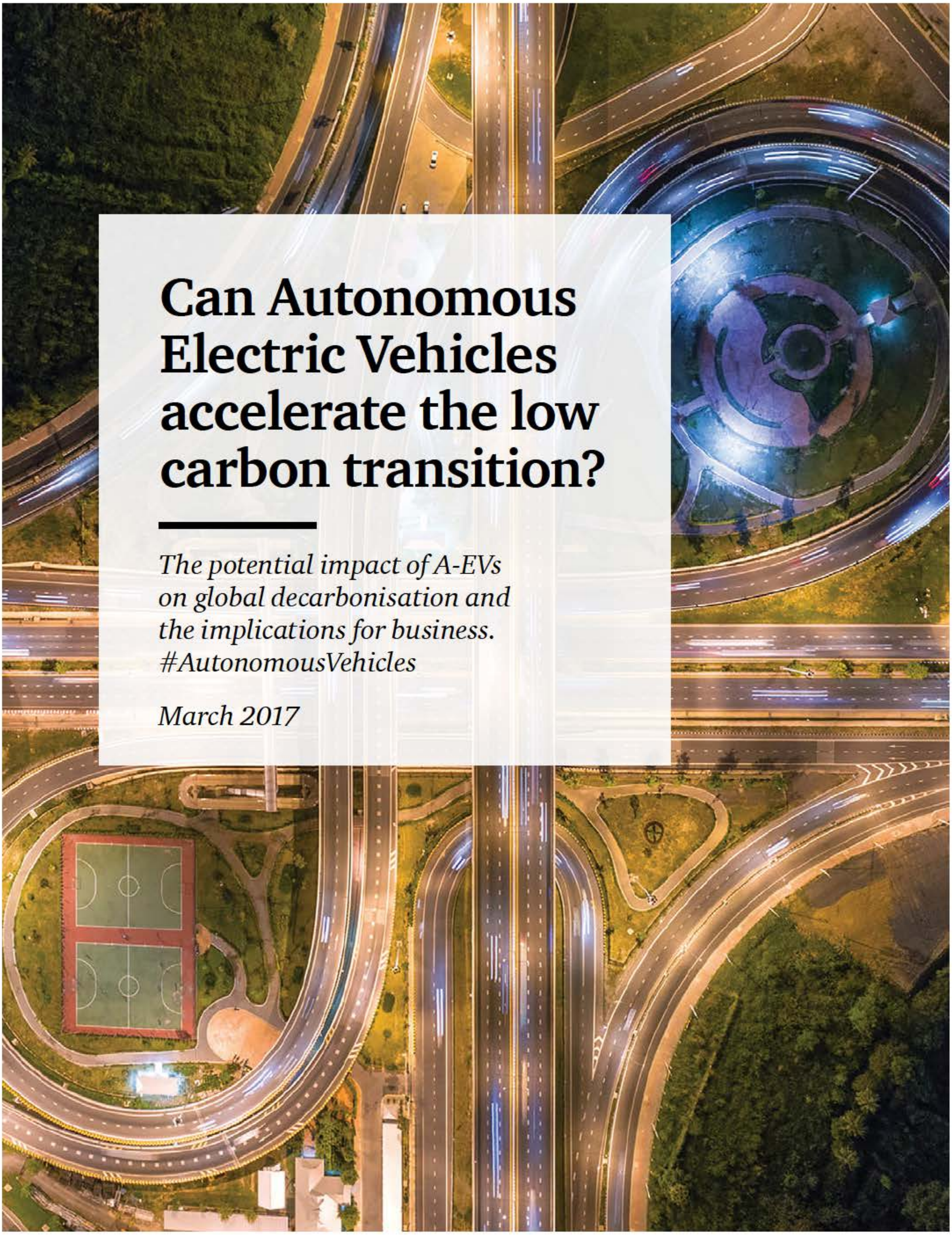

Can Autonomous Electric Vehicles accelerate the low carbon transition?

The potential impact of A-EVs on global decarbonisation and the implications for business.
#AutonomousVehicles

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Can Autonomous Electric Vehicles accelerate the low carbon transition?

1. Projections for Autonomous-Electric Vehicles (A-EV) deployment vary significantly, leading to uncertainty about their potential global decarbonisation impact.

2. In some projections, A-EVs alone could bridge around **1/3** of the gap between current decarbonisation rates and the rate needed to limit warming to 2 degrees, significantly disrupting oil and electricity demand.

3. Business can prepare for this disruption by better understanding the potential drivers that could inform A-EV deployment (e.g. low-carbon policy, cost, R&D, behaviours).

Introduction

20th century science fiction envisioned people piloting their own flying cars, with roads and traffic jams a thing of the past. Technological advances are now suggesting, however, that it is drivers who may be more likely to be surplus to requirements.

