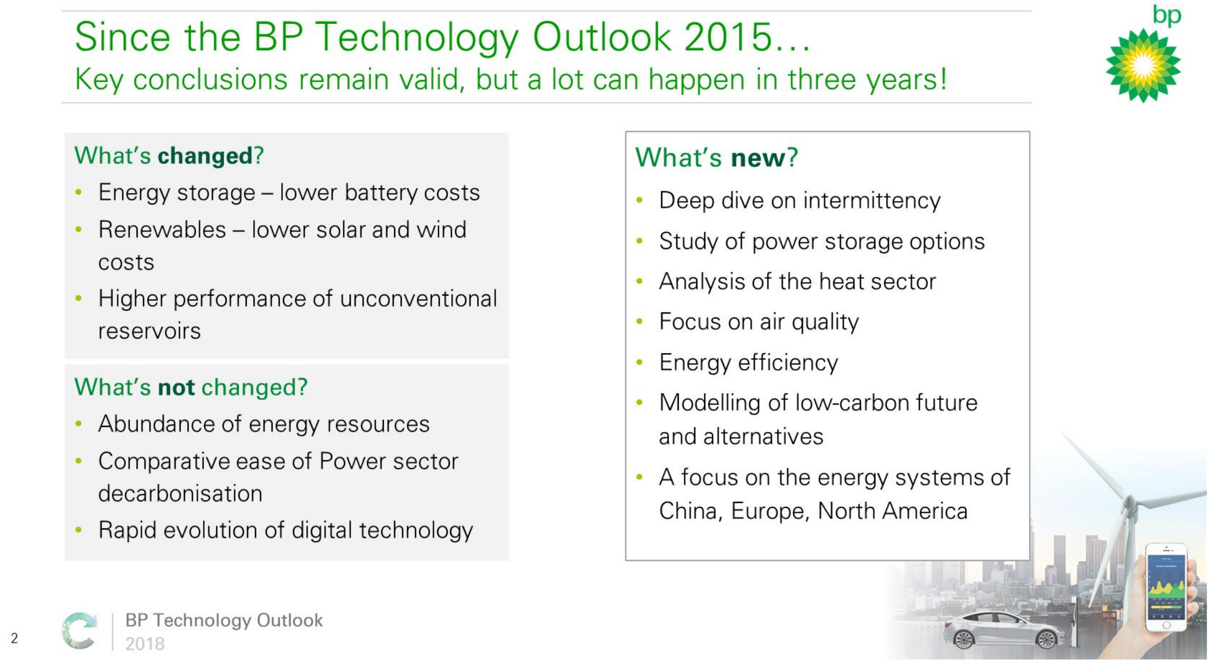
This work seeks to isolate some of major longer-term technology signals from other drivers, through to 2050.

In particular, that means we examine potential advances in technology and their impacts on costs without trying to second guess or model the potential impacts of policy - or indeed consumer choices.

That said, we do overlay a carbon price on our analysis, as a proxy for measures taken to deliver on the Paris Agreement, and to understand how merit orders could change if policy-makers act accordingly.

These are therefore not forecasts, they are technology signals, and comparison with the previous publication shows clearly that technology development is impossible to predict with any certainty!

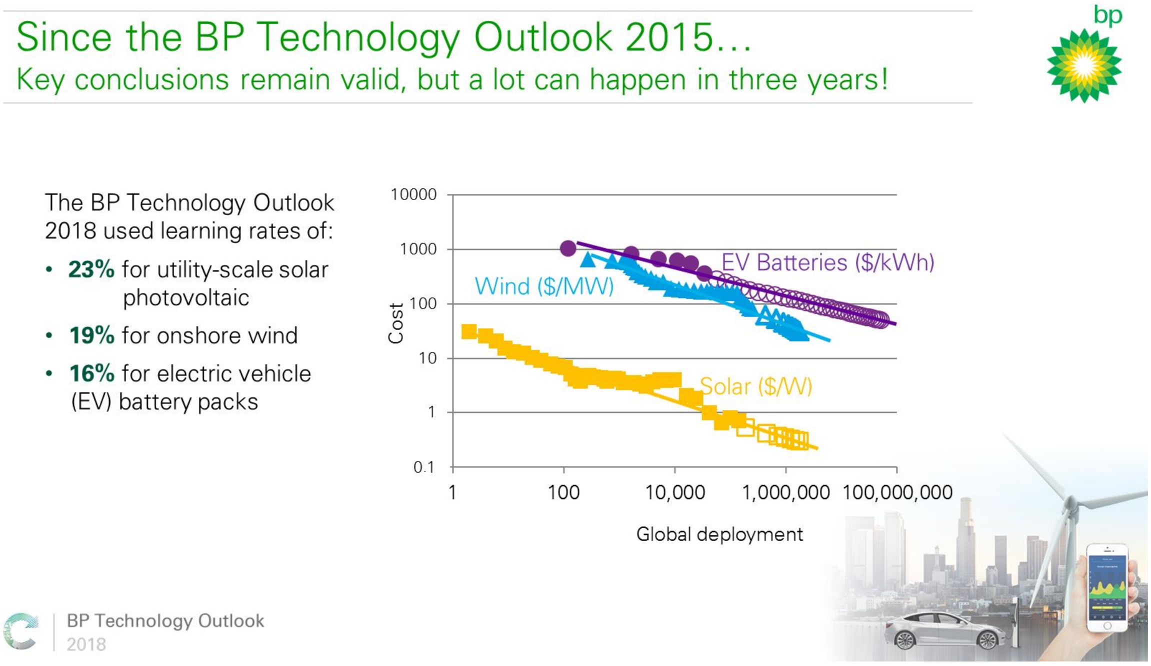
In carrying out our work, we have worked with many partners including, IHS Markit, Imperial College, Marakon, Ricardo, the Foreseer Group at Cambridge University and Kanors-EMR. Some of these partners are represented here today, and we are very grateful to all of them for the knowledge and expertise they have shared with us. You will also see some guest editorials in the publication, reflecting third-party views. Our thanks to all of these contributors.



