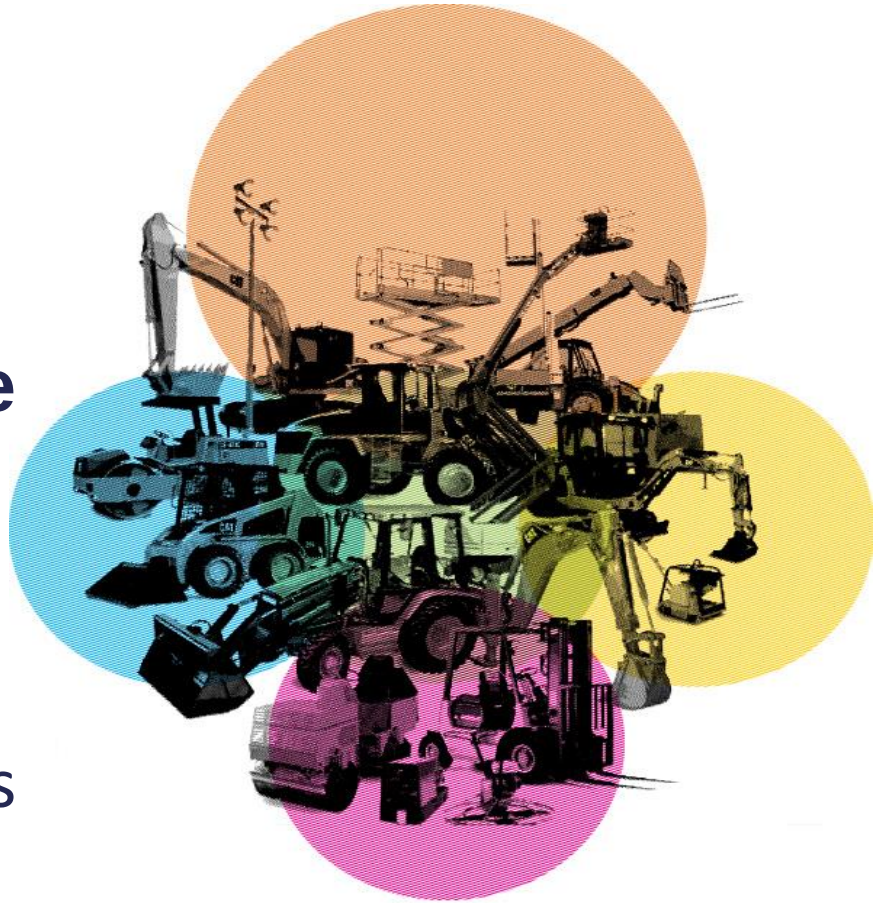
EUROPEAN
RENTAL
ASSOCIATION

State of play and trends in the energy transition

Decarbonisation and electrification of non-road machinery



Alex Woodrow

Knibb Gormezano and Partners

Please react on Twitter, @era_rental

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June 2022

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Global Commercial Powertrain Services 2022

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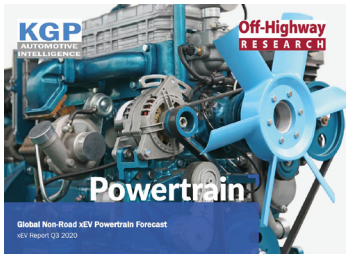


Global Non-Road Powertrain Forecast Launched 2009 with Off-Highway Research – Published January, April, July, October
Global Commercial Vehicle Powertrain Forecast Launched 2005 with LMC Automotive – Published January, April, July, October
Non-Road Electrification Report – Published May, November
Commercial Vehicle Electrification Report – Published May, November
Commercial Powertrain Intranet Portal Launched April 2019 – Published Daily
Annual Reviews – Published April

The Global Commercial Vehicle Powertrain Forecast is a collaboration between Off-Highway Research and Knibb, Gormezano and Partners, launched in 2009.

Genset , Marine from Q3 2022

CEA Construction Equipment Sector 2019

THE UK'S CONSTRUCTION EQUIPMENT SECTOR REPORT 2019

2018 FACTS AND FIGURES

TOTAL REVENUE
>£13bn 2018
>£11bn 2013
>£8.5bn 2004

GVA
>£2.3bn

TOTAL EMPLOYMENT
>42,000

EXPORT SHARE OF PRODUCTION
>60%

INVESTMENT IN R&D
>£220m pa

NUMBER OF COMPANIES
>1,550

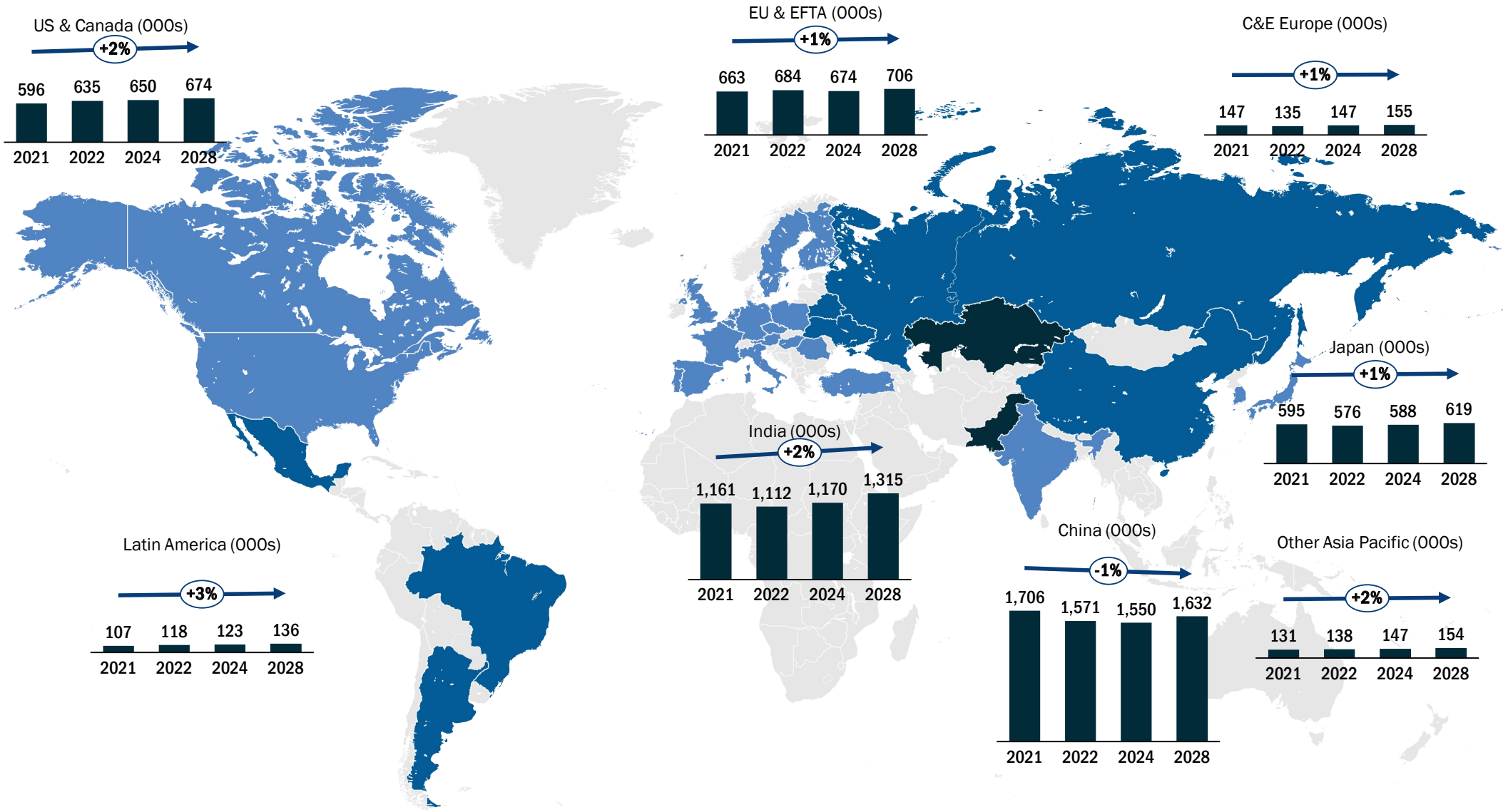
UK MACHINE PRODUCTION
>60,000 units

WORLD RANKING (MACHINES)
5th Globally
1st Europe

CEA Construction Equipment Association
Department for Business, Energy & Industrial Strategy
Knibb Gormezano & Partners
Off-Highway Research

