KGP POWERTRAIN INTELLIGENCE

Off-Highway RESEARCH

Off-Highway Conference October 2023

Non-road mobile machinery batteries & fuels – challenges and opportunities for standardization

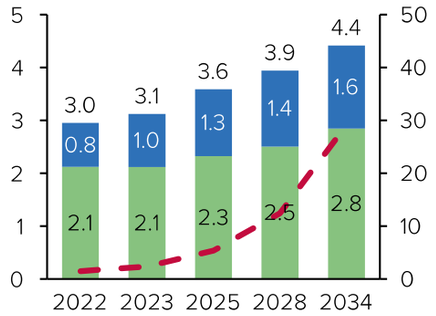
www.kgpauto.com

KGP Services

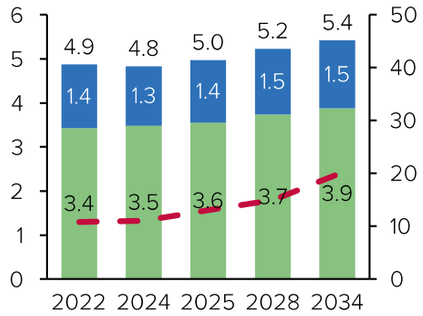
- Subscription based
- Quarterly Updates on CV, NRMM, Marine, Powergen
- Engine, Driveline, Electrification, Emissions
- Fuels and Energy
- Focus on reducing Noxious and Carbon Emissions

Verticals Outlook

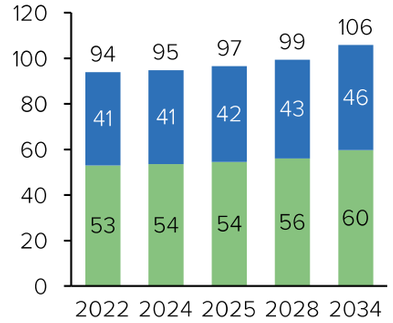
On-highway (OH) Mn



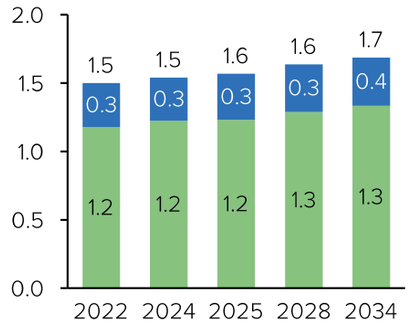
NRMM (AG, CE, MH) Mn



Marine (MAR) 000s



Powergen (PG) Mn



BEV/FCEV % (RH Axis) | China | Global (Ex China)

