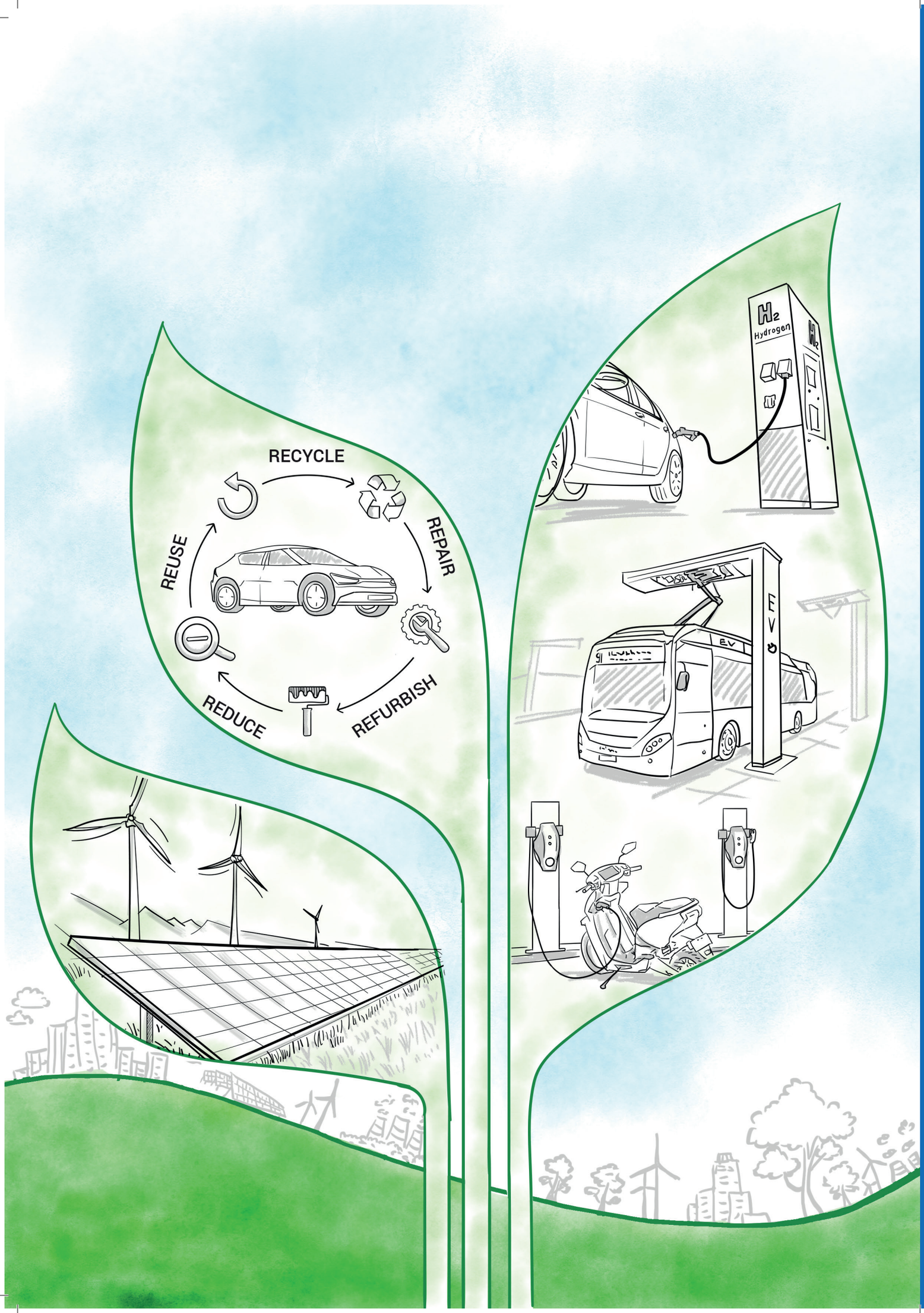
SIAM

63rd annual convention 2023

Building the Nation, Responsibly

12th September 2023, New Delhi

BACKGROUND PAPER


RECYCLE
REPAIR
REFURBISH
REDUCE
REUSE
H2
Hydrogen
EV

ACCELERATING SUSTAINABLE MOBILITY IN INDIA

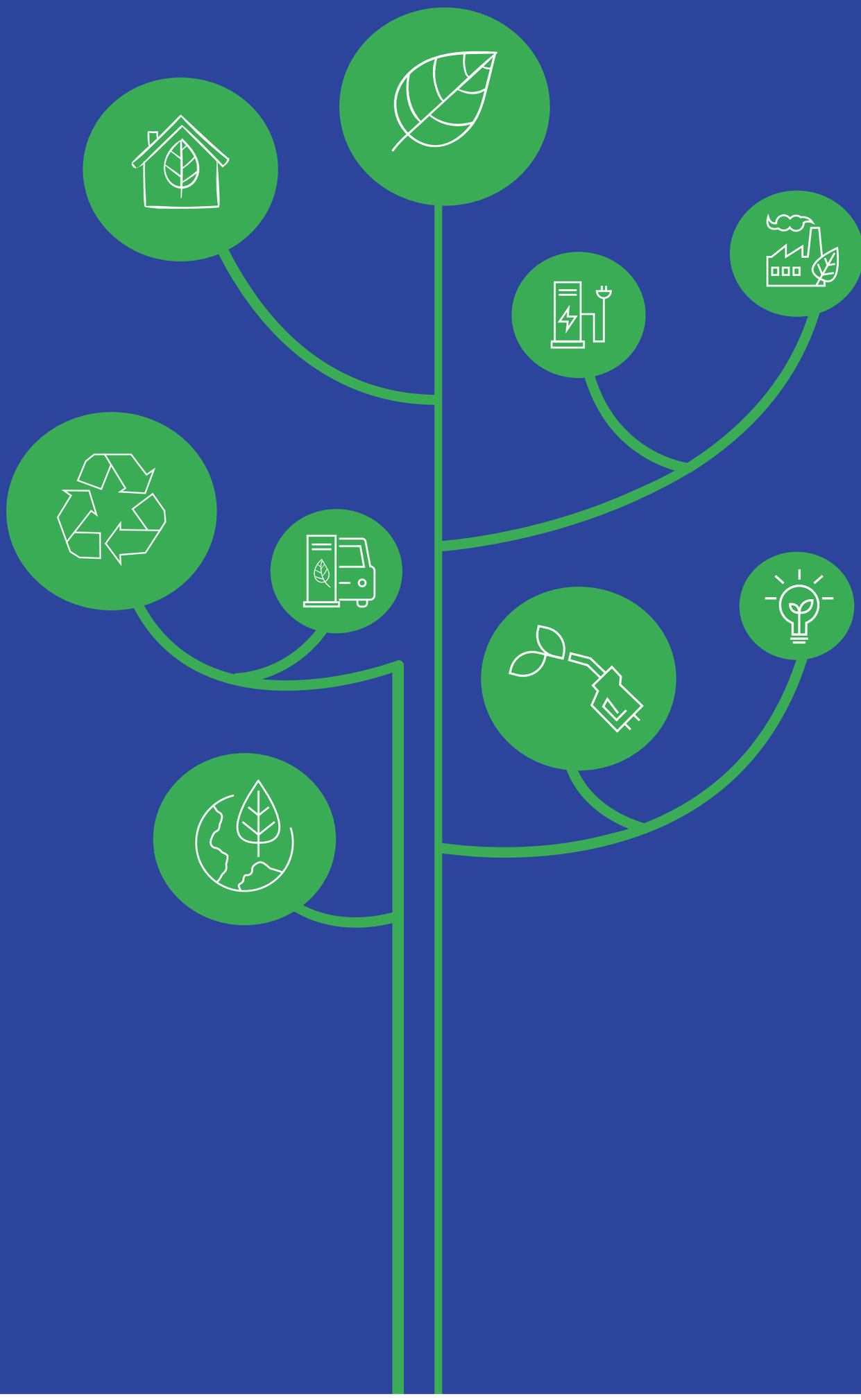
LEARNINGS FROM GLOBAL EXPERIENCES

September 2023

Acknowledgements

The Society of Indian Automobile Manufacturers is publishing this background paper on the occasion of SIAM's 63rd Annual Convention, held in New Delhi in September 2023.

SIAM would like to thank the many people who have shaped and contributed to the insights we share here, including our knowledge partner, McKinsey & Company, who provided the analytical fact base. We would especially like to thank the McKinsey team comprising Rajat Dhawan, Andreas Tschiesner, Shivanshu Gupta, Nitesh Gupta, Bikramjit Chaudhury and Alfonse Mathew for their overall guidance, as well as other McKinsey experts and the global team for their valuable perspectives and learnings from various geographies.



Contents

The imperative for decarbonisation

1

The impact of climate change has made headlines worldwide this year. Droughts, floods and heatwaves are adding to the already urgent case for mitigating environmental concerns. In this context, controlling greenhouse-gas (GHG) emissions is a shared and growing priority all around the world.

While India's per capita emissions as of 2019 were considerably lower than many countries[1] (one-seventh of US levels and one-third of EU and China levels), it still features as a top five emitter because of the size of its population and has committed to bring down its emission levels. The transport sector and within it, the automotive industry, can also play a valuable role in the pursuit of decarbonisation goals.

Positive about neutrality – global commitments to net zero

Governments worldwide have made commitments to achieve carbon neutrality (or "net zero") in the next few decades.[2] The two largest emitters, China and the USA, have set aggressive targets, aiming to reduce emissions by over 50 percent over the 2005 baseline. Like many other regions (such as Japan and the European Union), they have also framed interim commitments to ensure that they follow through, and remain on track to achieve their longer-term goals.

A few examples of such efforts by developing countries include Brazil's National Zero Methane Program.[3] Launched in 2022, the initiative incentivises the use of biomethane and biogas to limit methane emissions in the environment. In another example, China is putting a big thrust on installing wind and solar power capacity of 1,200 GW by 2030 to increase the share of non-fossil fuels in primary energy generation.[4]

India, too, is acting to achieve carbon neutrality, or net zero by 2070 – an important milestone in the fight against climate change.[5]

The government has announced a series of supporting initiatives for these goals, aimed at reducing carbon intensity and reliance on fossil fuels. These range from efforts such as setting up a National Carbon Exchange[6] and creating a deterrent in the form of Carbon Tax, to committing purposeful allocation in the Budget to the tune of INR 35,000 crore for energy transition.[7] It is also taking a strict view to control emissions in the transport sector.

India's 5 commitments[1]

1. Raise non-fossil energy capacity to 500 GW by 2030.
2. Bring the economy's carbon intensity down to 45 percent by 2030.
3. Fulfill 50 percent of all energy requirement using renewable energy sources by 2030.
4. Cut out 1 billion tons of carbon emissions from the total emission levels by 2030.
5. Achieve the target of net zero carbon emissions by 2070.

[1] India's Stand at COP-26, Press Information Bureau, 3 February 2022

[1] On a per capita basis, India's emissions are the lowest among the world's top five emitters at 2-2.5 tCO_2e per capita (almost 1/5th of the average of the other four emitters at 11-12 tCO_2e per capita); Climate watch data (from website as on August 2023)
[2] The data and initiatives cited for all countries are sourced from the website of United Nations Framework Convention on Climate Change (UNFCC). In addition, data was also referenced from 'The long-term strategy of the United States', published by the US Department of State and Office of the US President, November 2021; as well as the websites Net Zero Tracker and Eur-Lex - the official website for European Union Law
[3] 'National Program for the Reduction of Methane Emissions - Zero Methane', International Energy Agency, 14 February 2023
[4] 'China aims to push wind and solar capacity beyond 1,200 GW by 2030', *Reuters*, 12 December 2020
[5] 'India's Stand at COP-26', Press Information Bureau, 3 February 2022
[6] 'India to have two National Centres of Excellence in Carbon Capture & Utilization at IIT Bombay & at JNCASR, Bengaluru, supported by DST', announced on Department of Science & Technology's official website
[7] 'Government allocates INR 35,000 crore for energy transition, achieve net-zero by 2070', *Mint*, 1 February 2023

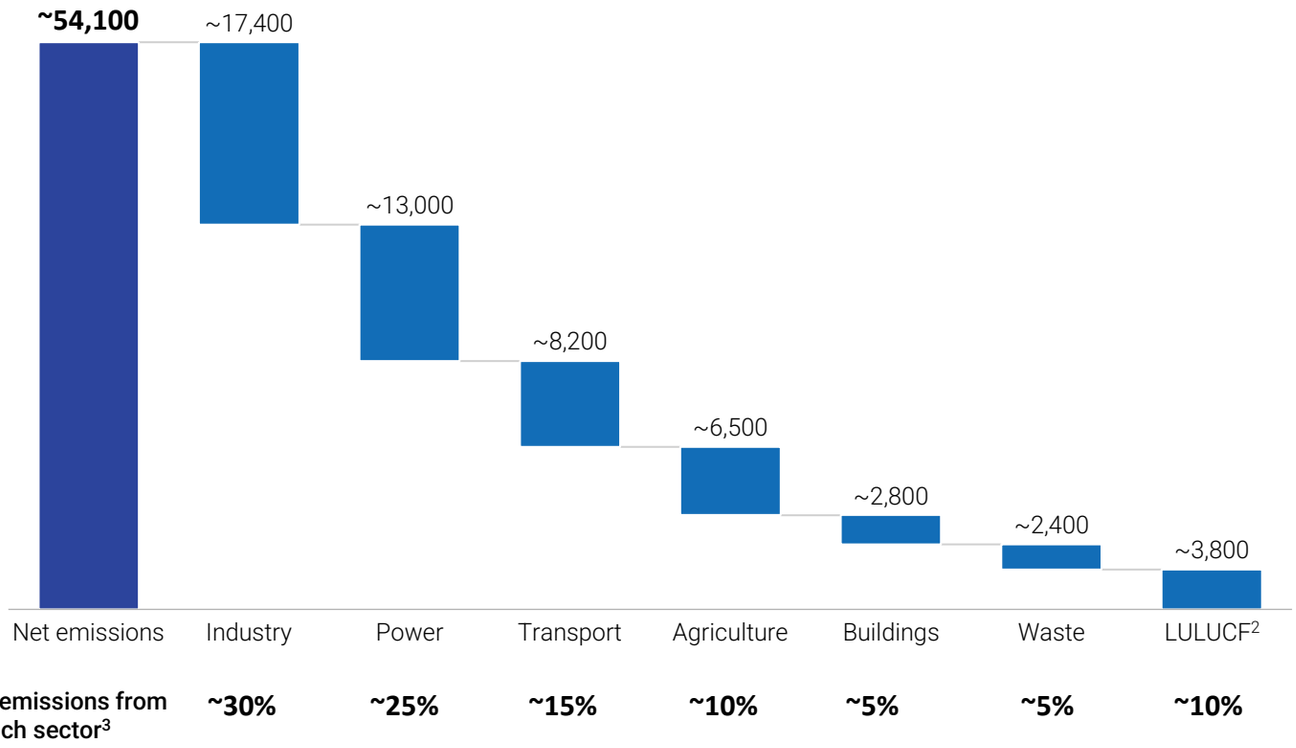
Transport sector – the power and responsibility for impact

Worldwide, four sectors – industry, power, transport and agriculture – contribute around 80 percent of all emissions. Transport ranks third in net global emissions, pumping around 8,200 metric tons of GHGs into the atmosphere annually – approximately 15 percent of the world total (Exhibit 1).[8]

Exhibit 1

Global scenario: Of the 4 sectors contributing ~80% of emissions, transport accounts for ~15%[1]

$MtCO_2e$, per annum



1. Non-CO_2 emissions are converted into carbon dioxide equivalents according to their 100-year global warming potential (GWP100)
2. Land-Use, Land-Use Change and Forestry
3. Only direct emissions from each segment considered; transport includes only tailpipe emissions

Source: McKinsey Emissions Inventory Tracker (EMIT) database, 2021; McKinsey India Decarbonisation Scenario Explorer; Climate Watch data as on August 2023

In India, the transport sector represents approximately 10 percent of all emissions, which is lower than global levels – possibly because vehicle penetration in India is lower than global averages (Exhibit 2).