Outlook - Geographic Production

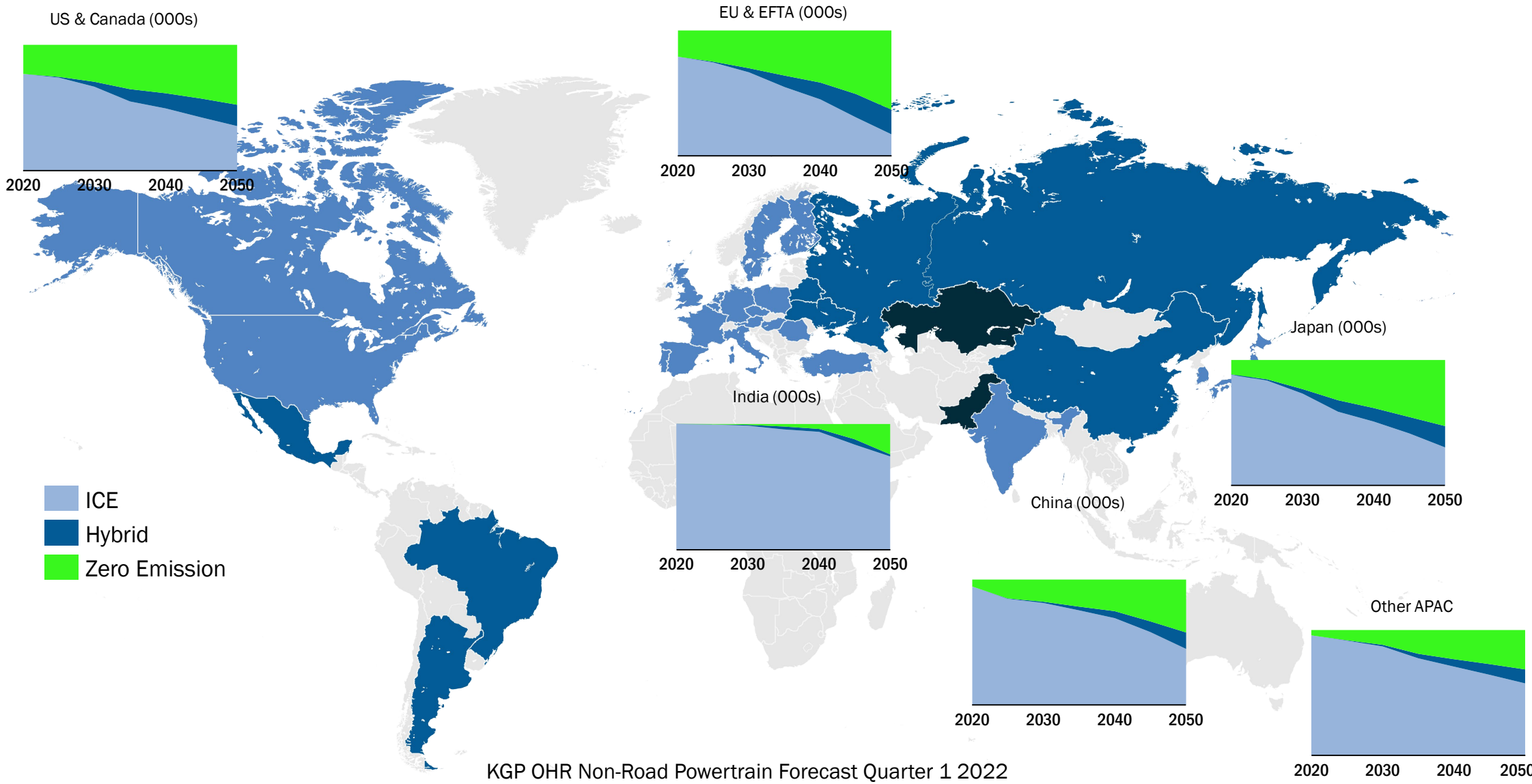
Short Term Production Forecast - 2028



KGP OHR Global Non-Road Powertrain Forecast GNRPTF Quarter 1 2022

Outlook - Powertrains

xEV Penetration Forecast by Region



KGP OHR Non-Road Powertrain Forecast Quarter 1 2022

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.

Legislation - CARB Tier 5 - Timelines

- CARB's proposal for Tier 5 is still subject to working group discussion to reviewing the feasibility of different limits and technology options.
- Both criteria emissions and GHG may be included.
- Source: EPA Working Group

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 2.0 (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**
   Green credtials, 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...

GHG Tipping Point Reached?

2021 Paris Agreement/COP 26

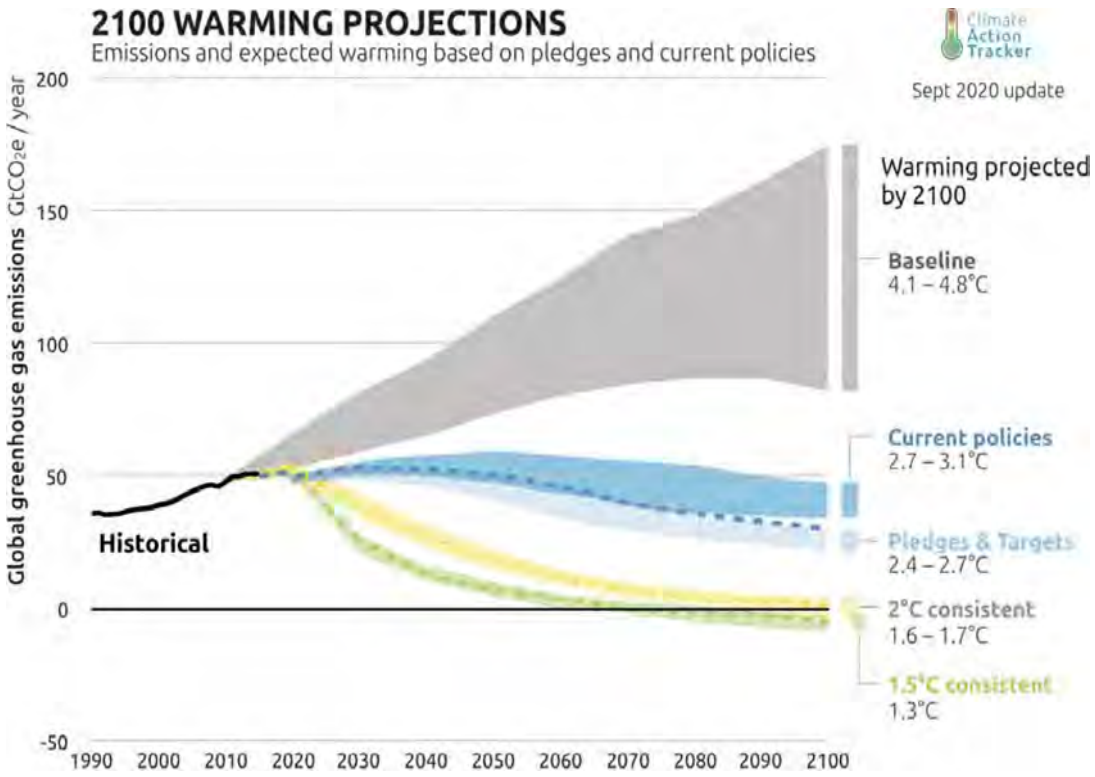
The Paris Agreement

- Introduced at COP 21 in December 2015, opened for signature in April 2016
- Due to begin in 2020 – 185 of 197 parties have ratified

Key Elements:

- Long-Term Temperature Goal – Limit the increase of surface temperature to 1.5 °C, hold increase in surface temperature to below 2 °C above pre- industrial limit – in the EU this means a reduction of 80-95% GHG below 1990 levels by 2050 (60% for the transport sector)
- Global Peaking – Parties to reach global peaking of GHG emissions as soon as possible, must achieve a balance between anthropogenic emissions by sources and removals by GHG sinks in the second half of the century
- Mitigation – all Parties to prepare, communicate and maintain a nationally determined contribution (NDC) to the fullest of their ability.
- Sinks & Reservoirs – Encourages Parties to conserve and enhance sinks and reservoirs of GHGs, including forests
- Global Stocktake – Due in 2023 and take place every 5 years, will assess collective progress and inform parties

Figure 15. Global Warning Predictions Based on Pledges and Policies



GHG Emissions Pledges

GHG emissions, targets and legislation

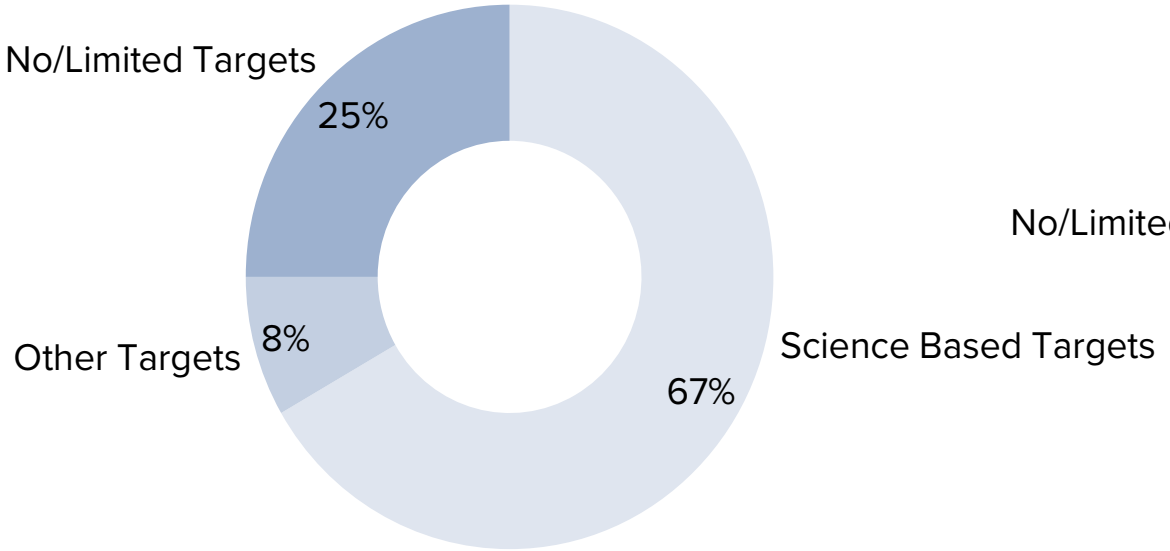
- Top 10 countries account for around 60% of global GHG emission - China, US, India, Russia, Brazil, Japan, Iran, Germany and Canada.
- Over 60% of global emissions covered by a net zero target (Carbon Brief 2021).
- California has most aggressive legislation for CV - non for NRMM - and is a Top 20 GHG emitter in its own right.
- China, India, Russia, Brazil and Indonesia are significant net exporters of GHG.

Region	Net Zero Target Updated	Net Zero Target	CV GHG Legislation	NRMM GHG Legislation
China	2020	Peak by 2030 Net Zero by 2060	Phase 3 - 2021	None
USA	2021	Net Zero by 2050	GHG 2 – 2027	None
EU	2020	-55% by 2030, Net Zero by 2050	2025, 2030	None
India	2021	Net Zero by 2070	Phase 2 - 2021	None
Russia	None	None	None	None
Japan	2020	Net Zero by 2050	Top Runner – 2015	None
Brazil	2020	-43% by 2030, Net Zero by 2060	None	None
Indonesia	2021	-29-41% by 2030, Net Zero by 2070	None	None
Iran	None	None	None	None
Canada	2020	-30% - 2030, Net Zero by 2050	GHG 2 – 2027	None
California	2018	-40% by 2030, Net Zero by 2045	ACT - 2024	None

CV vs NRMM OEM Pledges

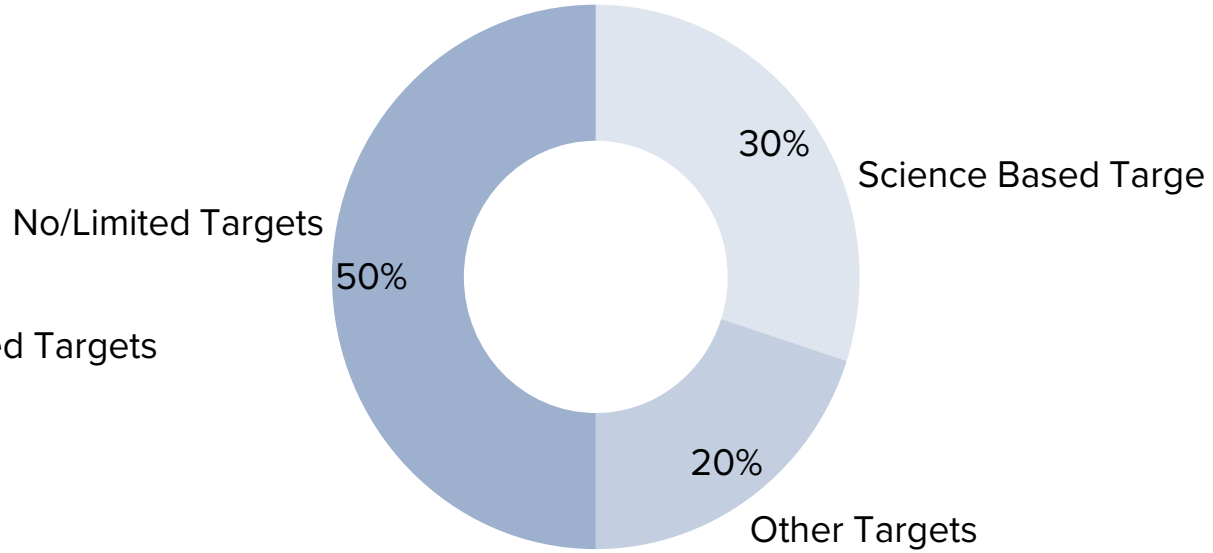
OEMs are introducing Science Based Targets (SBTs)

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)

Zero Emission Pledges

- Limited national targets to date
- Construction globally accounts for 23% of GHG and 30% of resources