Autonomous Electric Vehicles (A-EVs) use AI, next generation batteries and other ***Fourth Industrial Revolution (4IR)***[1] technologies to transport passengers more efficiently, without the need to drive or fossil-fuel-driven internal combustion engines (ICEs). A-EVs could potentially operate as personal taxis, picking owners up and dropping them off on demand. This could ultimately lead to better traffic management, routing and reduced need for vehicle ownership.[2]

A-EVs may be able to accelerate much-needed greenhouse gas emissions reductions in the transport sector, given the advantages of cleaner and quicker transport. Our ***Low Carbon Economy Index 2017*** highlights the considerable gap between current decarbonisation efforts and the Paris Agreement's goal to limit warming to 2 degrees Celsius. This 'transition gap' emphasises the need for immediate action, and indicates a number of risks and opportunities for business. These include market, technology and policy disruptions that could bridge the gap to 2 degrees but present substantial risks to a number of sectors. A-EV technology is an example of such a disruption.

So just how great an impact could A-EVs have? And how certain can business feel about the future of this technology? We've analysed a range of industry projections to model the impact of A-EVs and answer these questions.

1 See our Innovation for the Earth report – http://dpe-preview.pwc.com/content/pwc/uk/en/services/sustainability-climate-change/insights/innovation-for-earth/harnessing-technological-breakthroughs.html
2 See annex 1 for more details on autonomous vehicle technology.

Projecting Autonomous-Electric Vehicle deployment

A range of organisations have made projections about how EVs, A-EVs and road transport more broadly may fare over the coming years. The projections tell different stories, driven by the underlying assumptions behind these 'scenarios'.

We have focused on the following scenarios:

- **RethinkX (2017)** 'Rethinking Transportation 2020-2030' scenario.[3]
- **BP (2017)** 'Electric revolution mobility scenario'.[4]
- **WoodMackenzie (2017)** 'Carbon constrained scenario'.[5]
- **Bloomberg New Energy Finance (2017)** 'Electric Vehicle Outlook scenario.[6]

For comparison, we considered two additional scenarios. These project potential reductions in oil demand from road transport as a result of more stringent policy measures:

- **BP (2018)** 'ICE Ban Scenario'[7]
- **The International Energy Agency (2017)** 'Sustainable Development' scenario.[8]

These projections vary in the extent to which they are exploratory (e.g. beginning from current industry trends and extrapolating forward based on these trends) vs normative (e.g. selecting a desired future outcome and working backwards to the present day). For instance, Wood Mackenzie's carbon constrained scenario is primarily normative in plotting a course to a possible future scenario based on climate policy goals. It describes this as 'extreme for the world to go through... but not impossible given current policy, investment and technology drivers'. In contrast, BP and BNEF examine what might be conceivable for A-EVs given current technology trends. RethinkX follows a similar exploratory approach, but anticipates more rapid uptake and more system change in the transport sector. This is based on comparisons with other historic 'S curve' examples of new technology uptake.

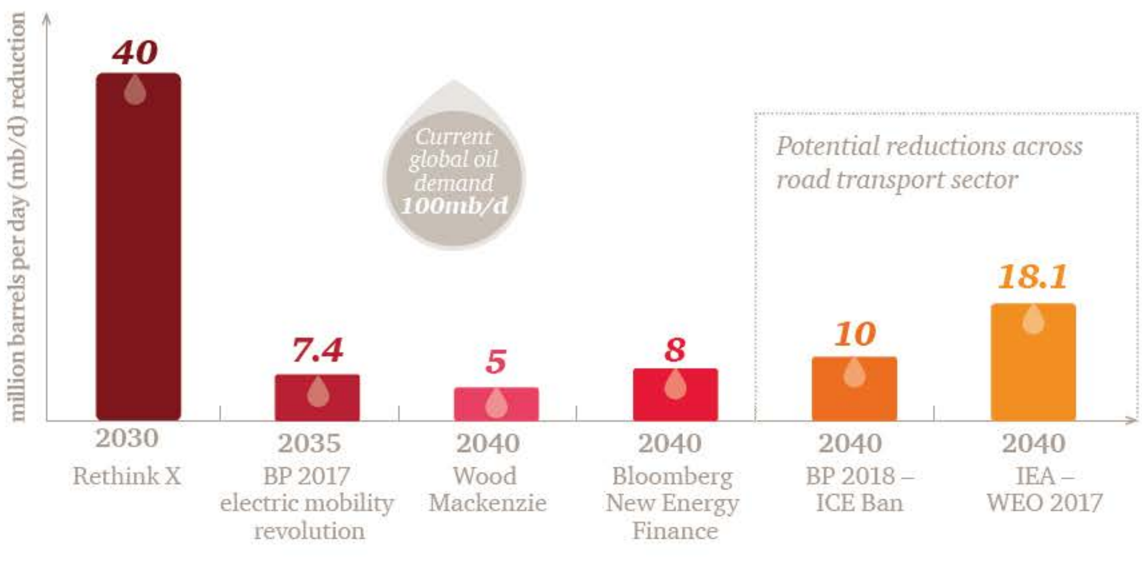
Despite contrasts in approach, all of the scenarios share the view that as the percentage of A-EVs in the vehicle fleet increases, this will catalyse a reduction in global oil demand relative to a 'Business-as-Usual' (BAU) scenario. While modest growth in electric vehicles (EVs) is expected under BAU, the scenarios each present a divergence from this trajectory *(see Table 1 for full details of each scenario)*.

