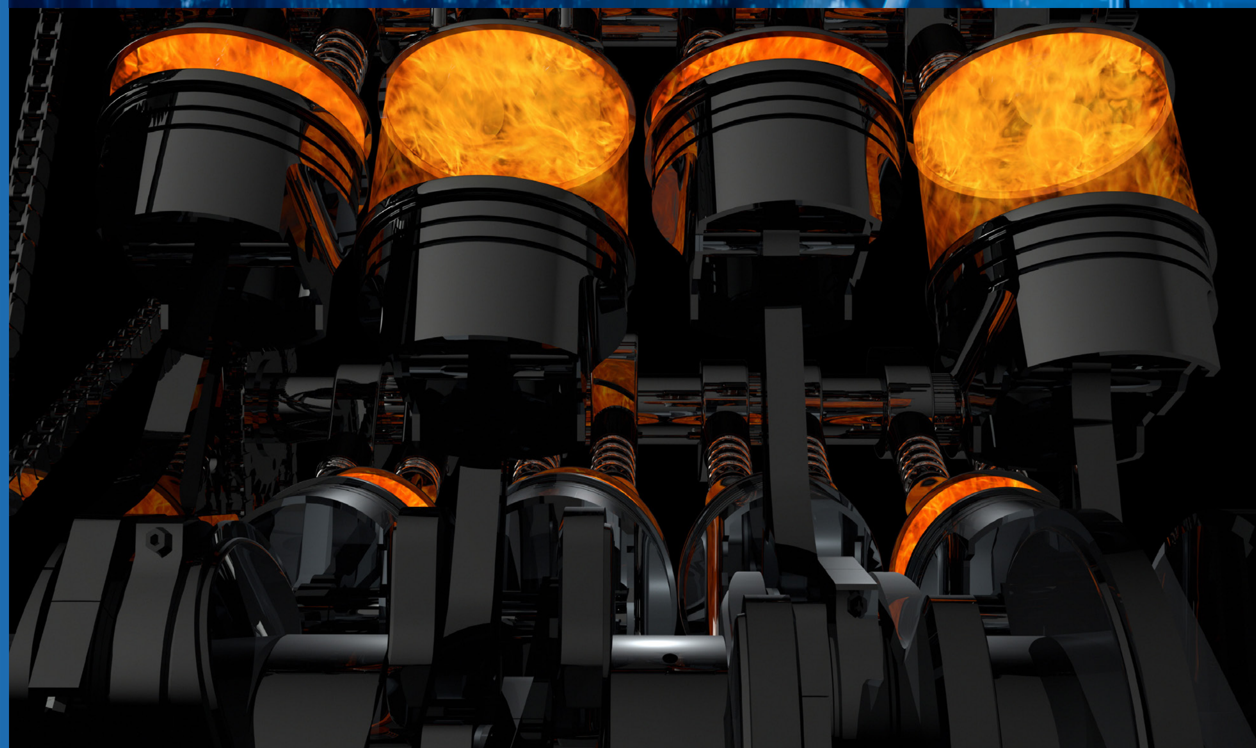
October 2022

2022 - 2040 Powertrain Outlook

KGP
POWERTRAIN INTELLIGENCE



www.kgpauto.com

ADW

KGP POWERTRAIN INTELLIGENCE

About KGP Powertrain Intelligence

Founded as Knibb, Gormezano and Partners in 1988, KGP is a specialist consultancy focused on automotive and related powertrain markets and technology worldwide. Working with various industry partners KGP has worked with 100s of clients worldwide, evaluating market and technology trends, providing strategic assessments of powertrain, related environmental technologies and due diligence.

www.kgpauto.com

Disclaimer
While Knibb, Gormezano and Partners endeavours to ensure the accuracy of the data, estimates and forecasts, provided in this document, decisions based upon them (including those involving investment and planning) are at the client's own risk and Knibb, Gormezano and Partners can accept no liability in respect of information, analysis and forecasts provided in this document.

Contents

Scope

This overview includes Light Personal and Commercial Vehicles <6t GVW, and >6t

Light Vehicles (LV)

Gross Vehicle Weight <6t
Segments: Passenger cars, Light Commercial Vehicles, Pickup Truck
Annual sales 100,000,000
Global Population /VIO >1,000,000,000

Medium & Heavy Truck (MHCV)

Gross Vehicle Weight 6t+
Segments: Medium Truck (6-15t), Heavy Truck (15+)
Annual Sales 3,400,000
Global Population/VIO 3>0,000,000

Heavy Bus

Gross Vehicle Weight 6t+
Segments: Transit Bus, Intercity Bus
Annual Sales 600,000
Global Population /VIO 2,500,000

Methodology

This summary is based on KGP's existing knowledge, with a literature review of key sources, listed on page 30, and interviews with a number of industry stakeholders. Material and battery demand was modelled, based on assumptions listed in the overview, with LMC-Automotive's current Light Vehicle forecast volumes as of August 2022.

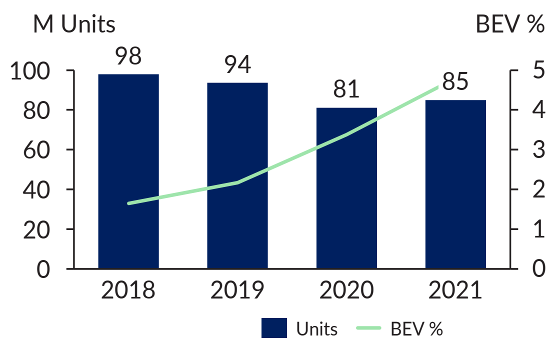
Glossary

BEV - Battery Electric Vehicle
CV - Commercial Vehicle
FCEV - Fuel Cell Emission Vehicle
GDP - Gross Domestic Product
GHG - Green House Gases - CO2, N20, CH4 etc.
GVW - Gross Vehicle Weight
H2ICE - Hydrogen Internal Combustion Engine
ICCT - The International Council on Clean Transportation
ICE - Internal Combustion Engine
IEA - International Energy Agency
k/GWh - Kilo/Gigawatt Hours
KGP-LMCA - KGP/LMC Automotive partnership
LCe - Lithium Carbonate equivalent
LiB - Lithium Ion Battery
LMC - LMC Automotive Forecasting
LV - Light Vehicle
MHCV - Commercial Vehicles >6t GVW
MOU - Memorandum of Understanding
NEDC - New European Drive Cycle
OEM - Original Equipment Manufacturer, Vehicle Manufacturer
PHEV - Plug-in Hybrid Electric Vehicle
VIO - Vehicles in Operation, aka parc, population
WLTP - World Light Duty Test Protocol
ZEV - Zero Emission Vehicle

Background

- This main objective of this report is to provide an independent review of BEV penetration in light and heavy vehicle powertrains to 2040
- Three scenarios examined the trade-offs between BEV (Battery Electric) and ICE (Combustion Engines) as transport is decarbonised to reduce green-house gas emissions, aiming to stay below 1.5 degrees warming compared to pre-industrial levels
- In 2021 BEV share reached almost 5% growing strongly to almost 9% in 2022. This report considers how the powertrain mix varies for each scenario
- All three scenarios are likely to face headwinds related to raw material, engineering and energy resources. Investment levels will need to double in many key areas.

Figure 1 Global Vehicles Sales vs BEV Share 2018-2021



Global Volumes to Recover, with BEV growing rapidly

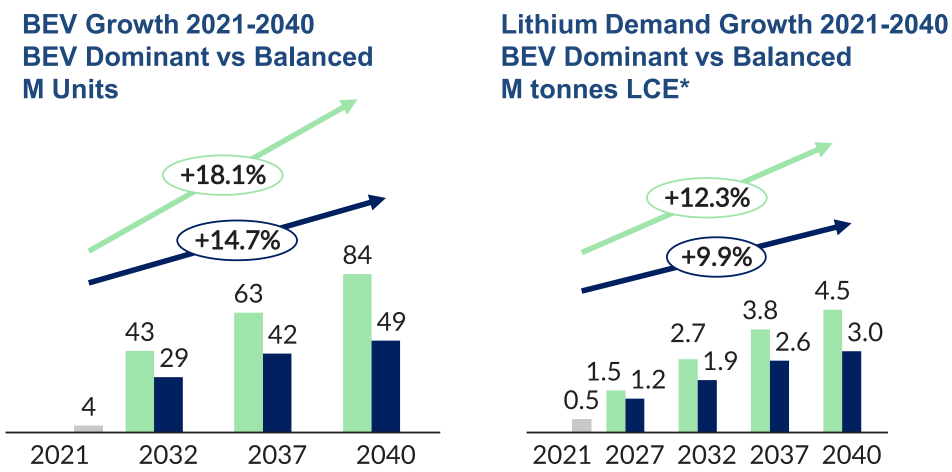
Light vehicle production will exceed 100m units by 2032, medium and heavy commercial vehicles over 6t will be over 4m units.
The fuel mix varies according to the three scenarios as described:

1. BEV Dominant scenario to meet 1.5 degrees warming. Supported by policy, incentives and fuel taxation the BEV share reaches 65% of global sales by 2040
2. The Delayed scenario assumes ICE bans are slowed by up to five years, as investment and supply chain lags policy, and government incentives fall, reducing the BEV share to 51% by 2040
3. In a pragmatic, Balanced scenario, we assessed material supply and matched it to a broader fuel/energy mix. This assumes accelerated supply chain investment, compared to historic levels, but the constrained global share of BEV would be 38% by 2040, with hydrogen and other fuels filling some of the sustainability gap.