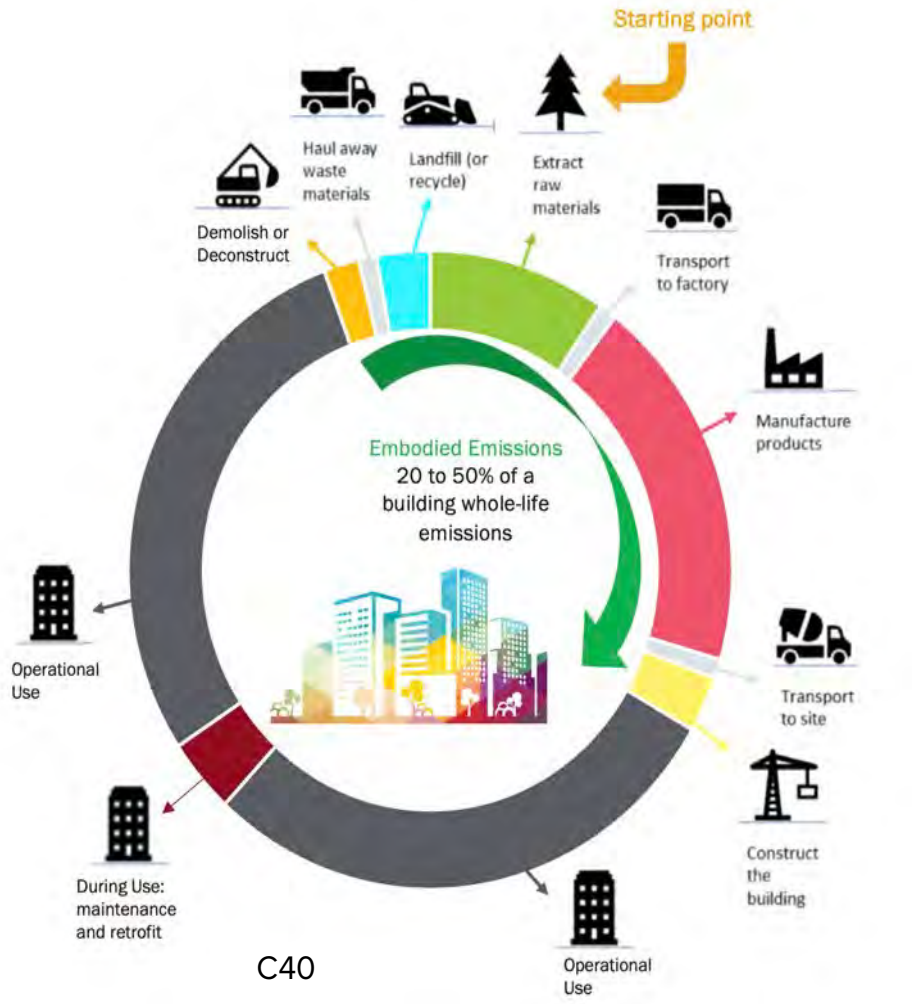
C40 Clean Cities Clean Construction

"Procure and, when possible, use only zero emission construction machinery from 2025 and require zero emission construction sites city-wide by 2030"

World Green Building Council

WORLD GREEN BUILDING COUNCIL

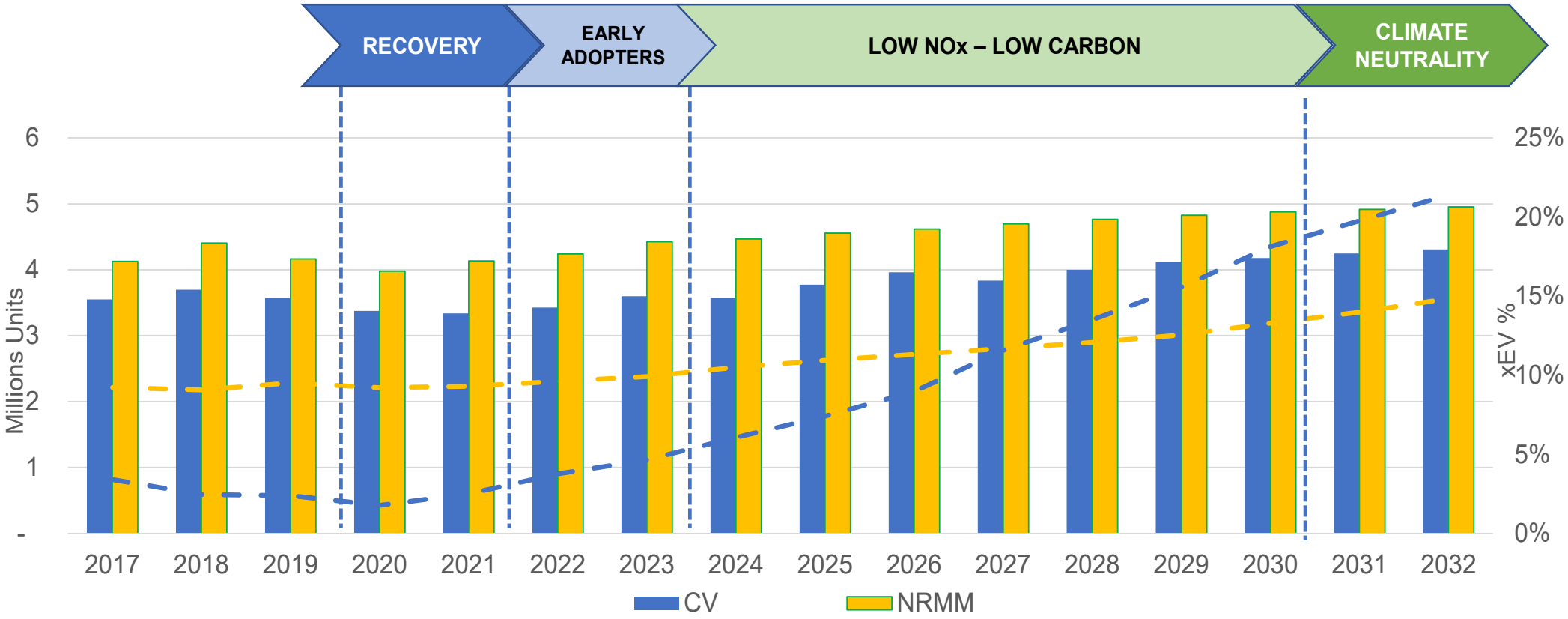
New buildings, infrastructure and renovations will have net zero embodied carbon by 2050. 104 Businesses, 28 Cities and 6 States & Regions signatories.



C40

ACS (E)	Hochtief (ACS - D)	Vinci (F)	Bouygues (F)	Strabag (A)
None	None	40% by 2030, Net Zero by 2050	30% by 2030	None
Bechtel (US)	**Costain (UK)**	**Balfour Beatty (UK)**	**LendLease (F)**	**Skanska (SE)**
None	Net Zero by 2035	Net Zero 2040	Net Zero 2040	Net Zero by 2045

Timeline to Increased Adoption



Sources:
KGP Global Commercial Vehicle Powertrain Forecast Q4 20
KGP Global Non-Road Powertrain Forecast Q4 20

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

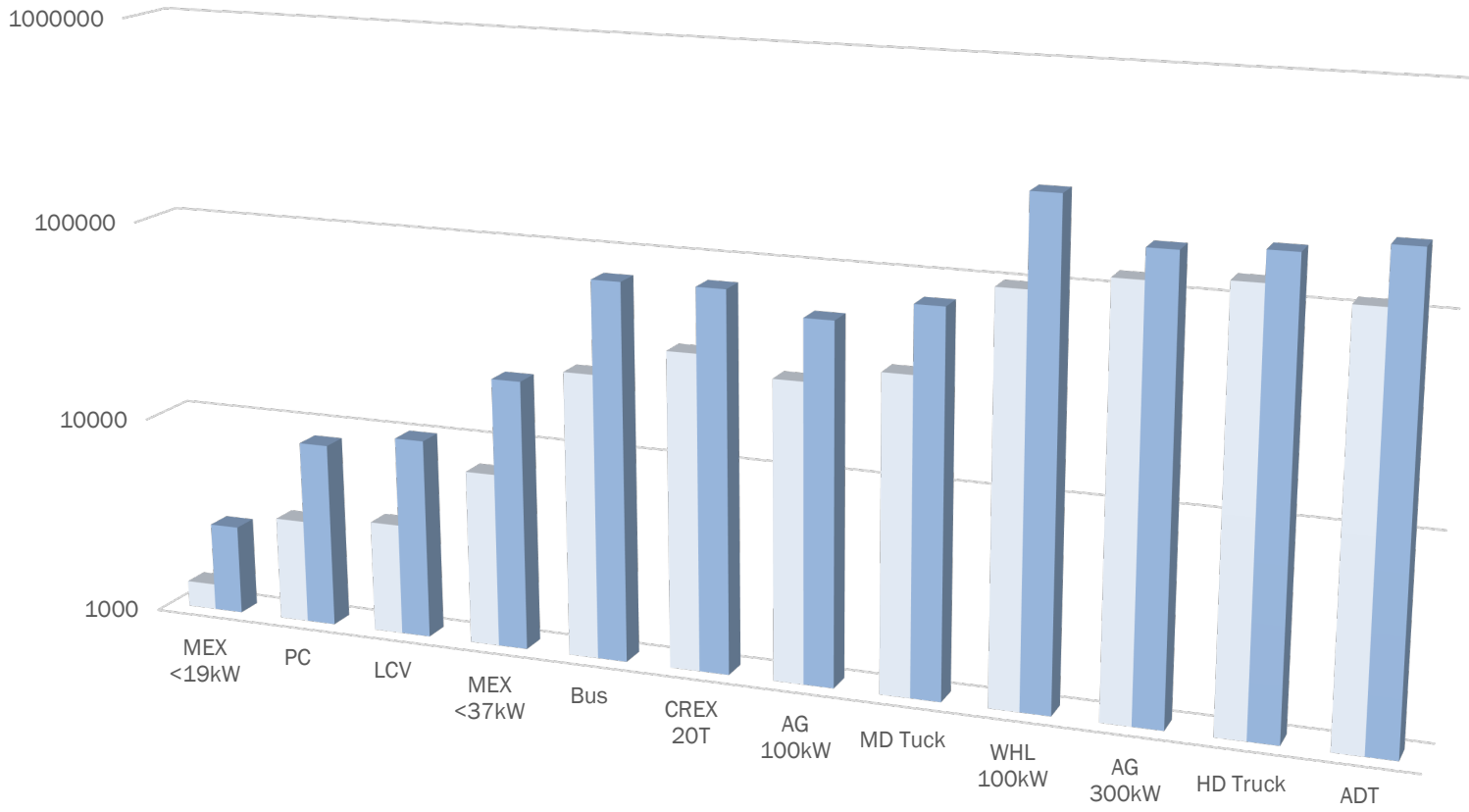
KGP Analysis:

- 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

Figure 30. Estimated kWh requirement per year by Application

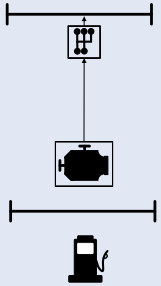
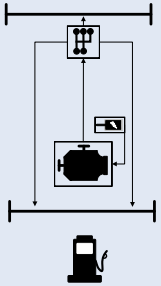
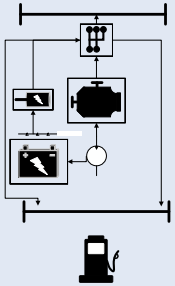
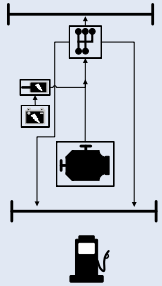
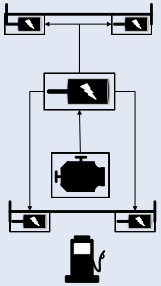
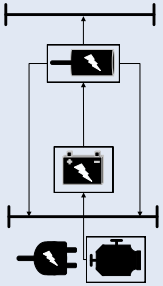
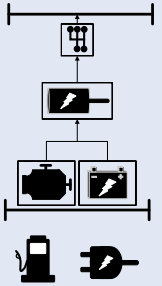
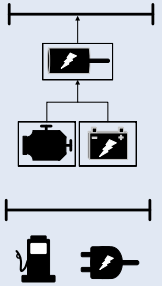
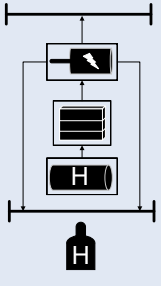
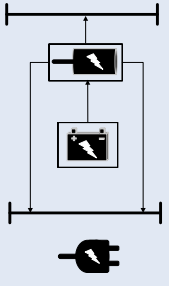


Source: Caterpillar, John Deere, CNHi, Kubota, Komatsu, XCMG, Liugong, Wacker Neuson, etc... KGP Analysis

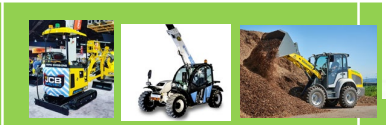
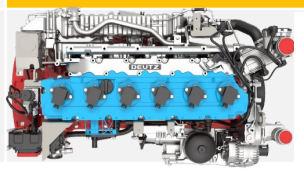
NRMM Electrification Technologies

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.

Figure 25. 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					
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

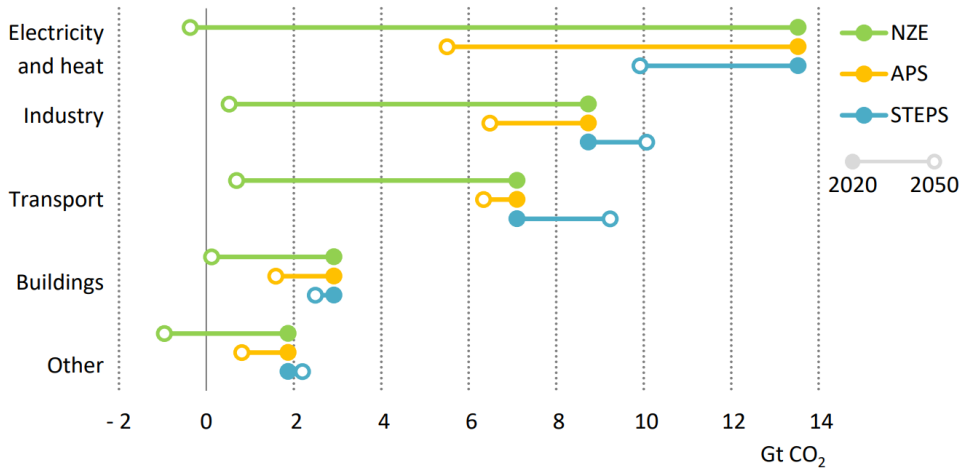
KGP has a model database looking at production and prototype xEV and alternative fuel machinery demonstrated by OEMs in the non-road sector. There are 348 models in the Q3 2021 edition of the xEV report, up from around 220 in May 2021 edition. We do not include electric forklifts, or lawn care as the technology does not transfer to other areas of the non-road sector easily. For information on these segments that are more readily electrified, please contact us directly.

The non-road sector is electrifying rapidly, and moving into heavier types of equipment as the drive for low carbon living intensifies.

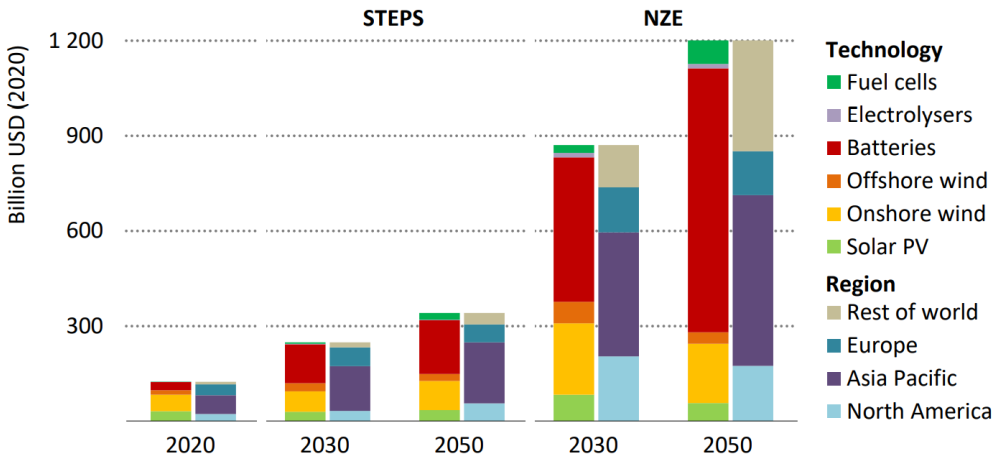
Source: KGP xEV Model Database November 2021