Each of these scenarios explain this potential impact as a deviation from a forecasted oil demand in a future year *(see Figure 1)*. We have modelled the emissions reductions associated with the reduction in oil demand in each of the projections. This enables comparison of the impact of each of the scenarios against a global BAU decarbonisation pathway as shown in *Figure 2*, consistent with our Low Carbon Economy Index analysis.

Under a 2 degree scenario, A-EVs are expected to be one of a number of low-carbon technologies delivering significant emissions reductions. While power for the A-EVs can be supplied by multiple fuel sources, for the purposes of this analysis, we assume they are powered by 100% renewable energy. Furthermore, while many of these organisations provide multiple scenarios for the technology, we have focused on the most ambitious deployment scenario from each. This provides an upper-bound 'best case' estimation of their potential impact on global emissions reductions, while also considering anticipated growth in GDP.

3 RethinkX, May 2017. Rethinking Transportation 2020-2030. Authors: James Arbib and Tony Seba.
4 BP, 2017. Energy Outlook 2017 Edition, p.99.
5 Wood Mackenzie, November 2017. The rise of the electrical car: how it will impact oil, power and metals? p.10-18.
6 Bloomberg New Energy Finance, 2017. Electrical Vehicle Outlook 2017.
7 BP, 2018. Energy Outlook 2018 Edition, p.45.
8 International Energy Agency, 2017. World Energy Outlook 2017

Figure 1: Reduction in oil demand by scenario compared to base case (mb/d)



How great an impact could A-EVs have?

A-EV projections vary significantly, with implications for their impact upon decarbonisation efforts.

All the scenarios imply that A-EVs alone could have a noticeable impact upon global carbon intensity (see Figure 1). There is, however, a wide divergence of views on the scale of the likely impact. RethinkX's scenario implies that renewable energy-powered A-EVs could bridge around a third of the gap between the 2011-16 decarbonisation rate of 2.7% and the 6.3% annual reduction needed for 2 degrees, up to 2030. This scenario suggests that A-EVs alone could reduce the gap to 2 degrees significantly, particularly if other low carbon technologies increase in penetration. BP and Wood Mackenzie's scenarios show a more modest impact, despite their characterisation as high-deployment scenarios. This would increase reliance on other technologies and sectors to bridge the gap to 2 degrees.

A host of factors besides A-EV penetration will impact whether net emissions from vehicles rise or fall.

The quantitative analysis in Figure 1 isolates A-EVs to show 'best case' decarbonisation impact from each scenario. However in real terms a range of other factors are likely to influence emissions. The number of Internal Combustion Engine (ICE) vehicles left on the road will play a key role, as well as the extent of their use in providing mobility. RethinkX's view that ICE vehicle ownership would actively fall while A-EV usage increases would represent a major deviation away from historic trends of rising ICE vehicle ownership. The IEA navigates this by noting stringent emissions standards (which would affect ICEs, EVs and A-EVs) as a tool to reduce total oil demand from road transport in its Sustainable Development Scenario.