For India, road freight traffic is a leading contributor to tailpipe emissions. Over 70 percent of freight by volume travels on national highways and roads, which means that commercial vehicles account for more than 90 percent of all tailpipe emissions. Trucks and light commercial vehicles (LCVs) contribute over 70 percent of the total.[9]

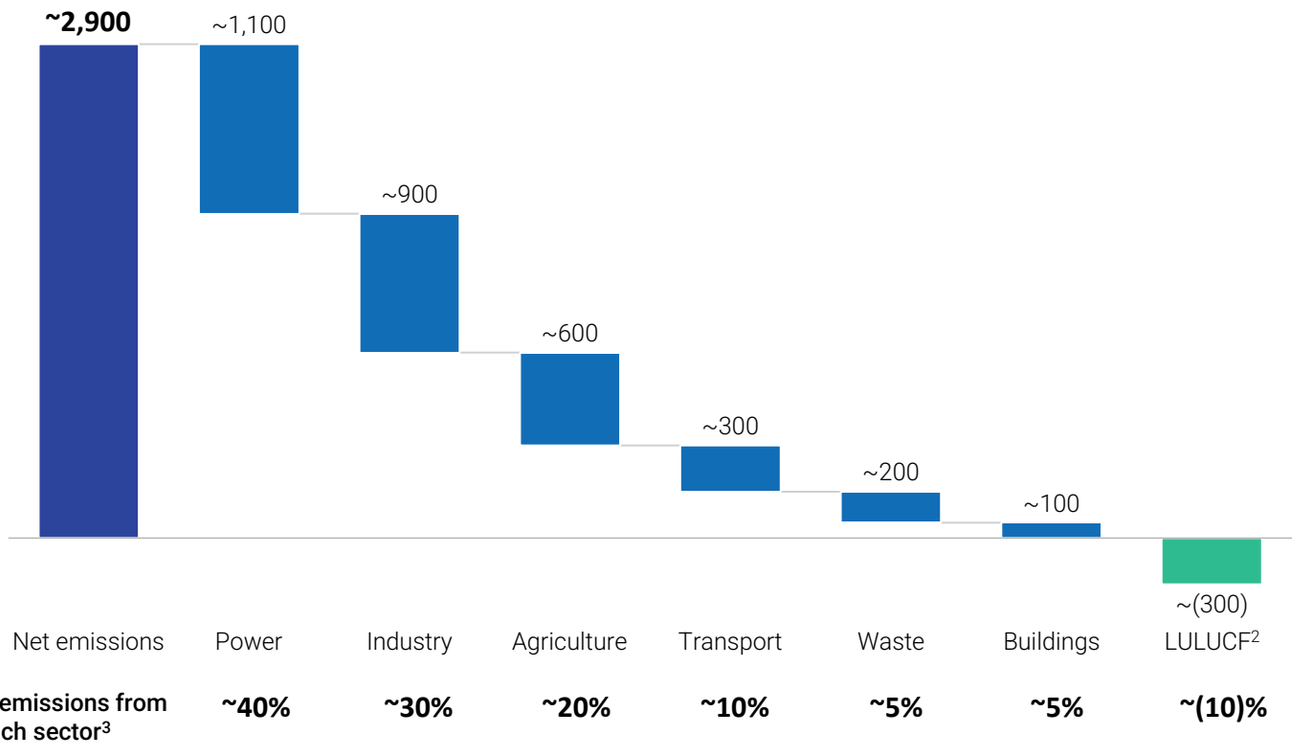
8 This section draws on analysis of data from the McKinsey Emissions Inventory Tracker (EMIT) database, 2021; McKinsey India Decarbonisation Scenario Explorer; and two McKinsey publications: 'Decarbonising India: Charting a pathway for sustainable growth', 27 October 2022 and 'The zero-carbon car: Abating material emissions is next on the agenda', 18 September 2020

9 McKinsey India Decarbonisation Scenario Explorer; 'Fast Tracking freight in India: A Road-map for clean cost-effective goods transport' report by NITI Ayog, RMI & RMI India, June 2021

Exhibit 2

India scenario: Transport sector accounts for ~10% of India's emissions

$MtCO_2e$,[1] per annum



1. Converting GHGs into CO_2 equivalent assuming GWP-100 and AR5 methodology with India's BUR-3 reported emissions for 2016 as baseline
2. Land-Use, Land-Use Change and Forestry
3. Only direct emissions from each segment considered; transport includes only tailpipe emissions

Source: McKinsey Emissions Inventory Tracker (EMIT) database, 2021; McKinsey India Decarbonisation Scenario Explorer; Climate Watch data as on August 2023

Within the transport sector, the greatest source of emissions are the traditional powertrain or "internal combustion engine" (ICE) vehicles. While multiple sources add to emissions from the transport sector, tailpipe and material production are the largest contributors, emitting around 70 percent and 20 percent respectively of total lifecycle emissions (Exhibit 3).

The Government of India has launched targeted initiatives to reduce emissions in the transport sector. It introduced BS-VI standards for vehicles manufactured on or after April 1, 2020, which aim to restrict particulate matter mass emission.[10] Norms for Corporate Average Fuel Efficiency (CAFE) have set fuel-efficiency standards for passenger vehicles to improve efficiency thereby reduce emission levels.

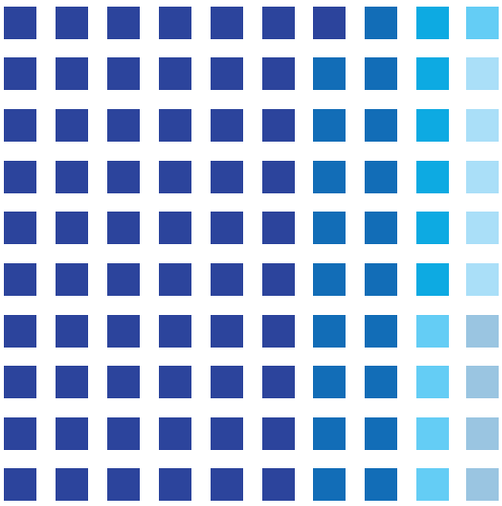
The authorities have also tried to ease access to cleaner fuels. The city gas distribution networks for CNG have been declared a public utility, and the government is meeting 100 percent of the gas requirements of these networks across India. It is also working to promote the availability and use of ethanol-blended petrol and hydrogen fuel.[11]

[10] Bharat Stage (BS) VI emission standards, International Energy Agency, 1 February 2023
[11] India's BUR-3 report, 2021

Exhibit 3

Tailpipe and material production emissions account for ~90% of lifecycle emissions in ICE vehicles

Percentage of total current lifecycle emissions of internal combustion engine vehicles[1]



Tailpipe	**60-70%**
Material production	**18-22%**
Fuel supply	**5-10%**
Production and assembly	**4-8%**
Logistics	**4-6%**
End-of-life materials recovery	**3-5%**

1. For C-segment vehicles
Source: Analysis of data sourced from the Nature and Bio Gas Vehicle Association

In addition, multiple initiatives reflect a sharp focus on promoting electrification in India:[12]

- The launch of the FAME II subsidy to promote electrification of high-utilisation vehicles, including two- and three-wheelers
- The Phased Manufacturing Plan for EV parts
- A USD 1-billion fund set up in association with the World Bank, Asian Development Bank and Small Industries Development Bank of India (SIDBI) to provide low-cost financing for last-mile mobility EVs (such as two- and three-wheelers as well as fleet cars)
- The National E-Bus Programme to electrify 50,000 buses

Concerted efforts from both government and industry could have a positive impact on GHG emission levels. While government efforts to attain net zero have been described above, the Indian automotive industry has also taken steps towards sustainable mobility.

[12] Web search, including, but not limited to: India's BUR-3 report, 2021; Press Information Bureau, Government of India

The automotive industry globally: Working towards decarbonisation

OEMs and automotive suppliers have made definitive decisions to cut down emissions. These moves focus on one or more of four themes:

1

Attaining carbon neutrality

Several Global OEMs have set their own, fairly aggressive targets, with some striving for net zero by 2025, and many others aiming for 2050.

2

Investing in alternative powertrains

Across OEMs, there is considerable investment to move the product portfolio towards zero emission vehicles. Many new EV launches have been announced till 2026, and several OEMs are aiming to go entirely electric by 2040.

3

Greener sourcing of materials

OEMs are increasingly moving towards incorporating recycled materials and extending the vehicle lifecycle through remanufacturing.

4

Transitioning to renewable or green energy

Many OEMs have already made the shift by setting up sources of renewable energy. For example, one leading Indian automobile manufacturer is installing solar panels and natural gas capacity to generate electricity at its manufacturing sites.

This is an encouraging starting point, and sets the course to navigate in the future. As OEMs, the industry and the government evaluate how they can contribute to India's pursuit of its net zero aspiration, they could focus most on two themes that might make the biggest difference to emission levels: limiting tailpipe emissions by promoting fit-for-purpose alternative powertrains, and controlling material production emissions by pursuing circularity for sustainable mobility.

The subsequent chapters outline the possibilities and potential based on the current landscape and learnings from other regions to pave the way for a net zero India by 2070.

The global pursuit of alternative powertrains

2

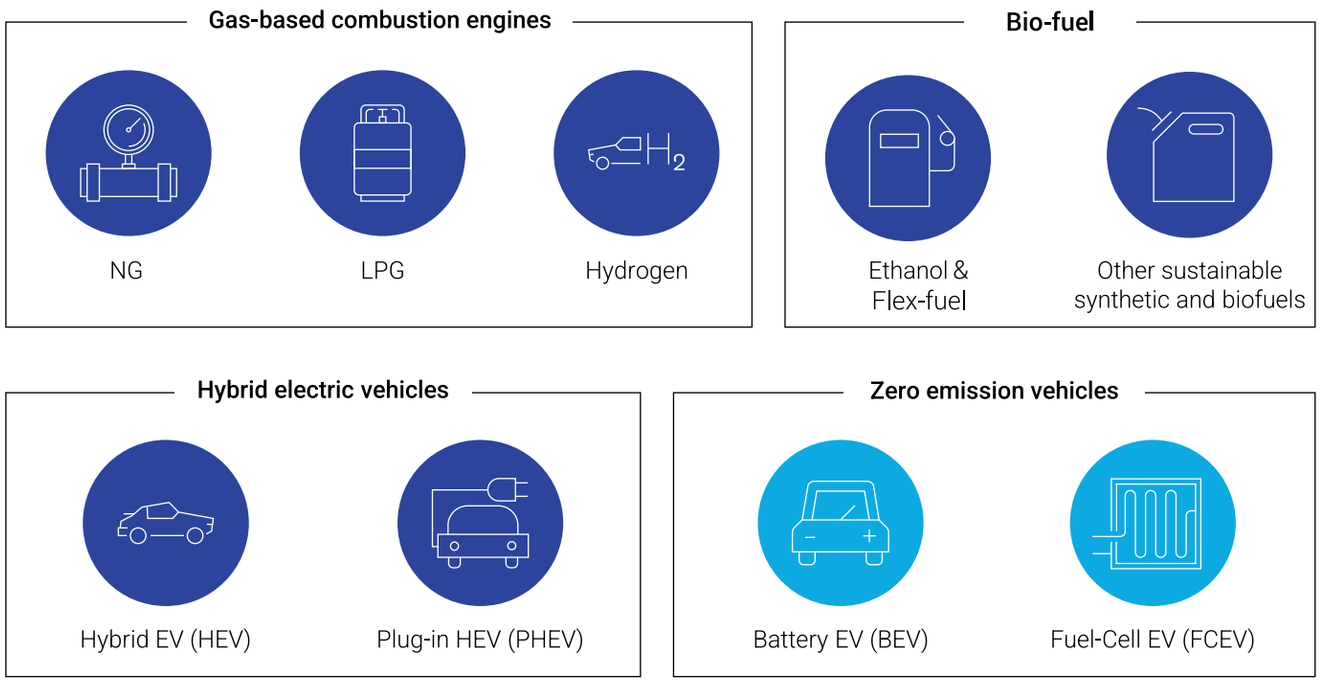
The global automotive landscape is fast changing, with alternative powertrains (PT) gaining momentum in the pursuit of decarbonisation. Governments and automakers around the world are playing an important role in accelerating the transition to alternative PTs that cut down on tailpipe emissions.

Looking beyond gasoline

The prevalence of the traditional gasoline-powered (petrol or diesel) internal combustion engine – that has driven vehicles for centuries now is complemented by alternative PT technologies. Mainly nine-types of alternatives have emerged globally (Exhibit 4). The increased traction of these technologies manifests in the availability of more and more options for consumers, and in turn, the rising sales of alternative PTs.

Exhibit 4

Nine powertrains have emerged globally as alternatives to the internal combustion engine



Growing market confidence in alternative powertrains

Market trends indicate that investors seem to view alternative PTs with growing interest,[13] with startup funding in alternative PTs surging 35 percent year-on-year between 2015 and 2022. Overall startup investments in various powertrain technologies nearly tripled between 2019 and 2020, reaching USD 44 billion, and then almost doubled to USD 86 billion in 2021 (Exhibit 5).

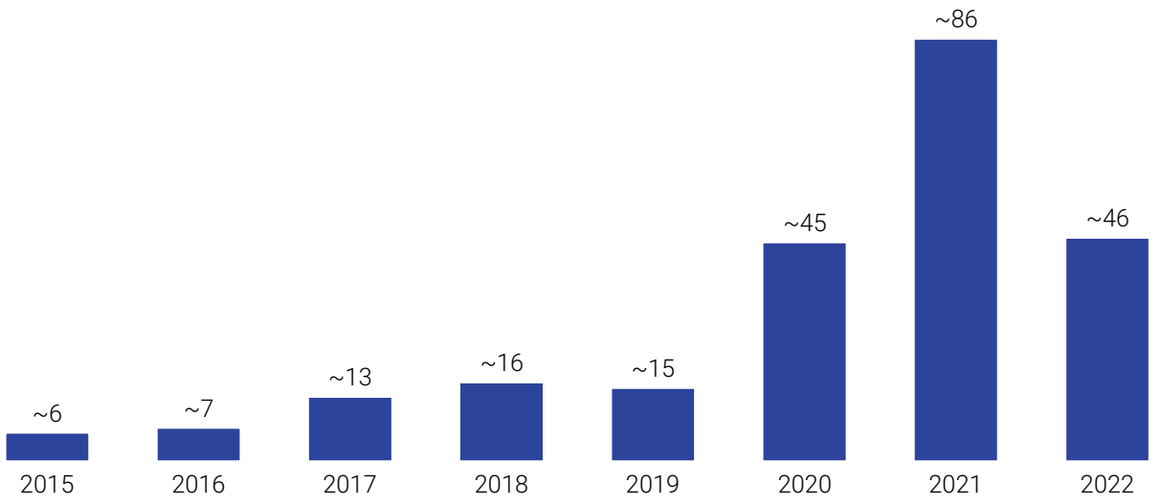
Electrification has emerged as the primary beneficiary of these investments with a majority of the investment directed towards the development of EVs, followed by investments in enabling areas of charging infrastructure and batteries. This investment pattern highlights the automotive industry's pursuit of net zero.

[13] Market information in this section taken from McKinsey Mobility SILA

Exhibit 5

The market shows confidence in alternative powertrains; startup funding in the sector has increased at ~35% YoY

Disclosed startup investment amount in alternative powertrains[1], USD billion



	2015	2016	2017	2018	2019	2020	2021	2022
Electric vehicles	81%	77%	68%	73%	67%	67%	57%	29%
Batteries	13%	16%	24%	22%	21%	22%	24%	53%
Charging	5%	5%	2%	4%	7%	3%	10%	16%
Hydrogen	1%	2%	6%	1%	5%	8%	9%	2%

1. Includes BEVs, HEVs, PHEVs, FCEVs
Source: McKinsey Mobility SILA

Electrification is gaining momentum

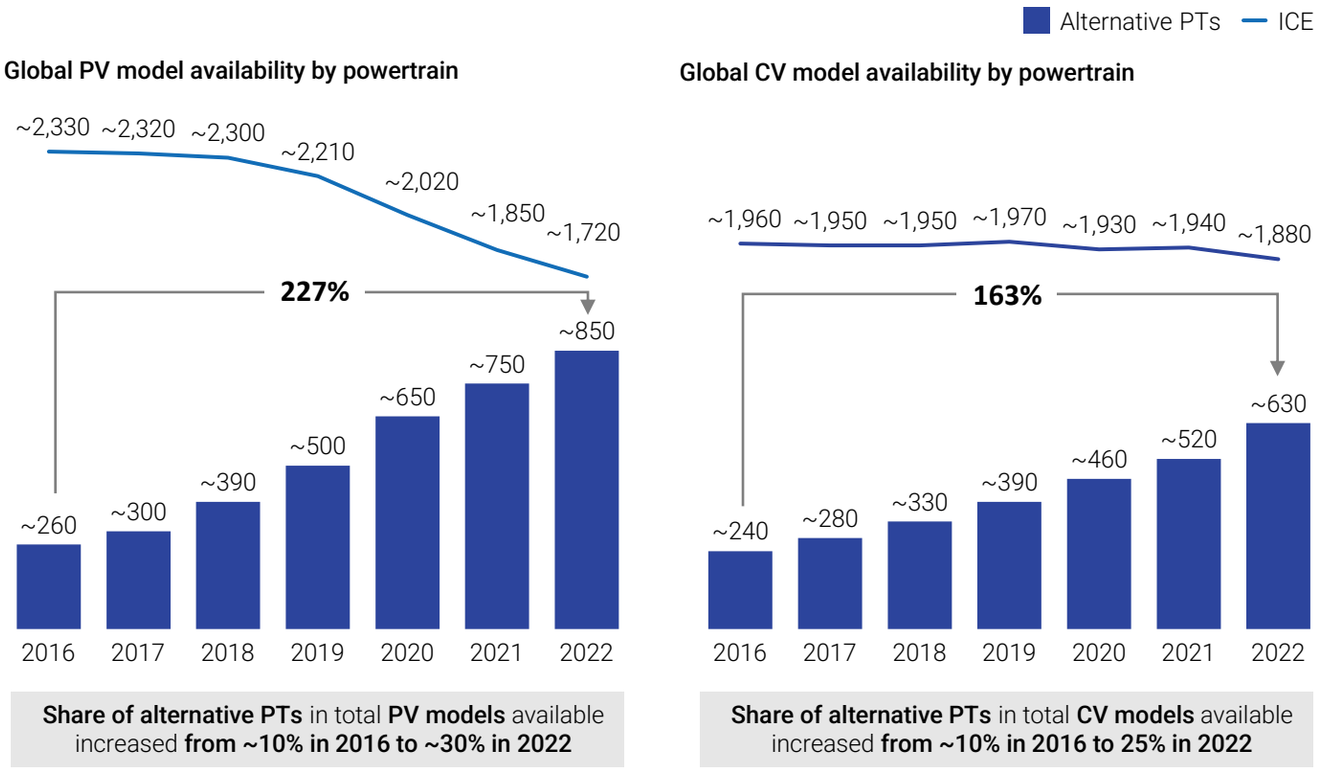
Several global OEMs are making strong commitments to electrification, determined to ensure that the majority of their sales are of EVs within the next five to seven years. To honour these commitments, they are investing heavily in research & development (R&D) and capacity upgradation. Till 2021, OEMs worldwide had committed to investing over USD 500 billion towards electrification over this decade. European OEMs are leading the way towards investing in electrification of vehicles. A leading global OEM has committed (till 2021) to invest over USD 100 billion to realise its target of 70 percent of all European vehicle sales being electric by 2025. Another leading global automaker has pledged to discontinue ICE production and exclusively offer EVs by 2030, with an over USD 50 billion investment.[14]

