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Alex Woodrow

Batteries for Construction Machines

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KGP POWERTRAIN INTELLIGENCE

Off-Highway RESEARCH

Batteries for Construction Machines

January 2023

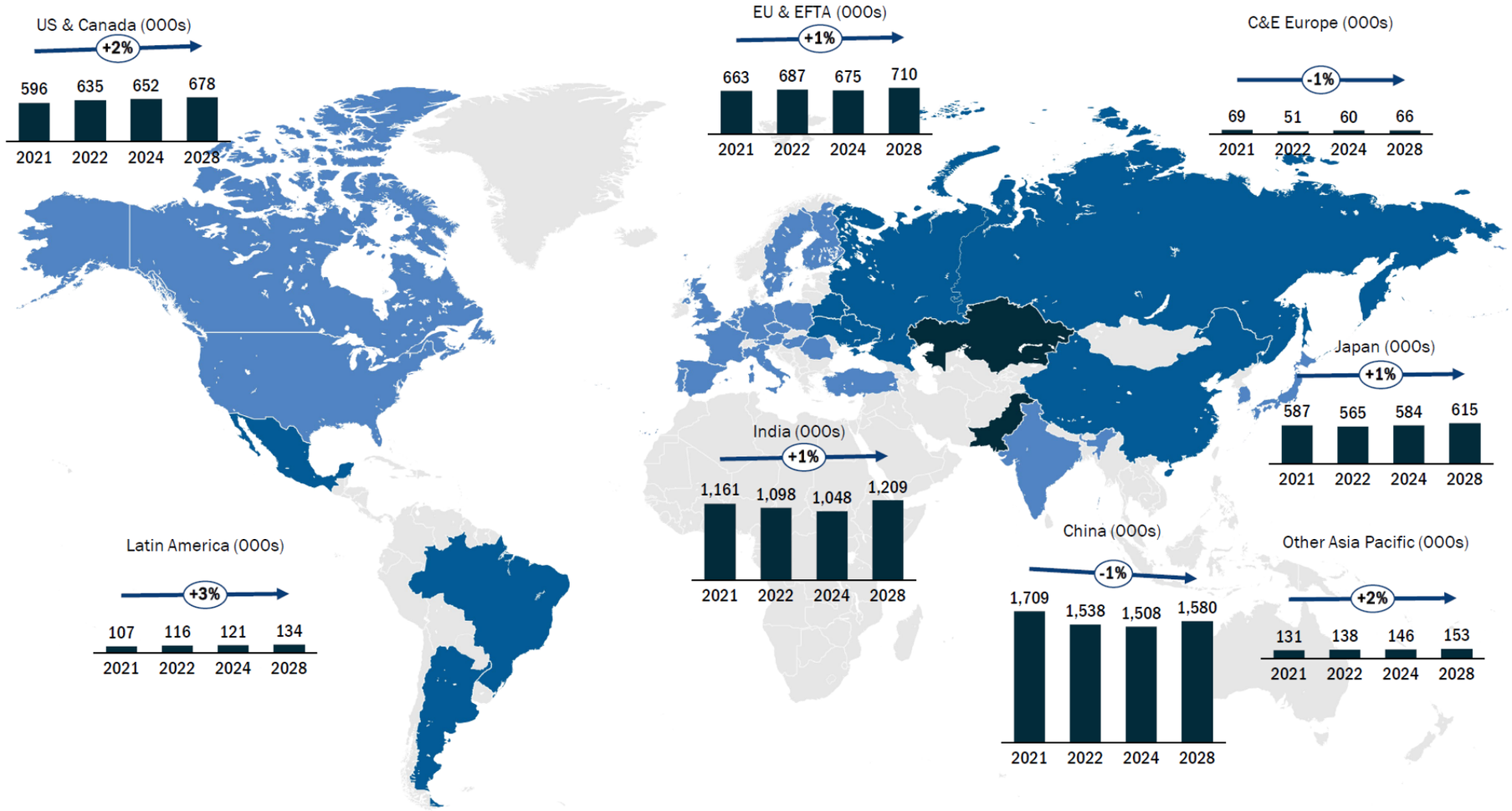
www.kgpauto.com

KGP Services

- Subscription based
- Quarterly Updates on CV, NRMM, Marine, Powergen
- Engine, Driveline, Electrification, Emissions
- Fuels and Energy
- Focus on reducing Noxious and Carbon Emissions