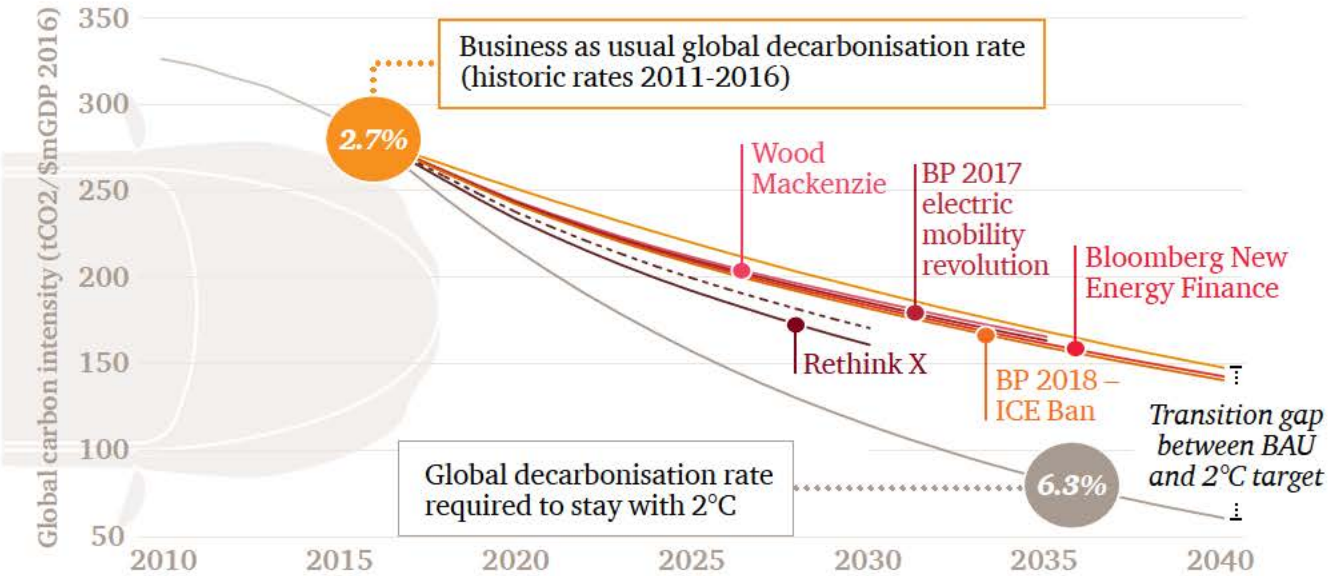
Increased deployment of autonomous vehicles that are not electric could also have a key impact. *We recently published a report* that suggests that both personal mileage and vehicle mileage will increase under a high-deployment scenario for autonomous vehicle technology. This is in part because the technology will enable people to travel who were previously excluded from personal mobility (e.g. children and the elderly). These trends could catalyse net emissions increases if new autonomous ICE vehicles outsell A-EVs.

Furthermore, public transport habits have a key role to play. RethinkX couple A-EV technology with improvements in public transport or ride sharing. This could lead to lower car ownership and lower miles travelled. Whether A-EVs form part of a broader transport revolution will determine total emissions, particularly in urban areas.

If A-EVs are to contribute towards a decarbonisation step change, they will catalyse major disruptions across the economy.

BP and Wood Mackenzie's scenarios are largely contingent on changes within the transport sector. The subsequent impact on oil demand and the wider economy is noticeable, but does not amount to a paradigm shift. BP emphasise a number of uncertainties, such as the extent to which car sharing could be adopted in conjunction with A-EVs. In contrast, RethinkX envision a total reshaping of mobility as an on-demand service. This fundamental shift leads to oil prices dropping to $25/barrel by 2030. This leads to oil fields, pipelines and refineries all increasingly at risk of becoming uneconomic or 'stranded assets', with knock-on effects for investors and operators.

Figure 2: Potential impact of A–EVs on global carbon intensity



Note: The solid lines show the decarbonisation impact of the scenarios, assuming 100% renewable energy powers the A-EVs. The thin dotted line alongside the RethinkX forecast show the decarbonisation impact of the same scenario if A-EVs are powered by electricity with 2016's grid intensity. For BP, BNEF and Wood Mackenzie, the difference between 100% renewable energy and current grid mix powering the A-EV is not material on the scale of this graph.

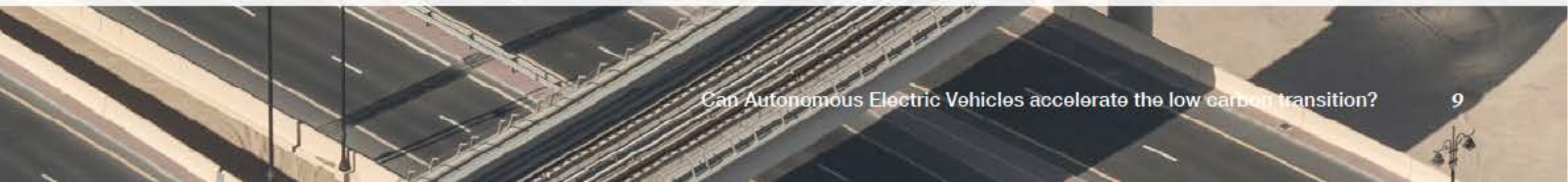
Table 1: Key assumptions of the scenarios

Scenario	*Scenario year*	*Disruptor that triggers scenario*	*Total number of EVs/A-EVs in scenario year (millions)*	*EVs/A-EVs % of vehicle fleet in scenario year*
RethinkX	2030	Electric vehicles with autonomous technology, incorporating ride sharing	Not specified, but significant reduction in total number of vehicles anticipated	60%
BP 2017 (Electrical revolution scenario + car sharing + ride pooling)	2035	Electric vehicles with autonomous technology, incorporating ride sharing	300m	18%
WoodMackenzie carbon constrained scenario	2035	Electric vehicles. It is not specifically stated that all of the EVs have autonomous technology, but this technology is cited as a key driver of EVs	350m	20%
BNEF & McKinsey 2017	2040	Light duty electric vehicles. It is not specifically stated that all of the EVs have autonomous technology, but this technology is cited as a key driver of EVs	530m	33%
IEA WEO 2017 – Sustainable Development scenario	2040	Combination of disruptors in 'road transport', not limited to EVs (included as a benchmark figure)	900m	Not stated
BP 2018 (ICE ban scenario)	2040	ICE ban leads to greatly increased share of EV sales. Impact on AVs not specified.	Not stated (100% of new vehicle sales are EVs by 2040)	Not stated

* RethinkX report states an 18% increase in electricity demand as of 2016 – figure shown is calculated with 2016 global electricity demand from BP Statistical Review of Energy 2017.