With the increasing acceptance of the economic and environmental benefits of alternative PTs, investments have fueled greater availability. In 2022, the number of alternative PT passenger vehicles (PVs) grew to around 3x and alternative PT commercial vehicles (CVs) grew to around 2.5x of 2016 levels (Exhibit 6).[15]

[14] This information is collated from various company websites and a web search, including, but not limited to: 'Global carmakers now target $515 billion for EVs, batteries', *Reuters*, 10 November 2021 and 'Japan and the global transition to zero emission vehicles', a research report by The Climate Group, May 2022
[15] S&P Global AutoInsight (June 2023)

Exhibit 6

Availability of alternative PT models: PV models grew ~3x and CV models grew ~2x since 2016



Source: S&P Global AutoInsight (June 2023)

Rise in sales of alternative powertrains[16]

The global scenario

Even as overall automotive sales declined from 2018 to 2022 globally, the alternative PT (mainly BEV and HEV) segment grew at a 20 percent compound annual growth rate (CAGR) since 2018. Penetration (defined as share in total vehicle sales) more than doubled, from around 11 percent in 2018 to around 27 percent in 2022 (Exhibit 7). This relative growth has come at the expense of the traditional ICE powertrain segment, which dropped by around 10 percent YoY over the same period. The PV landscape mirrors this trend – over 30 percent of sales in 2022 are of alternative PTs. Among these, BEVs emerge as frontrunners, exhibiting the highest market penetration, especially in the US, EU and China.

OEM and government efforts have also nurtured the growth of HEV and PHEV technologies, giving them greater heft over ICE. Their penetration grew from under 4 percent of annual sales volume in 2018 to close to 15 percent in 2022.

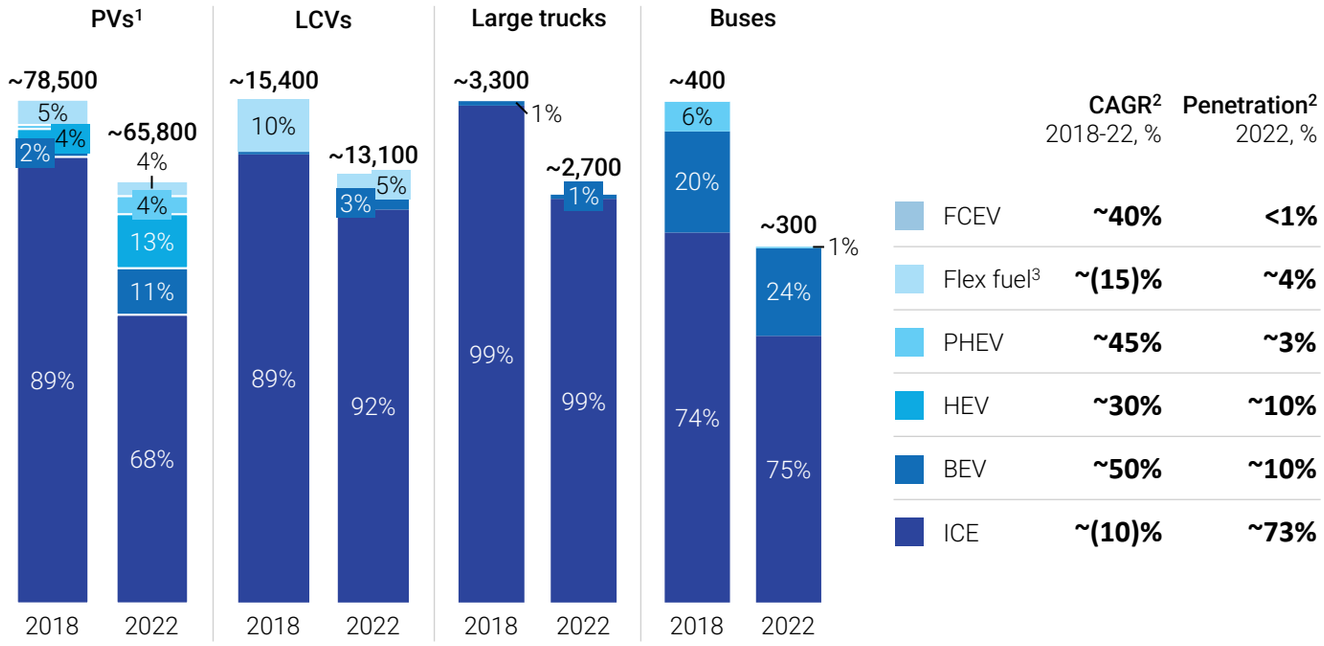
LCVs, however, remain primarily ICE-based, even though BEV sales have defied the trend and surged at a CAGR of 50 percent (between 2018 and 2022). Large trucks predominantly remain ICE; however buses have seen a rapid adoption to BEV, with approximately 25 percent penetration. Although at a nascent level, trucks and buses have also seen the entry of FCEVs. Diesel-based ICE commercial vehicles prevail because the supporting infrastructure for alternative PTs faces bottlenecks, such as inadequate charging infrastructure for long-haul trucks and buses, inefficient battery size, high electrolyser costs and lack of availability of green hydrogen. The higher overall cost of ownership resulting from these factors, therefore, has so far deterred the shift from ICE to alternative PTs for large trucks and buses.

[16] All data on global and India sales is collated from S&P Global AutoInsight (June 2023); S&P Global Mobility, Light Vehicle Sales Forecast (July 2023); S&P Global Mobility, Medium/Heavy CV Industry Sales Forecast (August 2023); EV-Volumes

Exhibit 7

Alternative PT (mainly BEV and HEV) sales rose at ~20% CAGR between 2018 and 2022

Total automotive sales (Volume, '000)



1. Does not include 2W/3W
2. Calculated for total vehicles (sum of PVs, LCVs, large trucks and buses)
3. Includes Ethanol, Biofuel powered flex ICE engines. Excludes gas powered engines (included in ICE); Production data used as proxy for sales

Source: S&P Global AutoInsight (June 2023); S&P Global Mobility, Light Vehicle Sales Forecast (July 2023); S&P Global Mobility, Medium/Heavy CV Industry Sales Forecast (August 2023); EV-Volumes

The India scenario

In India, the adoption of alternative PTs remains relatively low, with BEVs and HEVs making early inroads. This transition to greener mobility is being driven predominantly by the two- and three-wheeler (2W/3W) and PV segments (Exhibit 8).

Within the PV segment, the penetration of alternative PTs stands at around 25 percent, dominated by HEVs and BEVs. Penetration of HEV and BEVs was negligible in 2018, but has since been growing at a rapid pace, now constituting approximately 3 percent of total vehicle sales.

Meanwhile, in the 2W/3W category, the journey towards alternative PTs has been far more accelerated. Despite an overall sales decline of 25 percent over 2018 to 2022, the number of BEV units sold has grown by about sixfold over the same period. This growth can be attributed to the lower total cost of ownership for electric 2Ws, their prevalence in last-mile deliveries and strong subsidy support through the FAME II scheme.

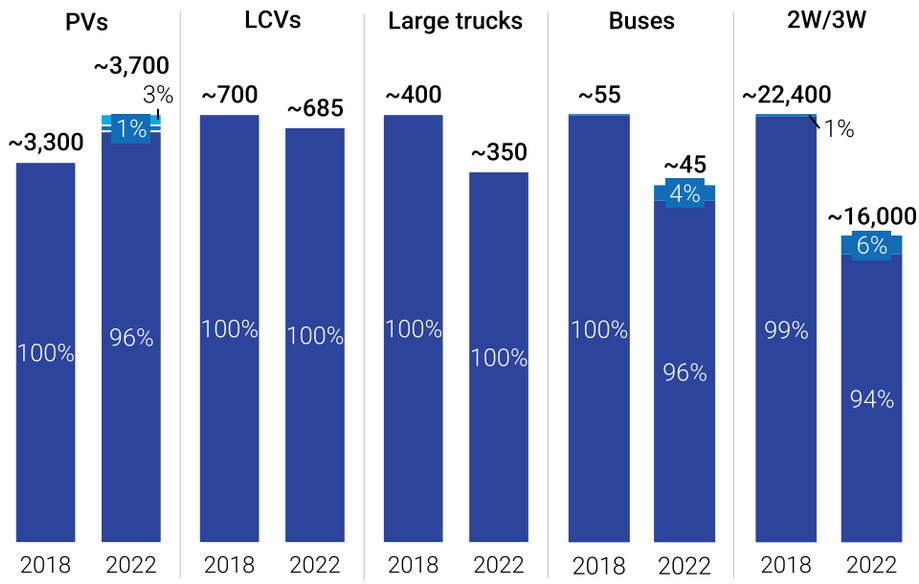
Conversely, large trucks have so far experienced limited adoption of alternative PTs until 2022. Buses have seen a slightly higher adoption, driven by BEVs. The Indian government has, however, tried to promote e-buses through recent initiatives.[17]

[17] 'India approves USD 7 billion plan for electric buses in nearly 170 cities', *Reuters*, 16 August 2023.

Exhibit 8

India currently has low penetration of alternative PTs; it is however growing fast for 2W/3W and PVs

Total automotive sales[1] (Volume, '000)



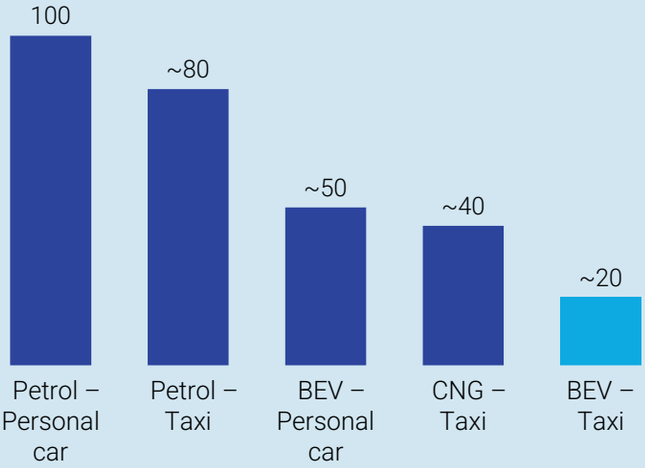
	CAGR[2] 2018-22, %	Penetration[2] 2022, %
HEV	~300%	<1%
BEV	~70%	~5%
ICE	~(7)%	~95%

1. Ethanol, biofuel and gas powered flex fuel engines constitute a substantial percentage of total sales
2. Calculated for total vehicles (sum of PVs, LCVs, large trucks, buses and 2W/3W)

Source: S&P Global Mobility, Light Vehicle Sales Forecast (July 2023); S&P Global Mobility, Medium/Heavy CV Industry Sales Forecast (August 2023); EV-Volumes; SIAM Automobile domestic sales trends; SMEV electric vehicle sales

Rapid growth in shared mobility will aid a faster transition to alternative powertrains

TCO per km for India;[1] Petrol Personal Vehicle indexed to 100



5x

Projected growth in shared mobility user base to 15 cr users by 2030 from 3 cr in 2020[2]

25%

Projected CAGR in shared mobility market size in India from USD 11 billion in 2021 to USD 43 billion in 2027[3]

4-5x

Higher utilisation/km driven per day by fleet vs personal vehicle[4]

1. TCO values calculated for a subcompact (B-segment) vehicle, could vary depending on multiple factors such as average distance driven, type of vehicle, cost of electricity
2. 'Shared Mobility in the Post-Pandemic World', article by Redseer, 11 April 2022
3. 'India's Increasing Demand for Transportation Services Expedites Shared Mobility Market Growth', Frost and Sullivan, 2 March 2022
4. Web search, including, but not limited to 'For Uber, Ola drivers, big dreams come to a screeching halt', *Economic Times*, 17 November 2016 and 'Indian commuters travel 35 km per day, says survey', *Times of India*, 3 March 2018

Source: Analysis of data from multiple sources, including, but not limited to the following: FAME II subsidy notification announced on the website of Ministry of Heavy Industries (accessed in July 2023); 'For Uber, Ola drivers, big dreams come to a screeching halt', *Economic Times*, 17 November 2016

This trend is already being witnessed in Europe, China and the US where ride-hailing players have made strides in fleet electrification, thereby driving an uptick in overall EV adoption. For example, one of the leading global ride-hailing players has made a commitment to completely electrify their fleet in North America and Europe by 2030.

The alternative PT landscape and learnings from around the world

As the world (and India) seeks to reduce emissions in the quest for net zero, a few countries could offer valuable lessons in facilitating a successful transition. Japan, Europe, Brazil, the US and China have emerged as frontrunners in this sphere. The rest of this chapter outlines an overview of their diverse strategies and offers some learnings for India's path towards sustainable mobility.

Japan[18]

~10% ▼
YoY decline in ICE vehicle sales

~1% ▲
YoY growth in alternative PT vehicle sales

CAGR considered between 2018-2022

~40%
penetration of alternative PT vehicles in 2022

Frontrunners among alternative powertrains

HEVs form ~95% of alternative PT vehicle sales

BEVs, though small, growing at ~20% YoY

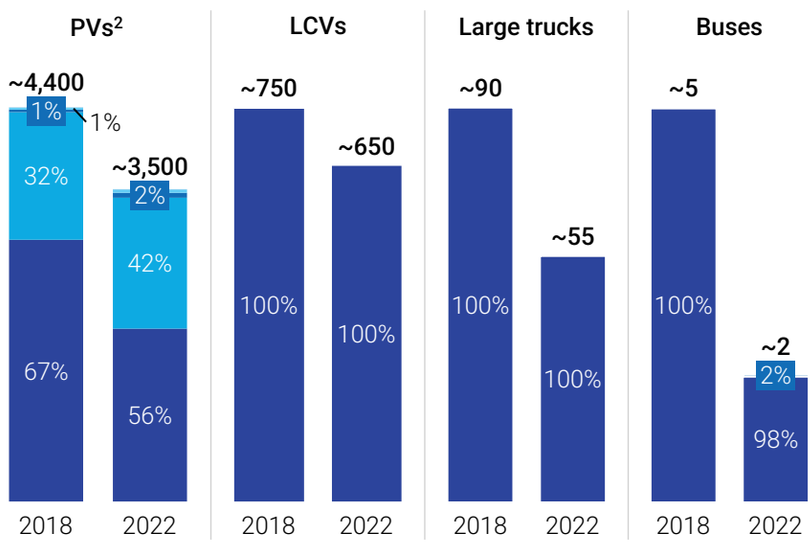
The rising penetration of alternative PTs stems from an enduring shift in consumer preferences in Japan. Government regulations to reduce emissions and falling ownership costs are making EVs attractive. Nearly every alternative PT vehicle in Japan is a passenger vehicle, and of these, approximately 95 percent are HEVs, which account for over a third of Japan's total automotive sales. BEVs too, though still very small, have started to pick up in Japan. In sharp contrast to PVs, LCVs, larger trucks and buses still cling to ICE PTs, with a negligible share of alternative PT sales (Exhibit 9).