Outlook - Geographic Production

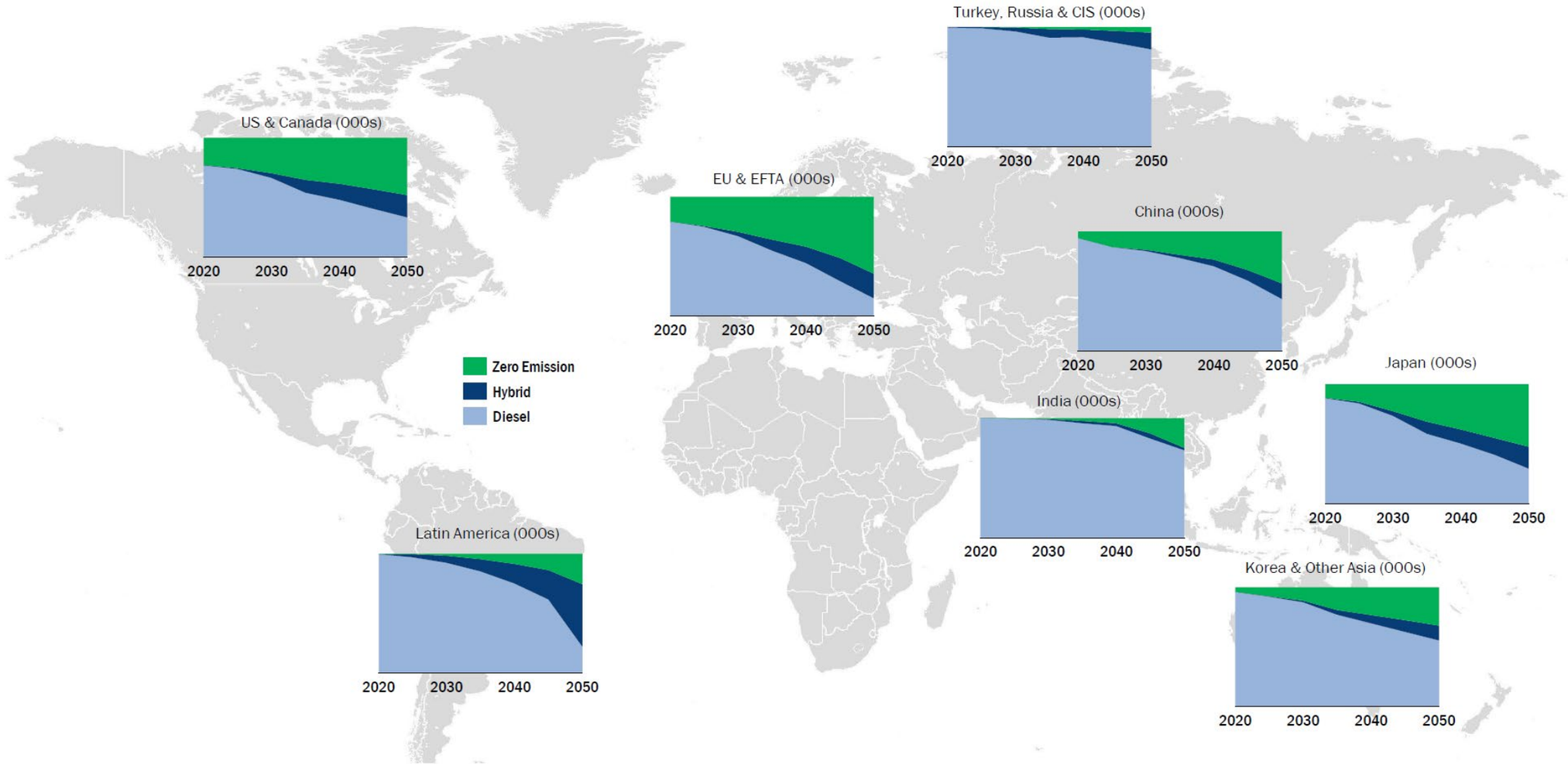
Short Term Production Forecast



KGP OHR Global Non-Road Powertrain Forecast GNRPTF Quarter 3 2022

Outlook – NRMM Powertrains – AG, CE, MH

xEV Penetration Forecast by Region (Fuel Economy Scenario)



Outlook - Regional Emissions Legislation

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).	Stage V equivalent legislation introduced in 2024 – 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 by 2028. Requires EPA to support, but significant aftertreatment challenges associated. EPA Tier 5 possible c. 2028-30.
	Stage IIIA equivalent introduced in 2015 through 2019. Staggered approach for Construction and Agriculture applications.	Stage IIIB legislation still uncertain.

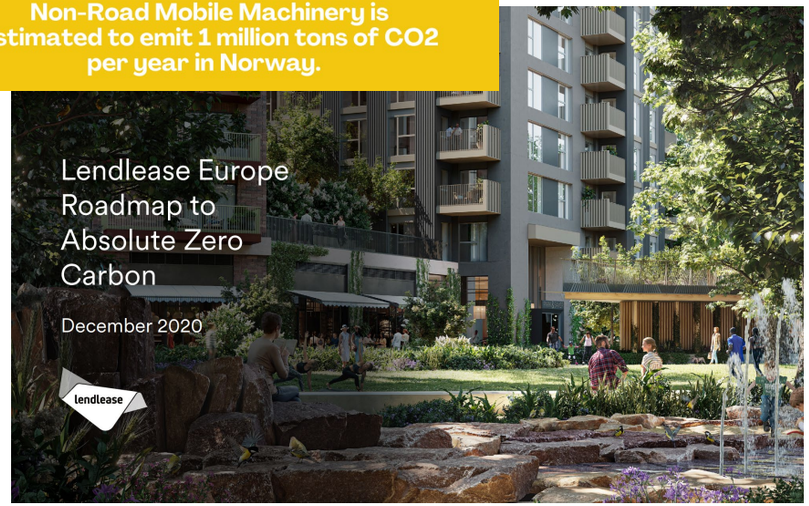
Drivers for Alternative Fuels

Methodology

- All of the factors listed below are analysed, evaluated and separated into three scenarios – each looking at a different potential future. Each scenario is then applied to the NRMM Forecast to create an accurate and robust forecast model for hybridisation and electrification penetration potential across three scenarios. Fuel Economy (base case); Fuel Economy & Environment (mid case) and Climate Change Target - IPCC 1.5 (high case).

1. **Air Quality & Environment**
   CO_2, CH_4, N_2O...
2. **TCO**
   Fuel, Operator, Maintenance, Depreciation...
3. **Legislative**
   Noise Limits, Clean Air Zone, LEZs, ZEZs...
4. **Corporate Social Responsibility**
   GHG Protocol, SBTi, Tax Breaks...
5. **Energy**
   Renewables, security, carbon taxation...
6. **Efficiency**
   Process Efficiency, Operational Efficiency...
7. **Competitiveness**
   Globalisation, R&D, Supply Chain...
8. **Investment**
   Finance, Investors, Subsidies, Business Models...

Tipping Point Reached?



Amount of CO_2 emissions by scope3

> Japanese

Independent Practitioner's Assurance ☑

Category	Rate (%)	Summary Data kt-CO_2
Scope3 (11)Customer Use	88.4	27,310
Scope3 (1)Manufacturing of Purchasable Goods	10.1	3,105
Scope3 (2)Capital Goods Construction and others	0.4	121
Scope3 (3)Fuel Procurement	0.4	116
Scope3 (4)Upstream Transportation disposal	0.3	108
Scope3 (5)Waste Transportation	0.0	13
Scope3 (6)Business Trips	0.2	50
Scope3 (7)Commuting	0.2	52
Scope3 (8)Upstream Leased Assets Operation	-	-
Scope3 (9)Downstream Transportation	-	-
Scope3 (10)Processing Sold Products	-	-

EXECUTIVE DEPARTMENT
STATE OF CALIFORNIA

EXECUTIVE ORDER N-79-20

WHEREAS the climate change crisis is happening now, impacting California in unprecedented ways, and affecting the health and safety of too many Californians; and

WHEREAS we must accelerate our actions to mitigate and adapt to climate change, and more quickly move toward our low-carbon, sustainable and

sect
publ

NOW THEREFORE, I, GAVIN NEWSOM, Governor of the State of California by virtue of the power and authority vested in me by the Constitution and the statutes of the State of California, do hereby issue the following Order to pursue actions necessary to combat the climate crisis.