All scenarios require significant investment

- All scenarios require significant investment in new vehicle models, renewable energy – generation infrastructure, generation and distribution
- Battery plant capacity growth has outstripped raw material mining and processing capacity, increasing battery prices
- Recycling of raw material will not provide sufficient supply until 2030s
- Other industries, including the grid decarbonisation and domestic consumption will require significant additional raw materials

Figure 2 Global ZEV Vehicles Sales (M), Lithium Demand Growth 2021-2040

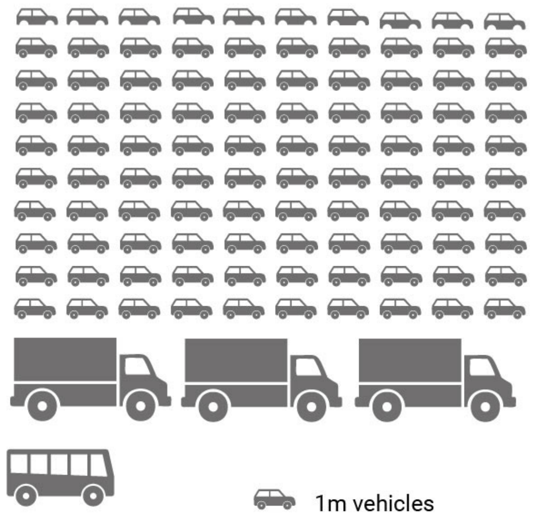


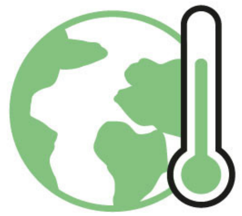
*Incremental Automotive Demand only

Conclusions

1. The Current pace of investment into the infrastructure as well as the raw material and supply chain is too slow to achieve Net Zero and BEV penetration targets as we see today.
2. However, the most constraining factor is the actual availability of the key raw materials needed to support the BEV production and associated infrastructure build-out. This may cause a short-fall in BEV penetration from 65% to 38% by 2040, with smaller and more efficient batteries. Mining industry lead times, costs, geopolitics and a lack of resources could dramatically delay raw material supply.
3. A more 'Balanced' fuel mix strategy is needed to sustain traction on the roadmap to Net Zero, as improved raw material supply, infrastructure and consumer affordability factors converge.
4. The demand for ICE and PHEVs, alternative fuels and hydrogen are expected to take up the slack in these intervening decades, providing ongoing and robust demand for these engines, technologies and the associated raw materials, such as PGMs for improved autocatalysts, well after 2040, particularly in developing markets, and harder to decarbonise segments.

c110m Vehicle sales per year by 2032





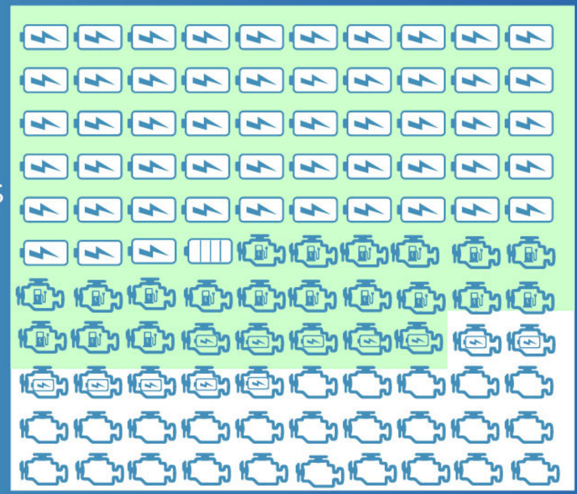
1.5° Target

Vehicle Volumes to Rebound, Post COVID, Supply Chain and Ukranie-Russia crisis. Vehicle sales will reach c110m in 2032. BEVs grew strongly during the 2020 & 2021 reaching 7% share in early 2022. Global Warming and GHG reduction has become imperative, Transport Accounts for 25%, of which PC 15% and CV 6%. In 2021 just under 4m electric light vehicles, 8k trucks and 50k buses sold were zero emissions worldwide.

High and Low BEV Scenarios for 2037

2037 BEV Dominant

51% Zero Emissions



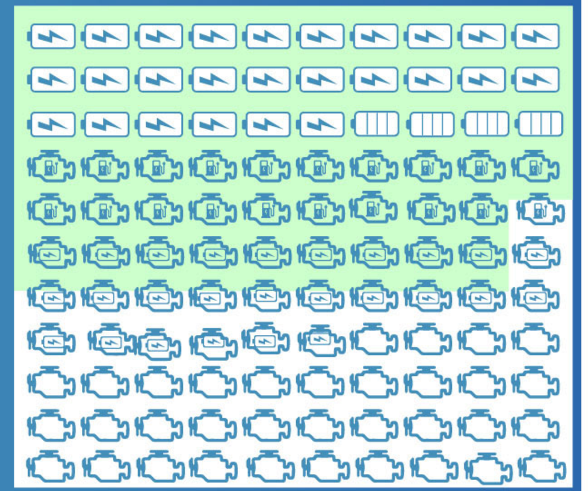
BEV	**63m**
FCEV	**0.5m**
PHEV	**19m**
HEV	**16m**
ICE only	**25m**

Battery Demand 5,400GWh
Non-Automotive Applications 10%
~5-7Kg Lithium per Battery (C-Segment)
60kWh Average

67% with AER

2037 Balanced Scenario

37% Zero Emissions



BEV	**42m**
FCEV	**4m**
PHEV	**23m**
HEV	**23m**
ICE only	**32m**

Battery Demand 3,800GWh
Non-Automotive Applications 13%

55% with AER

Estimated Growth Rates to 2037

	Li Lithium	Ni Nickel	Co Cobalt	Cu Copper	Nd Neodyium	Pt Platinum	Battery	Renewables	Chargers
BEV Dominant	12.3%	3.1%	6.3%	0.9%	>10%	-1%	11.7%	>12%	20%
Balanced	9.9%	2.1%	4.6%	0.6%	>7%	1%	10.4%	>12%	10%
2017–2021 CAGR:	>10% Lithium	2% Nickel	10% Cobalt	2% Copper	10% Rare Earths	15% PGM	20% Battery	10% Renewables	10% Public Chargers
	China share of processing >80% in 2021	Russia share of battery grade Ni 25%	Large share from DRC, non-sustainable 80% used for batteries	Widely used for all xEV, energy transmission, distribution and renewable generation	Rare earths include Nd, Dy, etc. 85% of supply from China	Increased share for fuel cells, electrolyser, Iridum to grow significantly	China share of cell production was c80% in 2020	Renewable Investment Transmission & Distribution Investment 2x past decade rate	Chargers Recharging Infrastructure Investment plus smart grid requirement

The Global Industry

Up to 100m personal light vehicles, 23m light commercial vehicles and 4.4m heavy vehicles to be sold worldwide by 2040.

Global light vehicle demand is expected to recover post-COVID, exceed 100m units by 2027, similar to the 2019 level. By 2050 additional growth may see volumes exceed 110m annually, a level originally forecast for 2026. Although the Russia-Ukraine crisis is likely to have a short term impact both economically and on supply chains we expect the volumes to recover towards the end of the forecast period. Inflation and interest rates, along with the threat of global recessions remain a downside risk factor however.

The focus is on new vehicle sales, as drivers of demand for raw materials, but the impacts of economics, drivers on the vehicle population and renewal rate will impact the future market, both impacting air quality and GHG emissions, but also raw material supply from recycled sources

With the population of light and heavy vehicles in excess of 1.2Bn, the cumulative volume over the forecast period exceeds this, so both new and in-use vehicles need to be considered from an economic and environmental point of view in any strategic developments. The sector is one of the world's largest single employers, with millions employed at vehicle OEMs, their supply chain, but also in aftersales and related services.

Figure 3 LV Sales Forecast (Million Vehicles)

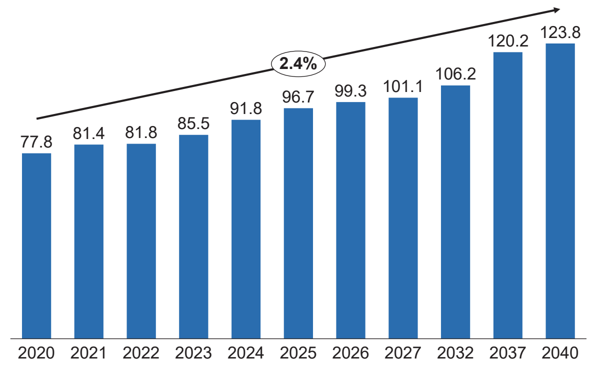
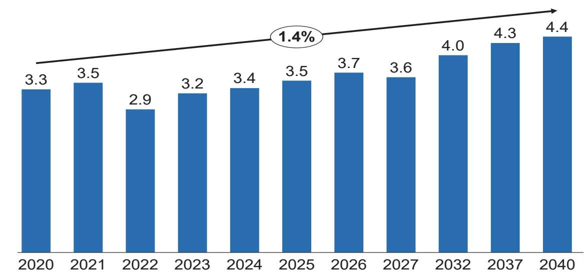


Figure 4 CV Sales Forecast (Million Vehicles)



Source: LMC-Automotive

Transport - a Key Global Industry

Transport accounts for 24% of global GHG emissions from energy, of which LV 45-50%, CV 27-30%, accounting for >3% of economic output, employing ~14m directly worldwide in production of vehicles and components.

Three Markets Dominate

China, USMCA, EU&EFTA accounted for 68% of sales in 2021, rest of Asia adds a further 17%.

Forecast for transport demand sees share of major economies decline slightly over time, although remaining dominant through 2040

- Light vehicle demand increases as wealth rises
- Commercial vehicle demand increases according to GDP and industrial output
- To meet Net Zero targets economies need to decouple personal and freight transport demand from carbon emissions.