This updated Technology Outlook builds on the previous body of work, updating some of the analysis and adding new modules - on intermittency, power storage, heat, air quality, energy efficiency, and energy system modelling, with a focus on China, Europe and North America.

The analysis shows that three years is a long time in energy and while some things move as expected, others do not.

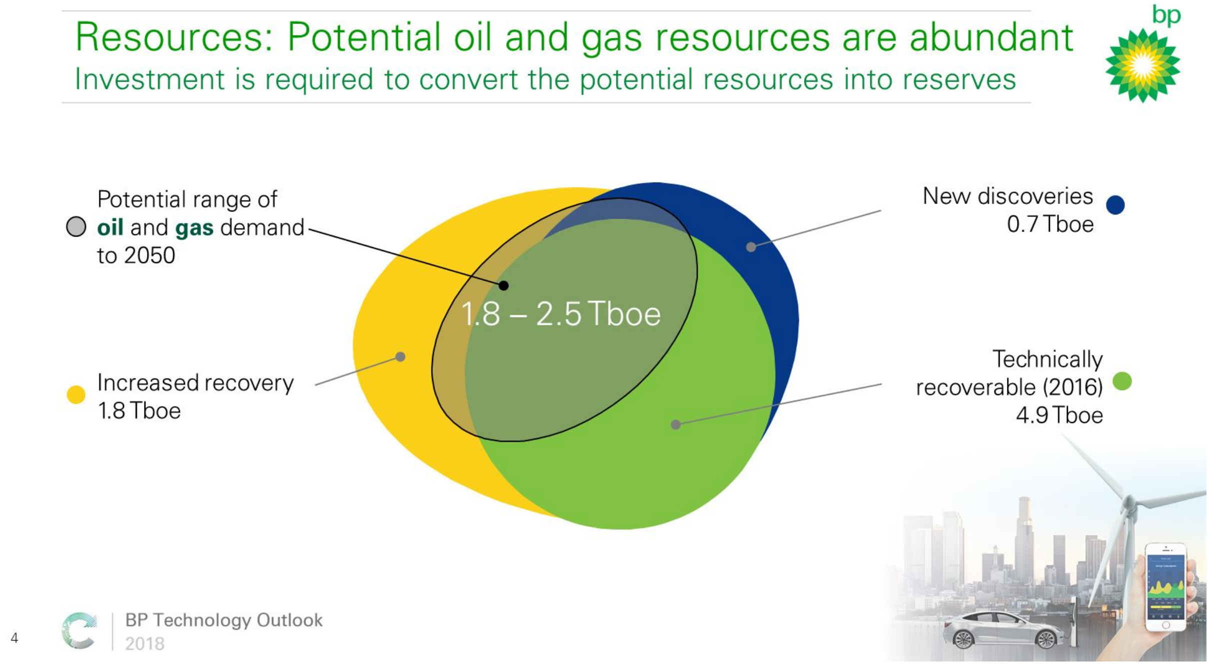
We have seen even more rapid declines in battery, solar and wind costs than we expected - as well as higher performance from unconventional reservoirs. However, several key messages still stand - related to resource abundance, the comparative ease with which the power sector can be decarbonised, compared to transport or heat, and the potency of digital technologies - but it seems a lot can happen in just three years!



As expected, unit costs of small, ‘modular’ technologies benefit from ‘do-learn-do’ manufacturing practices. But, we have seen even more rapid declines in solar, wind and battery costs than expected - we are assuming 23%, 19% and 16% respectively per doubling of global capacity in this Outlook.

Will now go through the key findings from each module in sequence, covering:

- Resources
- Power
- Transport
- Heat
- Energy system modelling



The world has abundant technically recoverable resources - coal, oil, gas, uranium, solar, wind, biomass, geothermal, waves, tidal and hydro.

We have not updated our analyses of all known resources, because together they exceed potential demand by more than an order of magnitude.

We have however updated our analysis of technically recoverable oil and gas resources, with a small increase from 4.7 to 4.9 Tboe, shown in green. That 200 bn boe increase is attributable to unconventional shale and tight reservoirs globally.

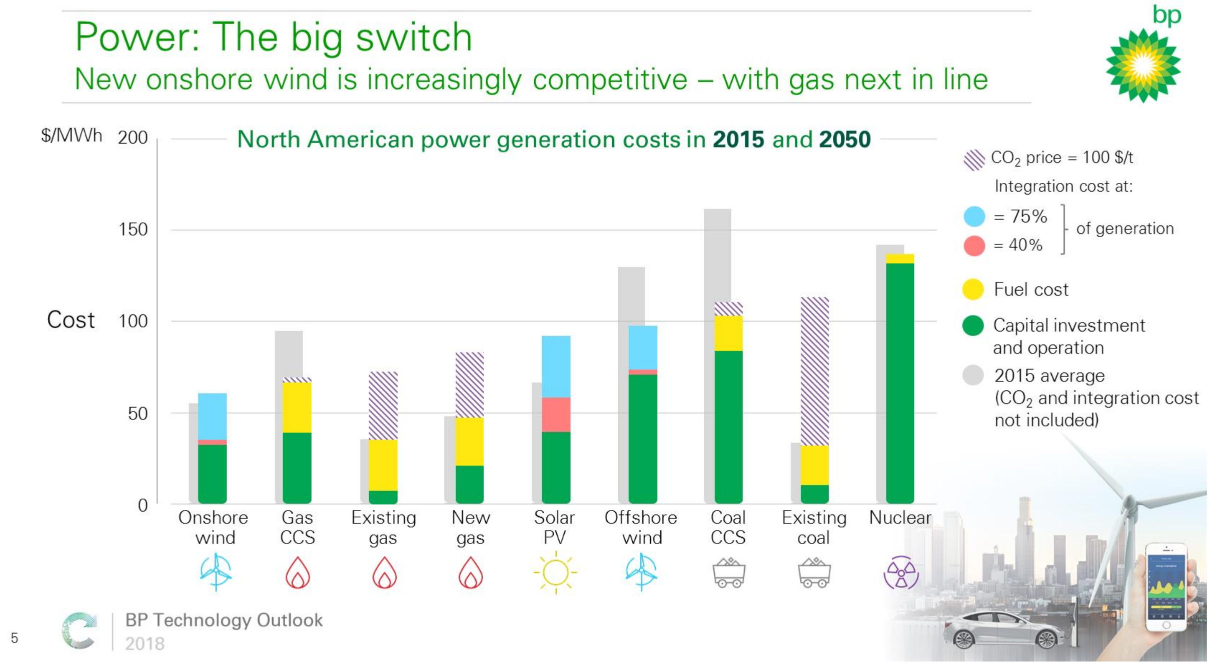
That's more than double the maximum expected potential demand to 2050, which is in the range 1.8 to 2.5 Tboe, overlaid in grey, depending on actions to reduce carbon, with the lower end of the range being consistent with a scenario to keep the global temperature rise to 2^{o} or below.

