KGP POWERTRAIN INTELLIGENCE

Future Propulsion Conference 2025

Decarbonisation of CV and NRMM

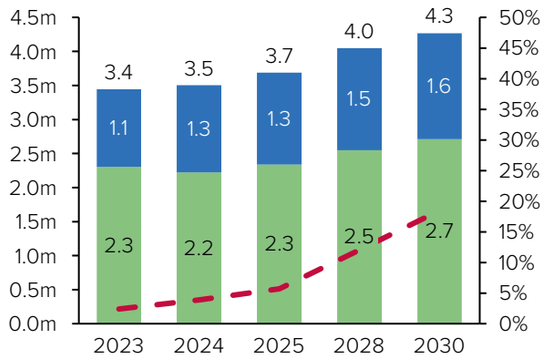
12th March 2025

Alex Woodrow, Managing Director, KGP

Vertical Outlook

KGP focuses on Commercial Powertrain markets, technology and energy use across 4 key verticals

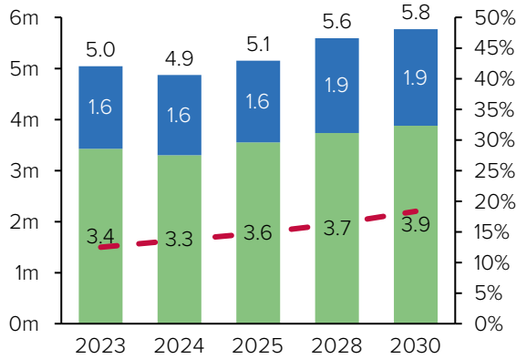
On-highway >6t (OH) Mn



Future Energies
- Battery Electric (BEV)
- Fuel Cell (FCEV)
- H_2 ICE
- Natural/Renewable Gas
- Hybrid (CN)

Mid-Term Drivers - 2030
- GHG/CO_2 Legislation
- Incentives
- EPA/EU Low NOx
- TCO
- CSR/ESG
- Local Air Quality

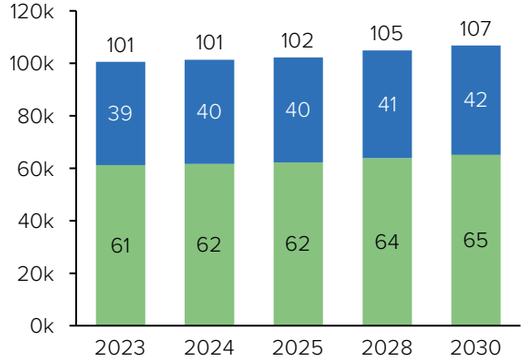
NRMM (AG, CE, MH) Mn



Future Energies
- Battery Electric (Compact/Ultra)
- H_2 ICE
- Renewable Diesel
- Fuel Cell
- Natural/Renewable Gas
- Hybrid (48V/400V)

Mid-Term Drivers - 2030
- CSR/ESG
- TCO
- Local Air Quality
- Incentives

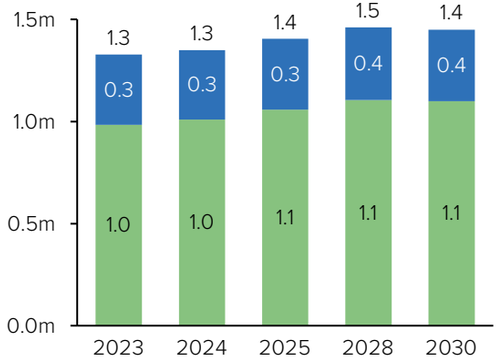
Marine (MAR) 000s



Future Energies
- Ammonia/Methanol (Medium/Low Speed)
- Full Electrification (Compact/Aux)
- Fuel Cell (Aux)

Mid-Term Drivers - 2030
- Local Air Quality
- CSR/ESG
- Repower

Powergen (PG) Mn



Future Energies
- H_2 ICE
- Renewable Diesel
- Hybrid
- Battery Energy Storage Systems

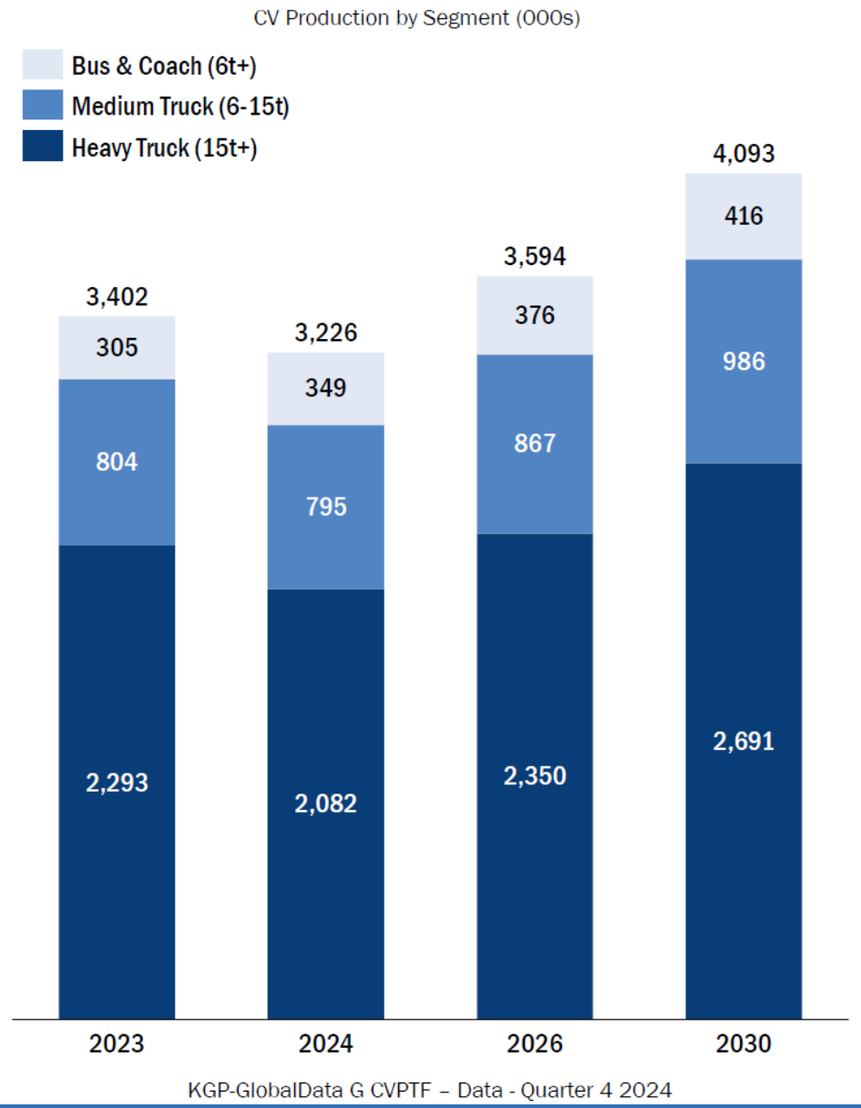
Mid-Term Drivers - 2030
- Incentives
- CSR/ESG
- TCO