Figure 5 LV Market Forecast (Million Vehicles)

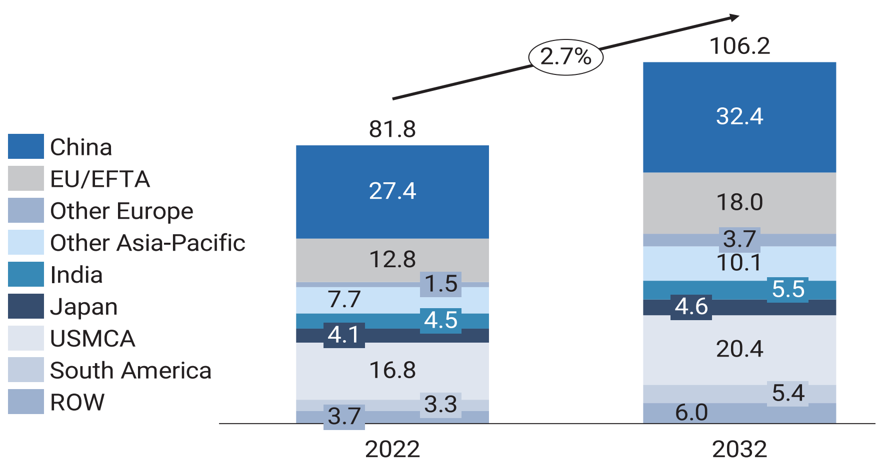
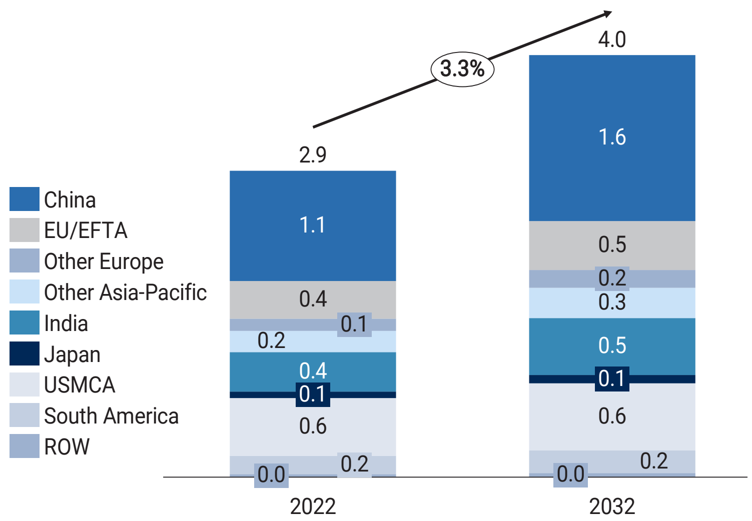


Figure 6 MHCV Market Forecast (Million Vehicles)



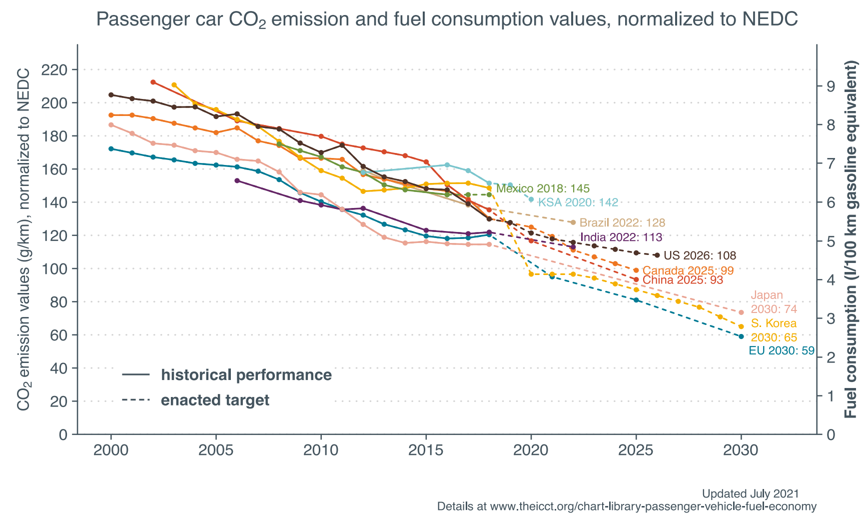
GHG Milestones

Pre-Paris Agreement targets, then ZEV mandates will drive BEV

LV GHG Legislation

Tailpipe emissions for CO_2 has only been regulated widely since the mid-2000s, with all major economies adopting limits and tightening them through the '10s and early '20s. These have allowed ICE to remain in widespread use as the slow pace of electrification was based on CO_2 and GHG targets set in the mid-10s, based on an 80% reduction in GHG by 2050. Since the Paris Agreement however many markets have tightened this to a Net Zero, or 100% reduction in GHG by 2050. This shift introduced an imperative to reach zero emission new car sales in the 2030s, with trucks following 5-10 years later, based on a 10 year useful life. EVs to date were largely driven by subsidies and early adopters.

Figure 7 Light Vehicle CO_2 and Fuel Consumption Targets (Source ICCT)

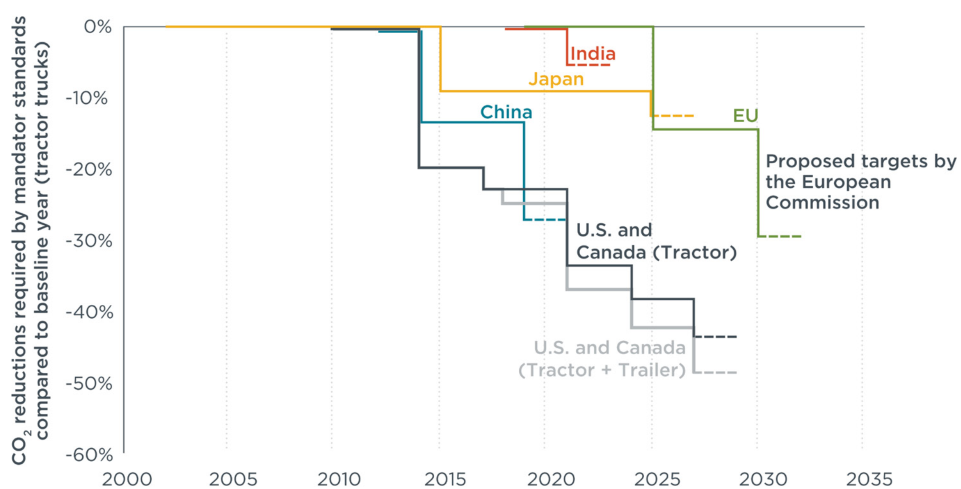


CV GHG Legislation

As GHG and fuel economy targets for light vehicles were adopted, targets have been adopted for heavy vehicles. These have accelerated in the early '20s and legislation for Net Zero by the early 30s has been implemented. The Triad markets, USA/Canada, EU and Japan, plus China and India, collectively account for 80% of global volume are targeting 30% plus reductions on average.

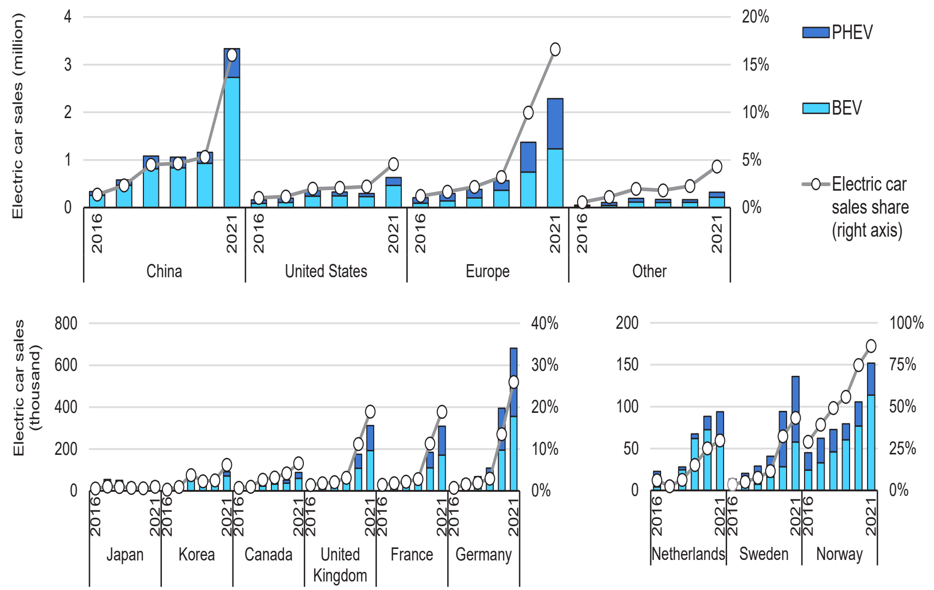
Although GHG targets are based on tailpipe emissions the drivers are for EVs shifting to being TCO and mandate driven, with legislation including strict CO_2 per vehicle, ICE bans, supported by subsidies in many markets. In California the Advanced Clean Truck legislation requires a minimum share of zero emission vehicles, dependent on segment by 2030. A broader MOU will see other US states adopt the same targets.

Figure 8 Heavy Vehicle CO_2 and Fuel Consumption Targets (Source ICCT)



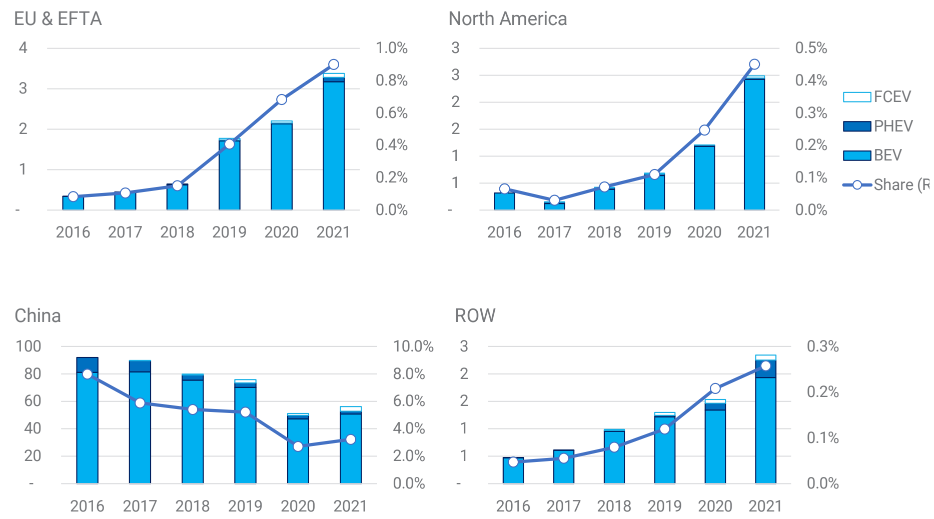
GHG Milestones - Electrification

Figure 9 Light Vehicle Electrification History (000s Units LH/% Share RH)



Source: IEA Electric Vehicle Outlook 2022

Figure 10 Commercial Vehicle Electrification History (000s Units LH/% Share RH)



Source: KGP-LMCA Global Commercial Vehicle Powertrain Forecast xEV 11/2021

Light Vehicle

Light vehicle electrification is growing in all markets driven by early adopters, incentives and TCO

Significant incentives have supported growth in many markets, further supported by policy and industrial strategy in China for example. European markets have followed with Germany having the highest incentives, but distorting demand, as consumers are buying new cars and selling outside Germany for inflated prices.