Furthermore a combination of better technology, particularly EOR and imaging, and new discoveries, could add a further 2.5 Tboe out to 2050, shown in yellow and blue respectively.

So, why look for more when we have more than enough? Simply because we may find more economical options with a lower environmental footprint - as in the Atlantis field in the Gulf of Mexico that Lamar mentioned.

In addition to increasing resources, new technologies could reduce the cost of production by on average around 30%, with better sensors and automation accounting for around one quarter of this reduction.

However, since oil and gas production from a reservoir declines naturally over its lifetime continual investment is required to meet this demand. Our analysis supports the International Energy Agency's estimate, in its New Policies scenario, that over the next two decades investment of around $600 billion per year on average industry-wide could still be needed to produce sufficient oil and gas to satisfy demand.



Taking each use sector in turn, power accounts for ca. 40% of global energy consumption.

This graph shows a comparison between the pre-tax average levelised costs of different sources of grid-scale power in North America - in 2015, and projected in 2050, shown left to right in terms of increasing 2050 costs as are all similar slides in this pack. We have assumed:

- cost of carbon - up to $100/t
- cost of managing intermittency - based on work by Imperial College - with renewables comprising up to 75% of all generation
- a gas price of $4/mmbtu Henry Hub and 7% cost of capital

- fugitive methane emissions associated with natural gas systems will be effectively managed to near zero by 2050.

- Note that hydropower has been excluded from the analysis because remaining accessible water resources are relatively limited, particularly in North America and Europe, and economics are determined by geography not technology.

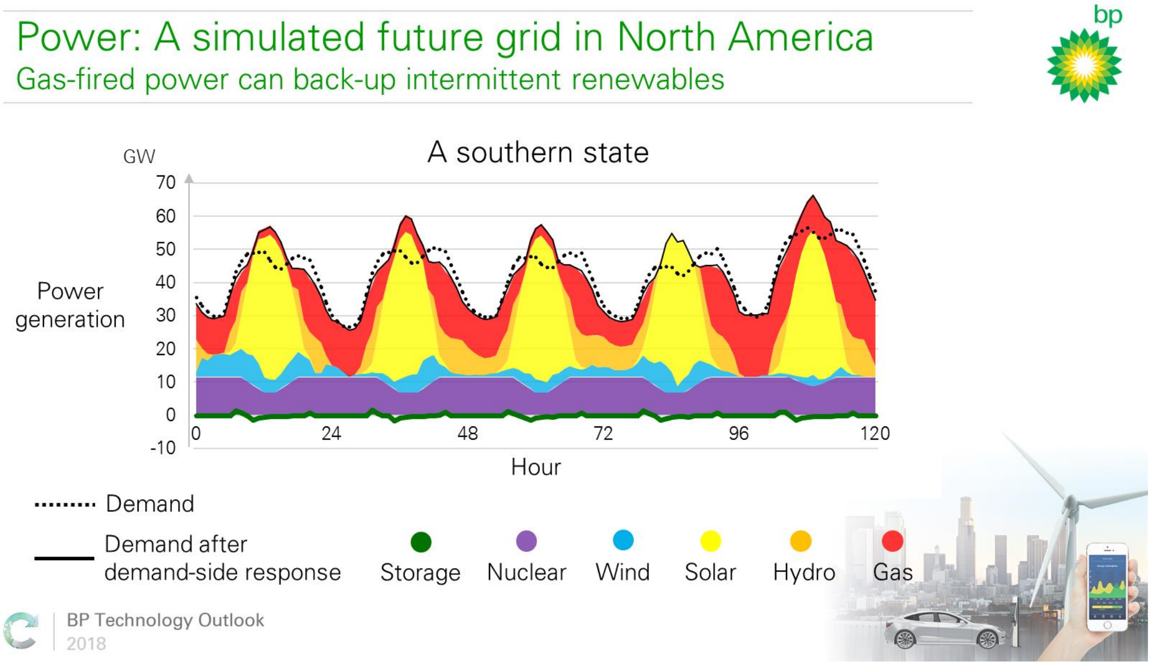
We conclude from this analysis that new onshore wind is increasingly the most economical source of new-build grid-scale power in North America, with natural gas the leading candidate to provide back-up when the wind is not blowing.

You might ask why we are projecting wind and solar costs in 2050 above those which have been achieved in recent bids? The simple answer is that these are averages - just as natural gas can be supplied at less than $4/mmbtu, so too the most advantaged wind and solar locations will be cheaper. And of course this analysis does not factor in any policy incentives

In the full publication we have included our range of projections for various cases, which highlights that uncertainties exist.

We expect gas to be decarbonised using carbon capture use and storage - or CCUS - if the effective price on carbon rises towards 100 $/t$CO_2$.

Doing so could also enable the creation of a low carbon gas system, including bio-gas, to store energy - as well as fuelling vehicles and industry. This concept is supported by the global, business-led, Hydrogen Council formed at the COP23 conference in Bonn last year, highlighting the many potential applications of hydrogen in energy, like natural gas but even cleaner.



The challenge in all power systems will be to balance increasingly intermittent supply with demand that also varies, perhaps even more so as transport is electrified.