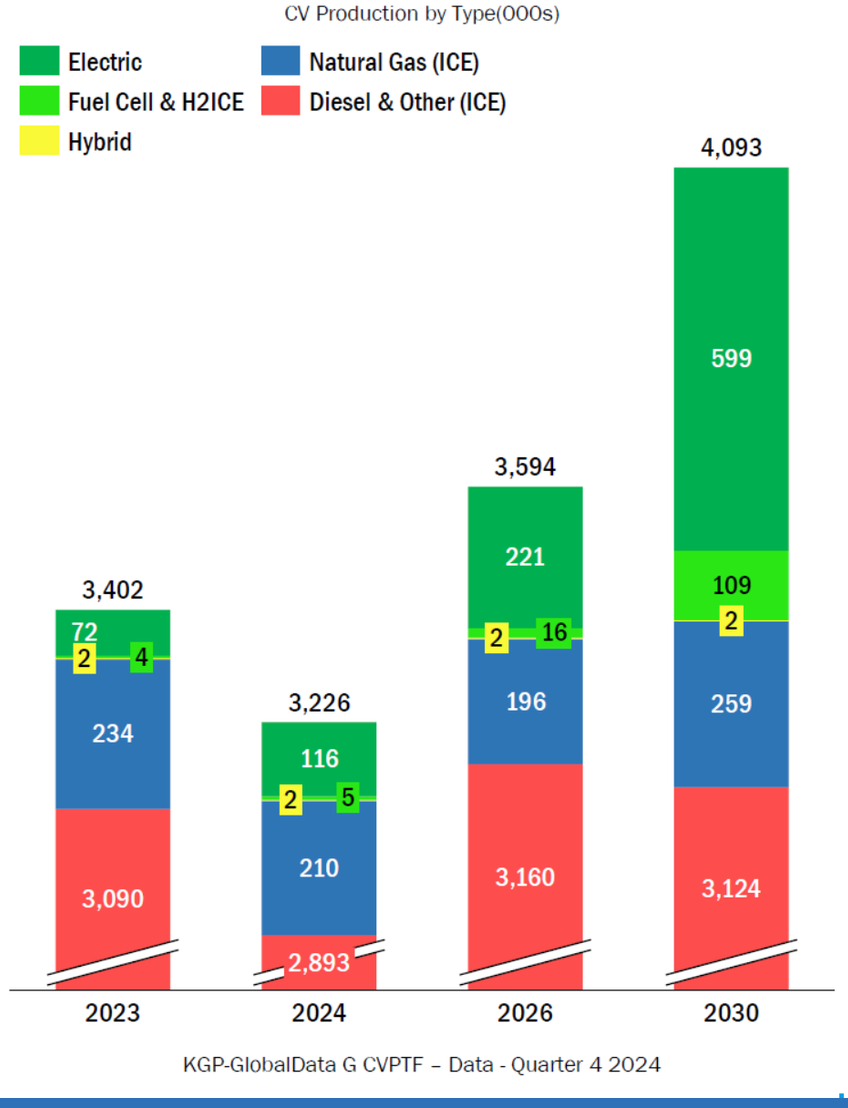
NRMM (AG – Agriculture, CE - Construction Equipment, MH – Materials Handling)
48v not included under CV hybrid

KGP-Off-Highway Research Q4 2024 Global Non-Road Powertrain Forecast

Global Commercial Vehicle Outlook

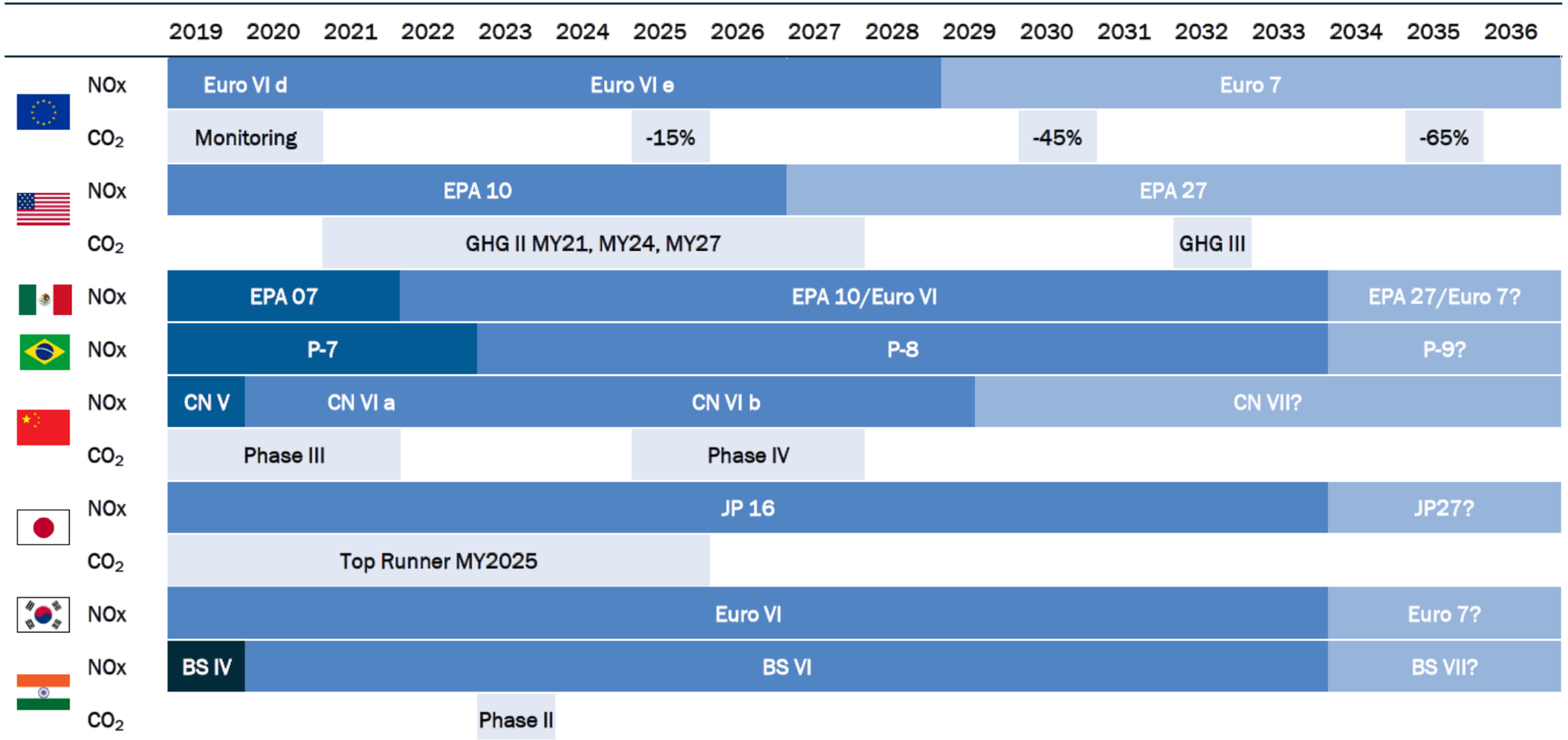
KGP's Quarterly Global Commercial Vehicle Forecast published since 2005 in partnership with GlobalData covers 6t GVW globally. Impact of a global trade war will be significant and is a major downside risk.





Emissions Roadmap

Global Emissions legislation is tightening, albeit new US administration may look to amend current timing, especially for GHG III. With pushback against California's waivers, slowing down of green truck drivers seems inevitable.



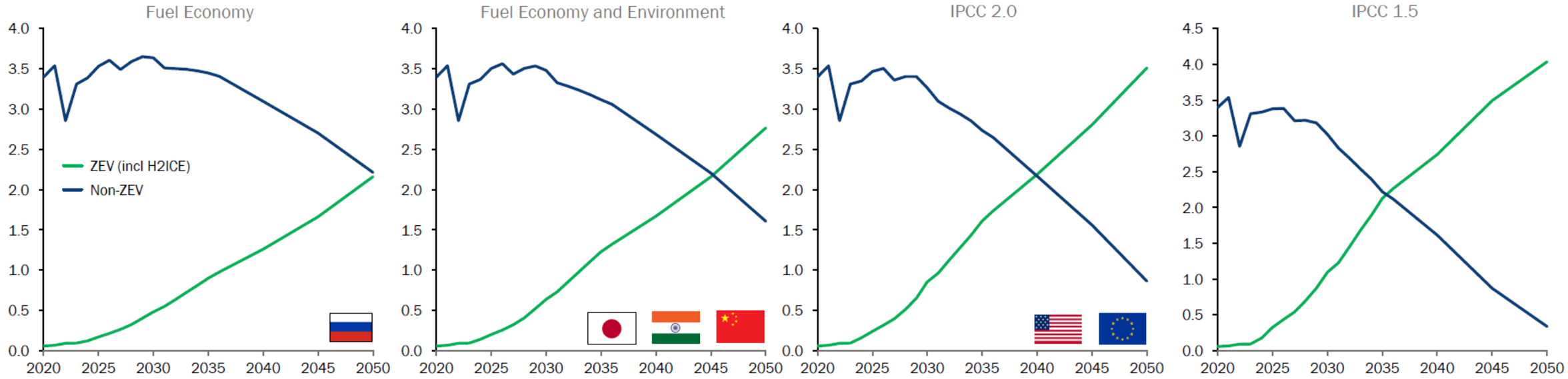
Source: KGP-GlobalData Commercial Vehicle Powertrain Forecast Q4 2024

Meeting Zero Emissions in the CV segment

US was on track to fit our IPCC 2.0 target, but may slip back into the Fuel Economy and Environment Scenario, which sees mid 2040's before Zero Emission tailpipe overtakes ICE volumes. Europe may still push ahead, China may shift right.