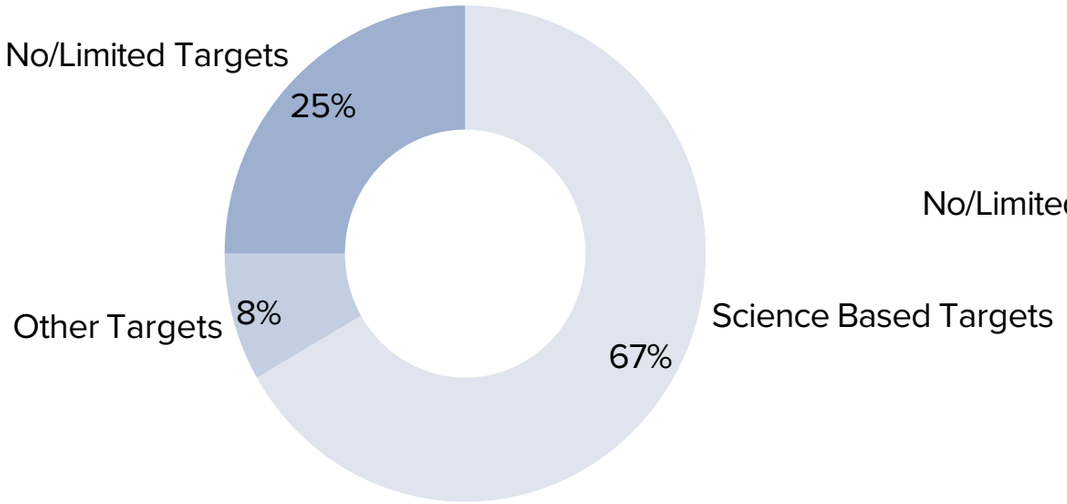
IT IS HEREBY ORDERED THAT:

1. It shall be a goal of the State that 100 percent of in-state sales of new passenger cars and trucks will be zero-emission by 2035. It shall be a further goal of the State that 100 percent of medium- and heavy-duty vehicles in the State be zero-emission by 2045 for all operations where feasible and by 2035 for drayage trucks. It shall be further a goal of the State to transition to 100 percent zero-emission off-road vehicles and equipment by 2035 where feasible.

CV vs NRMM OEM Pledges

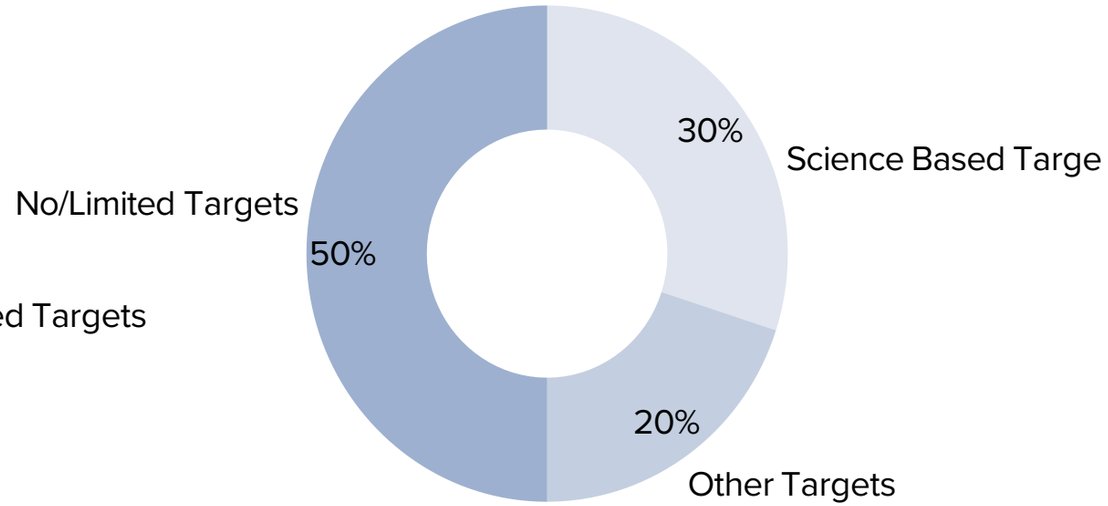
OEMs are introducing Science Based Targets (SBTs), reporting GHG emissions

Commercial Vehicle Major OEMs



n=12

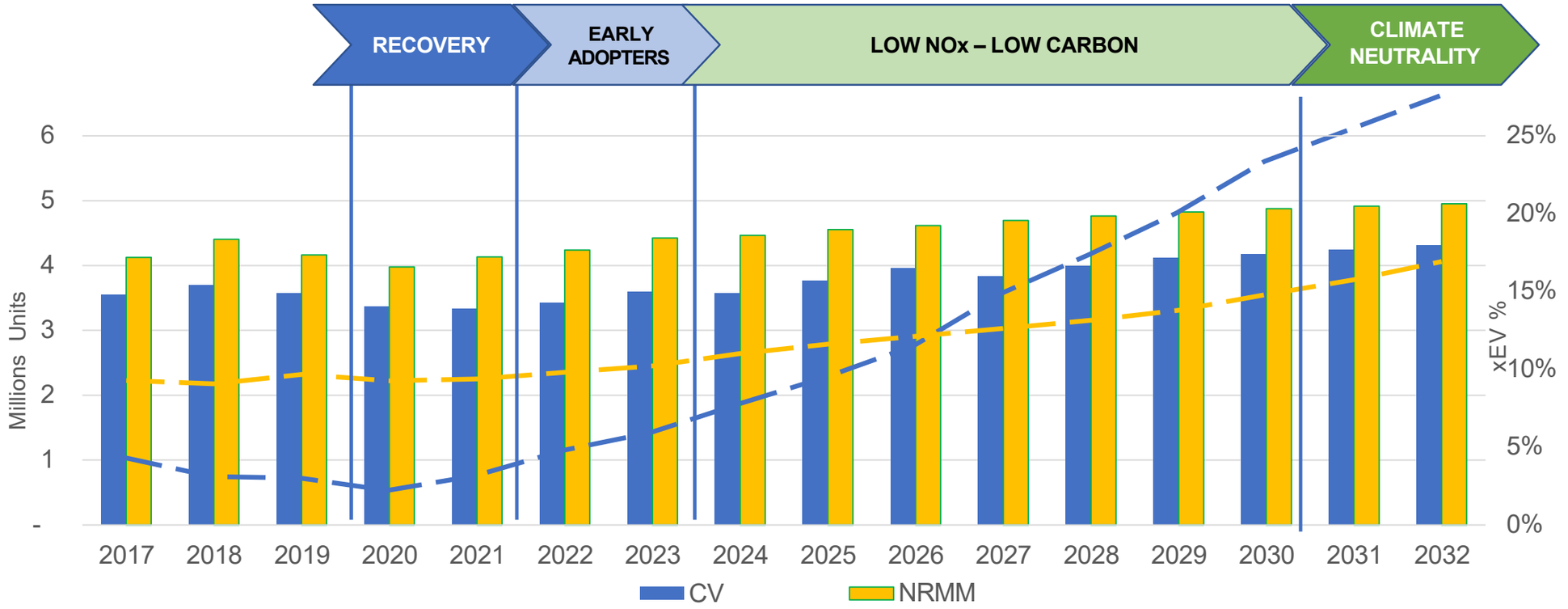
Non-Road Equipment OEMs



n=10

Science-based targets are a set of goals developed by a business to provide it with a clear route to reduce greenhouse gas emissions. An emissions reduction **target** is **defined** as '**science-based**' if it is developed in line with the scale of reductions required to keep global warming below 2C from pre-industrial levels. Source: Jargon buster: 'Science-based targets' (edie.net)

Timeline to Increased Adoption



Sources:
KGP Global Commercial Vehicle Powertrain Forecast KGP
Global Non-Road Powertrain Forecast Q4 22