Global LV BEV Share 7% in 2021

Other fuels included Ethanol (Brazil), Methanol, LPG, Natural Gas, Hydrogen. Bio-fuels are widely adopted blended into fossil gasoline and diesel, as well as 100% blends in some markets. Total gasoline c50m units, diesel 5m (Europe and LCV), Electric 2m. Hydrogen is very limited in light vehicles.

Heavy Commercial Vehicle

Heavy Vehicles driven by urban emissions, incentives (Bus) and TCO (Truck)

Heavy vehicle electrification is starting from a lower base than light vehicles, due to the challenges of energy density. Incentive programmes are becoming more widely available, but long haul electric truck availability is still very limited. Electric powertrains are therefore mainly found in bus options and delivery trucks.

Global CV BEV Share 2% in 2021

Diesel is dominant in the CV segment, with over 90% of global volume. Electric has a significant and growing share in bus, and later truck. Natural gas, and bi-methane, both compressed and liquefied also has a notable share. Renewable diesel (HVO) is also growing. Later we expect hydrogen to be widely available for fuel cells, but also potentially for hydrogen combustion engines.

Net Zero by 2050

Figure 11 IPCC Projected global GHG Emissions

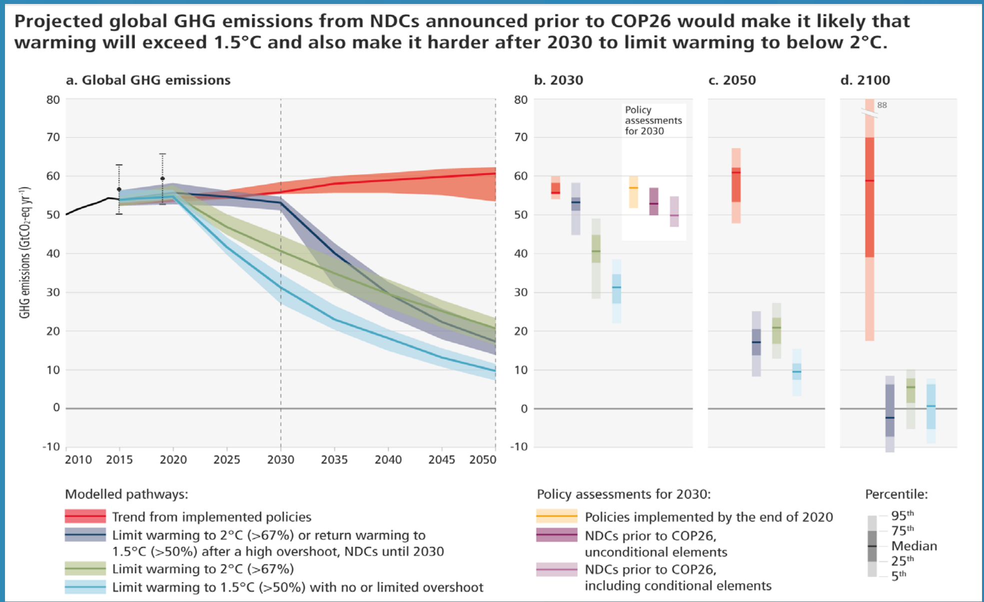
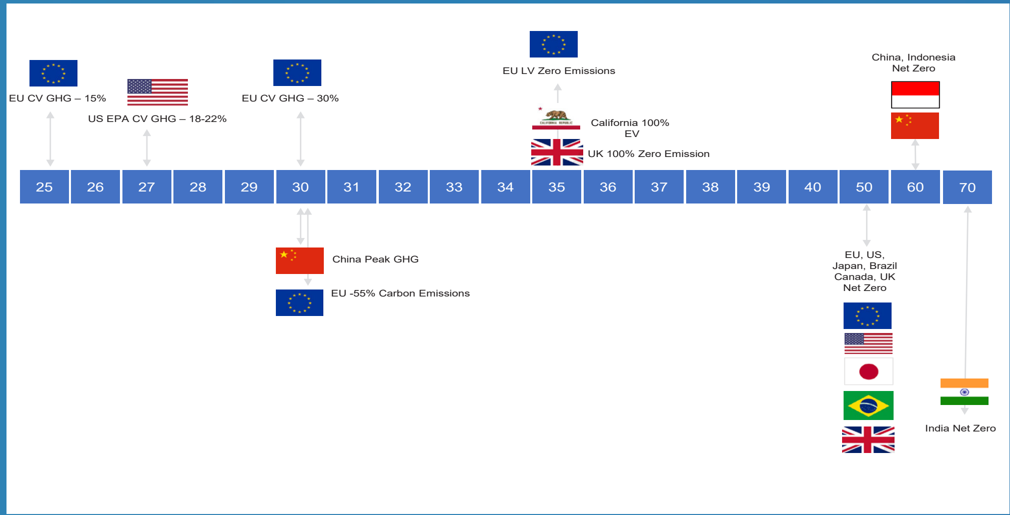


Figure 12 GHG Targets Enacted Since 2019



Net Zero Pledges

Following COP21 in Paris, the Paris Agreement as it is now known agreed to limit the global rise in temperature to 2.0 by 2050. Further pledges since have seen a target to keep the rise down to 1.5 degrees, but it seems likely the target will overshoot.

GHG Targets

To meet the more stringent targets there has been an increase in countries Net Zero targets, which have been tightened to Net Zero, rather than a 80% reduction in carbon emissions by 2050. These have been supplemented by tighter CO_2 reductions, and increasing Zero Emission Zones, plus mandates against fossil fuel ICEs.

xEV Scenarios 2030 to 2040

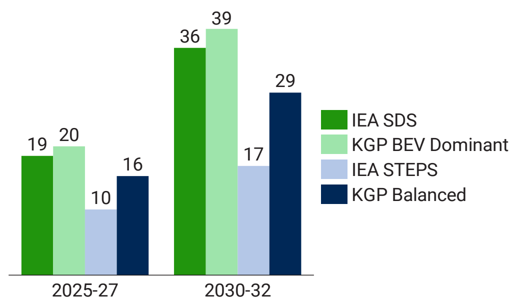
The pace of adoption of electric vehicles remains uncertain. Increasing Zero Emission mandates increases forecast share, but there are many challenges to the increased pace of adoption.

Market Acceptance remains uncertain

Excluding customer acceptance related to cost and range, for now, the three major barriers for the transition are

1. Model availability,
2. Fueling and energy, and
3. Resource/material availability.

Figure 13 IEA Industry Forecasts Vs KGP Scenarios BEV Share %

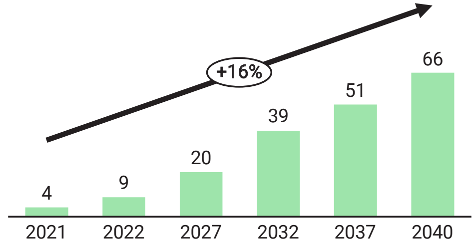


Economic, Energy, Social and Geopolitical Issues

To meet demand for electric vehicles the growth in charging infrastructure, renewable energy and distribution capacity must also increase significantly, especially for heavy commercial vehicles. Under the scenarios put forward by the IEA these must increase rapidly. Business models in the commercial vehicle sector will need to evolve, with a risk to smaller fleets that are unable to invest in up-front vehicle and infrastructure costs. Mandates and policy in the US (California regulations and the federal IRA - Inflation reduction Act), China's ongoing NEV policy and Europe's ICE ban support volumes as do high fossil fuel prices.

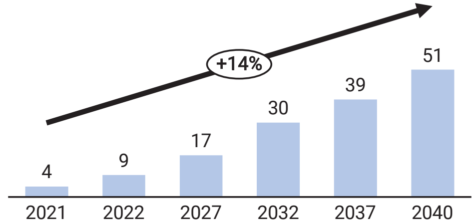
BEV Dominant

Figure 14 BEV focused scenario ZEV Share % (Inc. FCEV)



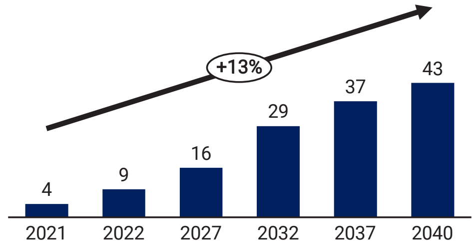
Delayed

Figure 15 Delayed BEV dominant scenario ZEV Share % (Inc. FCEV)



Balanced

Figure 16 Balanced Scenario ZEV Share % (Inc. FCEV)



BEV Dominant Scenario

The BEV Dominant scenario targets a 1.5 degree warming by 2050, based on new government pledges worldwide. It considers mainly BEV to meet the targets and limits other Zero/Low Emission options.

+ ICE banned in many markets by 2035
- Significant resource, renewable energy requirement
- Infrastructure capacity may also constrain reaching targets
- Highest Lithium, Nickel requirements
- Cost.benefit of more stringent noxious emissions limited

Balanced Scenario

Broader mix of solutions to meet Net Zero, with lower BEV share, higher FCEV and PHEV, with smaller batteries. Increased charging points, but lower energy demand

+ Higher mix of alternative fuels, with some ICE (Incl. H_2)
+ PHEV share increases, with mid-sized batteries
+ Widespread domestic plus workplace charging
- Needs incentives to ensure PHEV run as ZEV
+ Noxious emissions harmonisation for ICE

Delayed BEV Dominant Scenario

A 3rd scenario considering the impact of a five year delay to ICE bans for Net Zero on the resource requirements and investment.

+ ICE banned in many markets by 2040
+ PHEV required for all developed markets in interim
+ Battery technology and resource availability improves
+ Grid and renewable infrastructure ramps up

Conclusions

Reaching Net Zero with recent rate of investment, capital and resource availability will be challenging. A broader mix of powertrains may be required to optimise the short and medium term penetration, but a delay in full electrification may be the most likely outcome.