Note: The ~ sign indicates where a value has been estimated visually from a published graph.

Scenario	*BAU oil demand in scenario year*	*Reduction in oil demand triggered by disruptor vs BAU by scenario year (mb/d)*	*Increase in electricity demand vs BAU by scenario year (TWh)*	*Scenario summary*
RethinkX	110 Mb/d	40	4467*	Transport-as-a-Service (TaaS) fundamentally disrupts the whole transport sector, as vehicle users stop owning vehicles altogether and access pooled A-EVs when needed.
BP 2017 (Electrical revolution scenario + car sharing + ride pooling)	110 Mb/d	7.4	600	Projections of EV/AV penetration based on technology costs, policy and efficiency improvements in comparison with a base case.
WoodMackenzie carbon constrained scenario	~ 26 Mb/d (gasoline only – total oil not stated)	5	550	Carbon constrained scenario which reflects trajectories consistent with the Paris Agreement. Scenario does not specifically describe all EVs as autonomous, but autonomous driving and TaaS noted as a potential driver of EV uptake.
BNEF & McKinsey 2017	Not published	8	1,800	Breaks down electric vehicles to their component costs to forecast when prices will drop enough to attract consumers. Assumes autonomous vehicle technology is a key driving factor for EV uptake.
IEA WEO 2017 – Sustainable Development scenario	104.9 (from 'New Policies' scenario – closest to BAU oil demand of other sources)	18.1	Not stated	Stated reduction in oil demand is the reduction that could be expected across road transport in a 'sustainable development' scenario. EVs are one of a number of tools (e.g. vehicle emissions standards) used to reduce oil demand.
BP 2018 (ICE ban scenario)	~110 Mb/d (ET scenario)	10	Not stated	Projection of impact of a ban on ICE vehicles. BP includes lower carbon scenarios, but these do not specify reductions in oil demand from road transport.



What could lead A-EV deployment to cruise or accelerate?

A range of factors driving deployment levels underpin the potential decarbonisation impact of A-EVs. A-EV projections differ, both in terms of the types of drivers and constraints that inform penetration and the extent to which the underlying assumptions are visible in the scenarios.

Policy
Policy could drive or constrain the ICT, power and road infrastructure and regulations required for largescale A-EV deployment. Legal frameworks for self-driving cars will be required, including insurance regulations to clarify responsibility in accidents. Stringent safety standards may provide an additional regulatory hurdle for manufacturers. The RethinkX scenario points to the importance of approval of AVs for widespread use on public roads as well as a competitive policy environment with countries and cities competing to be at the forefront of the new technology. We recently published a report that emphasises the importance of clear signals from government in laying out a roadmap for EV deployment.

Policies favouring low-carbon technologies could also play a key role in accelerating A-EV deployment, with policy influencing both end-user cost and ease of adoption. The IEA point to emission standards as a tool to drive increases in EV penetration. While WoodMackenzie's scenario is exploratory, driven by decarbonisation targets, it does not describe the policies that might enable this projection to become reality.

Cost
Falling costs are cited as a critical driver by all scenarios, and with a reasonable degree of certainty. BP focus on falling costs of travel due to technological advances, including lithium-ion batteries. The BNEF and Wood Mackenzie scenarios both expect battery prices to fall to roughly a third of their current cost in the early 2030s. Even assuming a low oil price of $20 per barrel, BNEF suggest this would only delay widespread EV adoption to the early 2030s. In the RethinkX scenario, it becomes 2-10x cheaper to use 'transport as service' than owning a vehicle, leading to mass adoption.

Market and behavioural shifts
Markets and consumer behaviours could propel or constrain A-EVs, with loyalty to existing vehicles and transport modes a key deciding factor. The BP and WoodMackenzie scenarios highlight that growing emerging markets, such as China, India and the Middle East, will put a large number of new cars on the road over the next 20 years. This may double the global car fleet during the same period that A-EVs grow from their current status as a nascent technology. As the IEA observes, it could therefore take decades for A-EVs to completely replace ICE vehicles in the vehicle fleet. Similarly, EV battery production would have to increase at least threefold by 2035, which could potentially pose supply constraints.