KGP tracks key metrics on regional basis including: Economy, Legislation, Incentives, TCO, Infrastructure, Critical Materials.

M units



- Poor economic recovery
- No new rounds of legislation
- Minimal amount of LEZ/ZEZ and ICE bans
- Lack of government subsides
- Taxation on ZEV to meet revenue of ICE
- CSR for some companies
- TCO unfavorable
- Lack of refueling availability

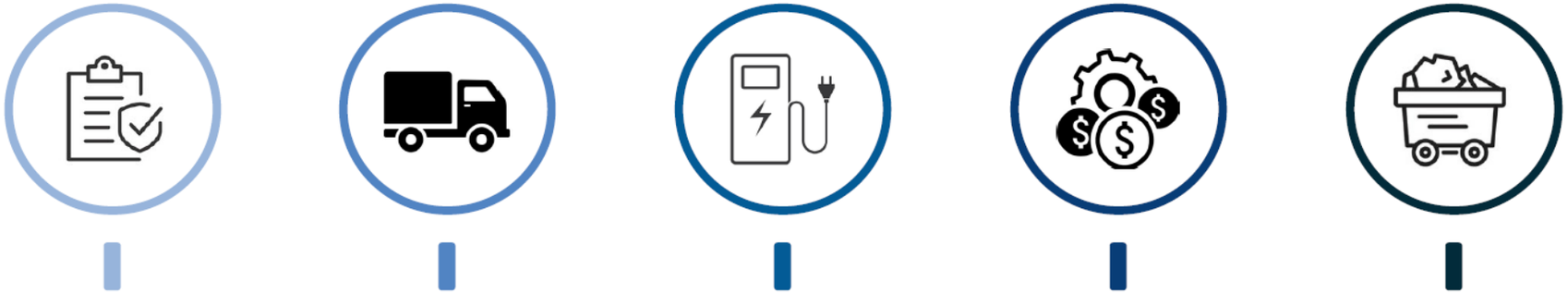
- Economies avoid recession
- More stringent CO_2 legislation
- Major cities with ZEZ
- Government subsidies for developed economies
- Fuel taxation on ZEV at a discounted rate to ICE
- CSR for all major companies
- TCO improvement
- Refueling availability good within cities

- Economies bounce back
- ICE bans by 2050
- All cities with ZEZ
- Government subsidies for all economies
- No fuel taxation on ZEV
- Increase taxation for ICE
- CSR for all companies
- TCO favourable
- Refuelling availability good along all main transport routes

- Economies strong
- ICE bans from 2040
- All cities with ZEZ
- Government subsidies for all economies
- Tax credits for ZEV
- Increase taxation for ICE
- CSR for all companies
- TCO favourable
- Refuelling availability accessible everywhere

Main Factors in Zero Emissions Adoption

Five key factors need to be considered when evaluating the roadmap to Zero Emissions, Lifecycle will become more important over the next decade.



Legislation

+ Widespread commitment for carbon neutrality
+ Stringent noxious emissions legislation in all major nations
+ Developed economies with stringent CO_2 standards
+ Mandates for ZEV adoption
+ Low and zero emission zones

OEMs

+ OEMs positive pledging very optimists ZE sales, continual development of model portfolio and production beginning to ramp up
+ Consolidation between OEMS and Tier 1s to reduce costs
- ZE models are still in a introduction phase, not yet mature
- New entrants facing financial difficulties

Infrastructure

+ Legislation e.g. AFIR
- Non-existent infrastructure network for electric or hydrogen fuelling
- High capital costs and lacking the investment required
- No standardisation
- Grid capacity has shortcomings that need to be invested in now in order to aid widespread adoption
- Hydrogen supply issues
- Clean electricity capacity

TCO

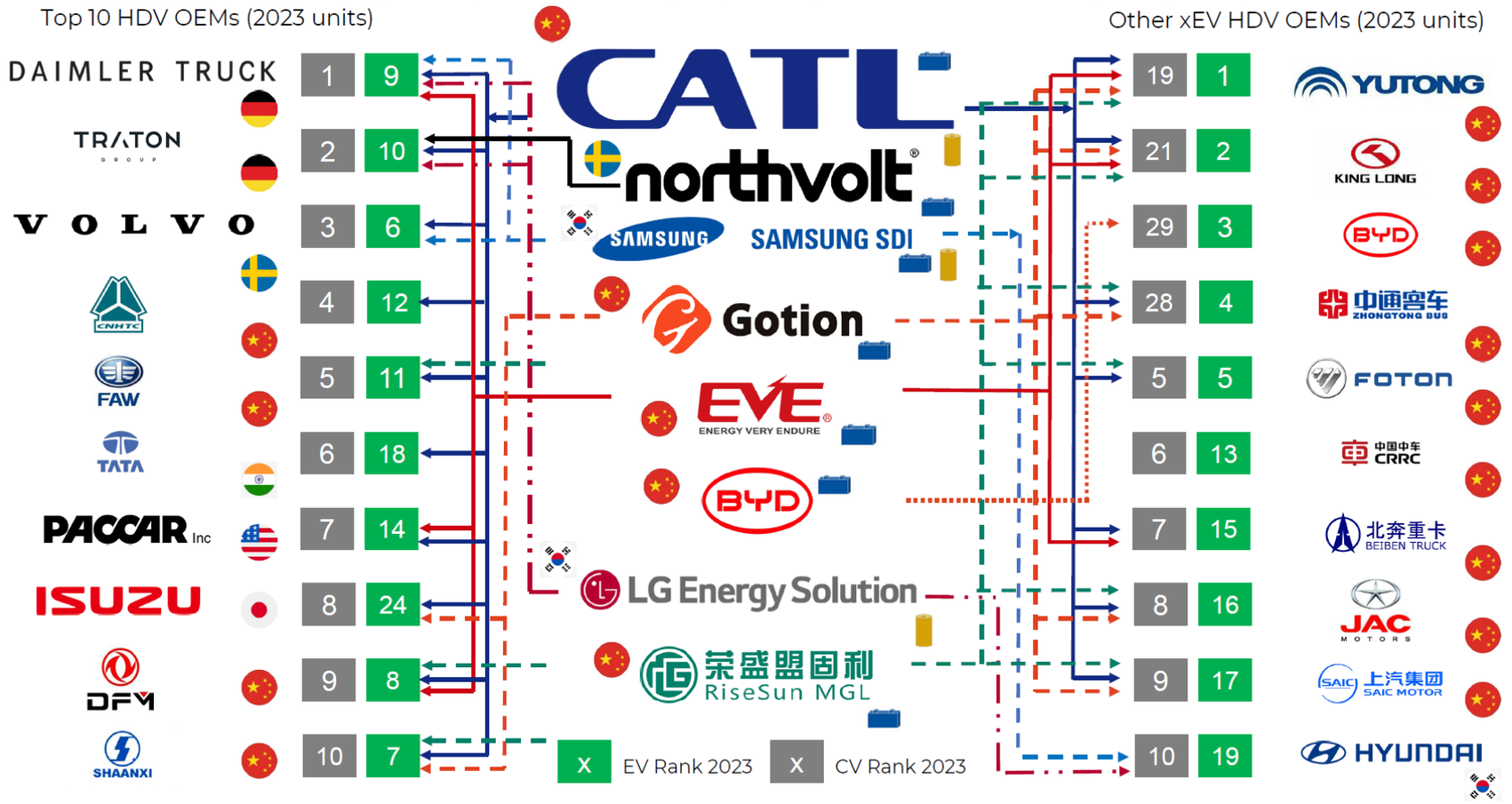
+ Legislation e.g. IRA
+ Battery costs keep falling while energy density improving
- Volume is needed to lower costs
- Subsidies will be required but are not feasible in the mid to long term
- Dependent on volatile costs e.g. fuel, raw materials

Critical Materials

+ Prices have fallen in 2023 after two years of high rises
+ Trillion dollar market will attract private investment of which billions is required
+ Recycling, alternative chemistries and correct battery sizing can reduce demand
- Potential supply shortages applicable to both electric and hydrogen e.g. batteries, electric motors, electrolyzers
- Unethical practices and emissions produced in mining
- Supply concentrated in certain regions

China’s battery dominance is a concern

China produced over 86,000 electric trucks in 2024, with over 109,000 expected in 2025. Of these just 7,000 were medium duty (6%) of production, compared to 9% for heavy trucks and 30% for heavy buses.