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

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

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

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

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

Drivers for Alternative Fuels

XGP POWERTRAIN INTELLIGENCE

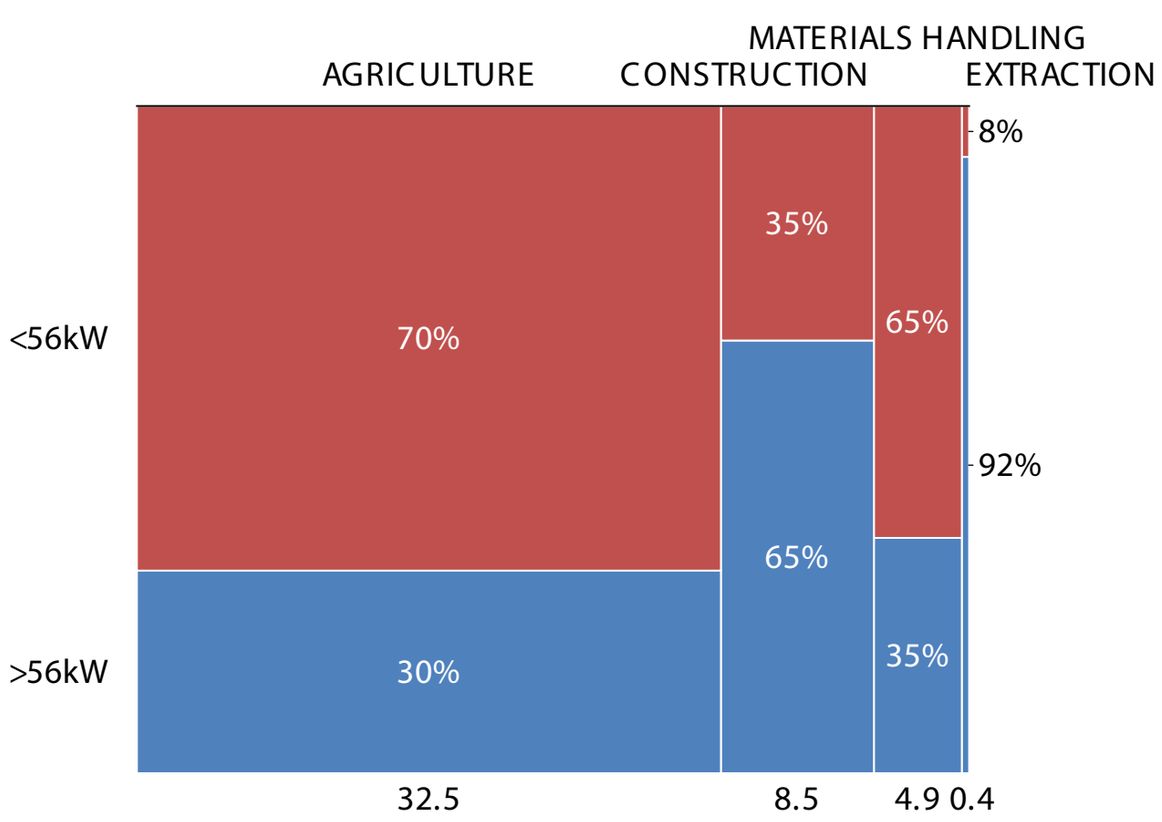
1. **Air Quality & Environment**
   CO_2, CH_4, N_2O...
2. **TCO**
   Fuel, Operator, Maintenance, Depreciation...
3. **Legislative**
   Noise Limits, Clean Air Zone, LEZs, ZEZs...
4. **Corporate Social Responsibility**
   GHG Protocol, SBTi, Tax Breaks...
5. **Energy**
   Renewables, security, carbon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