Rapid A-EV deployment scenarios are dependent on widespread early adopters willing to accept the lifestyle changes associated with autonomous technology. RethinkX suggest this behavioural shift could be faster than current industry expectations, as was the case with mobile phone technology in the early 21st century. Personal reasons, such as enjoyment of driving or a feeling of 'being in control', carry less weight than expected, with RethinkX citing the rapid abandonment of horse carriages in favour of cars a century ago as evidence of this.

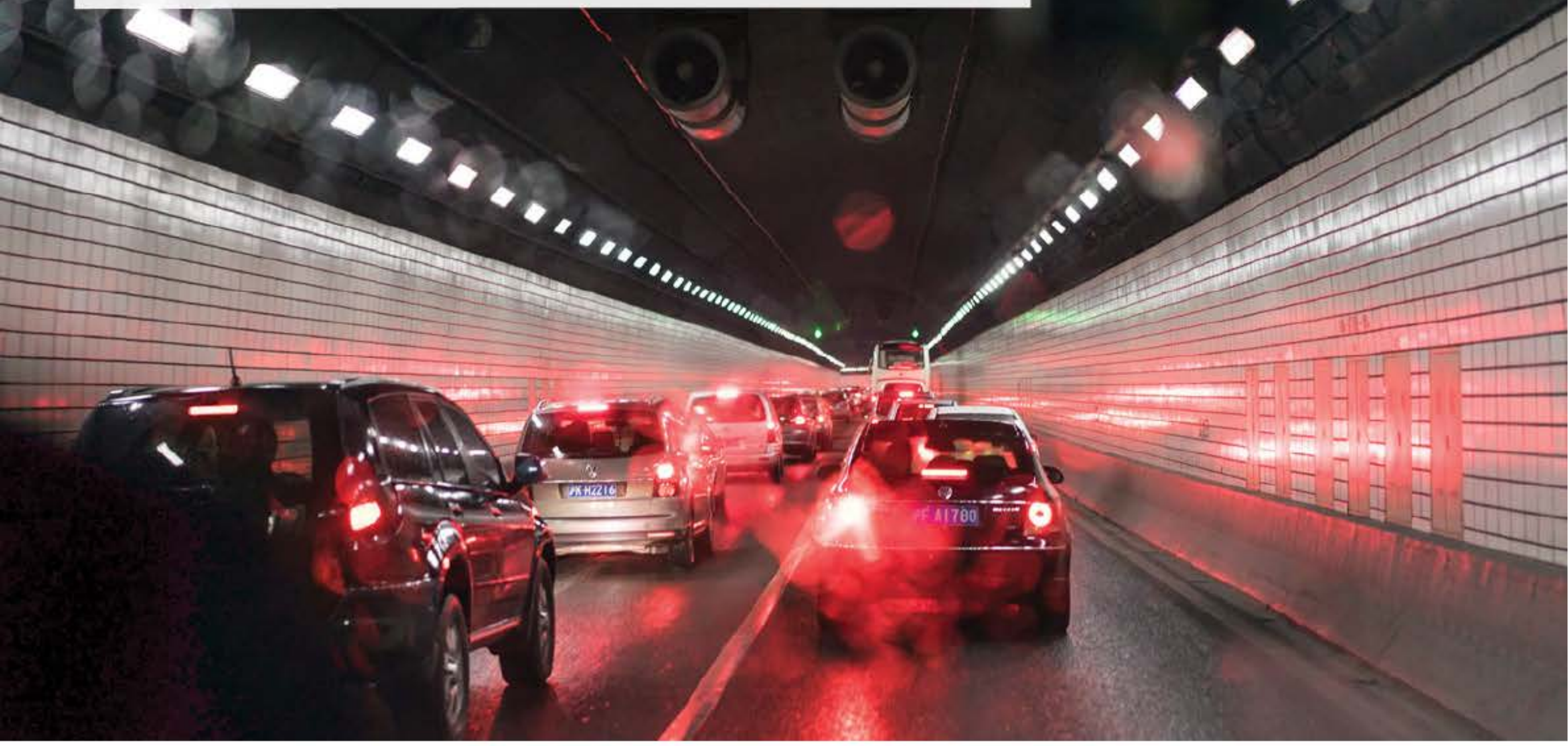
R&D
R&D into cheaper batteries, precise GPS and navigation mapping and affordable sensors will underpin wide-scale A-EV adoption. Improving the process of active data gathering during driving, training A-EV systems to rapidly make ethical decisions as well as ensuring the system cannot be hacked into, are other crucial technological developments.

How clear is the future of A-EVs?

While these projections provide glimpses of the possible future of A-EVs, they are rare. Relatively few organisations are quantitatively forecasting the potential impact of autonomous vehicle technology.