Energy Availability

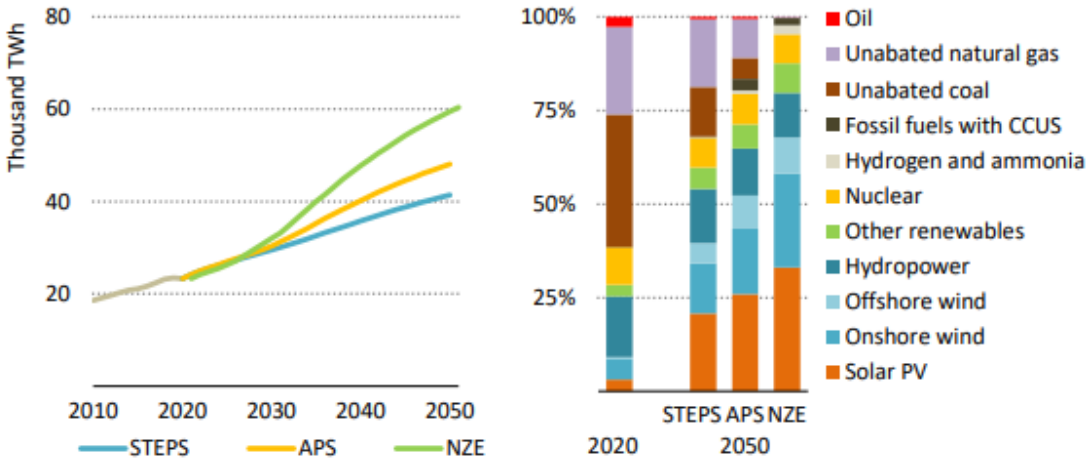
CO_2 Emissions by End Use 2020-2050



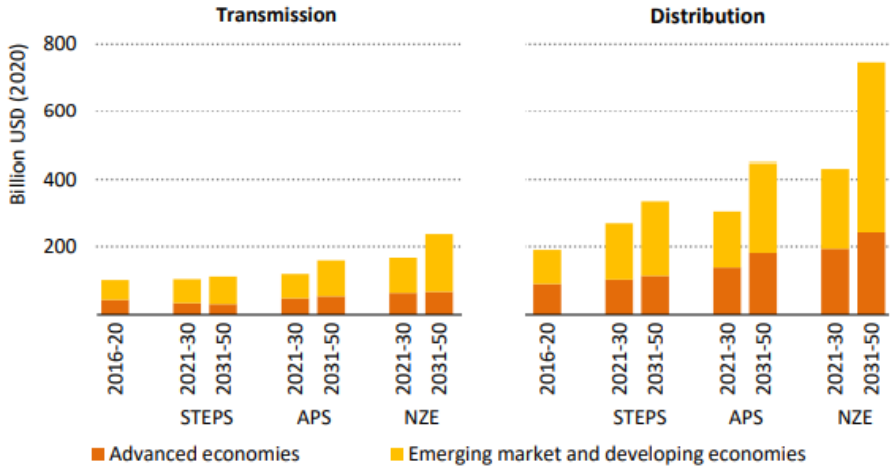
Annual Renewable Energy Investment



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 Policy Options

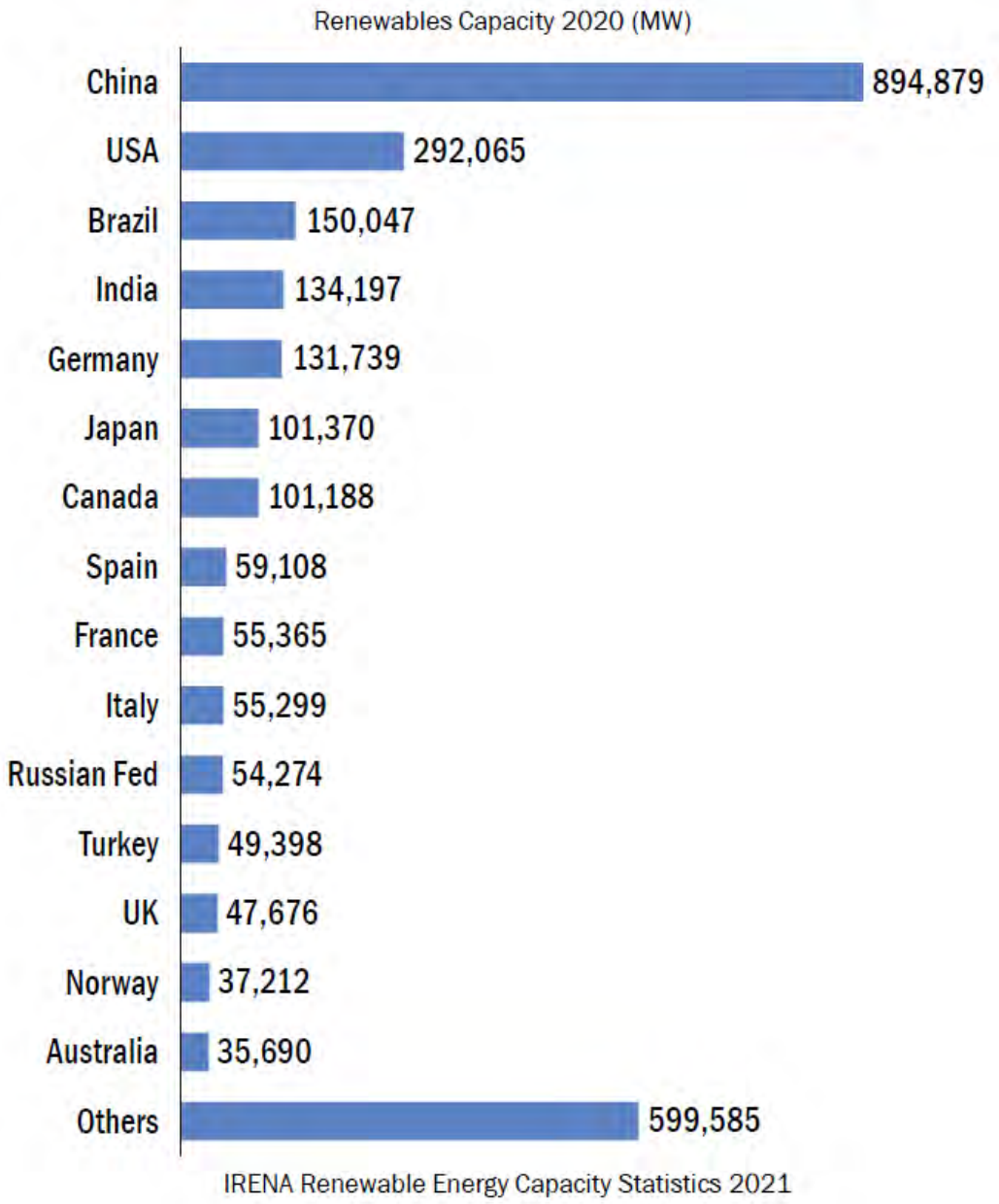
Policy options for effecting NRMM can be divided into three key subcategories - administrative (legal), economical and research/demonstrative. The policy could be general, not specifically targeting NRMM, but it would fall within the remit. Or the policy could be specific to NRMM. Some examples of what policies could come into force impacting the NRMM are outlined below.

Figure 19. Policy Options for Adoption of Alternative Fuels

Legal	Economics	Research/Demonstrative
Regulation of CO_2 emissions. • So far no EU regulation of CO_2 for NRMM. Expected in the future, but what shape it will take is uncertain. Minimal renewable contribution to fuel blends. • In Sweden requirements in the public procurement currently focus on machinery and not fuel used. Pilot project still in testing phase. Retrofitting of machinery • New machinery in Germany (above 18kW) had to comply with strict particulate number at all construction sites. In Switzerland all machinery above 37kW must have a DPF. Require compliance with certain standards for machinery used in municipal tenders. • Used in specific German municipalities. In Sweden, it is applied to municipalities of the three largest cities or when commissioned by the Swedish Transport Administration.	Refund of energy tax on use of biofuels. • Available in Germany (Bavaria) for the new acquisitions and retrofitting of tractors and other mobile machines. Fuels taxation to increase incentive to energy efficiency. Carbon neutral biofuels could be exempt from taxation or relieved of energy tax. • This tax would not target NRMM specifically, but would impact the TCO and operating cost to a degree that promotes alternative fuel use.	Demonstration of projects for the use of biofuels. • Pilot project in Germany for the use of vegetable oils in agricultural machinery. The aim is suitability and reliability for the machinery, and significant GHG reduction, whilst promoting domestic protein supply. Introduction of LEZ and ZEZ • London is current active NRMM emissions limiting zones for construction sites. Many other cities in the UK are under consideration. Expected to follow London. No CO_2 limits. Use working environments to spead technology. • In warehouses and underground mining for example, the specific requirements for these machines to have particulate filters, meant certain operators had cleaner machines when using them outside of specific working environments. • The EPA are considering GHG emissions limits for machinery operating within a designated area of ports in the San Francisco area.