[18] Japan landscape numbers are drawn from S&P Global Mobility, Light Vehicle Sales Forecast (July 2023); S&P Global Mobility, Medium/Heavy CV Industry Sales Forecast (August 2023); EV-Volumes

Exhibit 9

Adoption of alternative powertrains has been driven by HEVs in PV segment; however, BEVs are rapidly growing, led by PVs

Total automotive sales[1] (Volume, '000)



	CAGR[3] 2018-22, %	Penetration[3] 2022, %
FCEV	~5%	<1%
PHEV	~10%	~1%
HEV	~1%	~35%
BEV	~20%	~1%
ICE	~(10)%	~63%

1. Ethanol, biofuel and gas powered flex fuel engines constitute a very small percentage of total sales
2. Does not include 2W/3W
3. Calculated for total vehicles (sum of PVs, LCVs, large trucks and buses)

Source: S&P Global Mobility, Light Vehicle Sales Forecast (July 2023); S&P Global Mobility, Medium/Heavy CV Industry Sales Forecast (August 2023); EV-Volumes

The role of the government

With Japan determined to achieve net zero by 2050, the government plays an important role in nudging the automotive industry towards sustainability.

Incentivising fuel efficiency:[19] The Japanese government initially envisioned an automotive landscape powered by a mix of alternative PTs, and adopted a diversified portfolio strategy that included CNG vehicles. Over time, it doubled down on clean energy vehicles (CEVs) by replacing subsidies for CNG vehicles with subsidies of up to USD 8,500 per CEV, alongside tax breaks.[20] The emphasis narrowed to ZEVs in the early 2020s – with the government encouraging BEVs and FCEVs while excluding HEVs from CEV subsidies. For a complete transition to CEVs, the government is considering a ban on new sales of pure ICE vehicles by 2035.

Enhancing infrastructure:[21] The government also plans to enhance charging infrastructure, aiming to expand to 150,000 charging stations by 2030, a five-fold growth from 2021. To bolster local battery production, it dedicated an investment of USD 2.2 billion to expanding storage battery manufacturing, with a plan to reach 150 GWh of production capacity by 2030.

Augmenting hydrogen availability:[22] The government has ramped up supporting infrastructure for FCEVs, with an aim to double the number of hydrogen refuelling stations by 2025 (from 160 established by the end of 2021). It is investing in a hydrogen energy supply chain (HESC) project with Australia to reduce hydrogen costs through supply chain logistics and bulk hydrogen storage. Eleven entities, including prominent Japanese OEMs, infrastructure developers and investment banks, have united to establish the Japan H_2 Mobility Consortium (JHyM) for comprehensive development of hydrogen infrastructure (refuelling stations) catering to FCEVs across Japan.

The actions of OEMs

In alignment with the government's direction, leading Japanese OEMs have embraced the goal of moving to cleaner fuels, with an increased focus on BEVs. Leading Japanese OEMs have collectively invested over USD 165 billion, specifically to advance fleet electrification and phase out ICE. The policies and trends in place could likely point to a dominance of BEVs for PVs and light trucks, and of FCEVs for large trucks and buses.[23]

Europe[24]

~20% ▼
YoY decline in ICE vehicle sales

~55% ▲
YoY growth in alternative PT vehicle sales

CAGR considered between 2018-2022

~40%
penetration of alternative PT vehicles in 2022

Frontrunners among alternative powertrains

HEVs form 50% of alternative PT vehicle sales

BEVs form 30% of alternative PT vehicle sales

[19] Web search, including, but not limited to: 'Japanese government incentives for the purchase of environmentally friendly vehicles', announced on the website of the Japan Automobile Manufacturers Association; Global EV Outlook 2023 published by International Energy Agency; 'Japan aims to electrify nation's new car fleet by mid-2030s', Nikkei Asia, 3 December 2020; and 'Japan's transition to electric vehicles', published on the official website of the International Trade Administration, 7 July 2021

[20] CEVs comprise HEVs, BEVs, PHEVs, and FCEVs

[21] Web search, including, but not limited to, 'Japan increases support for domestic EV battery output', *Reuters*, 16 June 2023 and Global EV Outlook 2023 published by International Energy Agency; Battery Industry Strategy' report by Ministry of Economy, Trade and Industry Japan, April 22, 2022; 'Japan to relax rules on fast EV chargers, jump-starting rollout', NIKKEI Asia, January 4, 2023

[22] Web search, including, but not limited to the following: 'Toyota, Nissan, Honda in 11-firm Japanese consortium to accelerate deployment of hydrogen stations', *Autocar Professional*, 5 March 2018 and 'Japan commits $1.58 billion to HESC clean hydrogen project in Australia', S&P Global Commodity Insights, 7 March 2023

[23] Web search, including, but not limited to, 'Routezero: Japan and the global transition to zero emission vehicles', published by The Climate Group, May 2022

[24] Includes the European Union, European Free Trade Association (Iceland, Liechtenstein, Norway, Switzerland) and the United Kingdom

Passenger vehicles have been the biggest adopters of alternative PTs in Europe with around 50 percent penetration in sales, propelled by BEVs and HEVs.[25] The rapid rise of alternative PTs in Europe could be attributed to a convergence of factors – notably government subsidies and incentives that coincide with at-scale industry efforts. Unlike the trajectory of gasoline prices in Europe (which rose at 2 percent YoY between 2010 to 2023), the prices of alternative energy sources have dropped – battery costs fell by around 15 percent per kilowatt YoY since 2010 and hydrogen prices dropped around 15 percent per kilogram YoY since 2018. This combined decline, the lower cost of electricity per kilometer over gasoline, and government subsidies have effectively lowered the total cost of ownership for all types of EVs, but specifically BEVs and FCEVs.[26]

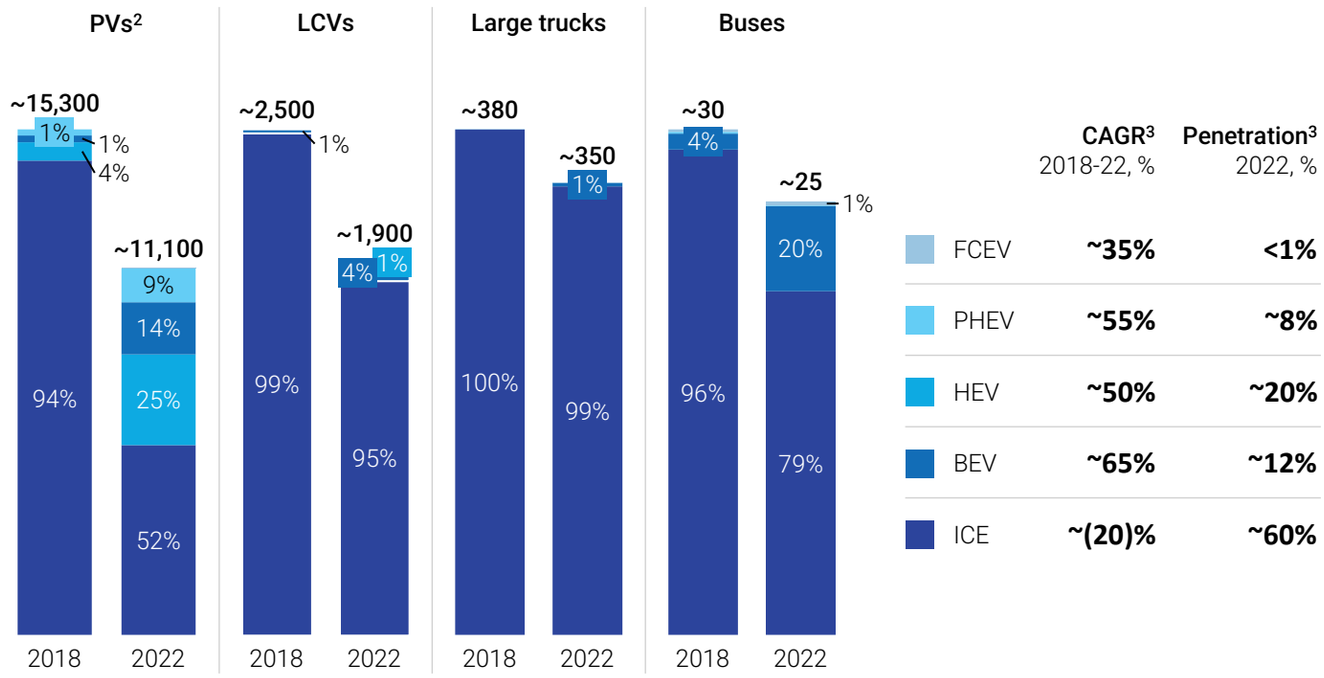
In the domain of commercial vehicles, LCVs are transitioning to BEVs, with segment sales in 2022 at 4 percent of the total. For large trucks, which are predominantly ICE vehicles, BEV sales grew around 13x between 2018 and 2022. Buses saw 20 percent penetration in 2022. Although FCEVs currently have a less than 1 percent penetration in Europe, further uptake is likely, with commercial vehicle OEMs in Europe now planning new model launches in the segment (Exhibit 10).[27]

[25] Europe landscape numbers are drawn from S&P Global Mobility, Light Vehicle Sales Forecast (July 2023); S&P Global Mobility, Medium/Heavy CV Industry Sales Forecast (August 2023); EV-Volumes
[26] 'Lithium-ion Battery Pack Prices Rise for First Time to an Average of $151/kWh', BloombergNEF, 6 December 2022; 'European Commission; Eurostat; MIBEL (Mercado Ibérico de Electricidade)'
[27] Europe landscape numbers are drawn from S&P Global Mobility, Light Vehicle Sales Forecast (July 2023); S&P Global Mobility, Medium/Heavy CV Industry Sales Forecast (August 2023); EV-Volumes

Exhibit 10

Adoption of alternative powertrains has been led by BEVs & HEVs

Total automotive sales[1] (Volume, '000)



	CAGR[3] 2018-22, %	Penetration[3] 2022, %
FCEV	~35%	<1%
PHEV	~55%	~8%
HEV	~50%	~20%
BEV	~65%	~12%
ICE	~(20)%	~60%

1. Ethanol, biofuel and gas powered flex fuel engines constitute a very small percentage of total sales
2. Does not include 2W/3W
3. Calculated for total vehicles (sum of PVs, LCVs, large trucks and buses)
Source: S&P Global Mobility, Light Vehicle Sales Forecast (July 2023); S&P Global Mobility, Medium/Heavy CV Industry Sales Forecast (August 2023); EV-Volumes

The role of governments[28]

European governments have steered EV adoption over time through targeted policies, subsidies, and strict emission mandates (Exhibit 11).

Granting tax exemptions and subsidies: The governments have offered this support with subsidies going as high as about EUR 7,000 per vehicle, in some countries. The subsidy is gradually being reduced as the cost of ICE and electric vehicles reach closer parity.

Establishing strict emission mandates and penalties: The European Commission has imposed a comprehensive ban on new registrations of ICE PVs and LCVs by 2035. The tough penalties on high-emission vehicles have prompted consumers to shift towards adopting ZEVs.

Relocating subsidy funds to expand charging infrastructure and set up other capabilities: By 2022, 450,000 public EV chargers had been installed, reflecting a 50 percent increase from 2021. The European Commission's objective is to have one charging station every 60 kilometers along all major routes within the region by 2026. France, Sweden, Netherlands, the UK and Ireland are adjusting ZEV incentives and ramping up charging infrastructure efforts. To further lower costs, the European Commission is investing in local battery manufacturing, and has made a substantial financial commitment to the Li-ion battery supply chain development and battery-related R&D.

[28] Information in this section is drawn from the European Commission publications and web searches, including, but not limited to, the following: 'Zero emission vehicles: first 'Fit for 55' deal will end the sale of new CO_2 emitting cars in Europe by 2035', press release by the European Commission, 28 October 2022; 'Communications and roadmap on the European Green Deal', report by European commission, january 15, 2020; 'Europe has over 450,000 charge points at present', Electrive.com, 20 April 2023

Exhibit 11

As BEVs market has matured (~12% penetration) in 2022, EU is rolling back vehicle-level subsidies and focusing investments on ramping up infrastructure to support higher adoption

Country	Incentive rollback	Focus on charging infrastructure
France	**Reduced incentives for EVs from EUR 7,000 in 2021 to EUR 6,000 in 2022 and EUR 5,000 in 2023.** However, the purchase incentive for lower-income households was increased from EUR 6,000 in 2022 to EUR 7,000 in 2023	Plans to **invest approximately EUR 2.5 billion to support the production of approximately 2 million EVs by 2030** Allocated **EUR 300 million to aid charging** installation projects
Sweden	In light of closer price parity between EV and ICE cars, Sweden **stopped incentives from Nov 2022**	**Charge-the-car grant** covers up to 50% of the cost of EVSE materials up to EUR 1,000-1,5000 for individuals and corporations per charge point **Fast charging grant** of up to 100% of the costs of fast charging public-use EVSE
Netherlands	Gradually reduced subsidies year-on-year, with a **EUR 400 reduction between 2022 and 2023**	
UK	**Subsidies for EV PVs ended in 2022,** having exceeded a 20% sales share (grant was gradually reduced between 2016 and 2021); **Subsidies remain in place for electric taxis, vans and trucks, as well as for company cars** with new tax exemptions	**Approximately EUR 1.9 billion of govt funding** has been committed to supporting the EV Infrastructure Strategy, **to install 300,000 public chargers by 2030** Also planning to **increase the availability of on-street chargers in residential areas**
Ireland	Ireland has **reduced average incentive from approximately EUR 3,500 in 2021 to EUR 3,070 in 2023**	

Source: Web search, including, but not limited to, 'Global EV Outlook 2023 Policy Developments', published by International Energy Agency, April 2023 and 'Changes to grants for privately purchased electric vehicles, a press release by the Department of Transport, Ireland, 22 March 2023

Brazil

~2% ▼
YoY decline in ICE vehicle sales

~100% ▲
YoY growth in alternative PT vehicle sales

CAGR considered between 2018-2022

~80%
penetration of alternative PT vehicles in 2022; majority from flex fuels

Frontrunners among alternative powertrains

16x increase in EVs, while flex-fuels maintain high share

HEVs form ~80% of EV sales in 2022

BEVs form ~15% of EV sales in 2022

In a departure from global trends, Brazil's automotive sales are dominated by flex-fuel PTs which enjoyed almost 80 percent penetration in 2022 (Exhibit 12). EV adoption remains significantly low in comparison, due to concerns around the reliable availability of clean electricity and adequate charging infrastructure. In the near term, PVs lead the transition towards alternative PTs, with HEVs (and early signs of a shift to BEVs and ethanol-powered hydrogen fuel cells) supported by government initiatives and OEM investments.

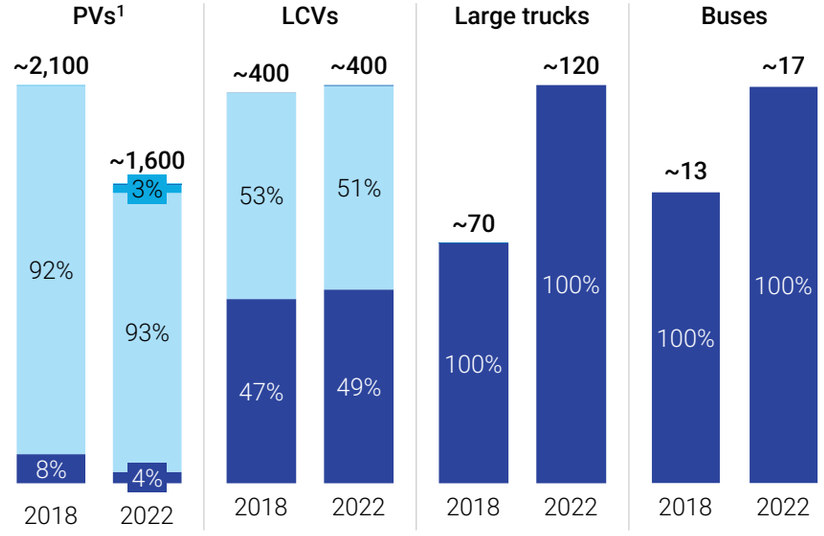
Large trucks and buses in Brazil remain almost entirely ICE-powered. Some OEMs are introducing trucks powered by biogas PTs, with biogas trucks already in the market.[29] With BEVs constrained by a higher total cost of ownership and infrastructure bottlenecks in context of the commercial vehicles segment, the long-term strategy (driven by policies and OEM investments) is seeing a shift to FCEV PTs in addition to biogas within this segment.[30]

[29] 'Brazil roadmap for natural gas and biomethane heavy duty trucks and buses, report published by gov.br, July 2021
[30] S&P Global Mobility, Light Vehicle Sales Forecast (July 2023); S&P Global Mobility, Medium/Heavy CV Industry Sales Forecast (August 2023); EV-Volumes; web search; S&P Global AutoInsight (June 2023)

Exhibit 12

Vehicle sales in Brazil are largely dominated by flex-fuel powertrains; uptake in EVs is growing with dip in flex fuel vehicle volume

Total automotive sales (Volume, '000)



	CAGR[2] 2018-22, %	Penetration[2] 2022, %
Flex Fuel[3]	~(5)%	79%
PHEV	80%	<1%
HEV	~100%	2%
BEV	~185%	<1%
ICE	~(2)%	19%

1. Does not include 2W/3W
2. Calculated for total vehicles (sum of PVs, LCVs, large trucks and buses)
3. Includes Ethanol, Biofuel powered flex ICE Engines. Excludes gas powered engine (included in ICE); Production data used as proxy for sales

Source: S&P Global AutoInsight (June 2023); S&P Global Mobility, Light Vehicle Sales Forecast (July 2023); S&P Global Mobility, Medium/Heavy CV Industry Sales Forecast (August 2023); EV-Volumes

The role of the government[31]

Brazil's journey to adopt alternative PTs and cleaner fuels began when the oil crisis hit in the 1970s and the government made a concerted effort to become self-reliant. A series of policies including programs like Proalcool came into effect to promote flex-fuel, intensifying ethanol production to replace gasoline. These were later augmented through programs such as Prorenova which targeted promoting sugarcane plantation and other biofuels derived from sugarcane.