Intermittency is a major feature of renewable energy, and it is misleading when commentators compare power sources simplistically on the basis of levelised cost of electricity, or LCOE, without taking account of the quality or availability of power. Intermittency costs need to be priced into comparative economics.

We worked with Imperial College, London to model various levels of renewable capacity in different regions with varying back-up options.

This chart shows how systems might look in a southern state of the US with renewables providing around 40% of power - more than twice today's level. In the South, solar is the main form of renewable generation, whereas wind might be in the North. The dotted line shows the natural demand as it rises and falls during a typical week. The solid black line shows actual demand once it is moderated by 'demand-side response' measures whereby industrial and business customers on special tariffs lower demand when called upon.

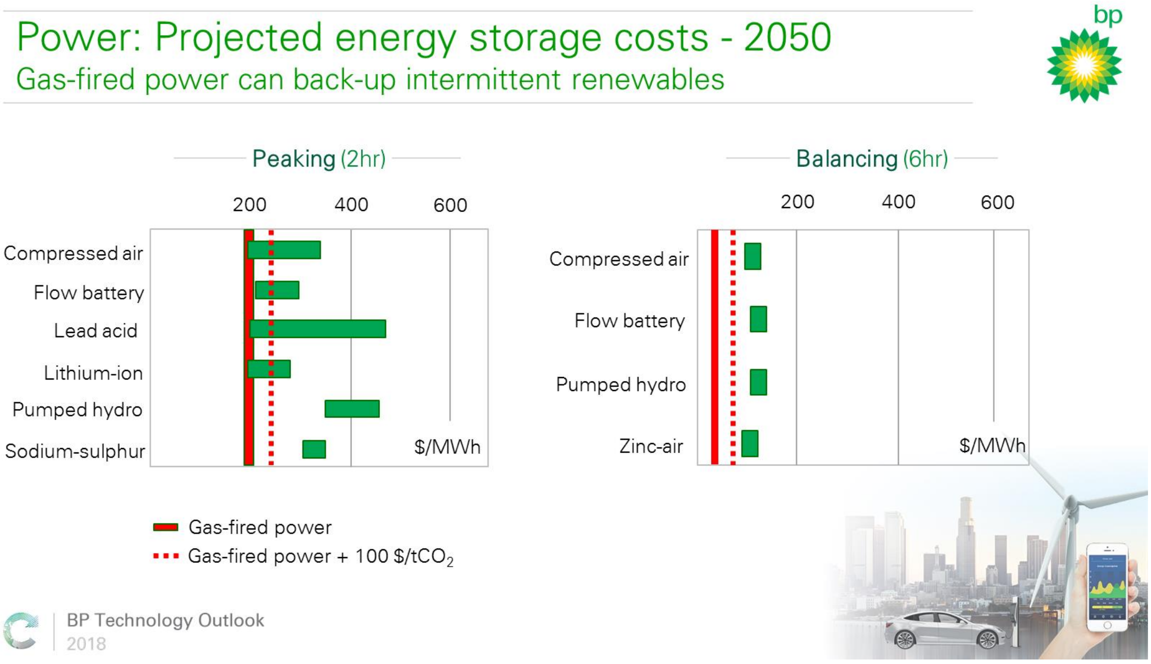
Looking at the major sources of power supply, we see nuclear energy providing a base level of supply, then on top of that the renewable component, with hydropower and gas being used to make up the remaining demand. Hydro and gas are better than nuclear at this role as they can be flexed up and down rapidly, including pumped hydro whereby water is pumped into dams until needed. At the foot of the chart you see a green line indicating power storage, typically in batteries or compressed air. Where the line falls below zero the batteries are charging up and when it rises above the line they are contributing to the mix.

Low levels of renewable power penetration (say 10%) are manageable, as we see today, but above around 40% the cost escalates significantly, because total power availability can both exceed maximum demand and at other times fall short.

From our study with Imperial college, London we found that for a power system in North America, with a 40% contribution from renewables, dominated by solar, integration costs would be around 20 $/MWh for each additional MWh of power generated. However, if wind were the predominant source, the integration costs would fall to around 5 $/MWh.

Very high levels of Solar PV are even more difficult and costly to accommodate than wind power - because wind blows variably through the day and night, but the sun declines as power demand peaks in the early evening.

The power system will also see transformation through digitization. More servers and vehicle charging will add demand while smart grids, smart buildings and optimization software could reduce it. Our current estimate is that the net outcome could be a double-digit net saving. But there are many variables and much uncertainty.



There are many forms of power system services - such as frequency, operational reserve, inertia, peaking and balancing services

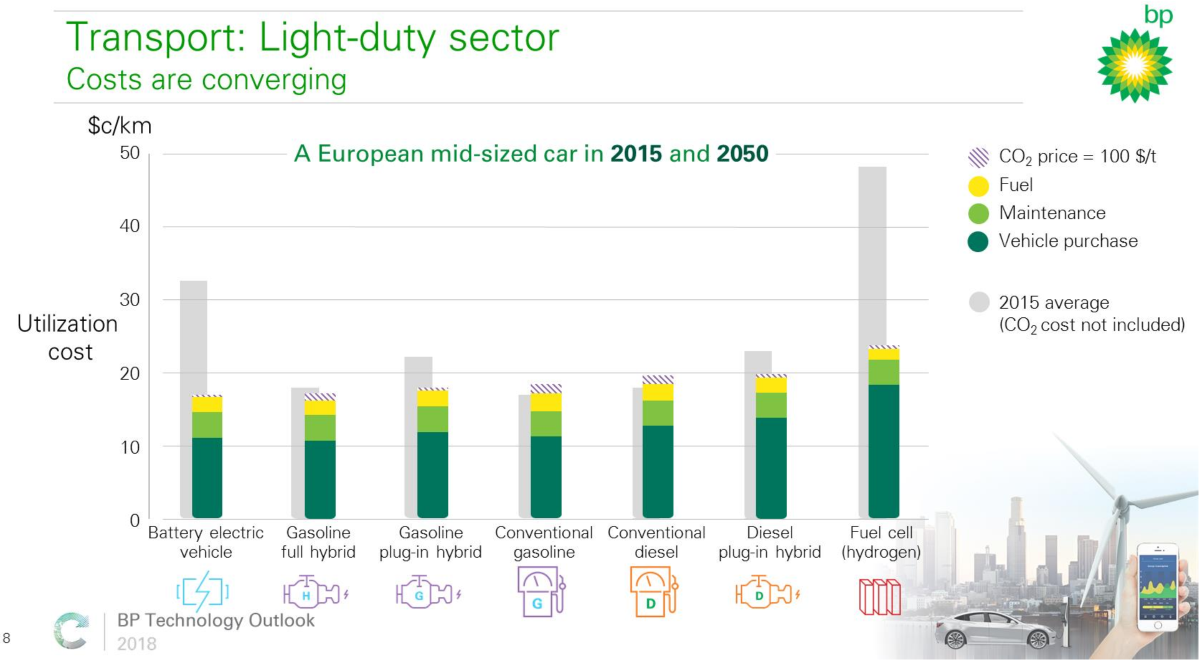
Options for back-up power for renewables include other forms of generation such as hydro, gas or coal, compressed air storage and batteries. Batteries are evolving rapidly, with traditional lead acid batteries now competing with lithium-ion, metal-air and flow alternatives.