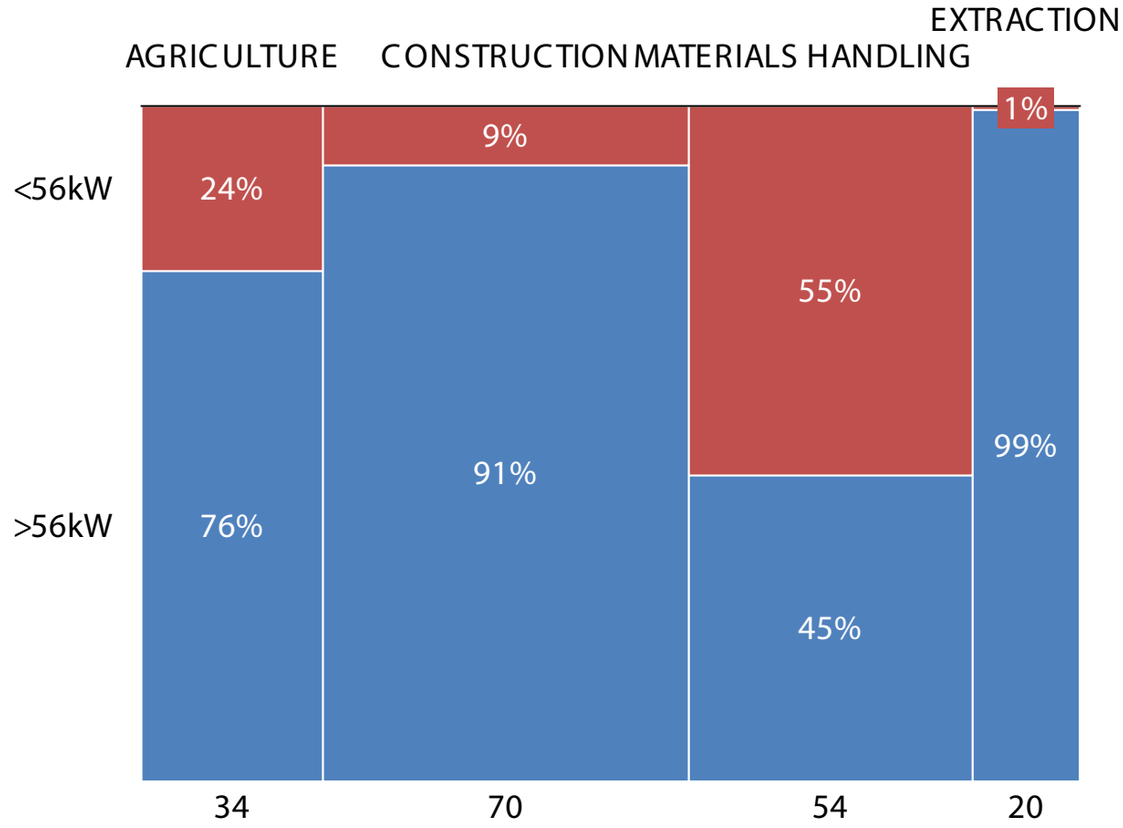
Noxious Emissions Tightening

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.

Fuel Consumption for NRMM

Fuel usage by segment, Population (Millions), Fuel Consumption (MT)





Source: KGP-Off-Highway Fuels and Emissions Model Beta

NRMM Model Availability & Battery Sizing

Source: KGP xEV Model Database May 2023

	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

Charging Standards (Europe)

No current standards for machines, and different ones for US, China, Japan. Typical, but not exhaustive values are shown below:

	Handheld/ Extra-Compact	Compact	Mid-Size	Large	Extra-Large
Typical Voltage	48V	48V-90V	100V-300V	400-800V	>1000V
Charging Rates	AC 3.3-22kW	AC 3.3-22kW	AC 3.3-22kW DC 50kW-750kW	AC -43kW DC 50kW-3.8MW	DC 50kW-3.8MW
Connector Standards	*IEC 62196-1/-2 Type 2* *Other*	*IEC 62196-1/-2 Type 2* *Other*	*IEC 62196-1/-3 Type 2/CCS*	*IEC 62196-1/-3 Type 2/CCS/MCS*	*IEC 62196-1/-3 CCS/MCS/Other* *Other*
Connectors					
MCS (-1250V)	No	No	No	Yes	Yes
CCS (200V-1000V/350A)	No	No	Yes	Yes	Yes
TYPE 2	Yes	Yes	No	No	No
OTHERS (i.e. DIN)	Yes	Yes	Yes	Yes	Yes

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

Volvo Opens 48V DC protocol

international construction

Construction BRIEFING
GLOBAL CONSTRUCTION INSIGHTS - EVERY DAY

Volvo CE's 'industry first' 48V DC charging protocol to drive electrification

By Andy Brown | 26 June 2023
2 min read

Volvo CE says that the announced will help contribute to a standardized, reliable and efficient electric ecosystem for construction

Volvo Construction Equipment (Volvo CE) is making available its 48 voltage DC protocol for electric charging solutions in a bid to accelerate electrification and make it easier for customers with a multi-branded fleet.

There is currently no industry standard for 48V DC (direct current) charging solutions – the power required for electric compact machines – which means customers currently likely need to source multiple different chargers if they have a multi-branded fleet.

Volvo CE has published its own brand-agnostic software protocol, as well as plug specifications, used on its 48V off-board DC chargers – with DC charging often commonly referred to as fast charging. This enables other OEMs and suppliers to use it in the development of their own charging solutions for compact machines.