Over the years, the government has made various efforts to promote alternative powertrains:

Incentivising EV adoption: In 2015, the government introduced legislation to nudge EV adoption, such as exemptions from import tax and a 50 percent reimbursement of ownership tax for EVs. Simultaneously, the government launched efforts to expand charging infrastructure, allocating approximately USD 1.65 billion and mandating electric energy companies to set up EV charging points in cities.

Encouraging biofuel production: The Renovabio program launched in 2017 aims to further expand biofuel production by commercialising decarbonisation through decarbonisation credits (CBIOs). Fossil-fuel producers and importers purchase these from ethanol biofuel producers to meet targets set by Brazil's National Petroleum Agency based on the proportion of fossil fuels they sell.

Restricting fuel consumption: The Rota 2030 program launched in 2018 (to replace the older Inovar program) aimed to cut fuel consumption by 11 percent on average from previously established targets by mandating energy efficiency and fuel consumption tagging for all vehicles.

Accelerating hydrogen availability: The government launched the National Hydrogen Program in 2021, prioritising public and publicly-oriented investment in Hydrogen energy R&D.[32] This program seeks to accelerate the development of a competitive hydrogen market and a low-carbon hydrogen economy through a multi-faceted approach.

The role of OEMs and other entities[33]

While the government is doing its share to embed sustainability, OEMs have also played an important role in the evolution of the automotive industry, both through their investment themes, and their partnership with various entities to innovate for a sustainable future.

OEMs are investing heavily to set up local manufacturing capacity and are launching EV and flex-fuel models. For example, a European OEM is investing heavily and launching two BEV models and 15 EV/ flex fuel models by 2025. A Chinese EV OEM is investing about USD 1.9 billion to produce 100,000 EVs annually.

OEMs are also investing in localised solutions for Brazil, banking on the current trajectory of ethanol-based powertrains, e.g., a Japanese OEM has developed a first of its kind Solid Oxide Fuel-Cell (SOFC) prototype car which consumes ethanol fuel - which is converted to hydrogen using a reformer to power the fuel cell.

Strategic partnerships are emerging as a means to foster this cross-industry collaboration: The University of Sao Paulo has brought together oil and gas companies, energy firms and startups to establish a hydrogen production facility, and unveiled a Hydrogen Refueling Station, dedicated to testing three bio-ethanol-based fuel cell buses.

These collective efforts of the Brazilian government and major OEMs underline Brazil's transformative journey towards sustainable mobility, characterised by a strategic focus on ethanol, incentives for EV adoption, and investments in FCEVs and hydrogen technologies.

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31 The information in this section is drawn from the Brazilian Development Bank (BNDES) and a web search, including, but not limited to, 'EV import subsidies divide Brazil's auto industry', La Prensa Latina, March 16 2023 and 'RenovaBio', published on the website of the Ministry of Mines and Energy, Government of Brazil, 26 April 2021

32 'Brazil publishes National Hydrogen Program', a press release by the Government of Brazil issued on 29 August 2022

33 Information on OEMs and other entities in this section is drawn from web search, included but not limited to: 'GH2 Country Portal - Brazil', published on the Green Hydrogen Organisation website; 'World's first hydrogen-from-ethanol plant will be built at University of Sao Paulo', *Agencia FAPESP*, 23 August 2023; 'China makes a big bet on electric vehicles with Brazil investment', *Aljazeera*, July 20, 2023

United States[34]

~10% ▼
YoY decline in ICE vehicle sales

~35% ▲
YoY growth in alternative PT vehicle sales

CAGR considered between 2018-2022

~17%
penetration of alternative PT vehicles in 2022

Frontrunners among alternative powertrains

HEVs form ~60% of alternative PT vehicle sales in 2022

BEVs form ~30% of alternative PT vehicle sales in 2022

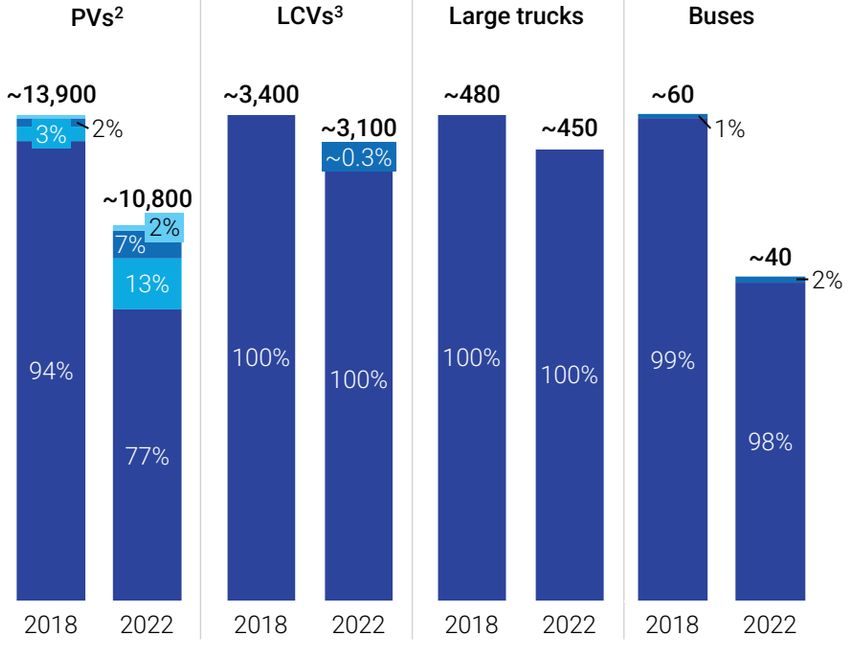
Passenger vehicles represent almost all alternative PT adoption in the US, led by BEVs and HEVs (Exhibit 13). While LCVs are still dominated by ICE, BEV adoption seems to be taking root. In 2022 alone, 58 new BEV and PHEV models were launched in the country. Large trucks resolutely remain ICE vehicles. Conversely, for buses, BEVs seem to be making inroads. These shifts stem from increased consumer awareness, enabling government policies and OEM investments in BEV technologies.

[34] United States landscape numbers are drawn from S&P Global Mobility, Light Vehicle Sales Forecast (July 2023); S&P Global Mobility, Medium/Heavy CV Industry Sales Forecast (August 2023); EV-Volumes

Exhibit 13

Adoption of alternative powertrains has been led by BEVs & HEVs (>35% YoY growth rate and 18% penetration)

Total automotive sales[1] (Volume, '000)



	CAGR[4] 2018-22, %	Penetration[4] 2022, %
FCEV	~5%	<1%
PHEV	~10%	~1%
HEV	~35%	~10%
BEV	~35%	~6%
ICE[5]	~(10)%	~83%

1. Ethanol, biofuel and gas powered flex fuel engines constitute a very small percentage of total sales
2. Does not include 2W and 3W
3. Includes all vehicles falling under <4.5T weight class including pick-up trucks
4. Calculated for total vehicles (sum of PVs, LCVs, large trucks and buses)

Source: S&P Global Mobility, Light Vehicle Sales Forecast (July 2023); S&P Global Mobility, Medium/Heavy CV Industry Sales Forecast (August 2023); EV-Volumes

The role of the government[35]

Both the Federal and State governments are developing and implementing policies to promote alternative PTs in the country, especially EVs. All emission reduction targets, tax credits and financing are aimed at supporting EV penetration, with focus also on incentivising local supply chain ecosystem, and ramping up charging infrastructure to lower total cost of ownership and aid EV uptake.

Setting strict emission targets: While California leads from the front in mandating automakers to shift to electric vehicle sales and encouraging overall adoption of alternative PTs, the Federal government has paved the growth of EVs by introducing a number of policies such as Corporate Average Fuel Economy Standards (CAFE) targets (which have undergone revisions over the years) and GHG emission reduction targets for each vehicle segment.

Offering tax credits: The Federal government has also extended the Clean Vehicle Tax credit to USD 7,500 till 2032, among other credits, with stricter local content and price requirements. Simultaneously, the government also introduced supply side subsidies for the development of a local EV supply chain, of upto USD 35 per kWh for domestic battery production, and an additional USD 10 per kWh for module assembly, which in total, could cover around one-third of total battery cost (on 2022 prices), alongside renewed, and expanded charging infrastructure installation credits.

Easing finance: A strong mover in the sustainability journey has been the government's Inflation Reduction Act (IRA) of 2022, which dedicated funding to accelerate EV adoption including the introduction of "direct elective pay" provisions and simplified tax credit system to enable more EV consumers and suppliers to claim them.

Targeting electrification: The Federal government has set a nationwide goal that ZEVs should constitute 50 percent of all new cars sold by 2030. In 2020, 15 US states came together to propose a full shift to ZEVs in MHCVs by 2050. Recently revised EPA emission norms have reduced the target for Model Year 2032 by 56 percent reduction over Model Year 2026 numbers. The EPA projects that OEMs would need to ensure that 67 percent of their total annual production volume shifts to EVs by 2032 to meet these targets.

Bus electrification is also on the anvil, with USD 10 billion already disbursed by the Infrastructure Law, split between funding for low or no-emission transit buses and school buses (the majority of buses in the country). Transit agencies can also purchase EV buses and related infrastructure through the Highway Transit Fund or other grants.[36]

And finally, to improve density of charging infrastructure, the government's National Electric Vehicle Infrastructure (NEVI) Formula program aims to set up 500,000 fast chargers by 2030 along all major routes across the US. A charging site will be installed every 50 miles, within a mile of all interstate highways.[37]

[35] Unless otherwise stated, the information in this section on the role of government (USA) is gathered from web search, including, but not limited to: 'Global EV Policy Explorer', International Energy Agency, 26 April 2023; 'Global EV Outlook 2023', International Energy Agency; 'FACT SHEET: Biden- Harris Administration Announces New Private and Public Sector Investments for Affordable Electric Vehicles', released by the White House on their official website on 17 April 2023; 'Proposed Rule: Multi-Pollutant Emissions Standards for Model Years 2027 and Later Light-Duty and Medium-Duty Vehicles', press release by the US Environmental Protection Agency, April 2023

[36] FHWA, White House, Bipartisan Infrastructure Law, P.L 117-58, US Code 5339-Grants for buses and bus facilities

[37] McKinsey Center for Future Mobility – EVCI; US DOE Alternative Fuels Data Center; NACS US Convenience Store Count, Inflation Reduction Act

China

~10% ▼
YoY decline in ICE vehicle sales

~50% ▲
YoY growth in alternative PT vehicle sales

~30%
penetration of alternative PT vehicles in 2022

Frontrunners among alternative powertrains
BEVs leading adoption with 60% of alternative PT vehicle sales
HEVs and PHEVs both form remaining 20% each

USD ~27,000
average BEV price in China (approximately half the cost of BEV in US and Europe)

~75%
share of global battery cell production capacity in China

20-25%
lower battery costs in China vs US

CAGR considered between 2018-2022

China's alternative PT story is one of rapid transformation, with EV volumes soaring at about 50 percent YoY growth rate. On the global stage, China leads in share of EV volumes across segments – approximately 60 percent of global PV volumes, approximately 60 percent of global LCV volumes, and approximately 80 percent of global MHCV volumes. China's EV volume in passenger vehicle (cars) segment alone is about 1.5 times that of Europe's and about 3 times that of US'.[38]

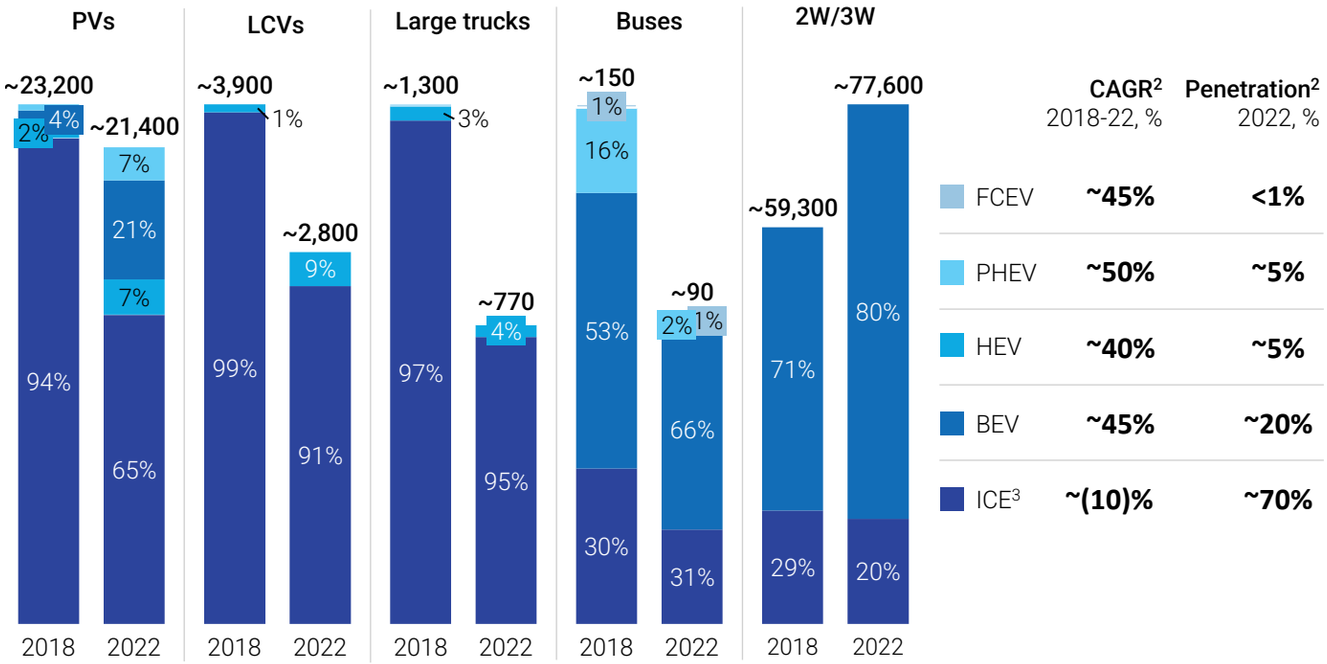
Within China, over the past five years, EVs have drawn away 25 percent of the market share from ICE vehicles. While this transition was initially propelled by governmental policies such as cash incentives and tax exemptions, customers also increasingly prefer EVs as they can choose from sophisticated and diversified EV options. PVs represent approximately 95 percent of all adoption, with BEVs in the lead and HEVs and PHEVs following. In the 2W/3W sector, EVs have reached 80 percent penetration in 2022. Around 10 percent of LCVs sold are BEVs (a CAGR of 45 percent between 2018 and 2022), approximately 5 percent of large trucks and approximately 65 percent of buses sold are BEVs too. FCEVs have also grown three-fold in sales volumes, pointing to a possible uptick (Exhibit 14).[38]

[38] Information for this section is collated from S&P Global Mobility, Light Vehicle Sales Forecast (July 2023); S&P Global Mobility, Medium/Heavy CV Industry Sales Forecast (August 2023); EV-Volumes; International Energy Agency Global EV Outlook 2022

Exhibit 14

Adoption of alternative powertrains in China has been purely EV-driven, led by BEVs particularly in PVs segment

Total automotive sales[1] (Volume, '000)



1. Ethanol, biofuel and gas powered flex fuel engines constitute a very small percentage of total sales
2. Calculated for total vehicles (sum of PVs, LCVs, large trucks, buses and 2W/3W)
Source: S&P Global Mobility, Light Vehicle Sales Forecast (July 2023); S&P Global Mobility, Medium/Heavy CV Industry Sales Forecast (August 2023); EV-Volumes; iResearch report; China Association of Automobile Manufacturers; Frost & Sullivan; China Chamber of Commerce for Motorcycle

A special mention in the case of China is the story of electric two and three-wheelers (E2W/E3Ws). E2Ws (e-bicycles and e-mopeds) constituted 80 percent of all two-wheeler sales in 2020. Banned in most big cities in China since the 1990s to ease traffic congestion, ICE motorcycles and e-scooters remain popular in rural areas – especially the lower-cost e-motorcycles. E-bicycles – authorised for use on all city roads and priced as low as USD 200 – hold the largest market share in China. Post COVID-19 there has been a notable shift in market preferences towards e-mopeds and scooters as a popular option for cost-effective last-mile delivery.[39]

Relative to E2W, E3Ws have grown even more, forming 85 percent of the total 3W sales in 2022. Over 80 percent of demand lies in rural China, where the 3W was always a reliable choice for family commutes and goods delivery.[40]

[39] Web search, including, but not limited to: 'White paper on China's two-wheeled electric vehicle industry in 2023', iResearch, 22 March 2023; '2022 China Two-Wheeled Electric Vehicle Industry White Paper', iResearch, 12 April 2022; 'Supply and demand market analysis of China's two-wheeled electric vehicle industry in 2023: Electric bicycle market demand is the highest', Qianzhan Industry Research Institute, 31 May 2023

[40] 'Asia-Pacific Electric Three-Wheeler Market - Competition Forecast & Opportunities, 2018-2028F', TechSci Research, June 2023

The role of the government

The government of China has steered the adoption of alternative PT vehicles through a mix of phased policy measures and regulatory guidance, with targeted emphasis largely on EVs. It is working towards a sales mix of 50 percent ZEVs and 50 percent Hybrid vehicles by 2035.