The costs of storing energy in batteries are directly proportional to the amount of time for which it is stored. And those costs can become prohibitively expensive as the storage duration increases.

The charts here show projected costs of storage and back-up options either to meet peaks when extra power is needed for around two hours; or to balance demand and supply over longer periods.

We can see that, without a carbon price, gas provides a cost-effective option, with batteries becoming cheaper than pumped hydro by 2050.

However, with a price on carbon, the gas bar would move to the right - putting it in the mix for peaking while remaining a winner for longer-term balancing.



Turning to transport - accounts for about 20% of global energy and 60% of oil demand today.

This slide addresses light duty transport, around 1/3[rd] of liquid fuel use today. It shows life of vehicle pre-tax cost per km travelled for a range of mid-sized vehicles. It assumes:-

- 320 kilometre range (65 kWh battery)
- 20 thousand km travelled pa, and a 10 year asset life - note that increasing this assumption advantages BEVs over ICEs
- oil price of 75 $/bbl
- Zero incremental infrastructure (grid and charging) costs

Note the dominance of upfront vehicle purchase costs. As the costs of batteries fall, ($50/kWh assumed in 2050) light duty BEVs can be increasingly competitive with their ICE counterpart.

From this analysis we conclude that light duty transport costs are converging, providing increasing consumer choice - the lighter the vehicle the easier it is to electrify, with factors other than cost likely to shape choices, for example policy (excluded in this techno-economic analysis) and, of course, consumer preference.

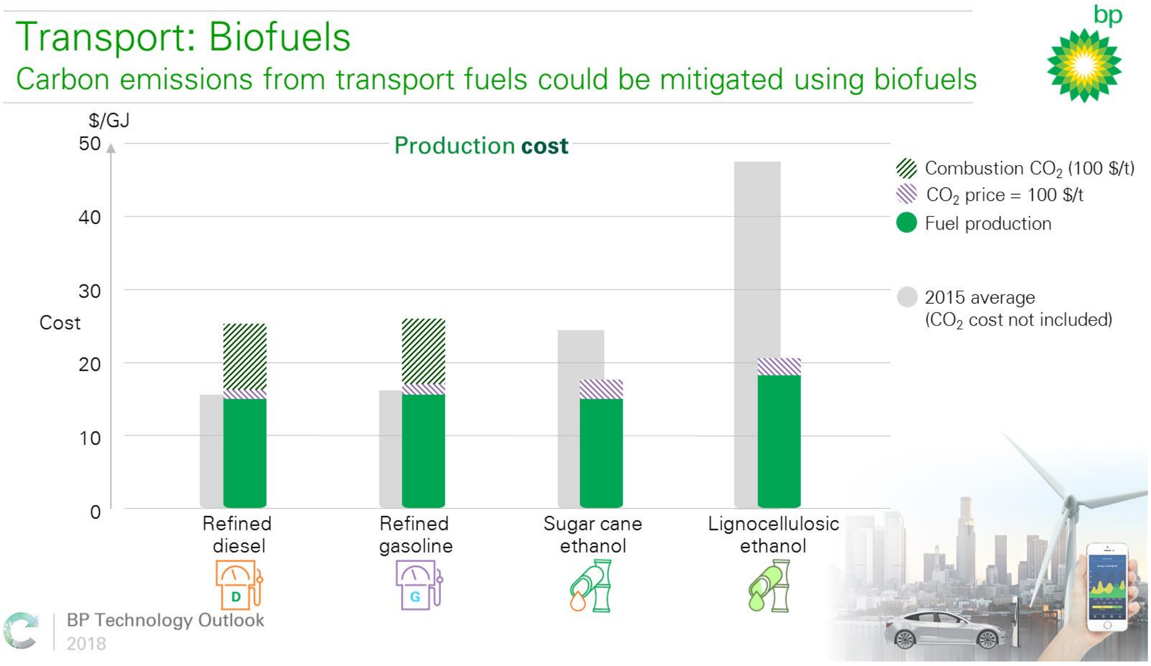
Other key uncertainties could also influence the trajectory of light duty transport:-

Light-weighting vehicles is the largest potential source of energy efficiency globally.

The coming decades will also see our roads transformed by digital technology.

- By 2050 our current projections are that self-driving vehicles will account for half of all vehicle kilometres travelled, while shared cars account for around a quarter.
- The combination effect of autonomy and ride-sharing is likely to change habits, potentially even facilitating increased usage over mass transit
- Access to charging could be a major issue for car-owners, without home-garaging

We examined the provenance of air pollution in three cities - Los Angeles, London and Beijing - with partners in the University of Cambridge. This served to show the complexity of the issue and the need for a range of solutions. In London, for example, one-third of the small particulates that cause most concern, those of 2.5 microns or less, come from within the city, many from vehicle exhausts, showing that electrification of transport can help – although around one-third of these emissions actually come from brakes and tyres rather than exhausts. More important, 2/3rd of those particulates come from outside the city, and a variety of sources. In Beijing pollution comes largely from regions several hundred kilometres away - from industry, power and farms more than transport.