POPULAR READS

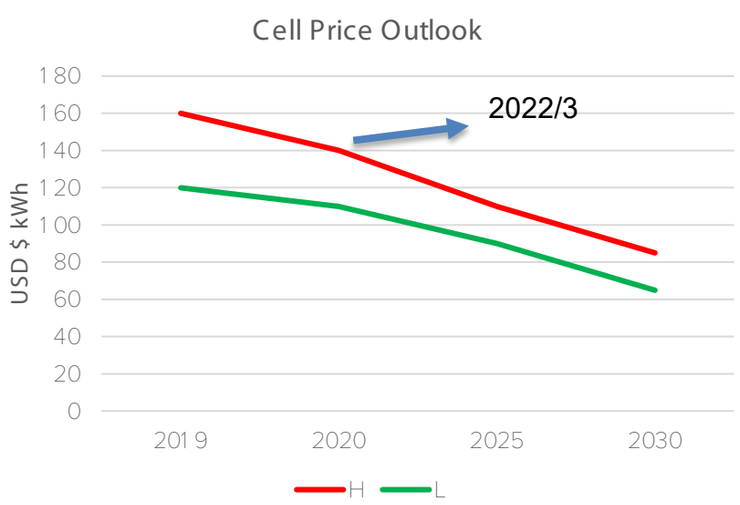
Local rules mandating water breaks for Texas construction workers face cut

NRMM Battery Pricing is a major barrier

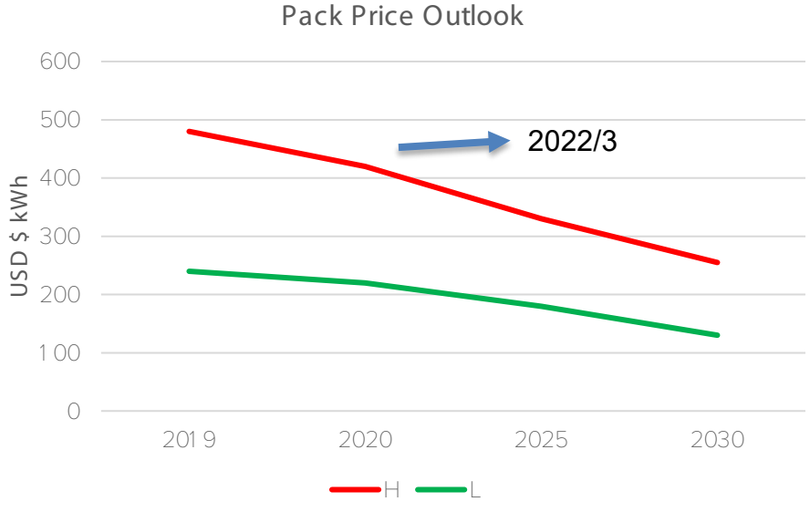
Volume battery cells for NRMM will be based on automotive cells, for volume reasons, as well as investment. Combining battery type, size, chemistry and volumes into a single analysis is difficult. The summary below shows the automotive cell price, and a range of the pack price for non-road. Smaller 48V 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 leveling out before falling after 2025.

Light Vehicle Cell Prices



NRMM Battery Pack Prices



Battery Durability Standards – A Big Challenge

Aims and Objectives

a) Establishing minimum durability performance criteria and developing guidelines for acceptable evidence that the requirements will be met;
b) Establishing measures to prevent substandard products from entering the market;
c) Allowing adequate room for continued development of the regulation as the industry continues to evolve; and
d) Implementing a mechanism for the collection of data that could provide a basis for refining the UN GTR in the future.

“all batteries exceeding 2kWh (such as those of electric vehicles) must have the digital passport associated with them, which must contain not only technical information on the battery, but also data associated with the environmental performance of the device, indicating key aspects such as its carbon footprint.”

No current standards for Non-Road Battery Durability – unlike road vehicles

- UN GTR 22 – Light Duty Vehicles Proposed
- UN WP 29 – Heavy Duty Vehicles Drafted

Starting point for WP 29 is GTR 22

- % of SOCE retained
- X years of Services
- Y Mileage

HDV metrics uncertain

- PTO Energy Throughput
- Total Energy Throughput
- Capacity Throughput

Testing schedule

- Standardised Charging
- Cycle test method

Low Carbon NRMM Model Availability Improving

	<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

Bauma 2022 – Over 100 New xEV Models & Batteries

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

Liebherr – Fortescue – WAE Technologies 1.4MWh

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.