Alternative Powertrains

Fuel Mix to diversify

+ Renewable electricity direct - battery
+ Renewable hydrogen fuel cell or ICE
+ E-Fuels
+ Advanced Bio-Fuels
+ Renewable electricity - catenary

A broad fuel mix will be needed to meet Net Zero targets.

BEV is likely to dominate as the alternative fuel in all scenarios as battery technology reaches a wider share of the market . However the volume for hybrid, fuel cell and ICE is widely different across the three scenarios. In all cases fossil fuels will be replaced by advanced bio-fuels, E-fuels in some applications, with direct electrification growing most quickly. Circularity will be required to switch from food based bio-fuels to waste streams.

Figure 17 ICE/HEV Share by Scenario %

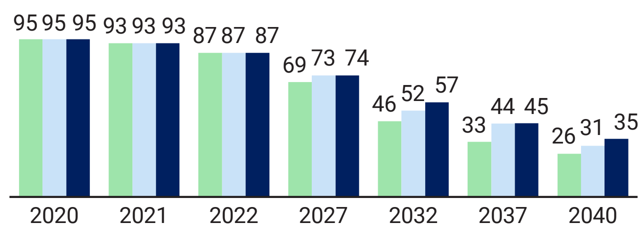


Figure 18 BEV Share by Scenario %

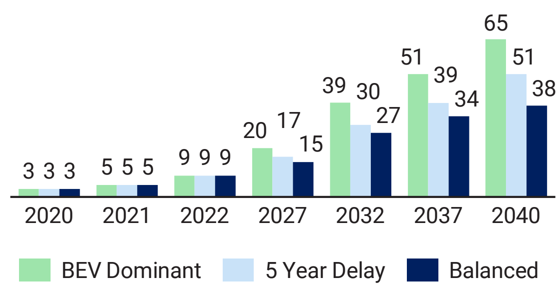
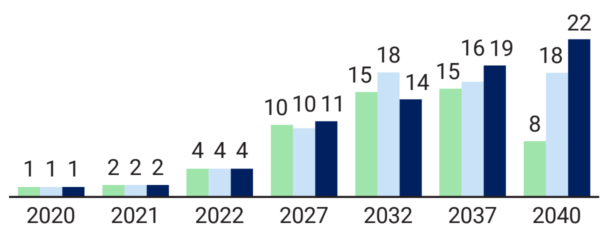


Figure 19 PHEV Share by Scenario %



ICE/HEV

ICE has dominated automotive production for over 100 years, and volumes are only now starting to fall, with 90% globally, down from 99% in 2015. Through the forecast period ICE will fall, but remain relevant in many markets and end use segments. Share will be lost to BEV predominantly, but also pure ICE will be replaced by hybrid (HEV) and plug-in hybrid (PHEV). Zero emission ICE could however be achieved with hydrogen or ultra-low emission with E-Fuels.

BEV

BEVs are the focus of current product launches, as OEMs try to position themselves for Net Zero, but also compete against new entrants, and their incumbent competitors, as well as meeting more stringent CO2 targets.
Lower overall market volumes, but with high BEV demand has seen their global share grow strongly, and this is forecast to continue in the short term as new models become available. but may be restricted by supply shortages, lower incentives, economic growth, lower fossil fuel prices.

PHEV

Plug-in Electric Vehicles use both ICE and battery electric modes to offer extended zero emission range. OEMs had been planning broader adoption, but incentives are being run out, and there is some criticism that the heavier engine/ battery combination makes the PHEV less attractive when it is not charged. Incentivisation of charging, along with larger newer technology batteries and smaller conventional powertrains may allow PHEV to contribute to the Net Zero target, at least as an interim powertrain.

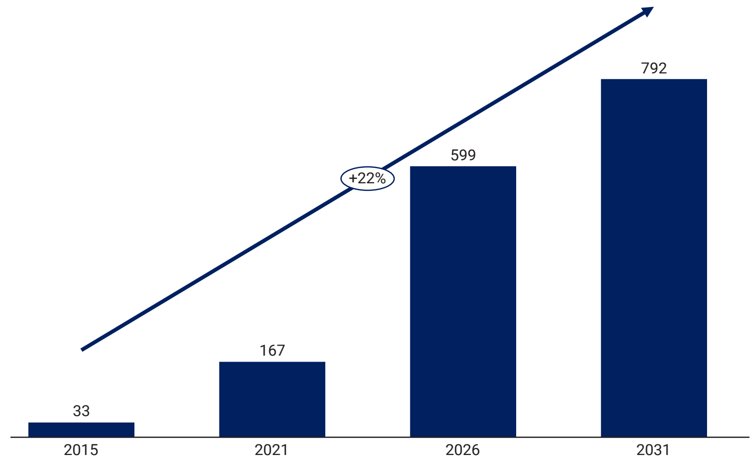
Model Availability

Lack of available models has limited demand historically, but CO_2 legislation is driving OEMs to expand their zero emission ranges

Despite the challenges of investment the supply chain for EVs has evolved quickly, alongside vehicle models. Automotive forecaster, LMC, forecast that almost 800 BEV models will be available worldwide, up from 167, and just 33 in 2015.

In the Commercial Vehicle segment we estimate over 500 models will be available across the truck and bus segments by 2023, including variants, outstripping that of the light vehicle industry, but with a much higher number of variants and lower volumes.

Figure 20 BEV Model Availability



Source: LMC Automotive Global Powertrain Forecast May 2022

BEV models worldwide to reach 799 by 2031, with a CAGR of 22%

Benchmarks

Efficiency is important for the future energy transition, with vehicles needing to improve efficiency to reduce battery and charging requirements. Typical benchmarks for different vehicle types are given below. ICE can continue to become more efficient, and use fossil free fuels. Here we see the average material use, energy efficiency and life-cycle CO_2 for typical of lower-mid-range vehicle globally

BEV - 70kWh

100-400km e
2-4km/kWh

Range/Efficiency

High efficiency, but low range due to poor energy density of batteries.

5-7kg Li, 70kg Cu, 30kg Ni
PGM - 0

Resources

All BEVs have higher raw material requirements, both batteries and motors, depending on chemistry*

10-250g CO_2/km

Lifecycle CO_2

Grid continues to shift to renewables. High fossil grid achieves poor life-cycle emissions

ICE 40l Gasoline (Fossil)

400-600km
5-8l/100km

Range/Efficiency

Improved efficiency, downsized engine, with Euro VI emissions

30kg Cu, PGM 5-7g

Resources

New technologies will reduce emissions, but remain higher than hybrid

100-150g CO_2/km

Life-cycle CO_2

Improving due to CO_2 legislation and micro/mild hybridisation. But needs bio or E-Fuels for lowest Life-cycle CO_2

PHEV 15kWh - 35l Gasoline

30-100km e,
400km Gasoline
2-3km/kWh e

Range/Efficiency

Most efficient when charged regularly, otherwise weight penalty impacts efficiency

2kg Li, 60kg Cu, 10kg Ni, PGM 5-7g

Resources

Less battery materials than BEV, but engine and electric materials greater than ICE

10-300g CO_2/km

Life-cycle CO_2

Grid continues to shift to renewables combined with bio content can reduce CO_2 30-40%

FCEV 5-8kg Hydrogen (Green)

400-600km
1kg/100km

Range/Efficiency

High range than BEV with zero emissions

8kg Li, 60kg Cu, 5kg Ni, 10g PGM

Resources

Similar to BEV, but fuel cell stack and plant combined with smaller battery. Pt requirement for stack high

10-20g CO_2/km

Life-cycle CO_2

Mainly Green Hydrogen, giving low overall life-cycle CO_2

*NB Values are indicated, averages of various sources

Battery Demand

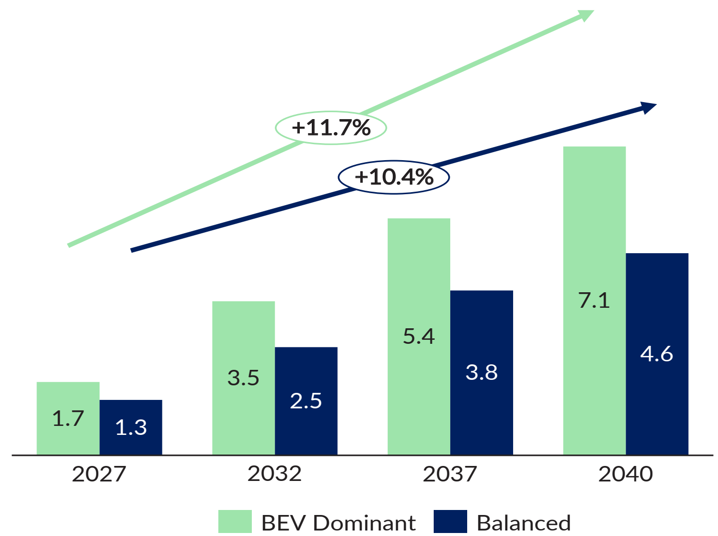
Headline plant capacity is sufficient but doubts growing over raw material supply, including mining and processing

Battery plant investment has outpaced both xEV vehicle demand and raw material investment over the past five years. Headline figures can be misleading, however and there are a number of broader considerations including:

- Chemistry availability
- Pack Format, Cell Type
- Raw Material Resources, including process waste
- Battery Legislation regulations (i.e. EU
- Recycling Requirements
- IP issues
- Non-Automotive certified applications

Future battery technologies and future chemistries may resolve a number of these issues, but none are expected to be mature before the late 2020s.