Source: Volta 2024 Annual Battery Report

Commercial Powertrains will adopt a range of low carbon fuels

KGP reviewed 33 fuels in an assessment in 2024. Results are based on public domain publications, OEM, supply chain interviews against suitability by segment. Score from 10 (Most suitable) to 0 (Least suitable)

	HVO			B7 FAME			B30 FAME			Electric			H2-FCEV			H2-ICE			E-Fuels			Ethanol			Methanol			Ammonia			Compressed Natural Gas			Renewable Natural Gas		
Year	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040
AG	5	6	4	7	6	4	1	2	3	1	2	4	0	1	2	0	1	3	0	1	2	0	1	3	0	1	2	0	0	0	0	0	0	1	2	2
CE	4	5	3	6	5	4	1	1	2	1	3	5	0	1	3	0	2	4	0	1	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
MH	2	2	1	3	2	2	0	0	0	8	9	9	0	1	2	0	1	2	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CV	3	2	2	6	5	2	2	1	0	2	5	9	1	3	5	0	2	5	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0	2	3	3
PG	6	7	8	3	3	4	0	0	0	0	0	0	1	2	4	1	2	3	0	1	3	0	0	0	0	0	0	0	0	0	3	4	5	1	1	1
M-L	5	4	3	3	3	4	0	0	0	1	2	3	0	1	2	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M-C	4	5	6	3	3	4	0	0	0	1	3	5	1	2	3	1	2	2	0	2	3	0	1	2	0	1	2	0	0	0	0	0	0	0	0	0
M-CL	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	2	1	2	4	1	2	4	2	3	5	3	2	1	0	0	0
AV	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	5	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

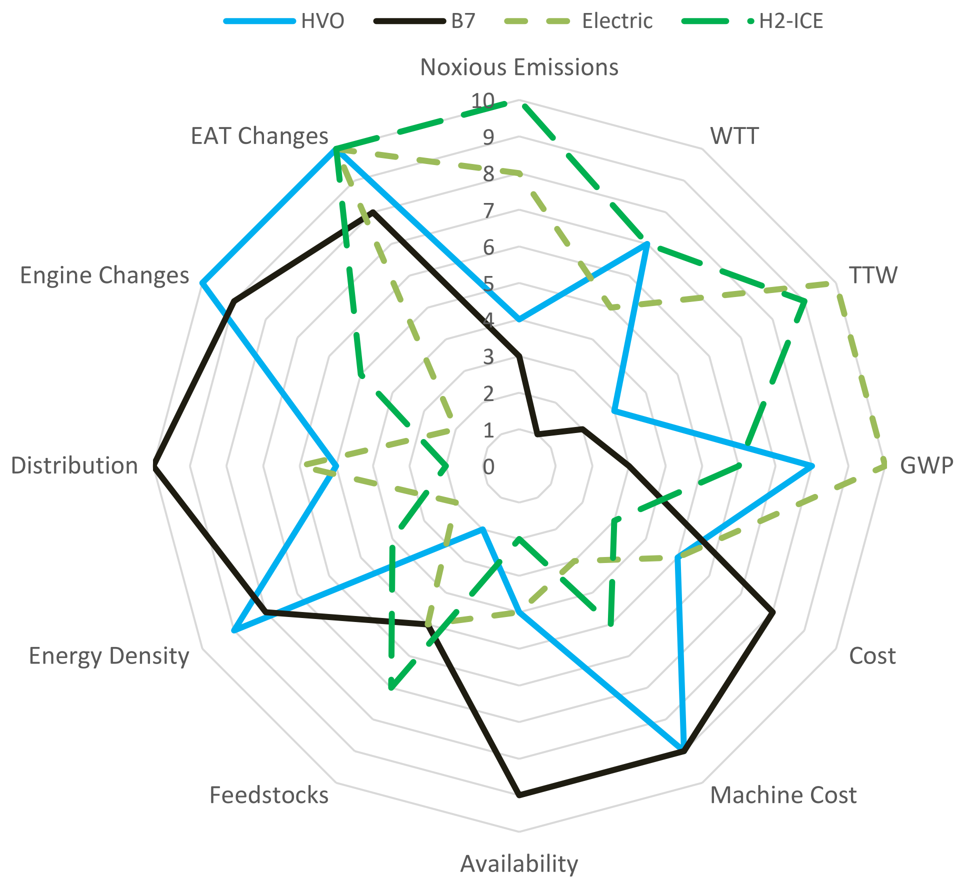
AG – Agriculture, CE – Construction Equipment, MH – Materials Handling, CV – Commercial Vehicle, PG – Power Generation, M-L – Marine Leisure, M-C – Marine Commercial, M-CL – Marine Low/Medium Speed Commercial, AV - Aviation

No fuel meets all end use case requirements

KGP POWERTRAIN INTELLIGENCE

Many fuels offer improvement over the next decade, but availability, cost and distribution remain an issue. Fuels will therefore need to be used on a case-by-case basis.

KGP, following stakeholder discussions, has scored 12 fuels against 12 performance criteria in 2025, 2030 and 2040. Results are built into KGP's production, population and fuel scenarios twice a year. An example is shown for B7 (FAME blend), HVO (Renewable Diesel), Electric and H_2-ICE.



12 fuels compared for all commercial powertrain segments, against 12 performance criteria.

	HVO			B7 FAME			B30 FAME			Electric			H2-FCEV			H2-ICE			E-Fuels			Ethanol			Methanol			Ammonia			Compressed Natural Gas			Renewable Natural Gas		
Year	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040
Noxious Emissions	2	4	5	2	3	4	2	3	4	7	8	10	9	10	10	9	10	10	2	4	5	2	4	5	2	4	5	2	4	5	3	4	5	3	4	5
WTT	6	7	9	1	1	2	3	3	4	4	5	6	6	7	8	6	7	8	7	8	9	7	8	9	7	8	9	7	8	9	1	1	2	10	10	10
TTW	2	3	3	2	2	3	2	2	3	10	10	10	10	10	10	9	9	9	2	3	3	1	2	2	1	2	2	1	2	2	3	3	3	3	3	3
GWP	8	8	8	4	3	3	4	3	3	10	10	10	5	6	7	5	6	7	10	10	10	10	10	10	10	10	10	10	10	10	3	4	5	3	4	5
Cost	4	5	6	9	8	8	8	7	7	4	5	6	1	3	5	1	3	5	0	2	4	8	8	8	8	8	8	8	8	8	7	8	8	5	4	4
Machine Cost	10	9	8	10	9	8	9	9	9	2	3	5	1	3	5	3	5	7	10	9	8	8	7	7	8	7	7	8	7	7	4	5	6	4	5	6
Availability	3	4	5	8	9	10	1	2	2	1	4	5	0	2	7	0	2	7	0	1	3	3	4	5	1	2	3	5	7	8	7	6	5	3	5	7
Feedstocks	1	2	4	6	5	5	5	4	4	3	5	7	5	7	9	5	7	9	0	2	5	6	7	8	1	2	3	2	3	4	10	9	8	2	4	6
Energy Density	9	9	9	8	8	8	8	8	8	1	2	3	3	4	5	3	4	5	9	9	9	8	8	8	8	8	8	7	7	7	5	5	5	5	5	5
Distribution	3	5	8	9	10	8	2	1	1	5	6	7	0	2	5	0	2	5	0	1	3	7	8	9	2	3	4	7	8	9	7	7	6	3	4	5
Engine Changes	10	10	10	9	9	9	5	6	6	0	2	5	0	2	5	3	5	7	9	9	9	3	5	7	3	5	7	3	5	7	5	6	8	5	6	8
EAT Changes	10	10	9	9	8	7	7	6	5	10	10	10	10	10	10	9	10	10	10	9	8	7	6	5	7	6	5	7	6	5	9	[illegible]	[illegible]	9	[illegible]	[illegible]
Total	68	76	84	77	75	75	56	54	[illegible]	57	70	[illegible]	[illegible]	66	[illegible]	53	70	[illegible]	59	67	[illegible]	70	77	[illegible]	58	[illegible]	71	67	[illegible]	[illegible]	64	[illegible]	[illegible]	55	62	[illegible]