Opportunities for Low Carbon NRMM

Benefits

- Improved air quality
- Lower noise
- Lower fuel costs
- Reduced maintenance cost
- Improved productivity

Challenges

- High energy use applications
- Low volumes compared to passenger car
- Widely segmented customer demands
- Durability requirements
- Remote locations, limited infrastructure
- Battery prices, raw material availability
- Limited incentives compared to light vehicle, commercial vehicle

Opportunities

- New OEM entrants
- Optimised energy usage
- New business models
- Infrastructure and charging investment
- Batteries
- Batteries/Energy as a Service

NRMM Energy Requirements

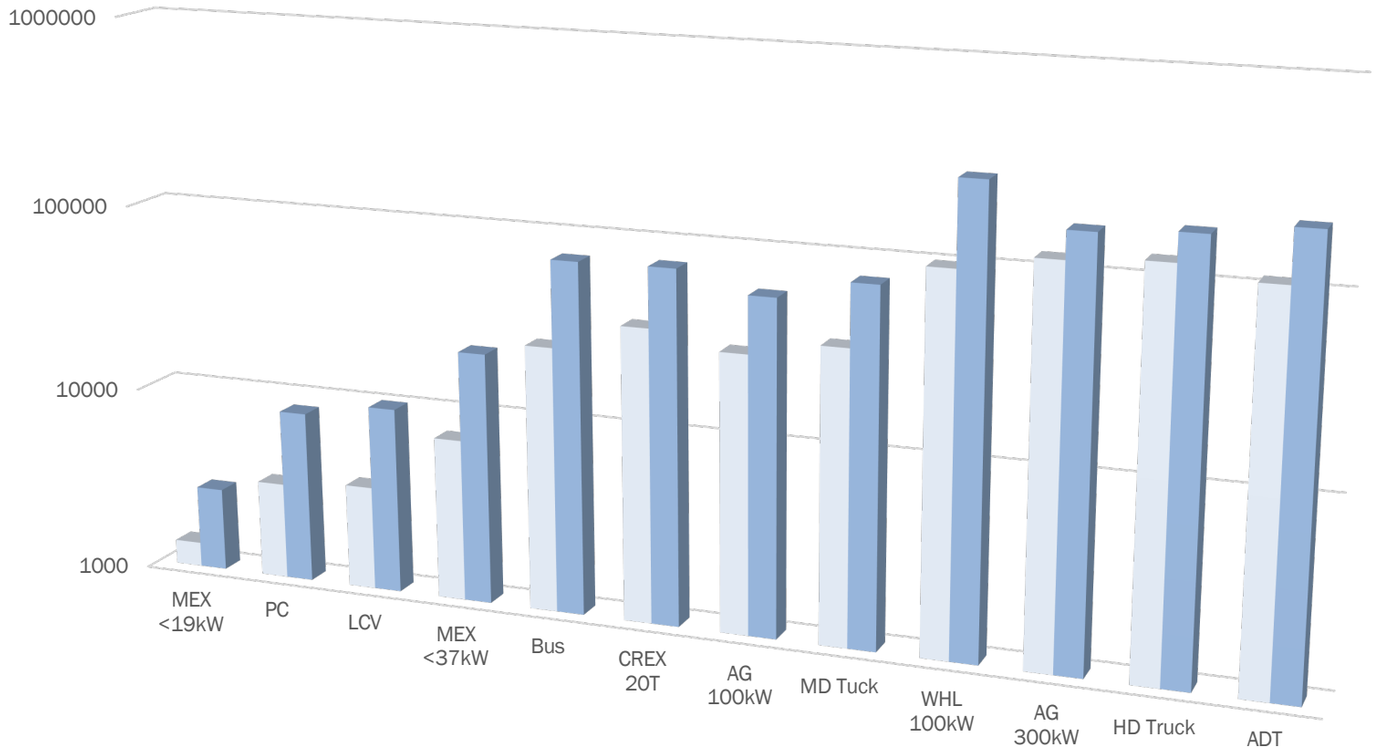
KGP Analysis:

- High/low average hours
- Various load factors
- Battery size and cost
- 100+ segments in TCO model
- Regional energy prices
- Infrastructure costs

Significant Implications:

- Productivity
- Renewable energy demand
- Charging requirements
- Battery sizing
- TCO calculations

Estimated kWh requirement per year by Application



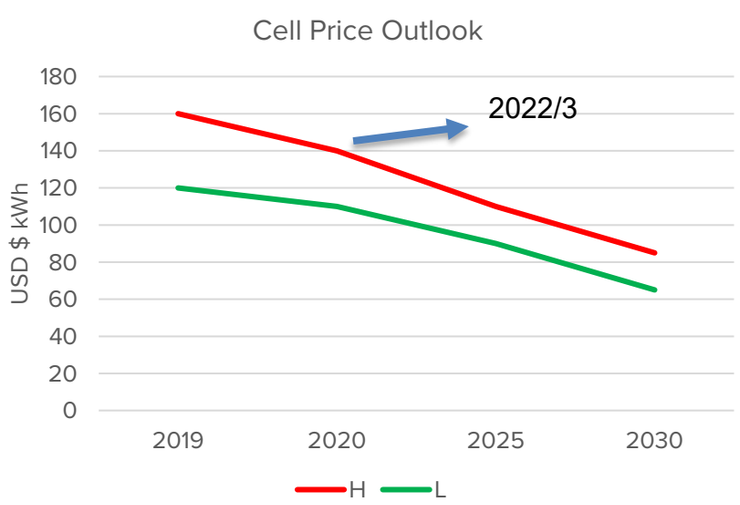
Source: Caterpillar, John Deere, CNHi, Kubota, Komatsu, XCMG, Liugong, Wacker Neuson, etc... KGP Analysis

NRMM Battery Pricing

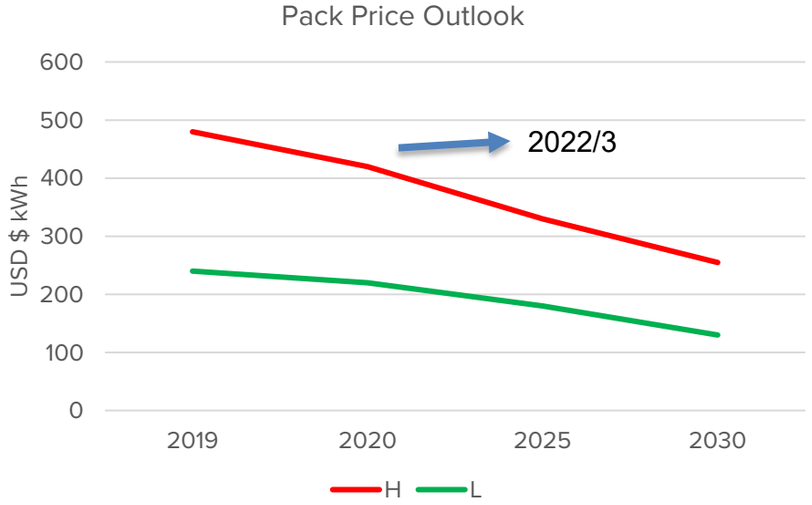
Volume battery cells for NRMM will be based on automotive cells, for volume reasons, as well as investment. Combining battery type, size, chemistry and volumes into a single analysis is difficult. The summary below shows the automotive cell price, and a range of the pack price for non-road. Smaller 48V as found in Mini-Excavators or Compact Construction equipment are being sourced from Automotive or Materials Handling (Forklift) vendors. Larger cells may be custom for NRMM, and also used in energy storage, rail, marine applications

Raw material pricing, and automotive demand is however increasing prices in the short term, and there may be a period of levelling out before falling after 2025.