Figure 21 Global Battery Estimated Automotive Demand (000s GWH)



Battery Plant Average Utilisation

70%

Raw Materials Processed in China

~80%

Benchmark Lithium Index increase 2022

>200%

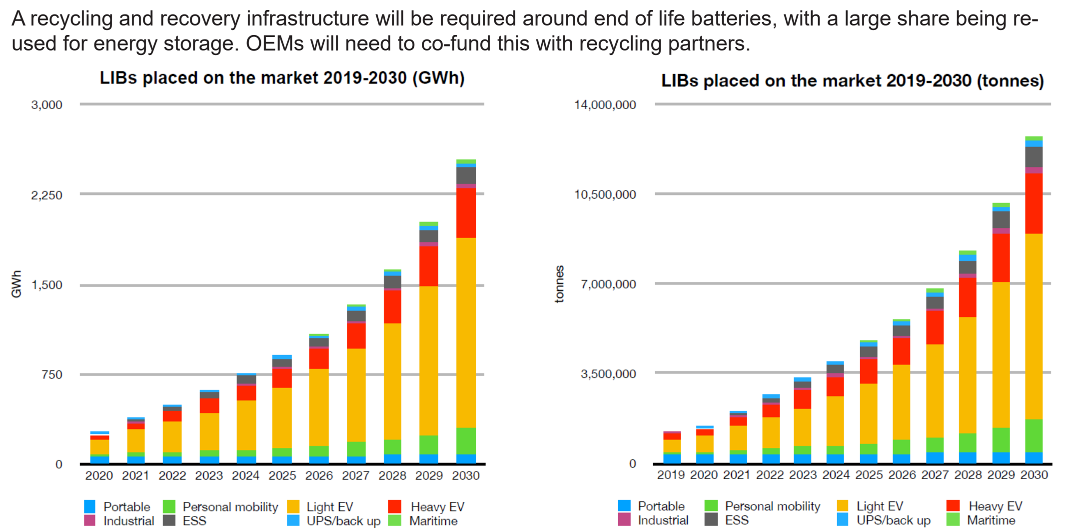
Battery plant capacity, a key indicator, shows capacity for over 6000GWH of battery capacity by 2030, if plants were at 100% utilisation levels. With automotive demand expected to take 80% of the total however there is likely to be a mismatch between chemistries, regions and OEMs, but this represents a commercial and engineering challenge rather than a resource constraint. Leading analyst, Benchmark Mineral Intellgence estimates **70%** capacity is effectively maximum capacity with the various constraints. Geopolitical considerations are also critical, with much of the supply chain currently focussed on China, which processes **90%** of raw materials currently. Pricing of raw materials for a typical battery has risen on average **200%** during 2022, ending battery price falls that are expected to achieve price parity between BEV and ICE vehicles during the late '20s.

Other Battery Applications

Automotive will dominate demand, but a low end forecast forecast adds 700 GWh (10% of current total demand) on top of automotive demand.

- Raw materials for batteries will take over a decade to be recoverable in sufficient volume from used batteries
- Used automotive batteries will be used in grid storage applications
- Other applications may use lower tier quality batteries
- Mismatch of supply and demand remains as for automotive batteries.

Figure 22 LIB placed on the market 2020-2030



Source: Circular Energy Storage (www.circularenergystorage.com)

$

Automotive Demand 7,000GWh Demand @$60kWh - $350Bn by 2040

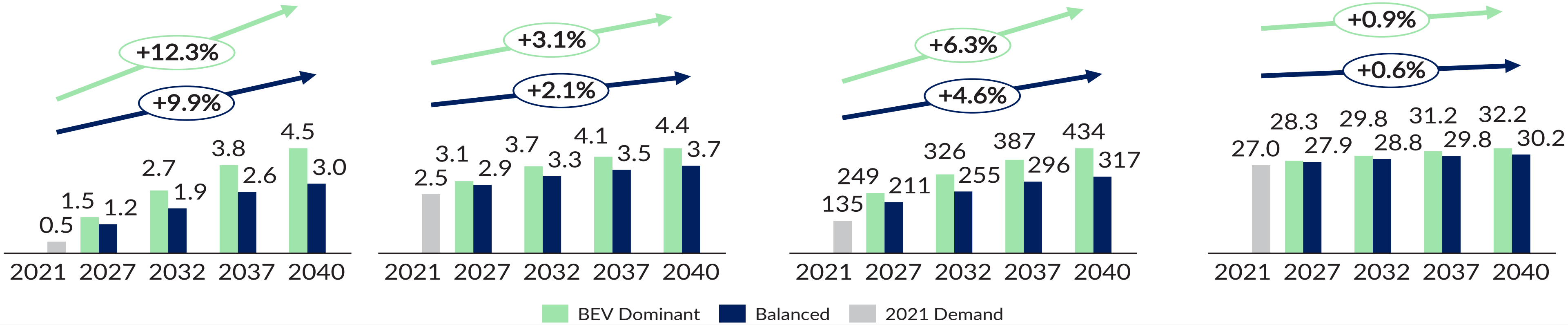
Non-Automotive Demand 700GWh Demand @$75kWh - $52Bn by 2040

Raw Materials

Automotive demand for many raw materials is outstripping supply. Increased capacity is being added, but the pipeline of near future capacity is not likely to achieve the Net Zero trajectory. Battery demand for Lithium, Nickel, Cobalt with grow from 10-20% of their demand to over 80% by 2030.

Raw Materials demand for batteries is a key concern for the Net Zero transmission. However it is not just demand for batteries that is critical, but other vehicle systems including the motor, and renewable energy. The assessment below only includes automotive demand illustrating the pace of demand increases likely. Not considered here is graphite for batteries, rare earths for motors, copper for motors and energy infrastructure.

Figure 23 Estimated Raw Material Automotive Demand vs Supply Outlook (Lithium Mt LCE, Nickel, Cobalt, Copper Mt)



LITHIUM

Lithium, whilst fairly abundant, will need a significant increase in production for the foreseeable future, as battery demand increases, and recycled material remains limited. From 85,000 tons in 2018, automotive battery volume increased to c 130,000 tonnes in 2021. Significant increases are required in both mining and processing of lithium, with geopolitical tensions impacting on cost and investment.

NICKEL

Nickel is widely used in various industrial processes and has a stronger supply chain than Lithium or Cobalt, but the Russia-Ukraine crisis highlights requirement for batteries having higher nickel grades. Improved processing in Indonesia will increase supply in the short and medium term.

COBALT

Used for higher energy Nickel Cobalt Manganese, plus other chemistries, Cobalt is being reduced by changes to higher nickel chemistries. However demand is still constrained, as it is for all of the raw materials. High cobalt batteries account for half of all demand currently, mainly for developed markets, and this is forecast to continue through the 2040 period.

COPPER

Only a small share of copper is used for vehicles currently, but the volume grows rapidly per BEV for motors, batteries and wiring. However this demand will also be matched by growth in demand from renewable energy and infrastructure investment.

Energy, Distribution & Charging

Meeting Net Zero targets will require investment in significantly increased capacity for generation and distribution of renewable electricity and other low carbon fuels, including hydrogen. The high and low investment estimates for the 2021- period illustrated here align partly to the BEV Dominant and Balanced Scenarios. The high requirements equate to 2.5 times growth compared to the past decade.

h

$400Bn-
$1600Bn

Generation

High scenario will require 100% increase capacity to meet un-constrained renewable generation requirements.

$80Bn -
$200Bn

Transmission

Increased electricity supply and demand will require more inter-region transmission capacity

$167Bn-
$400Bn

Distribution

Local grid connections, including sub-stations etc. need significant upgrades to allow for higher charging rates, smart grid capacity and increased renewables

1.2M
-16/24M

Charging

Increased charging capacity will shift investment from domestic to other charging locations, public chargers to grow at the highest rate

17GWh 2020
585GWh - 2030

Storage

Energy storage to overcome intermittency will require both grid level and behind the meter storage

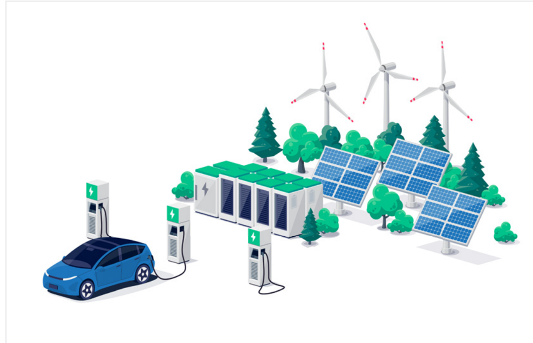
$38Bn-
$312Bn

Smart Management

Investment in Smart Grid, V2G will be required to increase efficiency, resilience

Source: IEA Energy Investment 2022, IRENA World Energy Transistion Outlook 2021

Charging



Battery Electric Vehicle charging infrastructure needs to expand significantly in terms of locations, power, cost, reliability and accessibility. IEA estimates 2022 l expenditure of $10Bn globally in public charging, less than 10% of power distribution total investment.

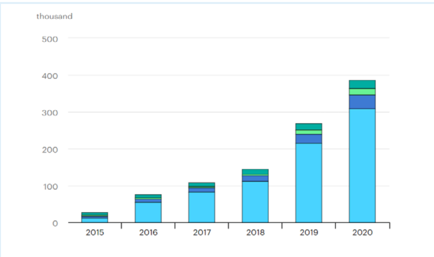
Charging Locations and power

A large share of investment in charging for early adopters has been in home chargers. In many markets the major of light vehicle owners do not have access to domestic charging, and will need alternative chargers, with growth in public, destination and workplace charging required across markets. In the top line scenarios this growth is expected to be significantly greater than that proposed under legislation such a AFID, and this is also expected for the lower case scenario where smaller batteries and a higher share of plug-in-hybrid with smaller batteries will also require more faster chargers.

Smart Charging required

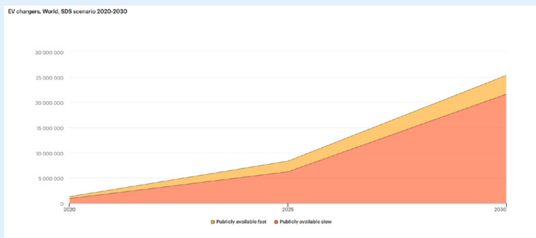
To increase the reliability and optimise the grid, vehicles will need to be integrated with V2G architectures. This will be most feasible for light vehicles, using smart charging, but for larger vehicles grid connected battery packs may be needed to provide intermediate smart charging capability, where the vehicle battery is not used for buffering.