NRMM Challenges - Renewable Energy

- The International Renewable Agency (IRENA) shows, under their estimates, we aren't moving fast enough in terms of renewables, which will limit xEV sales in most scenarios.
- In 2020 global renewable energy capacity stood at 2.8 TW, rising 10.3% on 2019 and double the level of 2012.
- Renewable energy capacity needs to reach to over 18 TW by 2050.
- EU's Green Deal will revise the Renewable Energy Directive II, which requires 32% of fuel to be renewable by 2030 with a 14% target for transport.



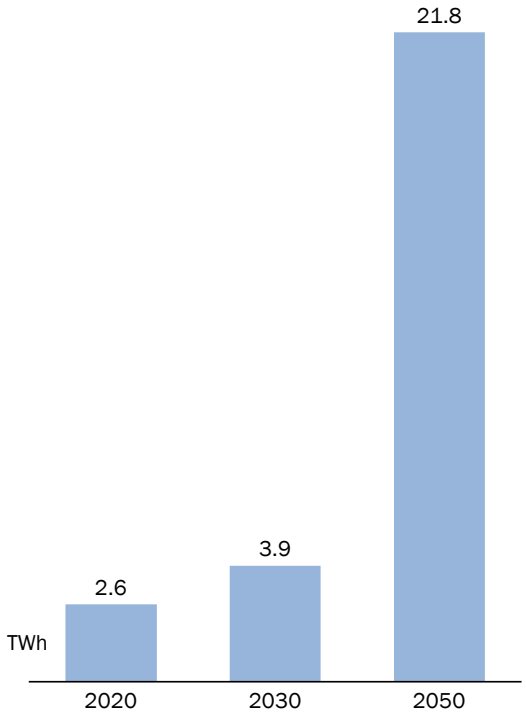
Hydrogen Usage & Policy

Hydrogen usage is expected to increase exponentially over the next few years as an energy dense fuel that is capable of mirroring current machine performance whilst producing much lower emissions.

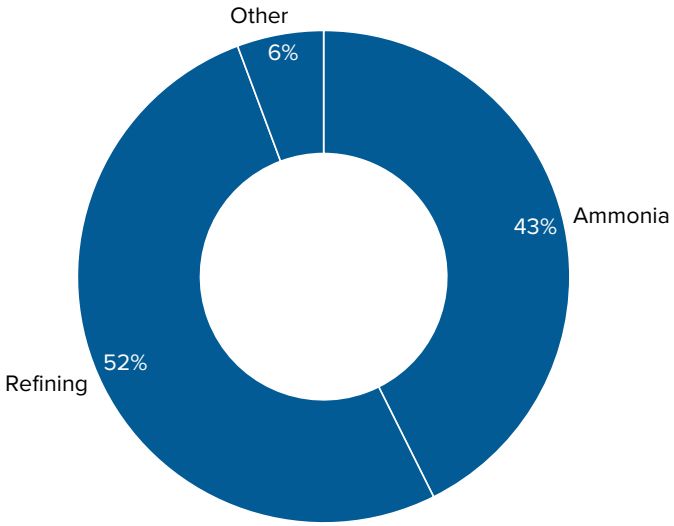
As discussed in the slide above there are several methods to produce hydrogen with each differently impacting the well-to-wheel emissions. However, performance optimism is strong and key stakeholders are investing heavily a future for hydrogen - some challenges remain:

- Significant investment in green hydrogen is being made by governments worldwide. A hydrogen strategy is being considered in most major markets
- Uncertainty remains over hydrogen type – Compressed vs Liquid.
- Pricing is very sensitive to a number of inputs. Operating hours impacts cost significantly.
- Urban delivery/creation and operation is key for the non-road sector, is small scale electrolysis commercially viable?
- Is containerised mobile storage and delivery a viable option? OEMs and suppliers are investing heavily and investigating.
- Concerns over safety of large quantities of highly flammable gas or liquid storage in densely populated areas.

Hydrogen Usage (TWh)



Current Hydrogen Usage 74Mt (2.5 TWh)



Hydrogen Policy Annoucements

Hydrogen	KG
China	R&D Programme 2020
USA	None
EU	Vision 2018, Strategy 2020*
India	None
Russia	Roadmap 2020
Japan	Strategy 2019
Brazil	Strategy due 2021
Indonesia	None
Iran	None
Canada	Vision 2019
California	Vision 2018

Source: LBST/Hydrogen Council

Hydrogen - OEM Developments

H2 ICE, fuelled using 'Green' hydrogen that produces minimal CO2 during its production, can be considered Zero Emission under the EU definition. Noxious emissions can be relatively easily eliminated, but concerns over specific power density and overall efficiency of hydrogen both against BEV and for H2 ICE vs H2 FCEV are major considerations, as is current fuel availability and refuelling infrastructure availability.

OEM	H_2 ICE	FCEV
Daimler	Possible	Yes (Volvo JV)
CNH Industrial	Possible	Yes (Nikola)
MAN	Yes	Limited
Scania	Yes	Limited
Volvo	Possible	Yes (Daimler JV)
Cummins	Yes	Yes
Deutz	Yes	No
JCB	Yes	Yes
Liebherr	Yes	No

Pros and Cons

+ ve

- Existing ICE investment
- Fuel Cell limitations
- Lower CO2/Noxious Emissions vs Diesel
- Doubts over Green H_2 supply
- Potential for Dual Fuel Engines
- European H_2 strategy/investment

+ ve

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NRMM Long Term xEV Outlook

KGP has expanded the xEV powertrain forecast to include a long term production outlook to 2050. This is a tentative estimate by equipment type and country. We have also added the IPCC 1.5 scenario in Q1 2022. In addition, we have added hydrogen ICE as a alternative fuel type to all scenarios and the main forecast.

The long-term scenario for each case considers changes within the market structure. With factors such as digitalisation, automation, autonomy, process efficiency, electrification and alternative fuels all interwoven in the future business strategy of the non-road sector. Key stakeholders within the sector are starting to see the equipment used as part of a larger whole because of the inherent challenges associated with electrifying non-road equipment.