Quantitative EV growth projections have been published by a range of organisations and reflect a wide variety of possible scenarios. However comparatively few have published quantitative projections of A-EV penetration, despite substantial media interest in autonomous vehicles. BNEF and Wood Mackenzie do acknowledge AV technology as a key driver of EVs, but do not specify exactly how many vehicles in the fleet will be autonomous. This makes a direct comparison with RethinkX and BP (who specify that the vehicles will be autonomous) challenging across the different projections.

Nonetheless, national governments are aware of the potential for specific countries to act as innovation hotbeds for next generation vehicle technologies, and to play a role in shaping A-EV deployment. They are acting now to seize this opportunity. For instance the UK recently announced in its Industrial Strategy that it is creating a new £400m Charging Infrastructure Investment Fund, £200m for Low Emission Vehicles R&D funding. It has also allocated £250m to position the UK as a global leader in the development and deployment of connected and autonomous vehicles.[9]



9 Department for Business, Energy & Industrial Strategy, 2018. Industrial Strategy – Automotive Sector Deal, p.9.

What are the implications for business?

The Paris Agreement's 2 degree goal presents a significant challenge, and opportunity, to business, government and consumers.

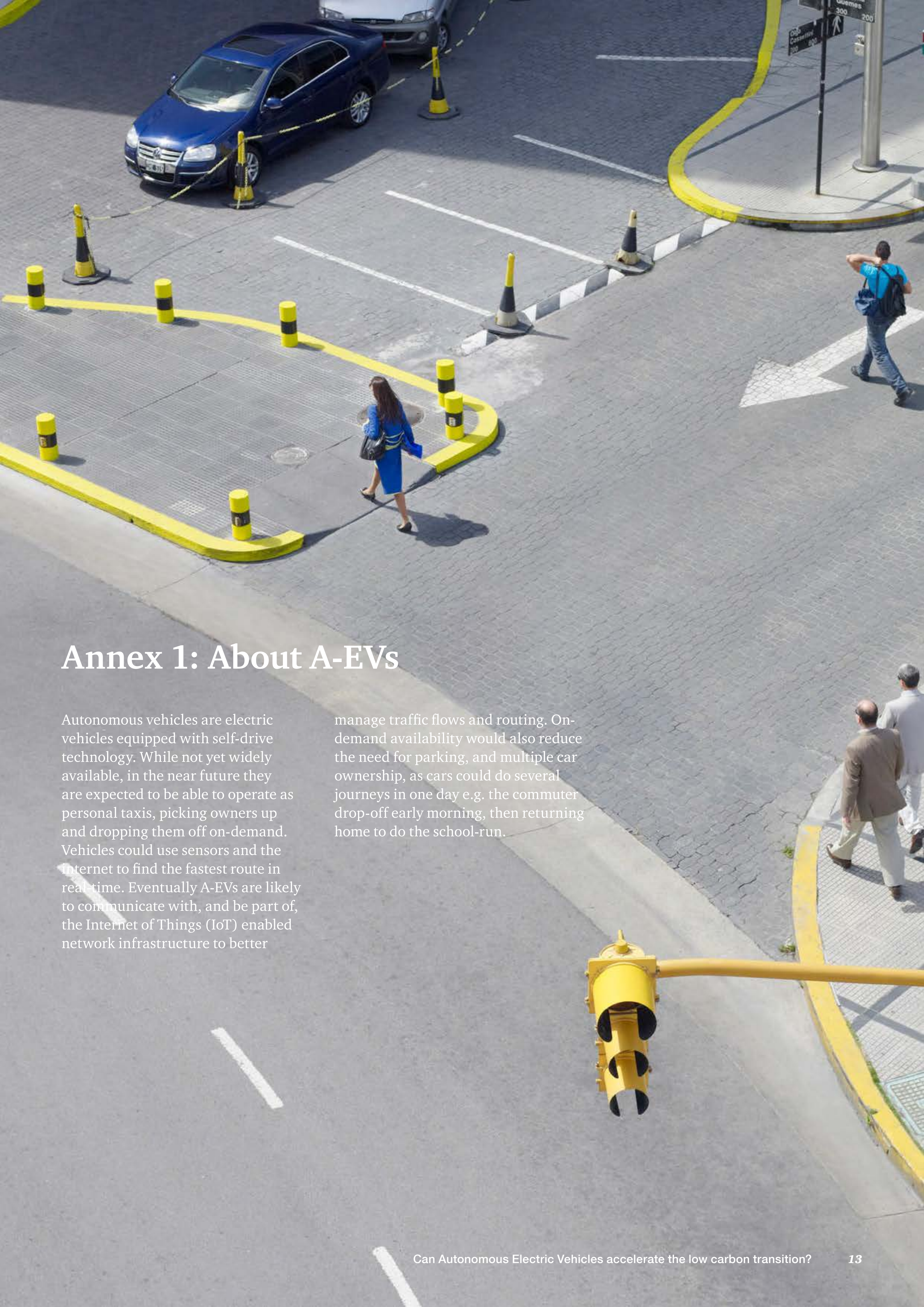
Renewables, efficiency improvements and electrification are seen as key tools to decarbonise the energy system by a number of international organisations, including the International Energy Agency, Shell and Greenpeace.[10] This implies that A-EVs may be able to make significant contributions to global decarbonisation efforts, and early adopters could benefit.