Figure 24 EV Charger Oulook - Fast Charger Globally, Public Fast vs Slow Forecast, NREL Cost Comparison



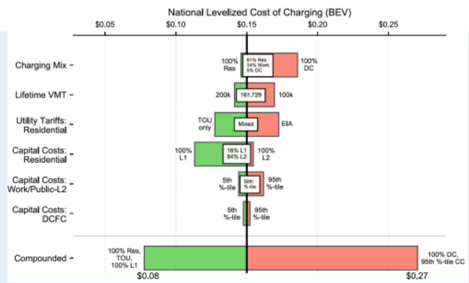
Type

Charging speed, access type and connection types need to be standardised across markets



Location

Access to charging locations needs to improve significantly, with domestic, workplace, destination and public charging required



Cost

Charging cost, including taxes for public charging needs to keep TCO below fossil fuels. Lack of taxes on electricity means future shortfalls in government revenues

Future ICE volumes

Despite electrification growing there will be a significant share of new Euro 7/VII or equivalent and current Euro 6/VI engine powered vehicles produced over the next two decades.

The adoption of a final round of emissions legislation will continue to improve air quality, with lower emissions limits, improved real world performance and longer durability requirements..

Figure 25 Total ICE vs Zero Emission %

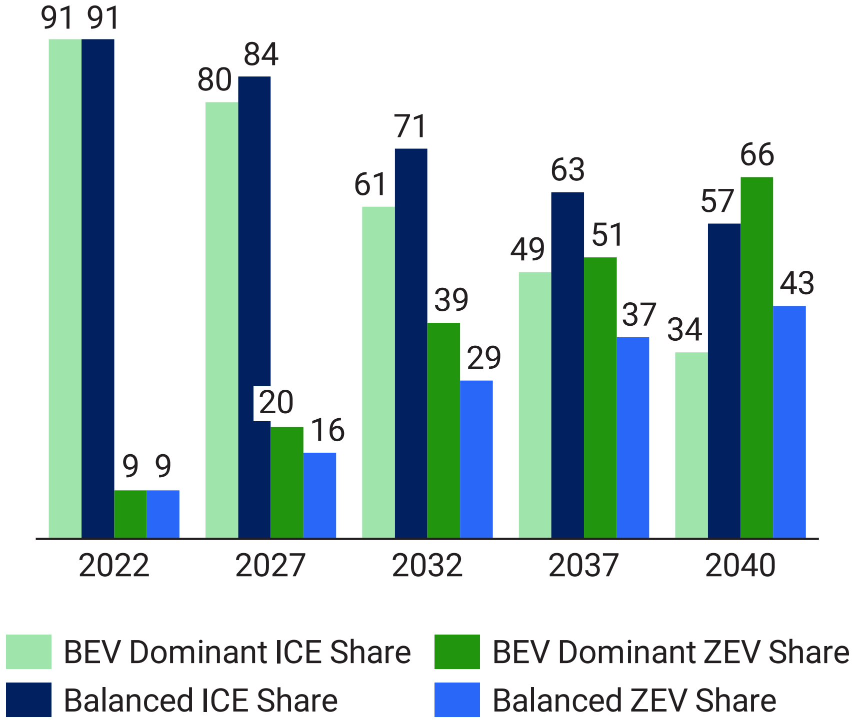


Figure 26 BEV Dominant ICE Share 2021-2040 %

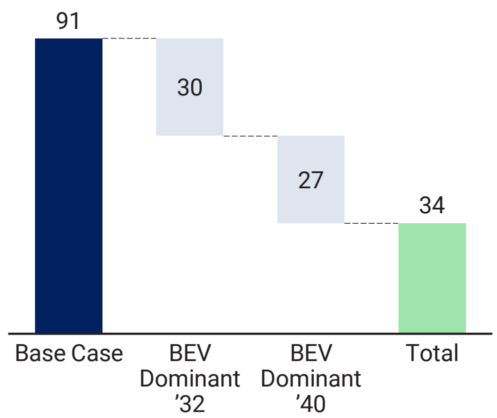
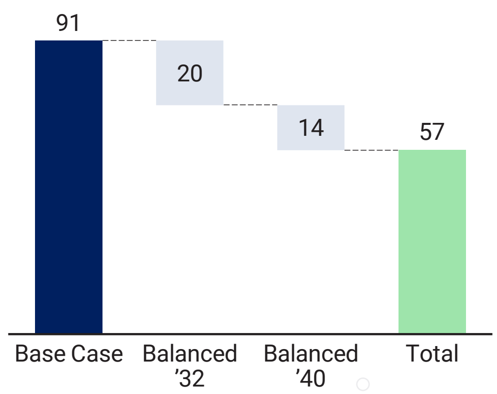


Figure 27 Balanced ICE Share 2021-2040 %



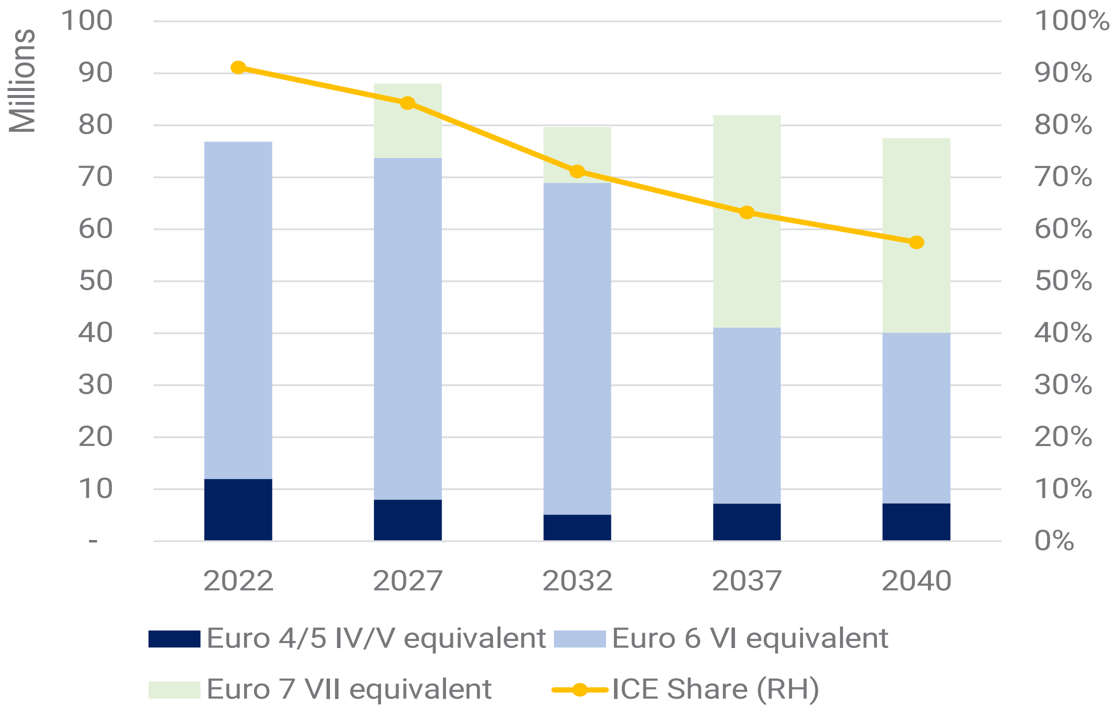
ICE Demand

Under the BEV Dominant scenario and the Balanced scenario we see a 10% difference between global ICE share in 2032, but greater divergence towards 2040, with a 32% difference, and ICE falling to just over 34%. Commercial vehicles will follow, with a five year delay. However green hydrogen availability following the European Green Deal, and other major economies also investing in hydrogen, may see Hydrogen ICE taking share. NB Future ICE also may adopt small lithium batteries as well.

Future ICE by emissions

With Euro 7 coming, followed by the equivalent in other markets, and remaining markets shifting to Euro 6, there will still be a significant number of engine vehicles produced over the next decade. A shift is needed to the most stringent emissions compliance to continue to improve air quality.

Figure 28 LV+CV Emissions (Millions Units LH, Share RH) Balanced Scenario



ICE Demand

Under the base case scenario and the constrained scenario we see the following share of engines, with fuel cells are restricted in the LV segment, increasing in the HD segment, with green hydrogen growth following the European Green Deal, and other major economies also investing in hydrogen.   Other ICE need batteries as well.

Emissions Timeline

Noxious Emissions regulation drives PGM demand. Despite electrification a further round of noxious emissions legislation will reduce noxious emissions, but add complexity and cost.

Noxious emissions legislation will tighten in all global markets before 2030

HC, CO, NOx, PM will fall to near zero, with improved real world emissions, longer durability and warranty periods, in-service compliance and on-board diagnostics.

USA & Canada

US is developing the next round of emissions legislation, under the Clean Trucks Plan which will target noxious emissions and carbon, phasing in between 2027 and 2031. California's Low NOx omnibus starts earlier in 2024. Light vehicles may be tightened post 2030.

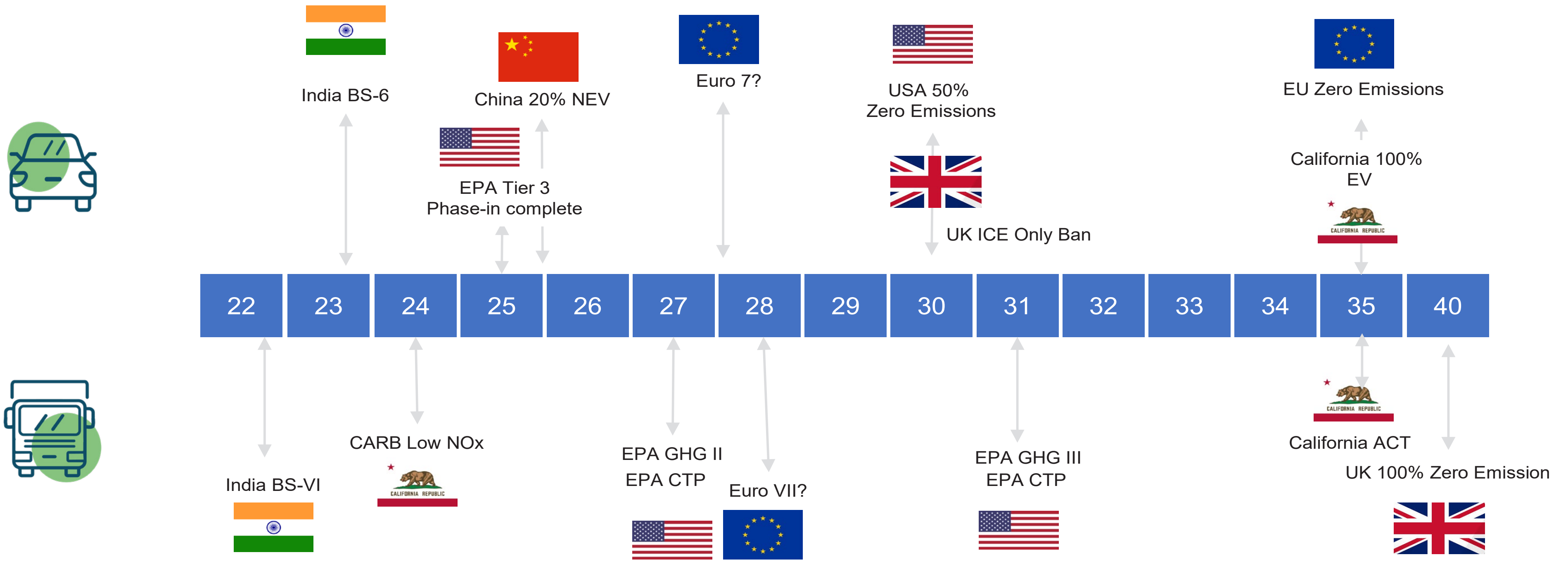
EU & EFTA

The EU is currently finalising both Euro 7 (Light Vehicle) and Euro VII (Heavy Vehicle) emissions legislation. Euro 7 will come slightly earlier than Euro VII, due to imminent ICE bans .