Implementing and continuously tightening fuel consumption standards: The government set stringent fleet corporate average fuel consumption standards across all OEMs and corporations. OEMs are compelled to evolve towards EVs to lower their overall consumption levels.[41]

Launching subsidies and incentives for EVs: Between 2009 and 2010, China introduced subsidies and incentives directed at EVs such as the approximately USD 9,500 purchase subsidy for BEVs, accompanied by purchase tax breaks. While the purchase subsidies have been gradually phased out with growing EV adoption, the purchase tax breaks remain and help sustain consumer demand levels. The government's proposed plan to promote only clean energy vehicles from 2035 has also pushed the industry towards EVs.[42]

Announcing complementary policies: The Dual Credit Policy encourages OEMs to intensify their ZEV manufacturing efforts by assigning new energy vehicle (NEV) credits based on their EV production and average fuel consumption of produced fleet. OEMs are required to have at least 18 percent of new energy credits in 2023. Failing that, they may face penalties or be required to acquire credits from other manufacturers.[43]

Developing necessary infrastructure at a rapid pace: China boasts of a favourable EV-to-public charger ratio in 2021 of about 7 vehicles per available charger (compared to a ratio of about 14:1 in EU and 18:1 in the US).[44] Public charger numbers have surged by around 65 percent annually since 2017, reaching 1.8 million units in 2022, with a target of 2.8 million by the end of 2023. With 3.4 million private charging units in 2022, China is likely to have nearly 10 million total charging points to cater to rising EV traffic on its roads.[45] The country has also invested to build robust battery cell production capabilities – comparatively lower labour costs, mature technologies, and economies of scale make batteries far cheaper in China than in other countries.

41 Web search including, but not limited to: 'Fuel economy in China: Part of Fuel Economy Initiative 2021', International Energy Agency, December 13, 2021; 'China: Light Duty Fuel Consumption', Transport Policy.Net

42 Web search, including, but not limited to: 'China to subsidise hybrid, electric car purchases', *Reuters*, 1 June 2020; 'Comparing U.S. and Chinese Electric Vehicle Policies', Environment and Energy Study Institute, 28 February 2018; 'China unveils $72 billion tax break for EVs, other green cars to spur demand', *Reuters*, 21 June 2023

43 Web search, including, but not limited to: 'Dual Credit System', International Energy Agency, February 2, 2023

44 'Which countries have 'enough' public chargers for electric cars?', Sustainability by numbers, April 10, 2022; Global EV Outlook 2022 published by International Energy Agency

45 'Electrifying the Road Ahead: Unlocking China's EV Charger Industry Potential', *China Briefing*, June 26, 2023

Planning ahead for hydrogen availability: China's commitment to net zero also extends to driving growth of FCEVs. The country's comprehensive hydrogen plan for 2021 to 2035 refers to the deployment of 50,000 hydrogen FCEVs on the roads and a commitment to producing 200 metric tons of hydrogen by 2025.[46]

Incentivising EV usage: Few large cities have enacted policies to favour EV over ICE. E.g., Shanghai charges an extra approximately USD 14,000 for ICE registration; Beijing has kept EV cars out of the odd-even rule, allowing them to operate on all days.[47]

[46] Web search, including, but not limited to: 'China to roll out 50000 fuel cell vehicles by 2025, eyes related infrastructure', *Hindustan Times Auto*, 24 March 2022

[47] Web search, including but not limited to: 'Shanghai adds auto plates for public bidding, offering subsidies to lift sales', May 20, 2020; 'Beijing Adds Another Electric-Car Incentive: Rush-Hour Access To Any Road', Green Car reports, June 3, 2015

For all the countries described in this chapter, stimulating consumer demand, supportive government initiatives and investment in appropriate technologies and infrastructure have shaped the journey beyond the gasoline-driven ICE vehicles. A combination of these three is needed to pave the way for any country seeking to embrace alternative PTs in a bid for environmental sustainability.

Embedding circularity for sustainable mobility

3

The automotive sector is witnessing a clear shift away from conventional ICE powertrains. As zero-emission vehicles or ZEVs gain traction, the current concern around high tailpipe-emission levels is likely to gradually give way to an enhanced focus on materials production emissions. The industry could address this through concerted efforts to identify and implement relevant initiatives.

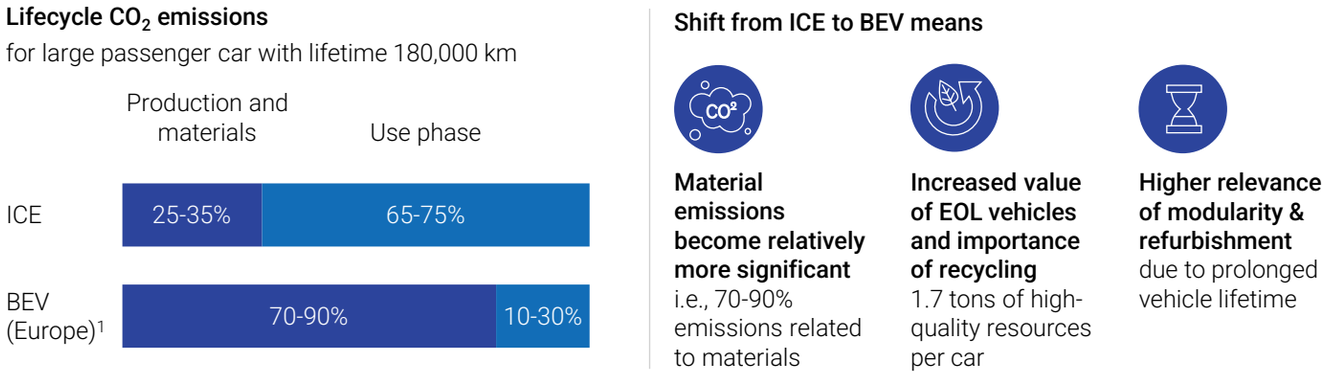
Embedding circularity across the value chain – reducing the use of finite resources and increasing the useful life of products and materials – could be an integral driver nudging the transport sector closer to its sustainability goals.[48]

The emphasis on slashing production-phase emissions

The total lifecycle emissions for a BEV are significantly lower than an ICE vehicle. While use-phase emissions account for almost three-fourth of the emissions during the lifetime of an ICE vehicle, they form a mere 10-30 percent of typical BEV emissions. Materials and production processes form the bulk of the lifecycle emissions for BEVs (Exhibit 15).

Exhibit 15

As penetration of alternative PTs increases, the share of material emissions could increase



1. Assuming green electricity in power mix; use-phase emissions and Production & material emission will vary depending on the emission intensity of electricity production and manufacturing

As a consequence, a model of circularity is gaining regulatory attention from governments around the world, with strict recycling expectations and policies mandating extended producer responsibilities (EPR). Many are already proactively initiating action around challenges such as toxic waste generation, illegal scrappage and recycling rates.

A number of holistic policies have addressed these issues, such as the Inflation Reduction Act (IRA) of 2023 in the USA and the EU Green Deal of 2020.[49] The former aims to combat climate change and reduce GHG from waste products through recirculation of critical materials. The European Green Deal aspires for net neutral GHG emissions by 2050, with the Circular Economy Action Plan serving as a key building block that operates along the entire lifecycle of products.

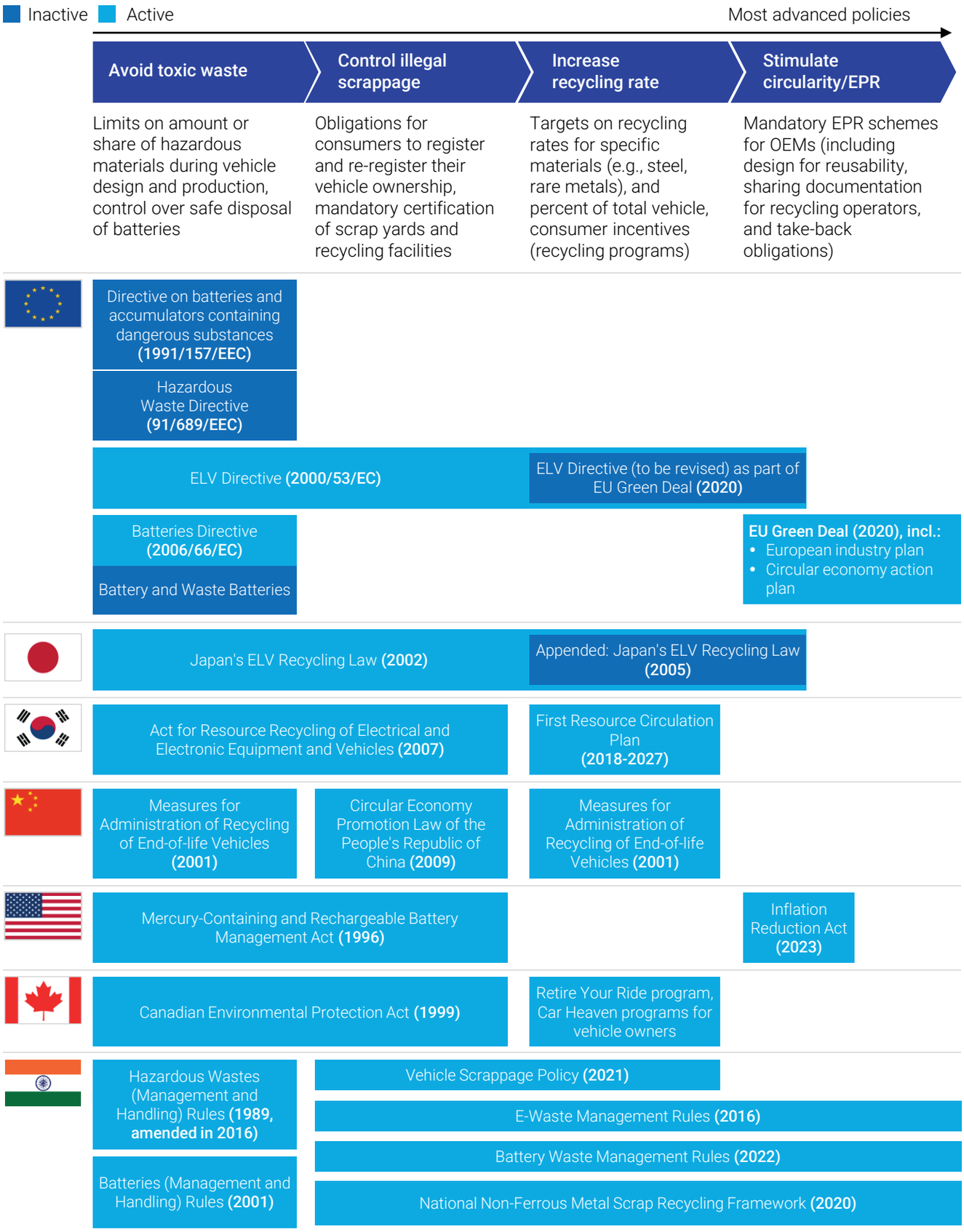
Many governments, including the Government of India, have also enforced vehicle end-of-life laws with clear directives on disposing and recycling vehicles. With each car comprising around 1.7 tons of high-quality resources, such as metals, high-grade plastics and lithium-ion batteries, the end-of-life value of vehicles is also tipped to increase notably. This could heighten the focus on recycling and repurposing (Exhibit 16).

48 Unless otherwise indicated in this chapter, emission calculations, the circularity model and the four value-creation levers presented here draw on research from McKinsey Sustainability Insights and McKinsey Center for Future Mobility

49 Web search, including, but not limited to: 'Providing efficient, safe and environmentally friendly transport', published on the official website of the European Commission, 12 April 2021; 'Advancing a Circular Economy to Meet Our Climate, Energy, and Economic Goals', released by the White House on their website on 5 July 2023

Exhibit 16

Governments around the world are developing policies to address material emissions



Source: Web search, including, but not limited to: 'Providing efficient, safe and environmentally friendly transport', published on the official website of the European Commission, 12 April 2021; 'Advancing a Circular Economy to Meet Our Climate, Energy, and Economic Goals', released by the White House on their website on 5 July 2023

China, for instance, has set a target to recycle 320 million tons of industrial and automotive scrap steel by 2025,[50] while the EU has planned to make battery passports[51] mandatory for each EV by 2026.[52] By 2030, the EU will insist that new products contain at least a 25 percent share of recycled materials, while targeting 50 percent reduction in material footprint and 80 percent recycling of lead-acid batteries.[53]

Cognisant of the emerging scenario, a few OEMs have announced initiatives addressing circularity along design, production, use phase and end of life. From designing products to ensure sustainability, to enabling initiatives like sharing and reusing throughout the product lifecycle, and eventually ensuring maximum recycling at the end-of-life stage, the circular economy principles span the entire product lifecycle. Future cars could contain between 30 to 50 percent recycled content. The current average recycling rate of ELVs is 75 to 85 percent (by weight) for mature markets. OEMs are running pilots to potentially take this figure above 95 percent.[54]

How circularity could make a difference across the value chain

By way of "circularity", companies have typically focused on recycling, re-manufacturing and reusing. However, the term "circularity" has a broader application: as an alternative to a linear business model, it could create a cycle that cuts down resource and energy demand, find ways to recycle materials, use waste to recover value and increase the life of products, components and materials.

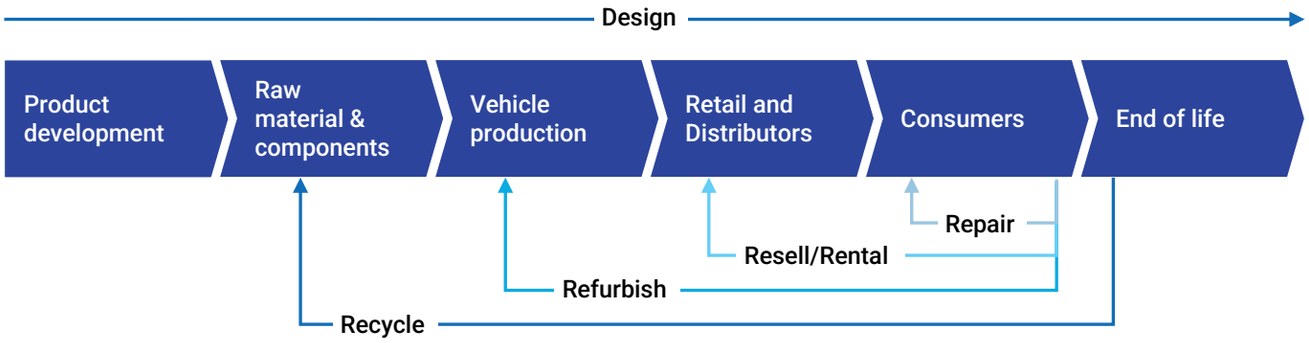
Circularity now spans the entire value chain. To keep products and materials within the value chain, circularity operates as four loops: repair, resell/rent, refurbish and recycle (Exhibit 17).