Light Vehicle Cell Prices



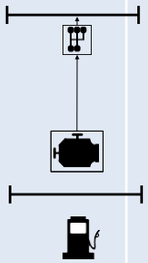
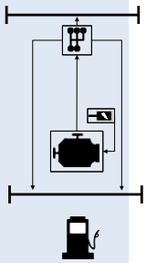
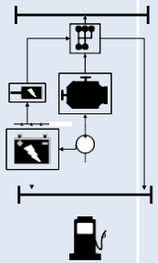
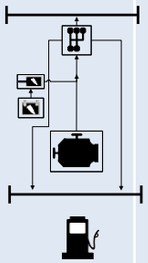
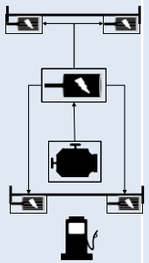
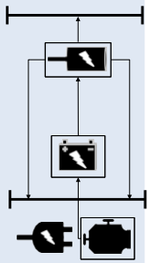
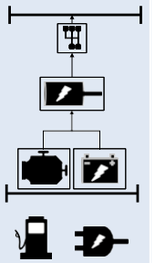
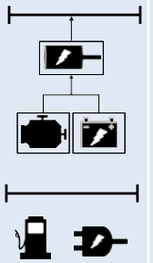
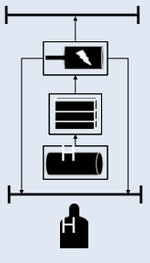
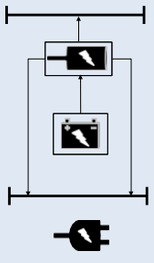
NRMM Battery Pack Prices



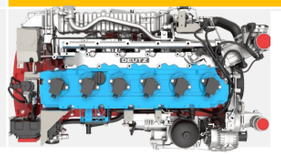
NRMM Electrification Technologies

Below is KGPs analysis of the characteristics of key electrification architectures for NRMM equipment. These technologies are explored in more detail throughout this report, but the examples below gives a concise view of available electrification types. The environmental impact and operational suitability for each of the architectures is also looked at briefly in the table below, but explored in greater detail throughout the report.

KGP Analysis of xEV Architecture for Low and Zero Emission NRMM

Characteristics	*ICE (Diesel/NG)*	*Mild*			*Electric Drive*	*Hybrid*			*FCEV*	*BEV*
Features	Conventional Powertrain	48V, engine boost, energy recovery			Diesel Electric Drive	Umbilical Hybrid	Parallel	Series	Fuel cell stack and Battery	Battery
Architecture										
Drivetrain	Standard	Standard	Standard	Standard	Electric Motor	Electric Motor	Standard or Electric Motor	Electric Motor	Electric Motor	Electric Motor
Energy Storage	Fuel Tank	Fuel Tank	Battery, Accumulator, Supercapacitor	Battery, Accumulator, Supercapacitor	None	Battery	Battery Supercapacitor	Battery Supercapacitor	Battery and Hydrogen Tank	Battery
TTW CO_2 Emissions	- -	-	-	-	-	-	+	+	+ +	+ +
WTW CO_2 Emissions	- -	- -	- -	- -	-	-	-	-	+	+
Noxious Emissions	- -	- -	- -	- -	- -	-	-	-	+ +	+ +
Range	+ +	+ +	+ +	+ +	+ +	+ +	+ +	+ +	-	- -
Refuelling Availability	+ +	+ +	+ +	+ +	+ +	+ +	+	+	- -	- -
Infrastructure Cost	+ +	+ +	+ +	+ +	+ +	+ +	-	-	- -	- -
Vehicle Cost	+ +	++	++	++	+	+	-	-	- -	- -
TCO	+ +	+	+	+	+	-	-	-	- -	- -

NRMM Model Availability

	<19kW	19-56kW	56-130kW	130-560kW	560kW+
Battery Electric					CAT, Liebherr
Other Electric					
Mild/Full Hybrid					
Electric Drive					
Fuel Cell					
H_2 ICE					

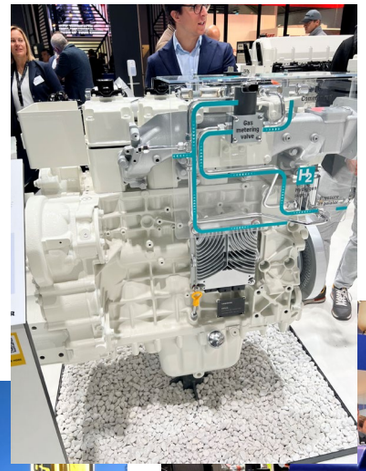
Prototype | <5% of Models | >5% of Models

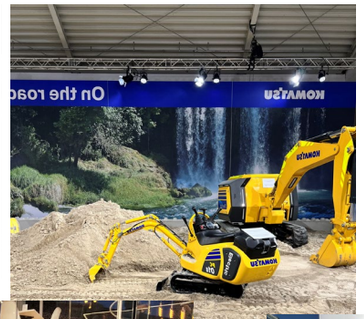
NB: List is non-exhaustive, for example only