	HVO			B7 FAME			B30 FAME			Electric			H2-FCEV			H2-ICE			E-Fuels			Ethanol			Methanol			Ammonia			Compressed Natural Gas			Renewable Natural Gas		
Year	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040	2025	2030	2040
AG	5	6	4	7	6	4	1	2	3	1	2	4	0	1	2	0	1	3	0	1	2	0	1	3	0	1	2	0	0	0	0	0	0	1	2	2
CE	4	5	3	6	5	4	1	1	2	1	3	5	0	1	3	0	2	4	0	1	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
MH	2	2	1	3	2	2	0	0	0	8	9	9	0	1	2	0	1	2	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CV	3	2	2	6	5	2	2	1	0	2	5	9	1	3	5	0	2	5	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0	2	3	3
PG	6	7	8	3	3	4	0	0	0	0	0	0	1	2	4	1	2	3	0	1	3	0	0	0	0	0	0	0	0	0	3	4	5	1	1	1
M-L	5	4	3	3	3	4	0	0	0	1	2	3	0	1	2	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M-C	4	5	6	3	3	4	0	0	0	1	3	5	1	2	3	1	2	2	0	2	3	0	1	2	0	1	2	0	0	0	0	0	0	0	0	0
M-CL	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	2	1	2	4	1	2	4	2	3	5	3	2	1	0	0	0
AV	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	5	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Learning across adjacencies – CECE's Four Pillars

Reading across an example from other adjacent segments we see many parallels to learn from. Continuous improvement in vehicle use – best GHG savings are by not using fuel, but this can't be at the expense of productivity.

Source: www.cece.eu

Collaboration is Critical

The system boundary is no longer the vehicle, operators/users need to collaborate more widely with other stakeholders

Chassis OEMs

Body Builder/Upfitters

Power Utilities

Dealers

NTEA THE WORK TRUCK ASSOCIATION

CALSTART NACFE NORTH AMERICAN COUNCIL FOR FREIGHT EFFICIENCY

NGOs

Rental Companies

Legislators/ Government

Finance

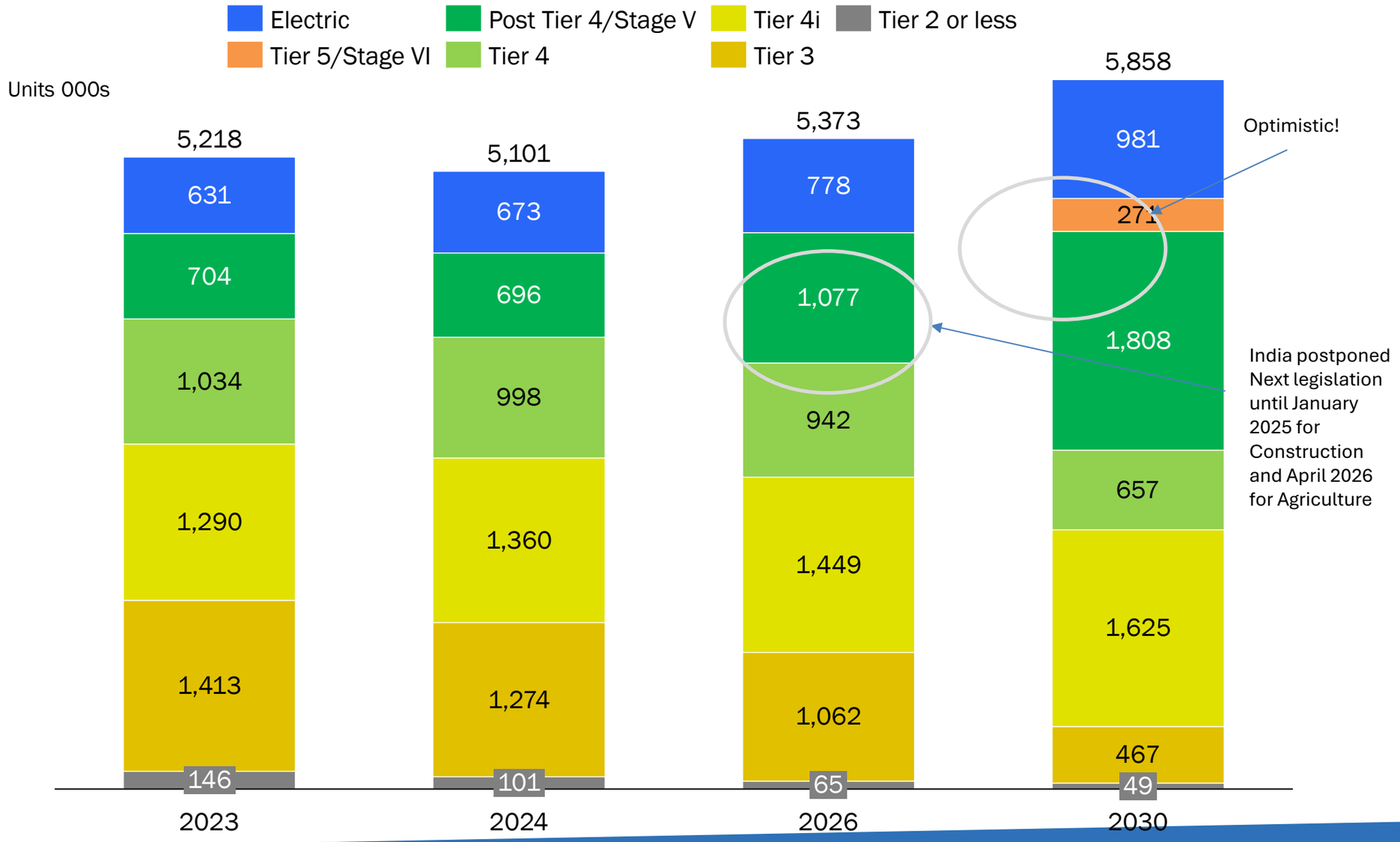
Data Companies

NRMM Legislative Outlook

No significant change in the legislative outlook for NRMM. India moving to Stage V equivalent, set for implementation in April 2024, will impact the market significantly, should see some increase in turbo penetration 37-56kW range, but legacy tractor models will make design and packaging problematic.