[50] New From Old: The Global Potential for More Scrap Steel Recycling' report by Institute for Energy Economics and Financial Analysis, December, 2021
[51] The digital system stores relevant battery data along the entire battery life-cycle. It is a key instrument for implementing circular battery value chains based on standardised data
[52] Digital Battery Passports: An Enabler for Sustainable and Circular Battery Management, World Economic Forum, June 2023
[53] Web search, including but not limited to: 'Making batteries more sustainable, more durable and better-performing', press release by European Parliament, 14 June 2023; 'Council adopts new regulation on batteries and waste batteries', press release by the Council of the EU, 10 July 2023
[54] Based on targets published by OEMs on their websites

Exhibit 17

4 circularity loops help keep products and materials within the value chain

Circular segments in automotive sector



Recycle

Manufacturers / recycling providers extract value (e.g., parts, components, materials) from products and **feed it back** into the next **production cycle**

Refurbish

Manufacturers / refurbishers enhance, refresh or refurbish products, which they collected from consumers, and sell those again

Resell/Rental

Owners resell products that are still highly functional, but that they no longer wish to use

Owners rent products from **peers or companies**

Repair

Owners leverage maintenance & repair services (professional or DIY) to prolong the life of their products

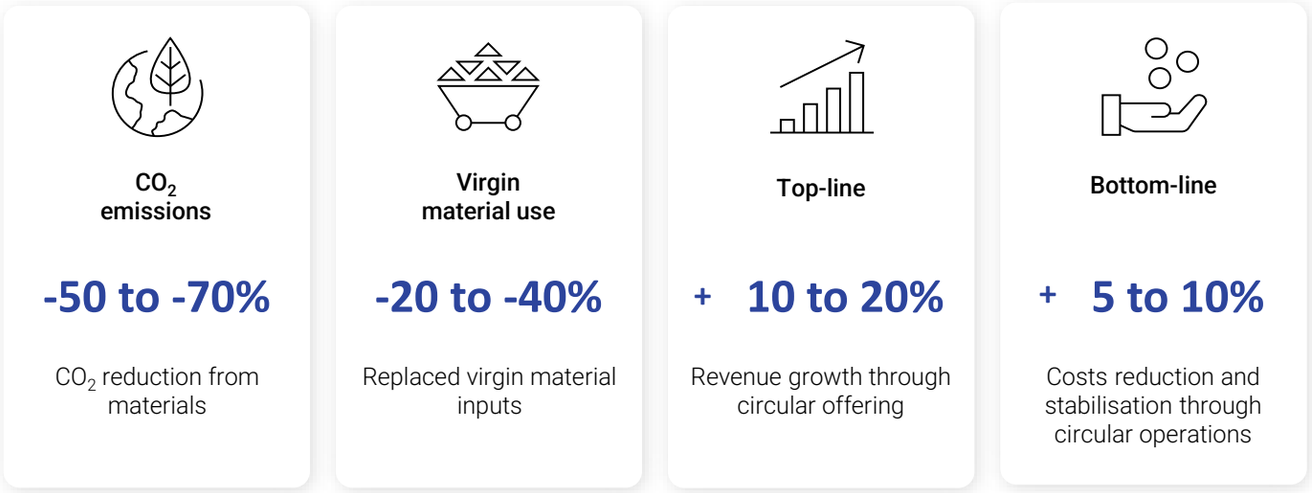
Circularity is more than a sustainability imperative: it also makes business sense. While organisations are likely to consider a circular business model because compliance is mandatory and it helps achieve sustainability targets, adoption would be faster if they also saw its business benefits.

Circularity presents the potential to help boost the top-line and bottom-line of a company (Exhibit 18). The four levers of circularity – recycled material sourcing, circular operations, circular business models and repair & refurbish services – can cumulatively reduce costs by up to 10 percent and yield incremental revenue of up to 20 percent (Exhibit 19).[55]

[55] Material economics estimates

Exhibit 18

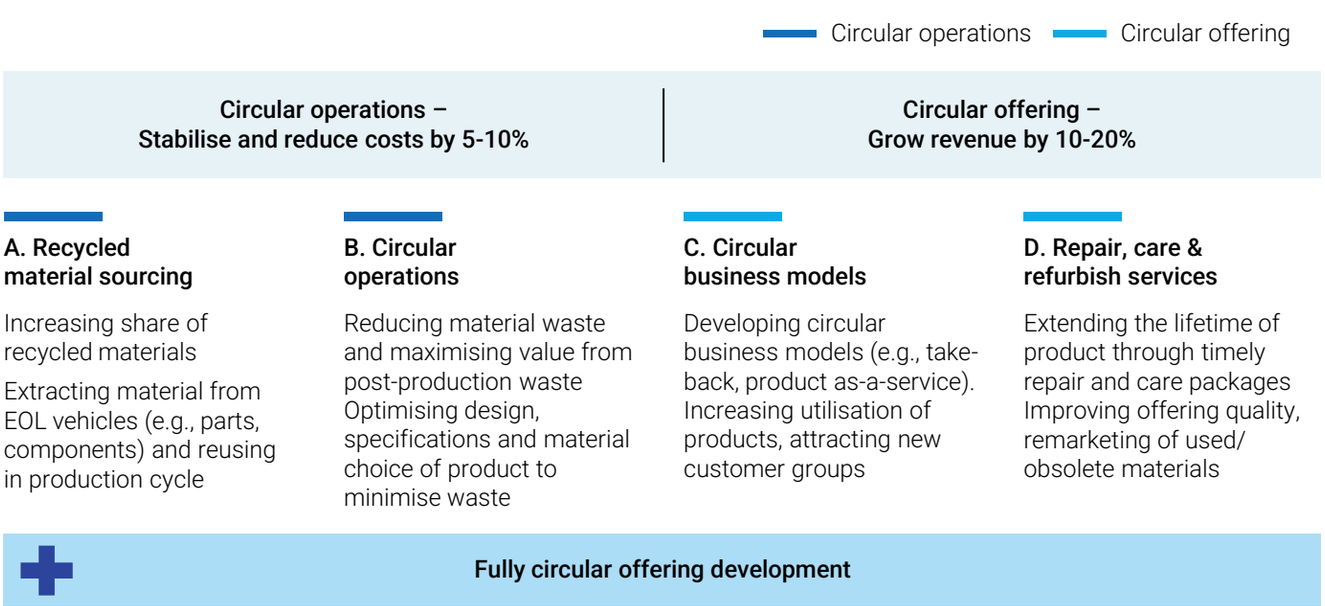
Circularity is positive for the environment, and for the top and bottom-line of a company



Source: Material economics estimates

Exhibit 19

Circularity is driven by a set of value-creation levers



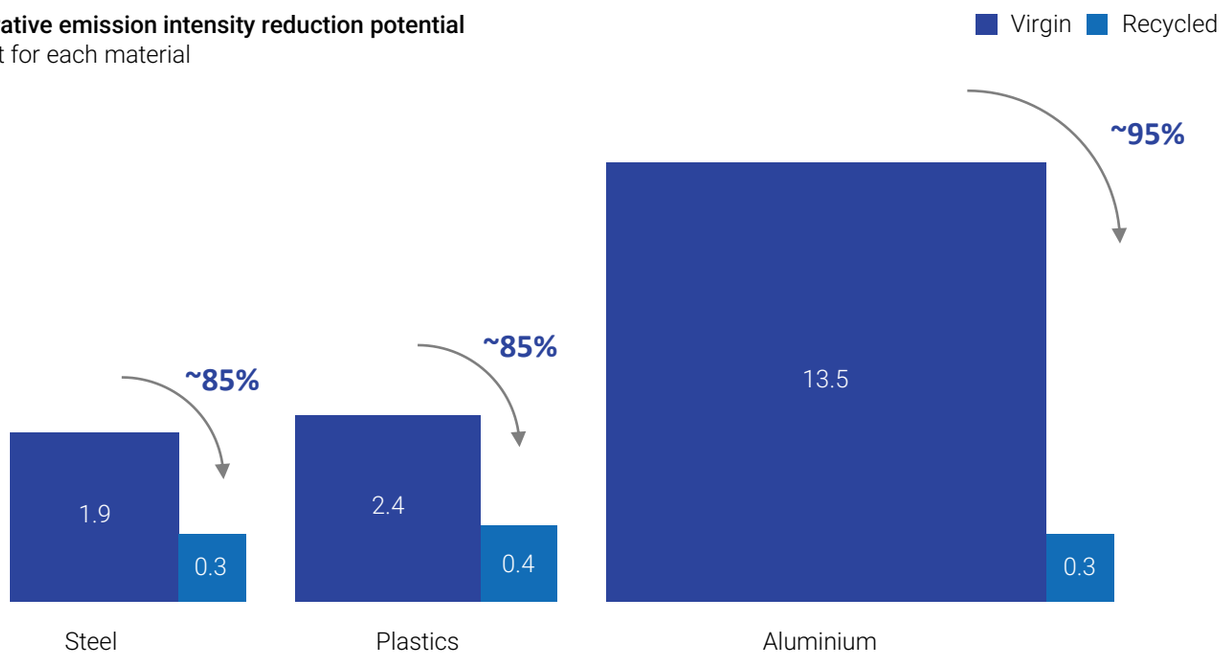
A. Lower emissions and costs from recycled material sourcing

Recycled material sourcing could reduce carbon emissions significantly, while delivering high-quality products. The use of key recycled materials in a typical car can yield 85 to 90 percent lower carbon emissions compared to virgin materials (Exhibit 20). In addition, significant cost benefit could accrue from sourcing recycled materials instead of virgin-quality raw materials.

Exhibit 20

Emissions from recycled materials are significantly lower than those from virgin materials

Illustrative emission intensity reduction potential
tCO_2/t for each material



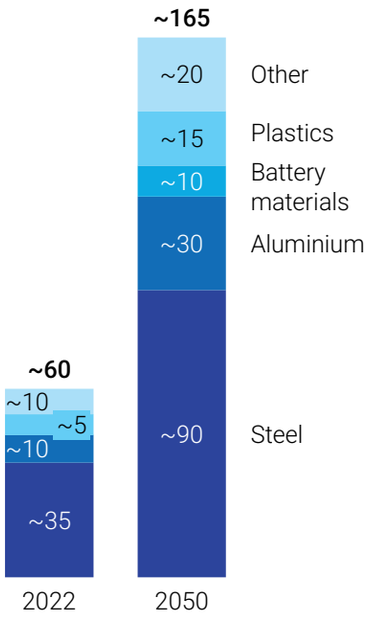
Worldwide, an estimated 165 million tons of potential recyclable materials might become available from end-of-life (EOL) cars by 2050. Vehicle manufacturers could use a part of these to produce new vehicles by building robust reverse supply chains. Implementing recycled material sourcing from EOL cars will necessitate setting up an ecosystem to extract the metals as well as repurpose batteries, plastics and other components (Exhibit 21). Some OEMs have already started taking initiatives to incorporate recycled materials in their offerings, such as reusing materials for seats, fittings, trims and wheels.

This reverse value chain will need to operate across all stages, including collection, assessment and classification, disassembly, dismantling, shredding, implementation of recycling alternatives, and disposal.

Exhibit 21

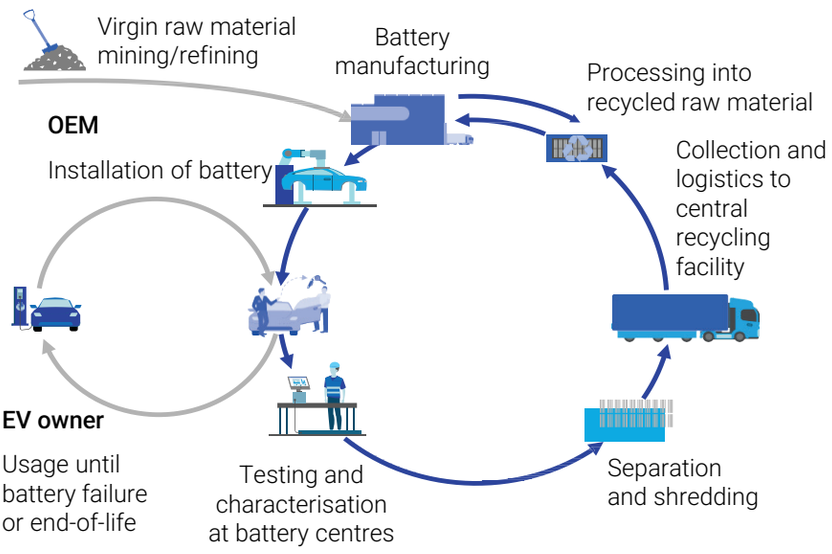
By 2050, EOL vehicles could potentially yield ~165 million tons of recyclable material; OEMs could build backward value chains to tap this source

Materials available from end-of-life vehicles, Global, million tons



Manufacturers will need to build backward value chains and capabilities to use these materials

Example of battery loop recycling



B. Circular operations to create value from production scrap

Circular operations aim to not only reduce material waste, but also maximise value from the remaining waste by creating additional revenue streams. Typically, of the total material used while manufacturing a passenger car, around 40 percent is production scrap (Exhibit 22). Circularity presents an opportunity to reduce waste and valorise the waste that is produced by reusing it in the production process.

Leading OEMs are already implementing processes to create value from waste. One manufacturer has instituted closed-loop recycling, by recycling aluminium scrap generated during production into aluminium alloy sheets. Raising the bar in circularity, a leading German manufacturer is attempting an entirely circular approach to introduce a car and issuing a 3D printing process to manufacture certain parts, which cuts production waste.

Exhibit 22

~40% of the total material used in car production is production scrap; circular operations can help address this wastage

Material inputs for passenger cars, tons per average BEV

1. Includes rubber, glass, copper, other metals

C. Circular business models for increased profitability

Establishing a circular business model could boost revenues and profitability for OEMs. It presents a significant business opportunity – a potential revenue pool of about USD 1.5 trillion by 2030, more than 100 million tons saved in CO_2 emissions and a profit pool of about USD 0.5 trillion.

Circular business models could increase the lifetime performance of OEMs' products through three key levers – sharing, leasing and reuse.

Sharing: A "Product as a Service" business model involves multiple entities using a single product, via subscription or shared mobility options. For example, a Vietnamese automaker has introduced a subscription model for batteries, allowing easy upgrades for better performance while ensuring the proper handling of EOL batteries.

Leasing: Once again, the principle of sharing comes into play, with a longer-term rental business model where the product generates revenue from multiple users over time. OEMs have already started offering this. To cite an example, a European car manufacturer has launched a flexible leasing service where the customer's monthly payment covers vehicle usage, maintenance and insurance.

Reusing: OEMs can resell/reuse products and give them a second life before they reach end-of-life. For instance, two leading automotive companies have entered a joint venture to create an ecosystem where they extract materials and parts from end-of-life cars to repurpose them.

In these ways, the OEMs can save on CO_2 emissions while creating new avenues to enhance profits.

D. Repair, care and refurbish services

The circularity-driven increased focus on care, repair and refurbish could extend the product and material lifetime, while providing alternative sources of revenue to manufacturers and aftermarket players. At the product level, cars once sold can be remodelled, refurbished, upgraded and retrofitted to be sold as second-hand vehicles. While care could entail improved preventive maintenance to extend longevity, repairing could be incentivised to ensure proper maintenance for longer usage. Refurbishment could be implemented through take-back schemes for used components with high remarketing value through second-hand sales (Exhibit 23).

Besides the incorporation of these standalone levers of circularity, a few OEMs and suppliers have started developing an end-to-end circular offering, where they take an integrated view of the entire lifecycle of a vehicle – from design to EOL scrappage.