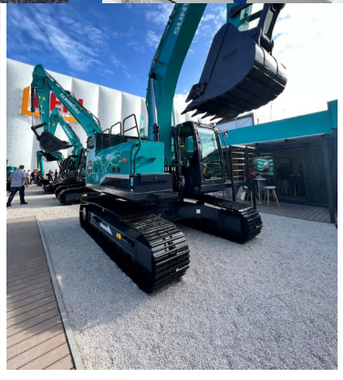
NRMM Model Availability

	Equipment Types	Tech Trends	Power/Voltage	Technology Transfer Segments	Number of Models
Handheld/ Extra Compact Equipment	Compaction, Mini Dumpers	**AG**: Battery Electric **CE**: Battery Electric **MH**: Battery Electric	48v <15kw 10-50kWh	Passenger Car Forklift	AG: 16 CE: 43 MH: 2
Compact Equipment	Mini Exc, Compact WHL, Site Dumpers, Small Ag, Rollers, Asphalt Finishers, Telehandlers, Compaction	**AG**: Battery Electric **CE**: Battery Electric **MH**: Battery Electric	48-90v 16-75kW 50-100kWh	Light Commercial Vehicle	AG: 40 CE: 110 MH: 11 Others: 9
Mid-Size Equipment	Crawler/Wheeled Exc, STL/CTL, WHL, Telehandlers Materials Handling Loaders, Forklifts, Graders, Compaction	**AG**: Mild Hybrid/Battery Electric/H2 **CE**: Battery Electric/H2 **MH**: Battery Electric/H2	100-300v 80-250kW 100—300kWh	Medium Duty Commercial Vehicle	AG: 14 CE: 86 MH: 19 Others: 4
Large Equipment	Crawler Exc, WHL, Mobile Cranes, Drilling/Piling Rigs, Processing Equipment, Large Tractors/Combines, Forestry, Port Handling, Large Materials Handling	**AG**: M.Hybrid/F.Hybrid/ H2 **CE**: M.Hybrid/Umbilical/ H2 **MH**: Umbilical/H2/Battery Electric	400-800v 250-500kW 0.3-1MWh	Heavy Duty/Bespoke NRMM	AG: 6 CE: 34 MH: 8 Others: 35
Extra Large Equipment	Mining Equipment, Marine, Rail	**CE**: Umbilical/H2 **MH**: H2/Umbilical	>1000v >560kW >1MWh	Bespoke NRMM	CE: 32 Others: 3

Bauma 2022 – Over 100 New xEV Models & Batteries & Other Innovations







Large Scale Batteries

- Rail, Mining, Marine all need MWh scale battery packs. Current mining haul trucks using 0.5MWh (Hitachi/ABB/Toshiba), up to ~4MWh in prototype. ProgressRail up to 14MWh Loco in assembly.
- Challenges related to cell types, durability, operating conditions (high or low ambient, dust, vibration), high C rates, cost, availability
- For Mining durability relates to high C rates, some applications need pre-heating, others advanced cooling
- Will need regular replacement due to high hours, with current chemistries.
- Variability of application demands mean some packs will need replacing regularly.
- Limited testing data on long term performance to date.

Requirement	Short Term	Future
Pack Size	0.5-4MWh	0.5-10MWh
Cell Format	Cylindrical/Prismatic	Cylindrical/Prismatic
Cell Chemistry	LFP (NMC/LTO?)	LFP (LFMP/LNO?)
Cooling	Air/Liquid	Advanced Liquid
Energy Density	<150Wh/Kg	>200Wh/Kg
Cycle Life	2000-2500	3000+
C Rate	1-2C	2C+
Cost (Pack)	>$250kWh	<$200kWh

Large Scale Batteries

Liebherr – Fortescue – WAE Technologies 1.4MWh Prototype

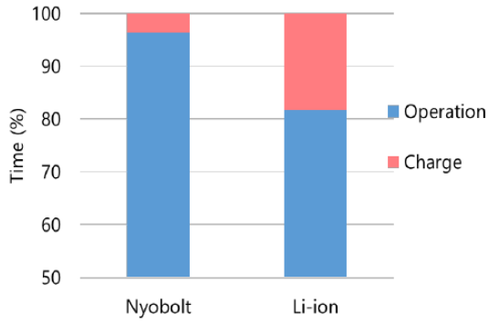
15 tonnes, measures 3.6m long, 1.6m wide and 2.4m high, and is made up of eight sub-packs, each with 36 modules, all individually cooled and each with its own battery management system.

Nyobolt Technology Advantage

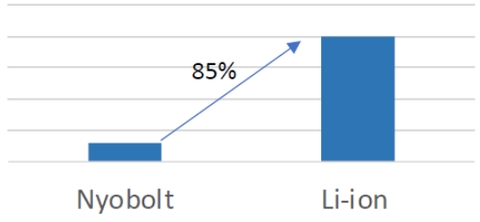
Mining Haul Truck Simulation Study shows 18% improvement in operational efficiency 50-70% reduction in operational cost

Fast charge	High Power	Competitive energy	10x durability	Lowest TCO	Improved safety
<5 min charge allows high up-time and productivity	Highest power density → smaller, lighter battery → greater payload	>20x more energy density than supercapacitors; similar to Li-ion	Expected cycle life 10x compared to Li-ion → Less battery packs in truck's lifetime	Lowest cost per kW and per kWh used, Competitive purchase price, Low TCO	No Li plating risk, wider temperature performance & reduced fire risk