Liquid transport fuels need not suffer from a heavy carbon ‘penalty’.

Their carbon footprint can increasingly be mitigated cost-effectively through a combination of advanced fuels, low carbon manufacturing, biofuels, ride-sharing and even offsetting. These can all help reduce the cumulative carbon emissions from what is today the overwhelming majority of energy transport system.

This chart shows how the costs of biofuels are set to fall as technology advances. Without carbon pricing, gasoline and diesel derived from crude oil look set to remain the most economical in 2050. However with a carbon price of $100 applied to production and combustion emissions, sugarcane and over time ligno-cellulosic ethanol could be attractive.

There are also a number of biological alternatives to diesel fuel, or bio-distillates including those manufactured from vegetable oils and animal fats, whose scale is limited today.

Note that the EU levies around €250bn pa on transport fuels - with electrification increasing, where will these tax revenues be sourced in future?

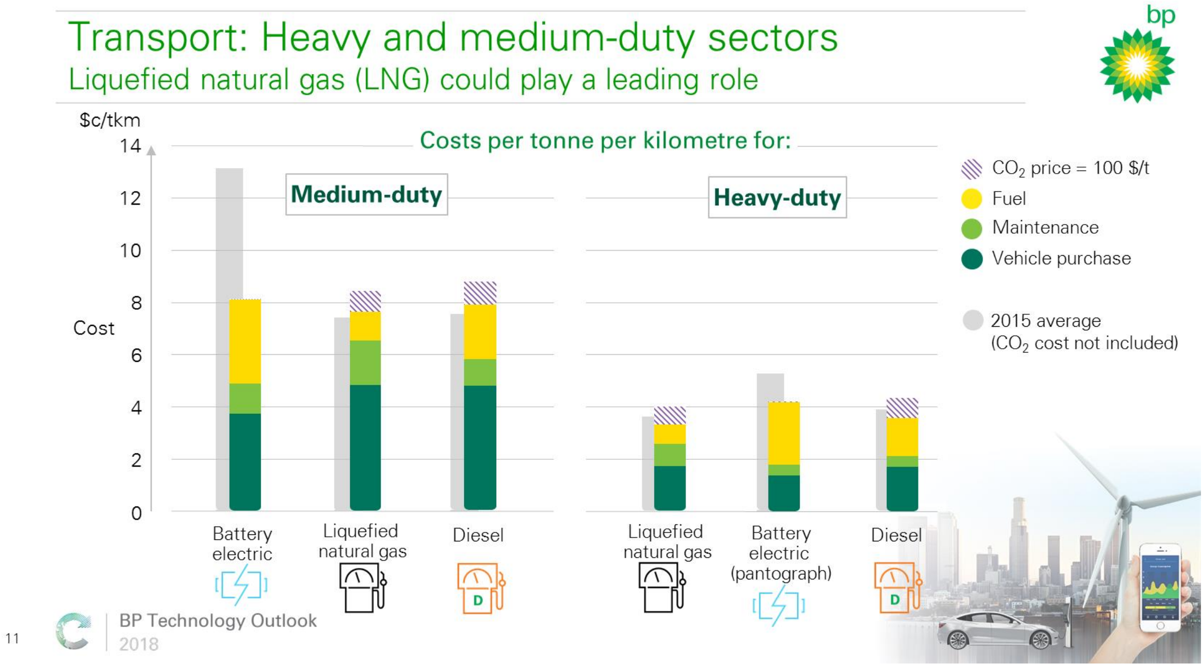
Decarbonising the remaining transport sectors is more challenging.

If the objective is to move people and goods with the lowest costs and carbon footprint, then mass transit must be part of the solution.

Electric engines are more efficient and will be used increasingly in nearly all forms of transport. But the question remains how do you carry your energy around with you?

Railways can be comparatively easily electrified.

Aviation is arguably the most difficult sector in which to achieve deep de-carbonisation. However, the air industry has committed to cap its emissions at 2020 levels and reduce them by 50% by 2050. Drop-in biofuels could be the best solution to achieve those, goals.

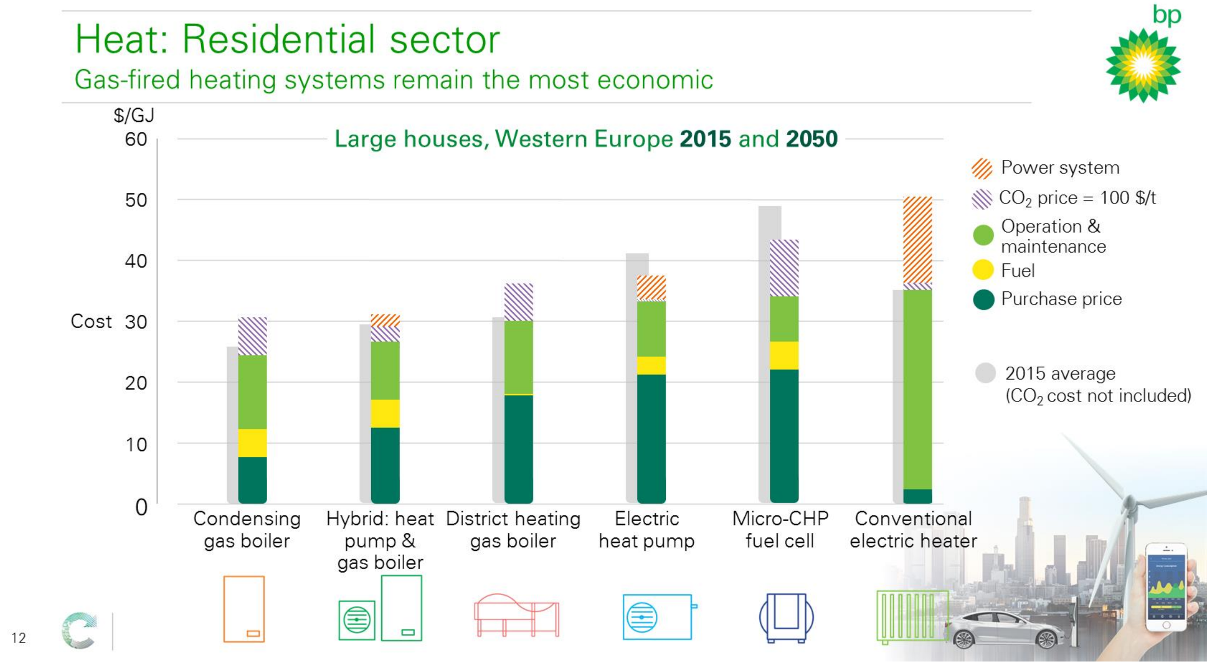


With medium and heavy duty trucks, we can see a similar pattern to cars. Costs of different options are set to converge.