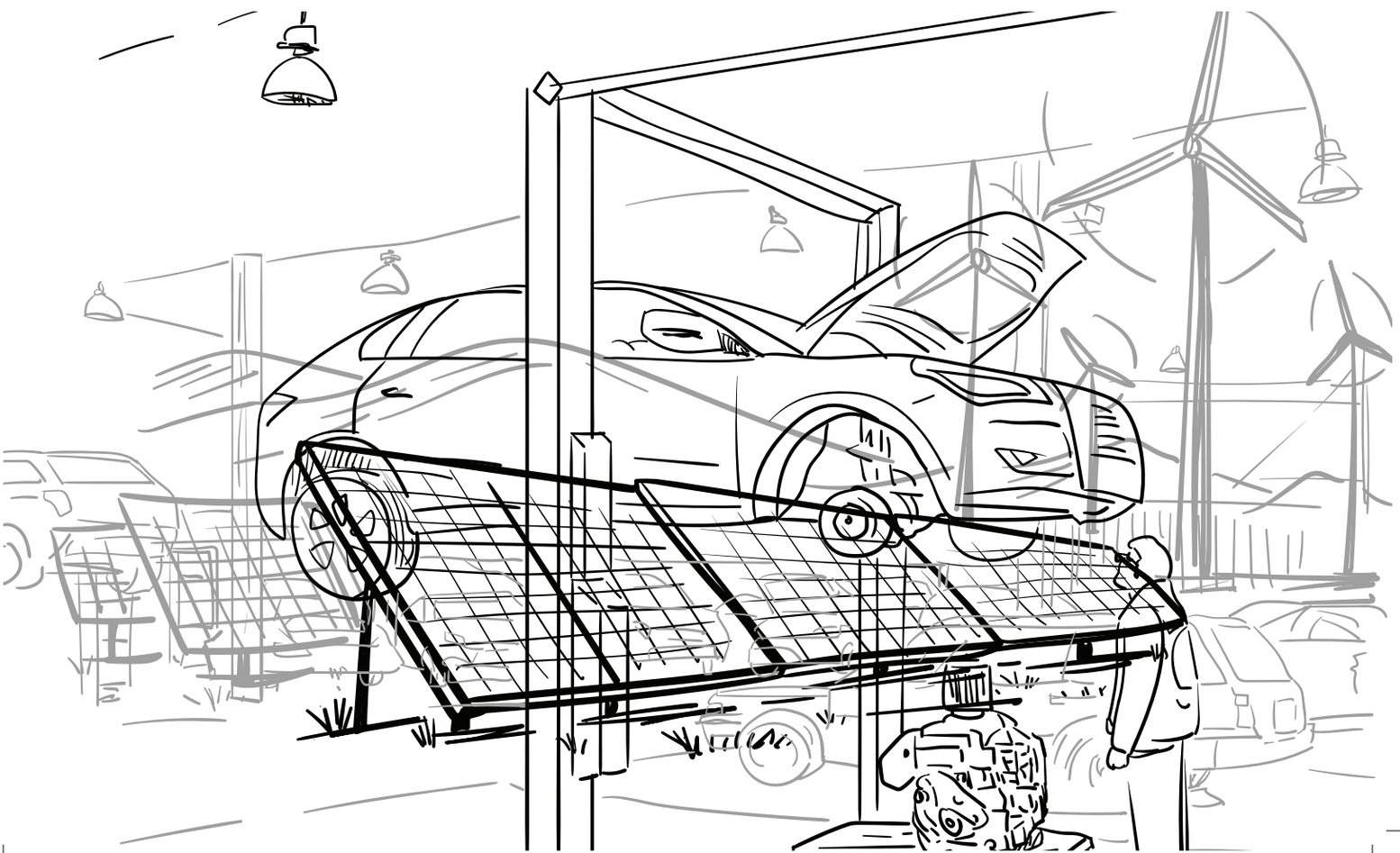
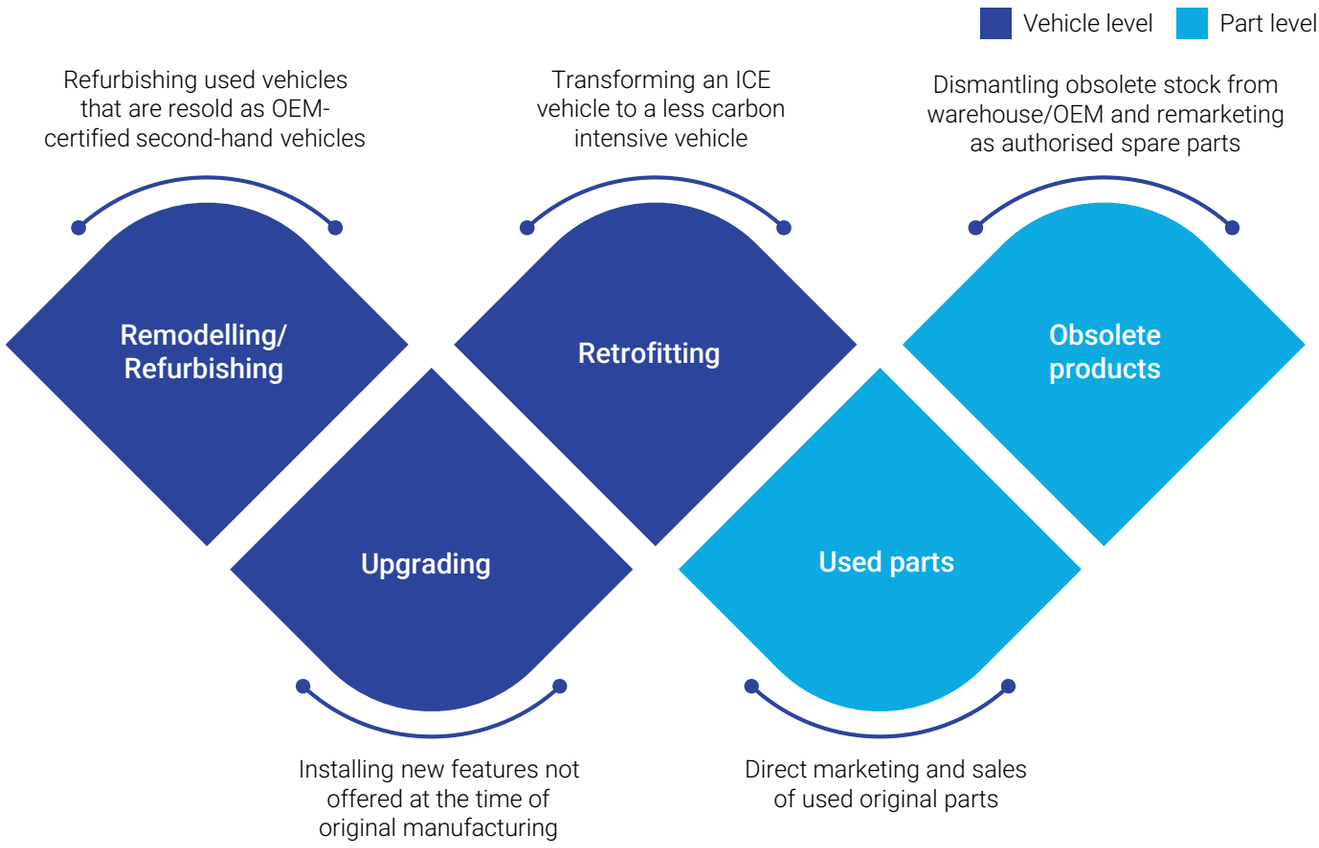


Exhibit 23

OEMs are capitalising on opportunities in the automotive aftermarket to increase product and material life



Source: Web search, including, but not limited to: 'Remanufacturing in the Automotive Aftermarket Picks Up Pace as the Automotive Industry Increasingly Embraces Circular Economy Models', Frost & Sullivan, 21 August 2023; 'Catalysing Circular Economy Practices In Automotive Industry', *Mobility Outlook*, 12 October 2022

Case example: A holistic approach to circularity

An automotive major is leading the transition towards resource neutrality.[1] It is emerging as a pioneer operating across the entire automotive circular value chain. Bringing together the existing expertise of the group and its partners, the company is pursuing closed-loop recycling solutions at each stage of a vehicle's life: supply of parts and raw materials, production, use and end of life.

The company has converted one of its production facilities into a site dedicated to circularity. It has developed key partnerships to retro-fit its cars, re-energise batteries, recycle parts, and research and innovate in the field of circularity at this production facility.

Through this initiative, the company aims to resell its cars and generate EUR 1 billion in revenues by 2030. It aims to have more than 100,000 reconditioned vehicles annually, reusing 60 percent of the batteries in its vehicles put in the market, and recycling 80 percent of EOL batteries to manufacture new batteries.

The objective of the company is to maintain the value of parts and materials for as long as possible and to enable the industry to achieve a much higher rate of recycled automotive materials in the production of new vehicles.

[1] Web search and company website of the OEM

Driving circularity in India

As demonstrated by automotive companies globally, circularity clearly makes sense for the environment, for the net zero aspiration, and for businesses. Yet, India faces real challenges that have to be addressed:

1. **Unorganised recycling facilities in India:** Individual-level capex investments by OEMs and recyclers for end-of-life vehicle material recovery leads to redundancies and low-capacity utilisation.
2. **Lack of integrated facilities:** Low supplier readiness and capability leads to loss of functional and reusable materials; isolated players working on individual value streams (e.g. batteries, steel) are unable to tap cross-sectoral synergies.
3. **Low recovery rates for e-waste, plastics:** Lack of integrated facilities and high number of unorganised players leads to components like plastics and electronics from vehicles getting landfilled and not being recovered due to the high costs (e.g. reverse logistics).
4. **Low demand for recycled raw materials:** With circularity at a nascent stage in the country, there is a limited demand for recycled raw material and much of the end-of-life material is scrapped.

The Government of India has announced a few initiatives that may make a difference to this scenario:[56]

— The Vehicle Scrappage Policy announced in 2021 aims to deregister and scrap unfit vehicles, to reduce emissions and implement EPR by OEMs.

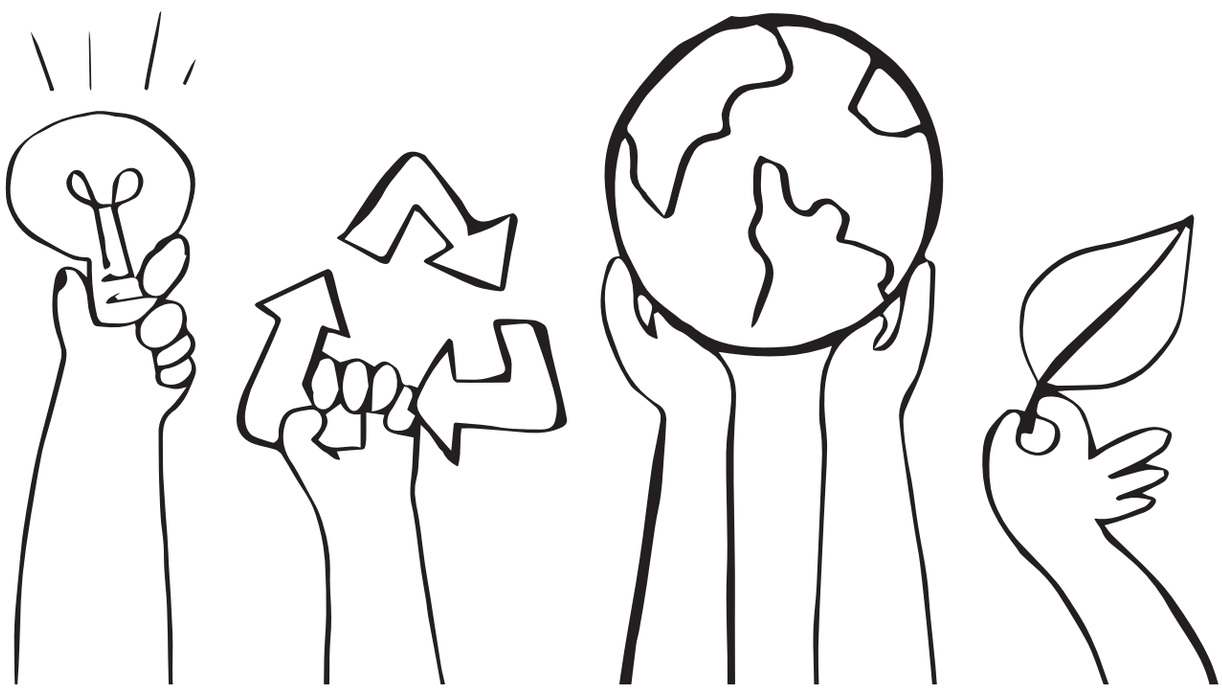
— The e-waste EPR policy implemented in 2016 mandates that all waste batteries be collected and recycled/refurbished (to be sold second-hand) to ensure high material recovery, including cell-level battery recycling.

— EPR policy of 2022 for tyres recommends 100 percent recycling of tyres by 2025. The policy lays out the norms for efficient, ethical and transparent collection, disposal and recycling of tyres.

Furthermore, the government is also planning an EPR policy for automotive (beyond the existing targets for tyres and batteries) to spur producers to adopt environmentally sound dismantling and recycling.

These initiatives are an early start. While many milestones lie ahead, this momentum reflects the belief that circularity could be a game-changer in the bid for a more sustainable automotive value chain. The Indian automotive industry could take up strategic initiatives and collaborate with all stakeholders to adopt circularity in a holistic approach – unlocking sustainability as well as business dividends.

[56] Web search including, but not limited to: 'Road Transport & Highways Minister, Shri Nitin Gadkari Announces Vehicle Scrapping Policy', *PIB*, 18 March 2021; 'Re-cycling of e-waste', *PIB*, 8 December 2022; 'EPR Portal for Management of Waste Tyre', launched by Ministry of Environment, Forest and Climate Change, GoI



Conclusion

4

Achieving net zero by 2070 in a fast-growing, populous country such as India will need a multi-faceted approach. To further curb its GHG emissions, the transport sector will require coordinated action from the government and the industry.

The momentum already exists, with both these entities setting goals and taking actions to facilitate a net zero transport sector. As the stakeholders evaluate their future actions, it could help to see what other countries – in their journey towards sustainable mobility – have done: what has worked and what has not.

The path chosen by each country is based on the availability of energy, materials and technology. While China and Europe have followed a policy-driven approach to transition to EVs, countries such as Japan and the US have a broader, portfolio-driven approach – leaving the door open for a mix of alternatives. Brazil, on the other hand, adopted a very localised approach, augmenting its local bounty of sugarcane to tap the advantage of ethanol-derived fuels.

A few common themes and learnings emerge from these global stories:

— Most countries have followed a fit-for-purpose approach, e.g., Brazil's focus on flex-fuel, Japan's focus on HEVs.

— Governments have played a pivotal role in nudging the penetration and subsequent adoption of alternative powertrains and circularity measures, with interventions along the following themes:

- **Emission policies** to cap emissions by industries and OEMs and tools to encourage carbon offset, e.g., stringent emissions and CAFE norms , ELV scrappage policies, EPR. Europe is a prime example of countries that have done this, and are moving towards more stringent emission norms and CO_2 regulations.[57]
- **Incentives for compliant OEMs and customers**, such as subsidies and tax exemptions. The US, for example, offers tax credits of up to USD 7,500 to BEV owners. In Europe, OEMs receive incentives to develop the Li-ion battery supply chain for more cost-effective EVs.
- **Focus on infrastructure development** to encourage the adoption of existing and emerging alternatives. For example, China's explosive growth in EVs has happened alongside a growth in public charging infrastructure, boasting of an impressive ratio of about 1 public charger per 7 EVs. The United Kingdom is trying to drive EV adoption by committing about EUR 1.9 billion of government funding to install 300,000 public chargers by 2030.

— OEMs and component suppliers also play an integral role and contribute to the shift by investing in their own R&D resources or driving innovations in production and design. The good news is that many sustainability opportunities have a positive business case already.

— A powerful synergy can come from governments and OEMs working in tandem for rapid, sustained momentum on establishing the right policies and infrastructure while addressing customer needs. The Japan Hydrogen Mobility Consortium is one such cohort uniting OEMs, infrastructure developers and investment banks to set up 400 hydrogen stations for FCEVs in Japan by 2028. Similarly, in Brazil, the University of Sao Paulo is collaborating with OEMs, energy companies, and oil and gas companies to develop localised solutions in the form of ethanol reforming technology.

All stakeholders across the automotive manufacturing value chain understand the importance of cutting down GHG emission levels. With the right support from the government, relevant learnings from around the world, and the determination to make a difference, the automotive industry in India could change the game – bringing the vision for net zero firmly into the realm of the possible.

[57] 'CO_2 emission performance standards for cars and vans', published on European Commission website (Climate Action page referenced in August 2023)

Glossary

BEV – Battery Electric Vehicle

BS-VI – Bharat Stage VI

CAFE – Corporate Average Fuel Efficiency

CEV – Clean Energy Vehicle

CV – Commercial Vehicle

E2W – Electric Two-Wheeler

ELV – End-of-Life Vehicle

EOL – End of Life

EPA – Environmental Protection Agency

EPR – Extended Producer Responsibility

EV – Electric Vehicle

FAME – Faster Adoption & Manufacturing of Electric Vehicles

FCEV – Fuel-Cell Electric Vehicle

GHG – Greenhouse gas

HEV – Hybrid Electric Vehicle

HESC – Hydrogen Energy Supply Chain

ICE – Internal Combustion Engine

IRA – Inflation Reduction Act

LCV – Light Commercial Vehicle

MHCV – Medium & Heavy Commercial Vehicles

NEV – New Energy Vehicle

NEVI – National Electric Vehicle Infrastructure

OEM – Original Equipment Manufacturer

PHEV – Plug-in Hybrid Electric Vehicle

PT – Powertrain

PV – Passenger Vehicle

YoY – Year on Year

ZEV – Zero Emission Vehicle

Notes

SIAM INITIATIVES TOWARDS SUSTAINABLE MOBILITY

सुरक्षित सफर SAFE JOURNEY
An initiative by SIAM

विद्युतीकरण Electrification
An initiative by SIAM

जैविक पहल
BIO-INITIATIVE
by SIAM

REDUCE • REUSE • RECYCLE
चक्रीयता CIRCULARITY
An initiative by SIAM

गैस गतिशीलता GAS-BASED MOBILITY
An initiative by SIAM

H_2
हरित हाइड्रोजन HYDROGEN MOBILITY
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Society of Indian Automobile Manufacturers

Building the Nation, Responsibly.

Core 4-B, 5th Floor, India Habitat Centre

Lodhi Road, New Delhi- 110 003, India

Phone : +91-11-24647810-12, 47103010, Fax: +91-24648222, Email: siam@siam.in

Website: www.siam.in

Social Media Handles siamindia siam SIAMIndia1 siamindia siamindia9379