Conversely, A-EVs have the potential to disrupt transport behaviours as well as shifting oil and electricity demand. It is important for business to prepare for this. The technology's growth and potential impacts remain unclear.

The range of scenarios demonstrate the current uncertainty of how this technology could impact the economy. A-EVs are just one of a number of emerging technologies under the Fourth Industrial Revolution (4IR) that could disrupt current business models. A range of stakeholders are likely to be impacted by these disruptions, including vehicles manufacturers; oil producers; utilities companies; regulators and consumers.

Speak to our team to discuss how 4IR technologies and the low carbon transition could affect your business.

10 Shell, 2013. New Lens Scenarios, 'Mountains' scenario; Greenpeace, 2015. Energy Revolution – A Sustainable World Energy Outlook 2015; International Energy Association, 2015. Energy Technology Perspectives, '2°C Scenario'.



Annex 1: About A-EVs

Autonomous vehicles are electric vehicles equipped with self-drive technology. While not yet widely available, in the near future they are expected to be able to operate as personal taxis, picking owners up and dropping them off on-demand. Vehicles could use sensors and the internet to find the fastest route in real-time. Eventually A-EVs are likely to communicate with, and be part of, the Internet of Things (IoT) enabled network infrastructure to better manage traffic flows and routing. On-demand availability would also reduce the need for parking, and multiple car ownership, as cars could do several journeys in one day e.g. the commuter drop-off early morning, then returning home to do the school-run.

Annex 2: Methodology

We have calculated global carbon intensity (tCO_2/$m GDP) under different A-EV adoption projections and compared these to the rate of carbon intensity change needed in the future to limit warming to two degrees by 2100 in our 2017 Low Carbon Economy Index (LCEI). This allows us to present a range of estimates on the potential carbon reduction impacts of A-EV technology.

The purpose of this analysis is to model the potential 'best case' estimation of the impact of A-EV technology in bridging the gap to 2 degrees, by using a range of secondary data sources with available projections. We have not modelled the outcome of A-EV technology using primary data. We assume that all else is equal besides the reduction in oil demand/increase in electricity demand attributed to A-EVs (e.g. GDP, penetration changes in other low-carbon technologies). The aim of this is isolate A-EVs and demonstrate the possible scale of their disruption relative to BAU, rather than to map out a prediction of future carbon intensity.

The scenarios used in this analysis – BP, RethinkX, WoodMackenzie and IEA – have been selected as they model the impacts of A-EV technology against a BAU trajectory. Whilst numerous additional projections purely on EV technology exist, we have chosen only to include those that acknowledge the potential impact of autonomous technology if coupled with EVs.

Key assumptions

The data used in these projections has been taken as seen in the publications released by each organisation. In some instances, estimate values have been taken based on published charts. Each of these scenarios model the potential impact as a deviation from a forecasted oil demand in a future year against a base case. Because assumptions underlying the base case scenario differ in each scenario, we have only used data for the reduction in oil demand compared to the base case. We have not verified or altered any of the assumptions in the base case. We have applied this to a BAU scenario forecasted by our LCEI model, based on trends from the last 5 years and GDP projections.

In order to provide an upper-bound 'best case' estimation of the potential impacts of A-EVs on global emissions reductions, while also considering anticipated growth in GDP, two key assumptions have been taken:

1. While power for the A-EVs can be supplied by multiple fuel sources which could cause an increase in CO_2 emissions depending on the electricity grid mix, for the purposes of this analysis, we assume they are powered by 100% renewable energy.
2. Many of these organisations provide multiple scenarios for A-EV deployment. However we have focused on the most ambitious deployment scenario from each organisation that specifies a reduction in oil demand attributable to A-EVs.

Calculation steps

1. We have calculated the associated CO_2 emission reductions in the data year for each scenario by converting the mb/d reduction in oil demand into CO_2 emissions using conversion factors applied in the 2017 LCEI.
2. The associated emission reductions for the data year of each scenario have been applied to our global 5-year BAU (2011-2016) used in our Low Carbon Economy Index. Using a compounded annual growth rate, the total CO_2 emissions in each year between 2017 and the data year of the scenario is found.
3. We have used GDP data from the 2017 LCEI to calculate the carbon intensity for each scenario. This is shown in the chart alongside the LCEI 5 year BAU and 2 degrees line.

For the full methodology of our Low Carbon Economy Index model, please *see the annex in our 2017 LCEI report.*

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