CHINA

China's final round of noxious emissions legislation will follow Europe's within a few years. Limits are expected to be similar, but expect to see China specific conditions.

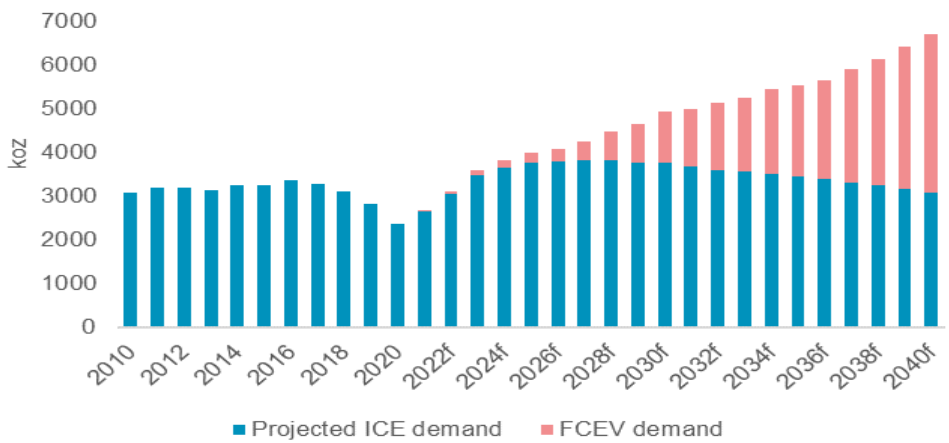
Figure 29 Global Noxious Emissions Timeline



PGM Demand

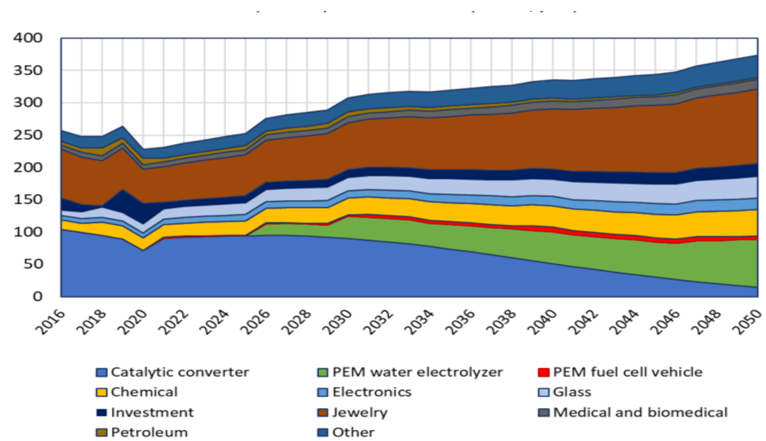
Autocatalyst PGM per vehicle will increase for the remaining ICE vehicles as noxious emissions limits are increasingly stringent worldwide. Higher durability targets, to improve real world performance, will modestly offset some demand lost from the shift to BEV. Smaller engine sizes for PHEV may longer term lower average demand per ICE vehicle. Increasing green hydrogen demand, and fuel cell vehicles in various heavy and industrial vehicle segments will add new demand sources for platinum and iridium, influencing the balance between palladium and platinum for gasoline auto-catalysts. Illustrating the broader trends 3rd party analyses show the peak auto demand c2030.

Figure 32 PGM Demand 2020-2040 (World Platinum Investment Council)



Source: World Platinum Investment Council June 2022 Platinum Essentials

Figure 33 Platinum Demand -2050 (US Department of Energy)



Source: US Department of Energy - February 2022

PGM per vehicle

PGM per light vehicle averages 5-7g for Euro 6, the dominant compliance for ICE engines through 2030. The average has declined as diesel's light vehicle share has dropped. CV diesel share will remain higher, and added Euro VI globally for CV has steadied diesel PGM demand. For gasoline light vehicle catalysts's the low relative price of platinum to palladium has led to significant substituion, boosting platinum's demand at palladium's expense in the short term.

Sources

1. LMC Automotive (2022). Global Light Vehicle Forecast August 2022, LMC Automotive, Oxford. https://lmc-auto.com/
2. KGP-LMC Automotive (2022). Global Commercial Vehicle Powertrain Forecast July 2022. Knibb Gormezano and Partners, Derby. https://www.kgpauto.com/
3. The International Council on Clean Transportation – ICCT (2021). Passenger Car Fuel Economy, ICCT, Washington DC. https://theicct.org/pv-fuel-economy/
4. Felipe Rodriguez (2018).The EU must go further on CO2 truck targets., ICCT , Washington DC. https://theicct.org/the-eu-must-go-further-on-co2-truck-targets/
5. International Energy Agency (2021). Global EV Outlook 2021. IEA, Paris. https://www.iea.org/reports/global-ev-outlook-2021
6. International Energy Agency (2022). Global EV Outlook 2022. IEA Paris. https://www.iea.org/reports/global-ev-outlook-2022
7. IPCC, Synthesis Report of the Sixth Assessment Report, IPCC, Switzerland. https://www.ipcc.ch/ar6-syr/
8. Benchmark Mineral Intelligence (2022). Benchmark Lithium Price Index. Benchmark Mineral Intelligence, London. https://www.benchmarkminerals.com/
9. IEA (2021), The Role of Critical Minerals in Clean Energy Transitions, IEA, Paris https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions
10. Circular Energy Storage https://circularenergystorage.com/
11. IEA (2022), World Energy Investment 2022, IEA, Paris https://www.iea.org/reports/world-energy-investment-2022
12. International Renewable Energy Agency (2022). World Energy Transitions Outlook: 1.5°C Pathway .Irena World Energy Transition Outlook 2022, Abu Dhabi. https://irena.org/publications/2022/mar/world-energy-transitions-outlook-2022
13. Volta Foundation. Battery Report 2021. https://www.batterybrunch.org/battery-report
14. NREL. Borlaug et al., Joule 4, 1470–1485 July 15, 2020 ª 2020 Elsevier Inc. https://www.cell.com/joule/pdfExtended/S2542-4351(20)30231-2
15. World Platinum Investment Council (2022). Platinum Essentials June 2022, London. https://platinuminvestment.com/files/847446/WPIC_Platinum_Essentials_June_2022.pdf
16. US Department of Energy (2022). Platinum Group Metals Supply Chain Report., Washington, DC. https://www.energy.gov/policy/securing-americas-clean-energy-supply-chain
17. Ricardo Energy and Environment for the European Commission, DG Climate Action (2020). Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA, Didcot, https://climate.ec.europa.eu/eu-action/transport-emissions/road-transport-reducing-co2-emissions-vehicles_en#tab-0-1
18. Liesbet Gregoir et Al, KU Leuven (2022). Metals for Clean Energy: Pathways to solving Europe's raw materials challenge, . https://eurometaux.eu/media/jmxf2qm0/metals-for-clean-energy.pdf
19. Transport & Environment (2021), From Dirty Oil to Clean Batteries https://www.transportenvironment.org/wp-content/uploads/2021/07/2021_02_Battery_raw_materials_report_final.pdf
20. Ben Jonesa, Robert J.R. Elliottb,c,*, Viet Nguyen-Tien (2020). The EV revolution: The road ahead for critical raw materials demand, Birmingham, https://www.sciencedirect.com/journal/applied-energy
21. Gielen, D. and M. Lyons (2022), Critical materials for the energy transition: Lithium, International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/Technical-Papers/Critical-Materials-For-The-Energy-Transition-Lithium
22. Fraser, Jake;Anderson, Jack;Lazuen, Jose; Lu, Ying;Heathman,Oliver; Brewster, Neal; Bedder, Jack; Masson, Oliver (2021). Study on future demand and supply security of nickel for electric vehicle batteries, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-29139-8 https://publications.jrc.ec.europa.eu/repository/handle/JRC123439
23. IEA (2021). The Role of Critical Minerals in Clean Energy Transitions. https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions
24. Cristiano Façanha, Ph.D., Owen MacDonnell, (2021) Calstart. Review of Commitments for Zero- Emission Medium- and Heavy-Duty Vehicles https://globaldrivetozero.org/site/wp-content/uploads/2021/12/Review-of-Commitments-for-Zero-Emission-Medium-and-Heavy-Duty-Vehicles_Dec_2021_Final-.pdf

Contact

AUTOMOTIVE INTELLIGENCE

Knibb Gormezano & Partners
1st Floor, St Katherines House, Mansfield Road, Derby, DE1 3TQ, UK

Alex Woodrow
Managing Director

alexwoodrow@kgpauto.com
+44 (0)1332 856 301
+44 (0)7545 787 971

www.kgpauto.com

Knibb Gormezano Limited
1st Floor, St Katherines House
Mansfield Road
Derby, DE1 3TQ, UK
C

T: +44 (1332) 588192
E: consult@kgpauto.com
www.kgpauto.com

POWERTRAIN INTELLIGENCE