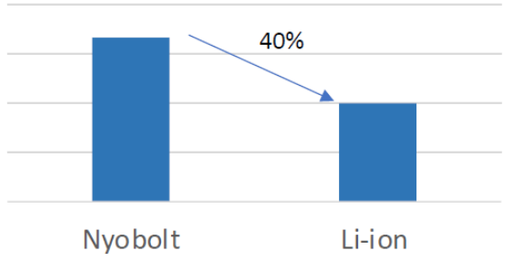
Time (%) in Operation vs. Charge



Number of pack replacements in haul truck's lifetime



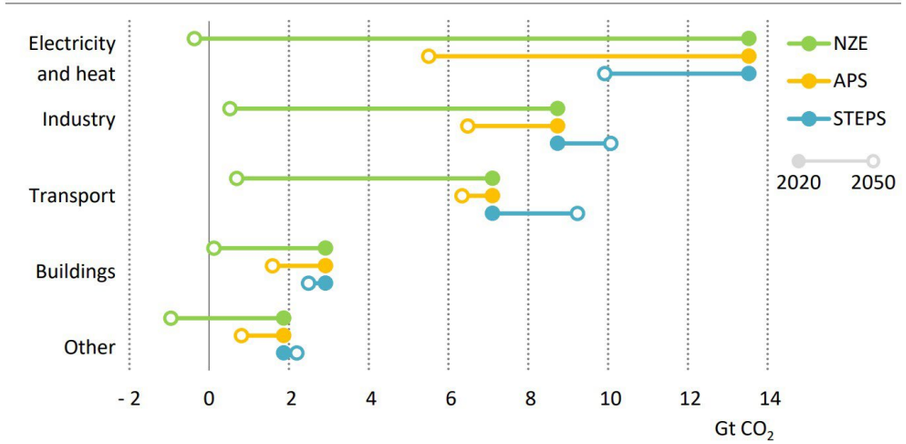
Payload volume availability



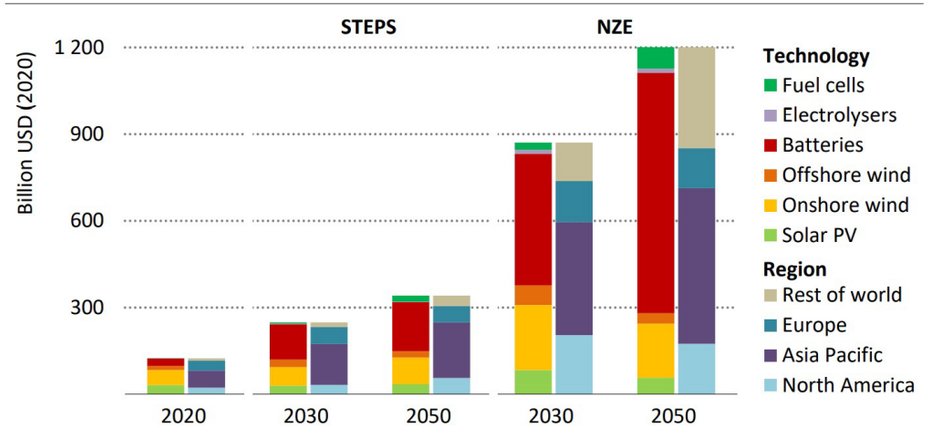
www.nyobolt.com

Energy Availability

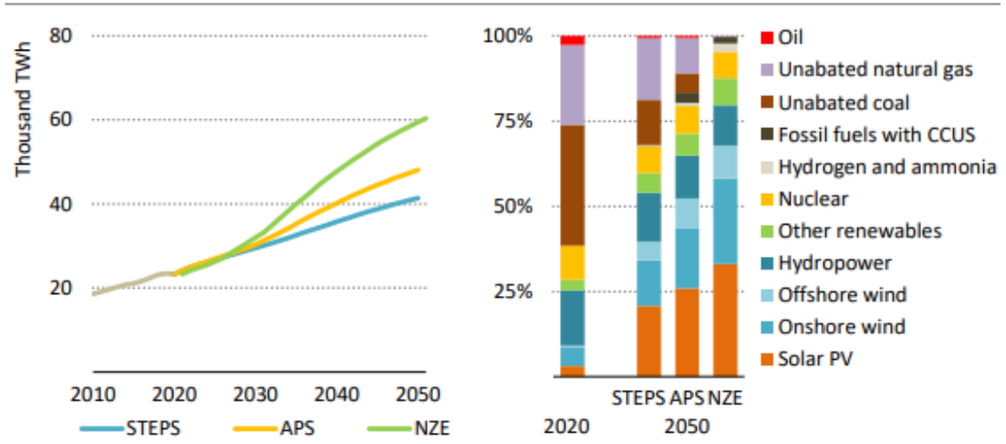
CO_2 Emissions by End Use 2020-2050



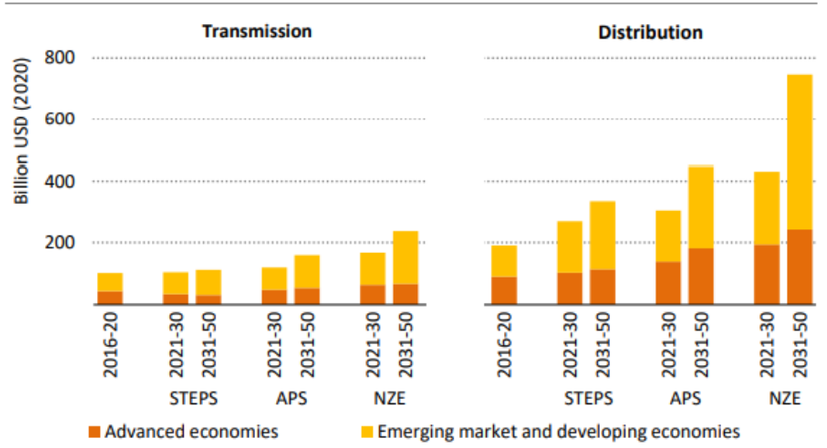
Annual Renewable Energy Investment



Annual Electricity Demand, Source



Annual Infrastructure Investment



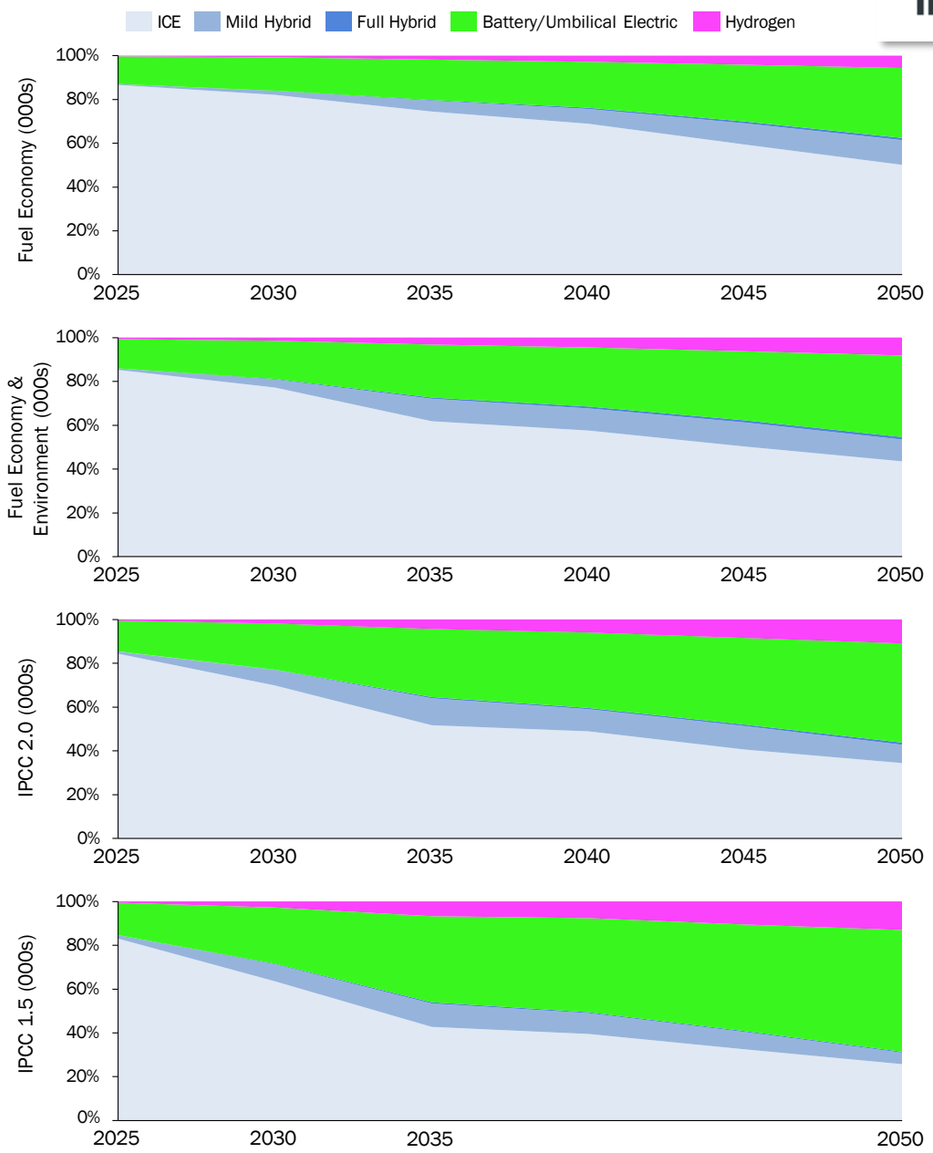
STEPS – Stated Policies Scenario, APS – Announced Pledges Scenario, NZE – Net Zero Scenario