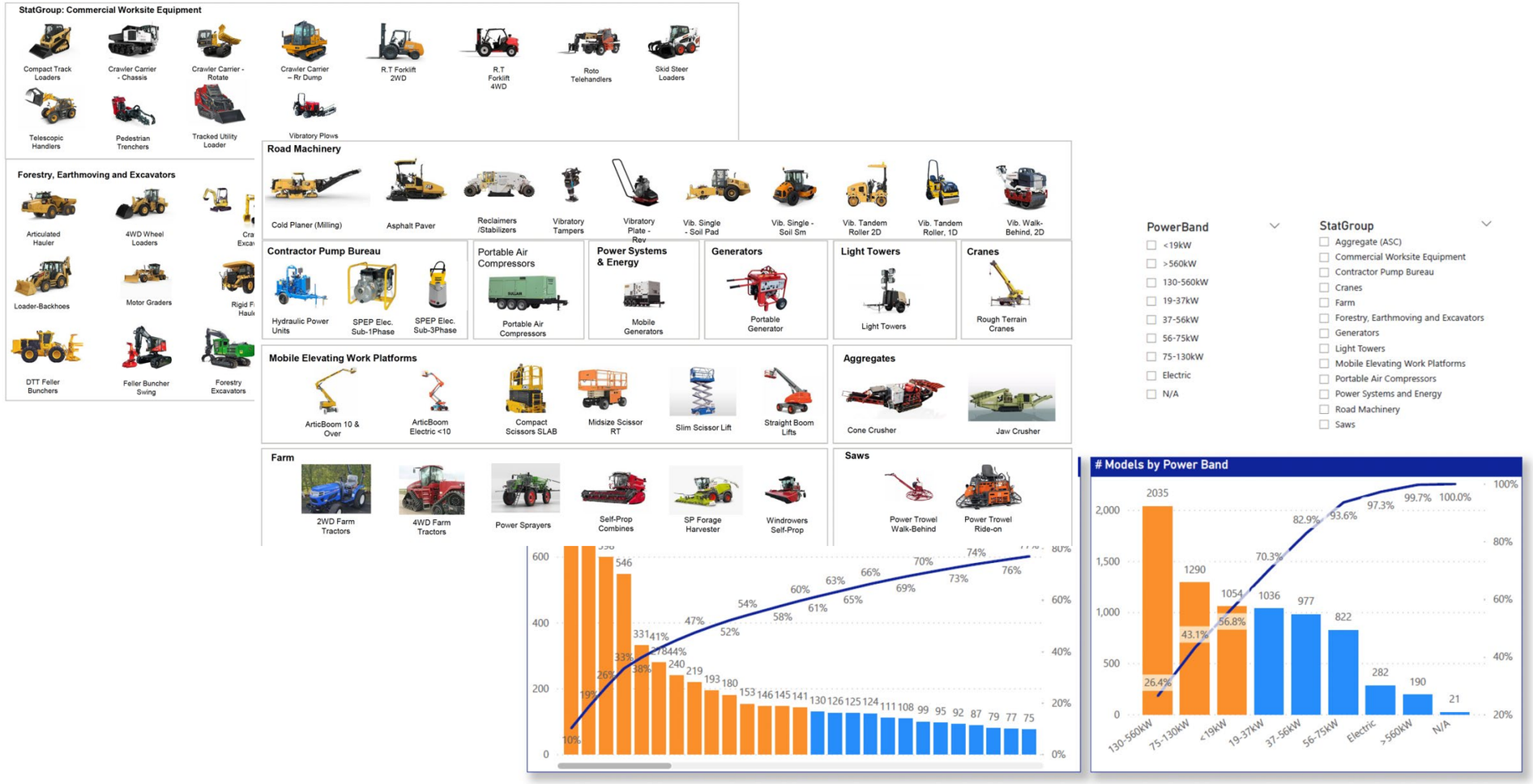
Market	Short Term Outlook (2Y)	Medium Term Outlook (2-5Y)
	Shift to China State IV (Tier 4i/Stage IIIB equivalent) plus PN limit requiring DPF for all engines above 37kW.	Stage V equivalent expected to be drafted but not implemented until post 2025.
	Stage V for all engines (56-130kW to be implemented in 2020).	Additional regulations for SI engines. Possible ultra low NO_x. Possible CO_2 legislation for non-road. Possible EU Stage VI c. 2030-2032
	Bharat Stage IV which is equivalent to EU Stage IV for all engines above 37kW (75% of Indian production is below 37kW). FAME III offering $124m for electric tractor adoption. Up to 40% of total cost.	Stage V equivalent legislation introduced in 2025 and 2026 – timing is an issue. Legislating below 8kW could present electrification opportunity for the low power Indian market
	No Major Change – Stage IV Equivalent as of 2015.	Stage V equivalent legislation uncertain – key Japanese engine and equipment OEMs have Stage V technology available for European Export.
	No major change – Stage IV equivalent implemented in 2015.	Stage V equivalent still uncertain.
	No major non-road change. Possible low emission zone implementation in ports. Zero Emissions under <19kW possible, timing uncertain.	CARB Tier 5 Low NOx & Low PM uncertainty. Requires EPA to support, but significant aftertreatment challenges associated. EPA Tier 5 possible c. 2029-32.
	Stage IIIA equivalent introduced in 2015 through 2019. Staggered approach for Construction and Agriculture applications.	Stage IIIB legislation still uncertain, MAR-2 post 2028

Volumes by Emissions Legislation



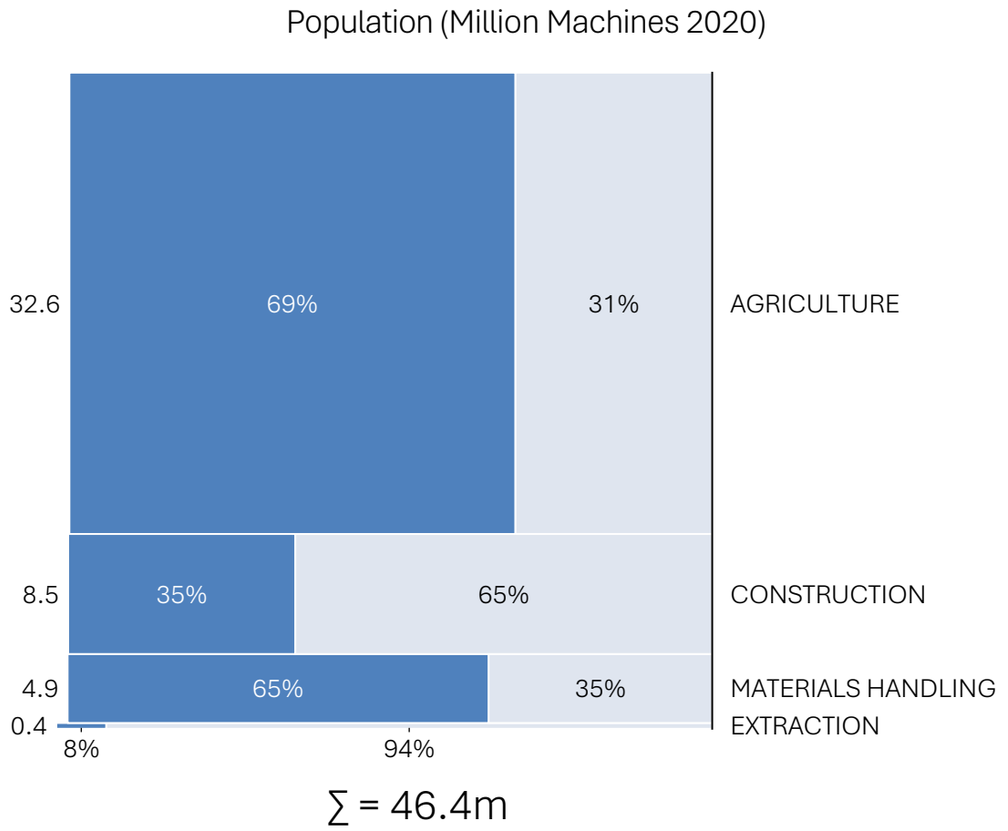
NRMM Product Mix – Very Complex!