Smaller, medium-duty trucks could also become battery-driven as the overall utilization costs involved are similar to those of LNG and diesel.

But for heavier duty trucks and ships, natural gas and improved energy efficiency would appear to be more effective levers to reduce carbon emissions.

That said, the use of freight vehicles using pantographs like trams, in conjunction with batteries, is not inconceivable as their costs are not that far away from those of diesel and LNG.



Heating and cooling in industrial and residential settings account for most of the remaining global energy demand. In the EU for example, heating and cooling account for around half of energy demand.

It is much easier to design new homes, cities and industrial complexes to be carbon efficient, than it is to retrofit new technologies into old structures. For example, heat and thermal power should be combined where practicable to increase efficiency - heat networks offer opportunities in this respect.

Unlike the power and transport sectors, our analysis suggests less convergence between established and emerging technologies in residential heating.

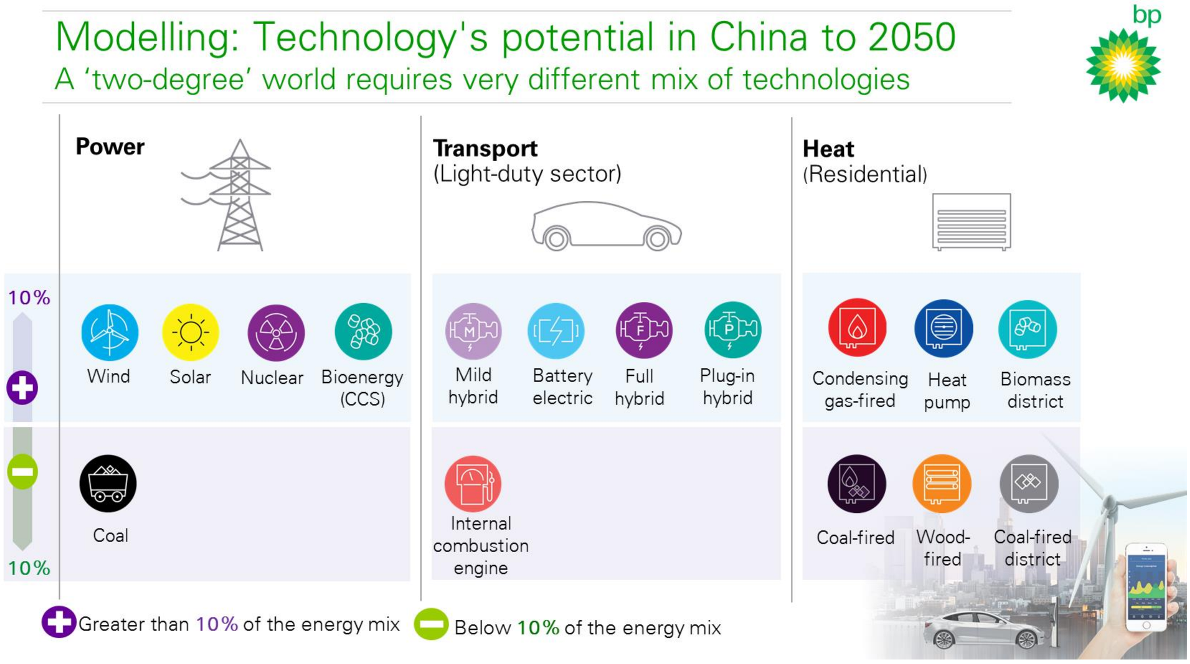
Natural gas boilers and furnaces are cheap. In a world where carbon is priced at or over $100/te, heat pumps and hybrid systems become competitive.

However it may be more cost effective to decarbonise natural gas systems, including the use of biogas, than to replace natural gas appliances - especially in high temperature heat applications.

With regards to the carbon footprint of the rest of industry it is worth noting that:-

- Purer sources of carbon dioxide emitted from industry, such as in metal processing, can be captured and stored (or used) at comparatively low cost, ie a few tens of $/te.

- The carbon footprint of cement manufacture, at around 5% of the total today, can be reduced by up to 70% using technologies which have been proven today.



That concludes the sectoral analysis. However, we felt our work would be incomplete without asking some obvious environmental questions. How far do technology advances take us along the road towards a lower-carbon future? How different would the future look in a 'two-degree world'? And how would that play out regionally?

So we used a widely employed energy system model known as TIAM World, to project the broad shape of the energy mix in 2050 with and without carbon constraints.

The modelling indicated that in an unconstrained future, technological progress could limit the rise in emissions to 15% across China, Europe and North America, a lot less than the 70% seen in the last 35 years but a lot more than the 70% fall needed for a two-degree world;

Or, put another way, that technology developments alone appear insufficient to meet the dual challenge of increasing demand for energy while reducing emissions of greenhouse gases.

A two-degree world would be very different. This chart shows what could happen in China. It highlights technologies rising above or dropping below a 10% threshold in each sector.