Source: IEA World Energy Outlook 2021

NRMM Long Term xEV Outlook

- KGP's base view flexed with four scenarios
- To meet Net Zero the IPCC 1.5 has a very rapid shift to zero carbon solutions
- H_2 ICE likely go grow in all scenarios
- Optimised job site for all machines will reduce absolute fuel consumption

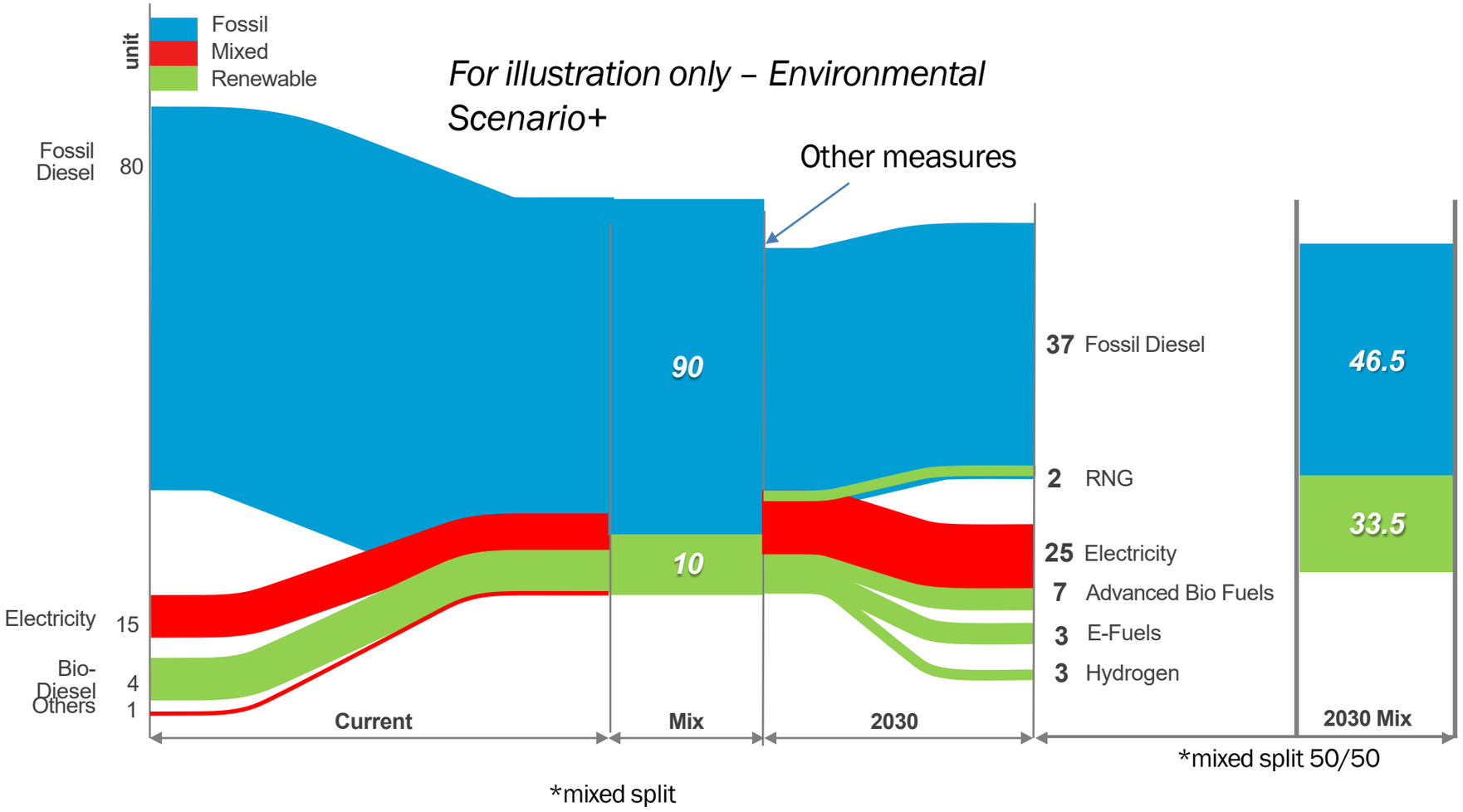
Figure 24. xEV Production by Type - Four Scenarios



NRMM xEV Powertrain Forecast Q3 2022

KGP NRMM Energy Environmental Scenario

Starting to see potential for greater decarbonisation in Non-Road, up from 2018/2019



Contacts

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Acronyms

AG - Agricultural Equipment
APU - Auxillary Power Unit
AWP - Aerial Work Platform
BEV – Battery Electric Vehicle
BET - Battery Electric Truck
CAGR – Compound Annual Growth Rate
CCC - Closed Coupled Catalysts
CE - Construction Equipment
CH_4 - Methane
CO_2 - Carbon Dioxide
CSR – Corporate Social Responsibility
CV – Commercial Vehicle
DOC – Diesel Oxidation Catalyst
DPF – Diesel Particulate Filter
EGR – Exhaust Gas Recirculation
FCEV – Fuel Cell Electric Vehicle
FLT - Fork Lift Truck
GHG – Greenhouse Gas (CO_2, CH_4 etc.)
GVW - Gross Vehicle Weight
HCCI – Homogeneous Charge Compression Ignition
HDT - Heavy-Duty Truck (>15t GVW)
HDV - Heavy-Duty Vehicle
HEV - Full Hybrid Electric Vehicle
ISC/ISM – In-service Compliance/Monitoring
LEZ – Low Emission Zone
LULUCF - Land use, land-use change and forestry
MDT - Medium-Duty Truck (6-15t GVW)
MH - Materials Handling Equipment
NDC - Nationally Determined Contribution
NH_3 - Ammonia
N_2O - Nitrous Oxide
NO_2 - Nitrogen Dioxide
NOx - Nitrogen Oxides
NRMM - Non-Road Mobile Machinery
OBD – On-board Diagnostics
PHEV – Plug-in Hybrid Electric Vehicle
PM - Particulate Matter
PN - Particulate Number
PTO - Power Take Off
RCCI – Reactivity Control Compression Ignition
REV - Range Extended Vehicle
SCR – Selective Catalytic Reduction
TCO – Total Cost of Ownership
TTW – Tank to Wheel
V2V – Vehicle to Vehicle Communication
VECTO – Vehicle Energy Consumption Calculation Tool
WTT - Well to Tank
WTW – Well to Wheel
ZECV - Zero Emission Commercial Vehicle
ZEV - Zero Emission Vehicle
ZEZ – Zero Emission Zone


Thank you for your attention!
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