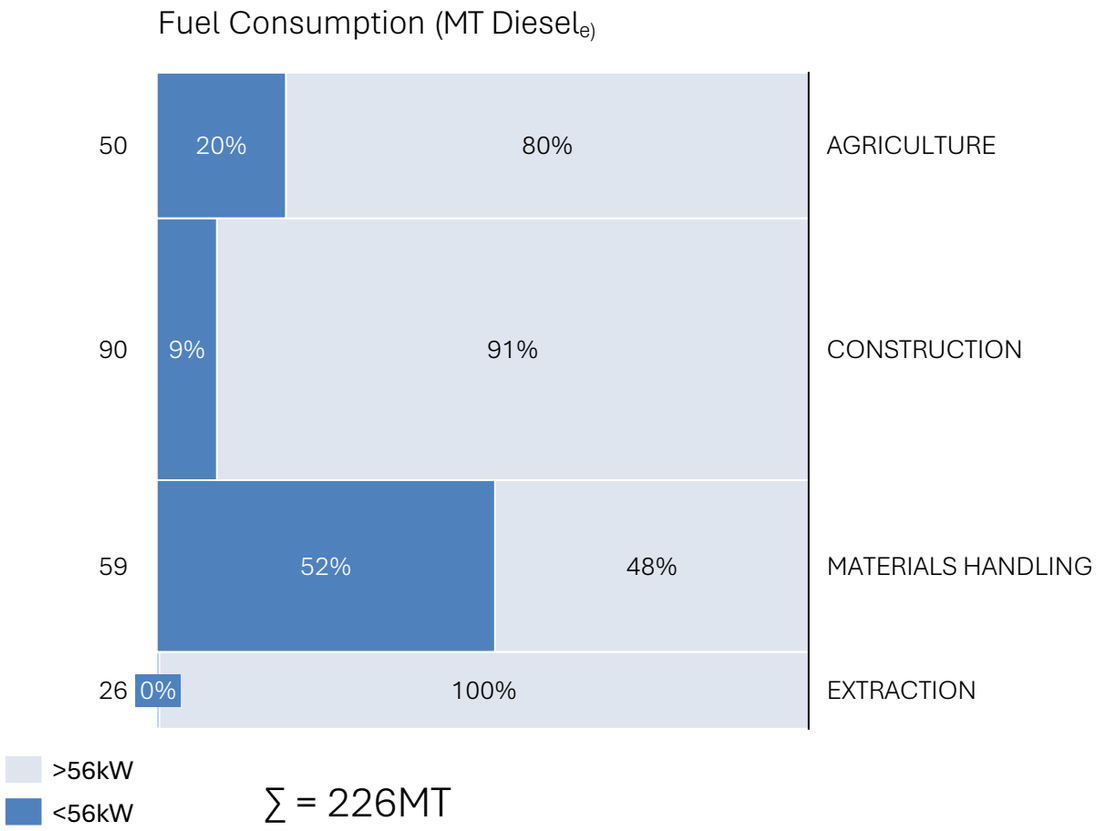
Analysis of 13 Product Groups, 70 machine types has over 7,000 models across 114 machine OEMs on sales in the US



Global Population, Fuel Consumption (MT Diesel$_e$) – 30 machine types

Understanding the global industry accounting for machines in-use, working hours, lifecycle and load factors is critical to understand energy demand, and electrification opportunities.

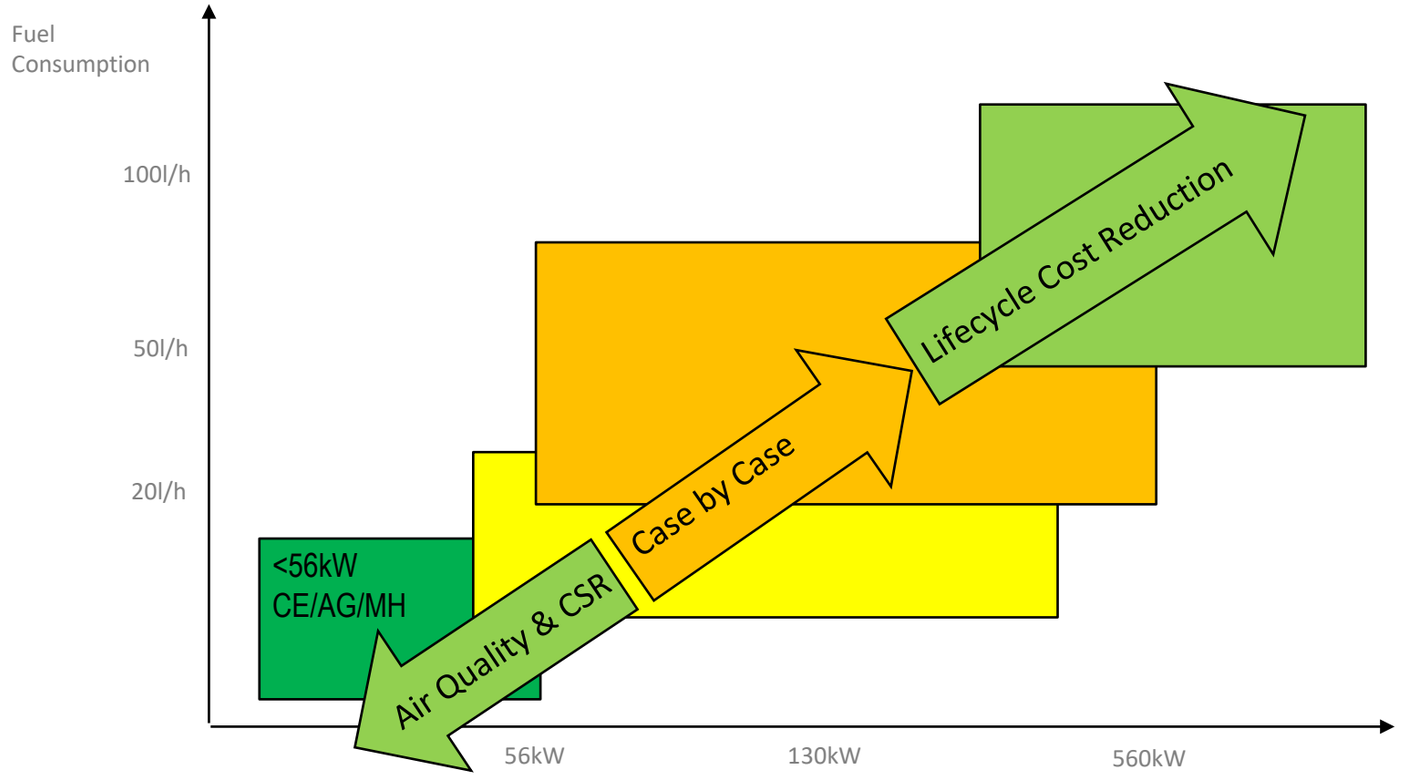




Source: KGP-Off-Highway Fuels and Emissions Model

NRMM TCO Considerations

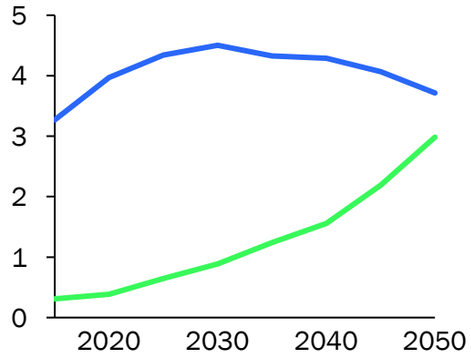
For Off-Highway Machinery there are many more Total Cost of Ownership considerations than in Light Vehicle and Commercial Vehicle. This will impact on ability to electrify and decarbonise end use applications. A systems measurement of GHG impact may be required, combining incentives, infrastructure investment, carbon taxation and ESG/CSR considerations to achieve positive payback in many applications.



NRMM xEV Scenarios

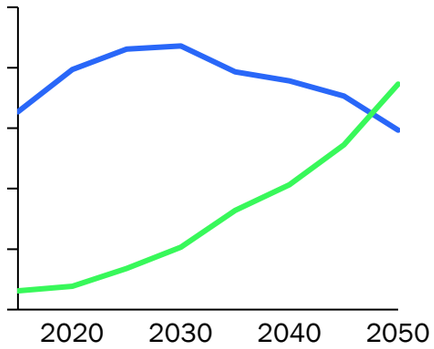
KGP's xEV Scenarios look at different drivers and the demand they can place on the market under certain pre-defined conditions.