So for example, we saw:-

- Nuclear and all 4 renewables achieving 10% shares in the power sector, with nuclear largest

- Electric and hybrid vehicles achieving the highest share in the light duty fleet

- District heating and electric heat pumps widely used alongside gas-fired appliances;

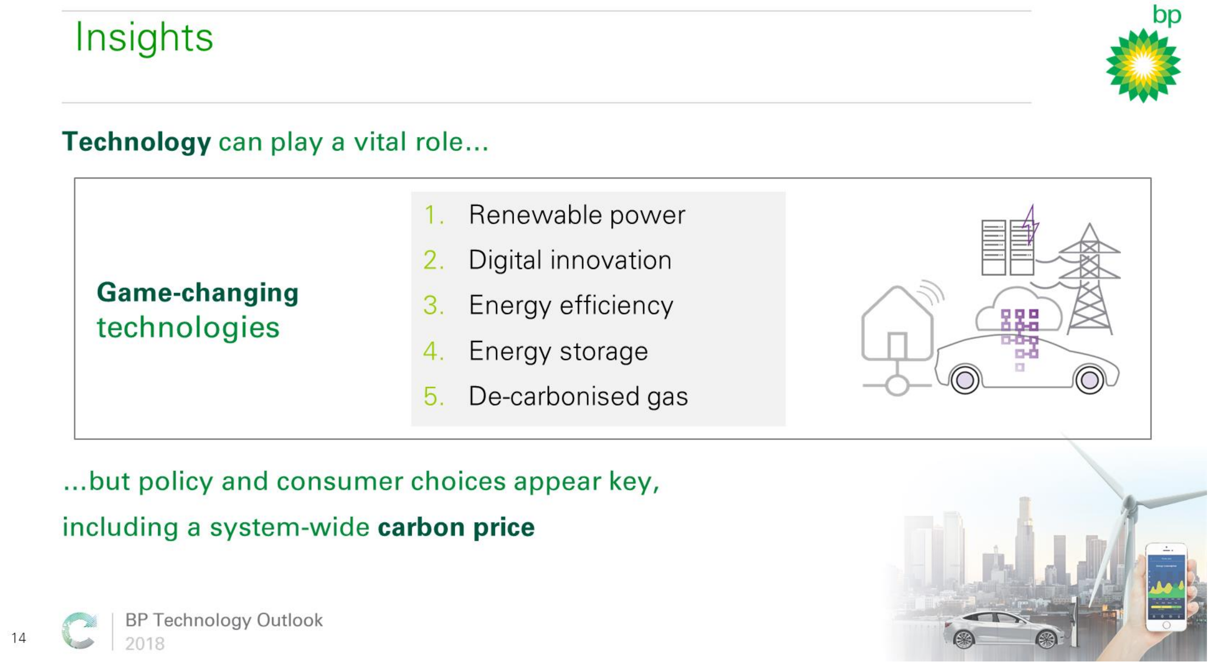
It is interesting to note that the currently-dominant forms today all drop to below 10%: Coal-fired power falling from 70% today; internal combustion engines - from 99%; and coal-fired district heating and wood boilers from 50 and 34% respectively.

Europe and North America had some similar patterns, but with:

- More renewables and less nuclear and hydro in the power sector - including bioenergy with CCUS (or BECCS), creating a carbon-negative grid;

- More gas coupled with CCUS, especially in the North America

This techno-economic modelling assumed a certain level of increased energy efficiency across all technologies, resulting from better technology, increased know-how, economies of scale and other factors. However the Outlook also includes a contribution by the Foreseer Group and Resource Efficiency Collective at Cambridge University that looks at the scope for game-changing energy savings - of 50% or more in some cases - in areas from passenger transport and space heating to cooking - if they can be made affordable - which is a big if in many cases.



In publishing our second edition of the BP Technology Outlook we considered the potential impact of advances in technology throughout the global energy system to 2050.

The Outlook shows that technology can play a major role in resolving the dual challenge of meeting increasing demand for energy, while reducing greenhouse gas emissions.

But technology alone is not the answer. New policy measures will be required to achieve a lower-carbon future, critically wider carbon pricing - measures that will encourage consumers to make more sustainable choices.

The Outlook explores five areas where BP believes technology can play a game-changing role - and can be accelerated by policy: renewable power; digital innovation; energy efficiency; energy storage; and decarbonized gas.

Renewable Power

Oil and gas are cost competitive, and hence a major component of the world's energy systems today, but alternatives could catch-up by 2050, in at least some sectors. Renewable power is already growing fast and our analysis suggests that that costs will continue fall to 2050.

However, our work with Imperial College, London, has shown how intermittency costs rise as more renewables are deployed. The intermittency of wind and solar can create significant back-up costs when deployed at scale.

When looking for the most economical ways to manage that intermittency, gas provides a viable high quality, flexible back-up power generation source.

Digital innovation

Digital technologies are expected to have profound impact on the way energy is used and how its managed.

Digital technology, including sensors, big data and artificial intelligence, is the most significant source of system-wide efficiency improvement.

From smart grids and demand management in power systems to self-driving vehicles that lower fuel consumption, digital technology enables the entire energy system

Energy Efficiency

Game-changing energy savings could be achieved - of 50% or more in some cases - in areas from passenger transport and space heating to cooking - if they can be made affordable.

Energy Storage

Energy storage options are developing rapidly - particularly advanced batteries. These advances can help address shorter term intermittency issues but struggle to be economic long-term.

However, developments in batteries are particularly significant for the transport sector. Conventional cars, hybrids and electric vehicles are projected to converge in costs by 2050. And that means that factors other than cost could determine the shape of the vehicle parc - for example policy and consumer preference. But less so heavier duty applications, where energy density really matters. Aviation is perhaps the most extreme example, where bio-jet could be the only viable solution to reduce emissions.

Decarbonized Gas

The power sector offers greater scope for least-cost emissions reduction than transport or heat. And carbon capture, use and storage (CCUS) is critical in that process of reducing emissions at the least cost.

However it isn't competitive or commercial today so there is an argument to apply transitional incentives to CCUS so it can be deployed at scale once the right carbon price is reached.

Liquefied natural gas is projected to become a competitive fuel for trucks and some ships.

Heating looks set continue to be primarily provided by gas-fried appliances although carbon pricing could favour hybrid appliances using heat pumps and gas.

All in all, technology promises to help us create a very different and very exciting future, and of course one that BP intends to be part of.

Let me hand back to Lamar to briefly expand on that point.