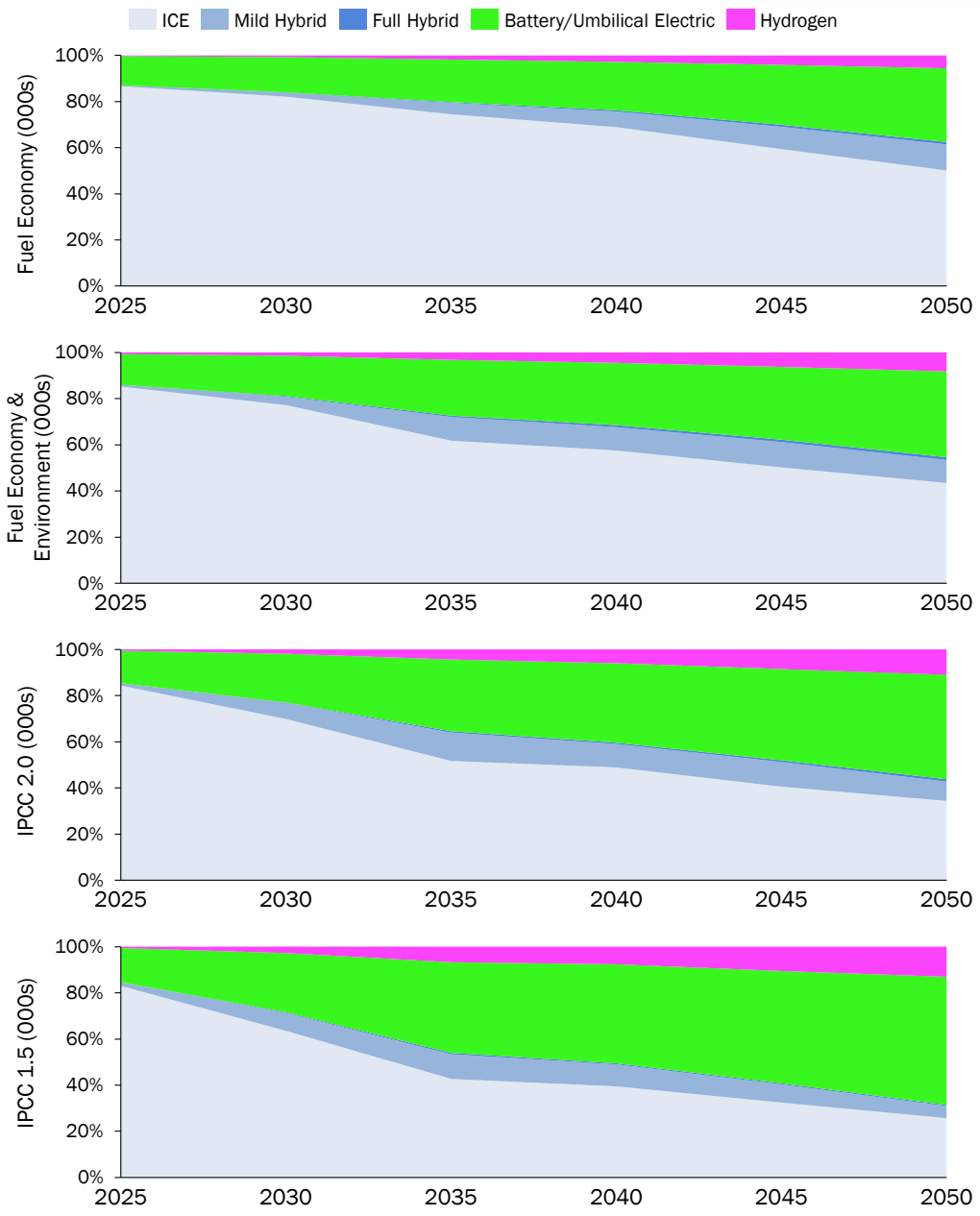
There are likely to be wholesale changes to the way in which construction, agriculture and materials handling business operate will mean the portfolio of machines we see supporting these sectors today will be different in 30 years' time.

Smaller autonomous robotic machines doing the job of one or two machines today, drones and other support technology – LIDAR, GPS, Sonar, etc... could become an integral part of operation.

From a Net Zero point of view, this is the best-case scenario because as the product fleet exists currently, even by 2050 it's hard to make an economic case where process efficiency can improve as much as it needs to (especially in agriculture and construction sectors), to support an increasing population, demand for high yields, less waste, lower emissions, lower operation hours, better occupational health standards. All whilst switching to a net zero fleet.

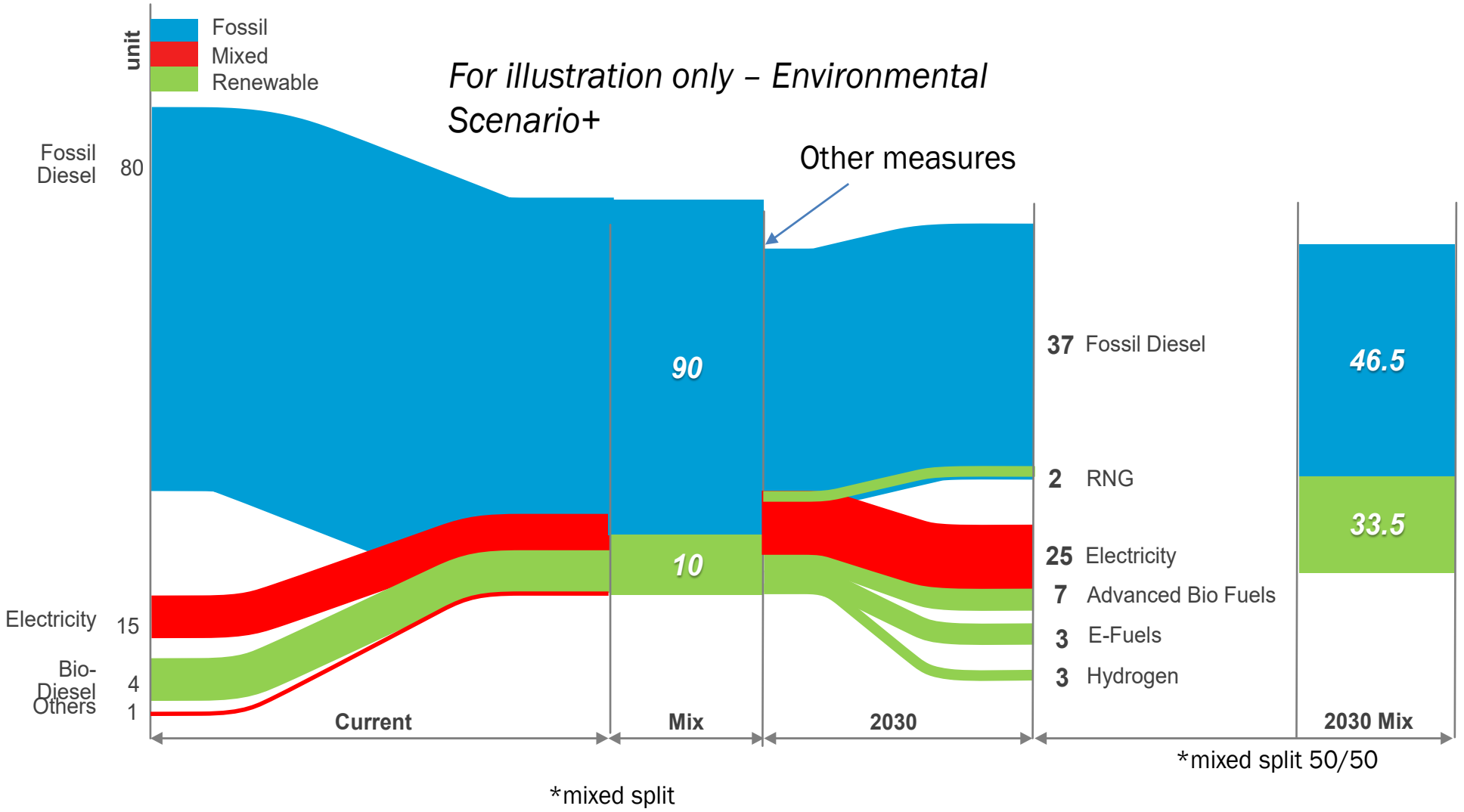
The question OEMs and suppliers now ask themselves, is, what the most effective way is to perform any given task, without the IC engine as the keystone of process. With improvements in electrification, digitalisation and telematics technology, is the answer to that question the traditional fleet of machines?

Figure 24. xEV Production by Type - Four Scenarios



KGP NRMM Energy Environmental Scenario

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



Contacts

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KGP AUTOMOTIVE INTELLIGENCE

Alex Woodrow
Managing Director

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

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

www.kgpauto.com

KGP AUTOMOTIVE INTELLIGENCE

James Dorling
Senior Consultant - NRMM

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

jamesdorling@kgpauto.com
+44 (0)1332 856 301
+44 (0)7525 052 009

www.kgpauto.com

KGP AUTOMOTIVE INTELLIGENCE

Paris Kiernan
Senior Consultant - CV

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

pariskiernan@kgpauto.com
+44 (0)1332 856 301
+44 (0)7453 239 605

www.kgpauto.com

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

KGP AUTOMOTIVE INTELLIGENCE

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Off-Highway RESEARCH

For experts
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Knibb, Gormezano & Partners

consult@kgpauto.com

UK +44 1332 856301

www.kgpauto.com