Fuel Economy Scenario



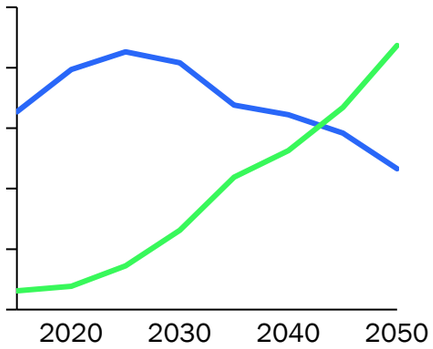
- CSR Targets
- Local Air Quality
- Positive Payback for Low Power CE & MH

Fuel Economy & Environment Scenario



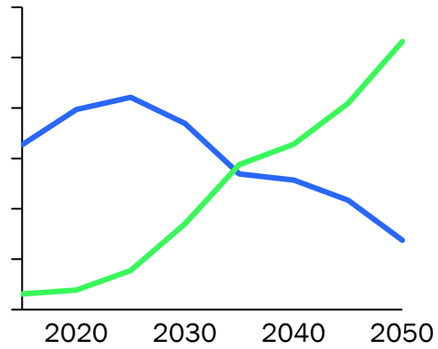
- OEM Pledges
- Operator/Infrastructure Pledges
- Government Targets
- Incentivisation
- LEZ/ZEZ
- Stringent Noise Limits
- Fuel Duty Cuts
- Charging and Hydrogen Distribution Development
- Some GHG legislation for <37kW CE

IPCC 2.0



- TCO Payback for High Powered Equipment (Fuel Cell/H2 ICE)
- Renewable Energy Cost & Capacity
- Carbon Taxation
- Suitable On-Site Charging Infrastructure
- Low Cost Hydrogen Distribution Solutions
- Key Market GHG limits for <75kW CE

IPCC 1.5



- Strong Economy
- Zero Emission <37W in all markets
- Gov subsidies for all segments
- Tax credits for machinery (50% of value)
- Robust refuelling infrastructure
- TCO for all applications all load cycles
- Enforcable SBT for companies and OEMs

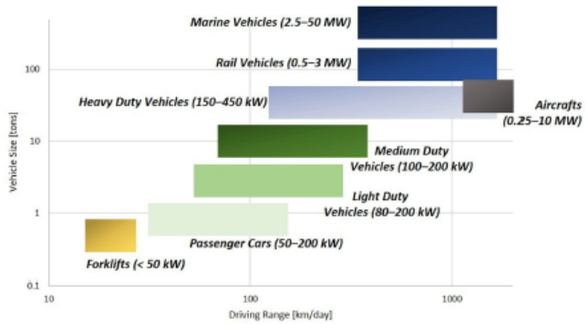
Non-ZEV
ZEV

Key Factors in Each Scenario

NRMM xEV Benchmarks

Off Highway Vehicles growing adoption of electrified propulsion systems, with some technology transfer from Commercial Vehicles facilitating adoption

- Largest machines account for <1% of units but 20% fuel/energy demand
- Construction, Mining & Quarrying, Materials Handling and Agriculture make up majority of Non-Road Machinery globally. Total industry units are circa 4.4M in 2023
- Energy requirements dependent on size, application and hours used, with most vehicles housing >100kWh battery
- Batteries need high-cycle-life chemistries, with mix of energy/power for energy recovery
- Number of electric machine models available globally increased 50% between 2021 and 2023



Typical Battery Capacity & Equipment Size	Equipment Types (Examples)	Power/ Voltage	Technology Transfer	Model Availability
10-50 kWh Handheld/ Extra-Compact	Compaction, Dumpers, Lawn care	48V <19 kW	Passenger Car Forklift	AG - 16 CE - 43 MH - 2
50-100 kWh Compact	Mini-Excavators, Compact Wheel-Loaders, Compact Tractors, Asphalt Finishers, Forklift	48-90V 19-75 kW	Light Commercial Vehicle	AG - 40 CE - 110 MH - 11 Others - 9
100-300 kWh Mid-Sized	Wheeled, Crawler Excavators, Skid-Steer, Compact Tracked Loaders, Telehandlers, Wheel-Loaders	100-300V 75-225 kW	Medium Truck	AG - 14 CE - 86 MH - 19 Others - 4
0.3-1 MWh Large	Crawler Excavators, Wheel-Loaders, Crushers, Screens, Port-Handling, Mobile Cranes, Piling Rigs	400-1000V 225-560 kW	Heavy Truck Bespoke NRMM	AG - 6 CE - 34 MH - 8 Others - 35
>1 MWh Extra-Large	Mining Dump Trucks, Marine, Rail	>1000V >560 KW	Bespoke NRMM	CE/Mining - 32 Others - 3

CE - Construction, AG - Agricultural, MH - Material Handling

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VF | VOLTA FOUNDATION

Source: KGP input: Volta Foundation - Battery Report

NRMM xEV Charging Standards (Europe)

Connectors

European Automotive Standards

Mennekes – Type 2
AC 43kW

CCS – Combined Charging System
DC 350-500kW

MCS – Megawatt Charging System
DC 3.75MW

Industrial

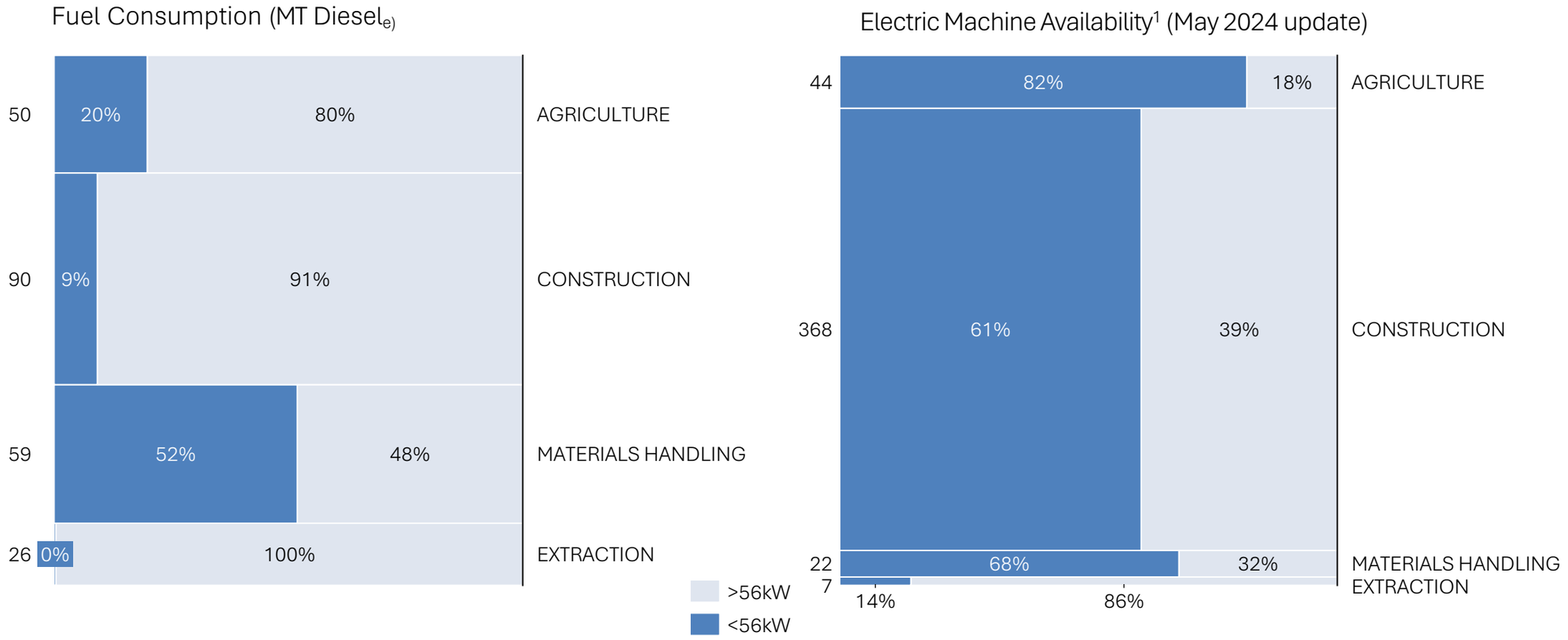
Anderson Flat Connector

Euro DIN

Mennekes CEE

NRMM xEV Model Availability vs Fuel Consumption

- KGP tracks Electric Models across 28 core products, 28 ‘Niche’ types
- 950 machines in production, near series prototypes
- [1]Skewed in material handling where electric MEWPs and Forklifts and underground mining which are not included



Source: KGP-Off-Highway Fuels and Emissions Model, xEV Model Database H1 2024

KGP – Founded as Knibb Gormezano and Partners in 1988 is a UK based specialist consultancy focussed on Commercial Powertrain Markets and Technology research. Clients are global OEMs, Tier Ones and other stakeholders across the automotive and related industries.

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