Battery Chemistries to Evolve

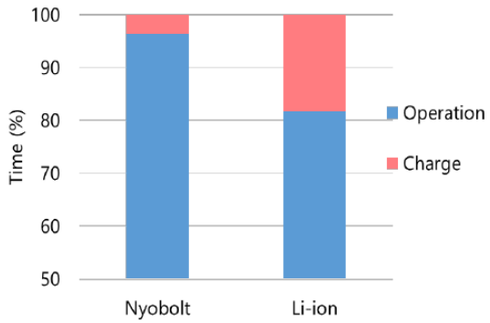
XGP POWERTRAIN INTELLIGENCE

Nyobolt Technology Advantage

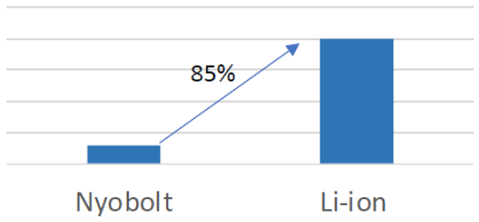
Mining Haul Truck Simulation Study shows 18% improvement in operational efficiency 50-70% reduction in operational cost

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

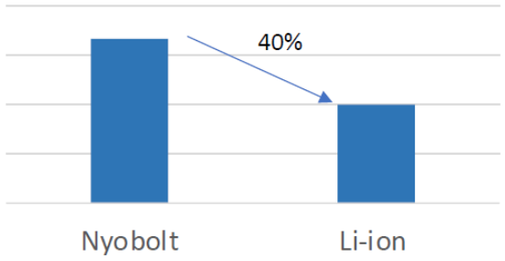
Time (%) in Operation vs. Charge



Number of pack replacements in haul truck's lifetime



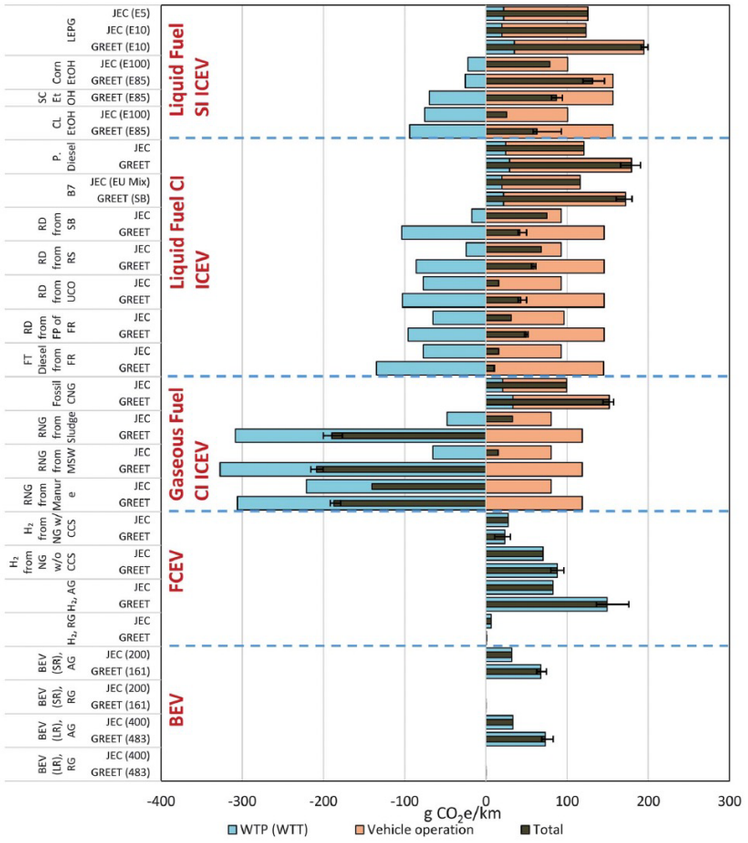
Payload volume availability



www.nyobolt.com

Low Carbon Alternative Fuels Required

Trucks use Well-to-Wheel, Ships – Well-to-Wake, Non-Road has no Well-to-Work standard



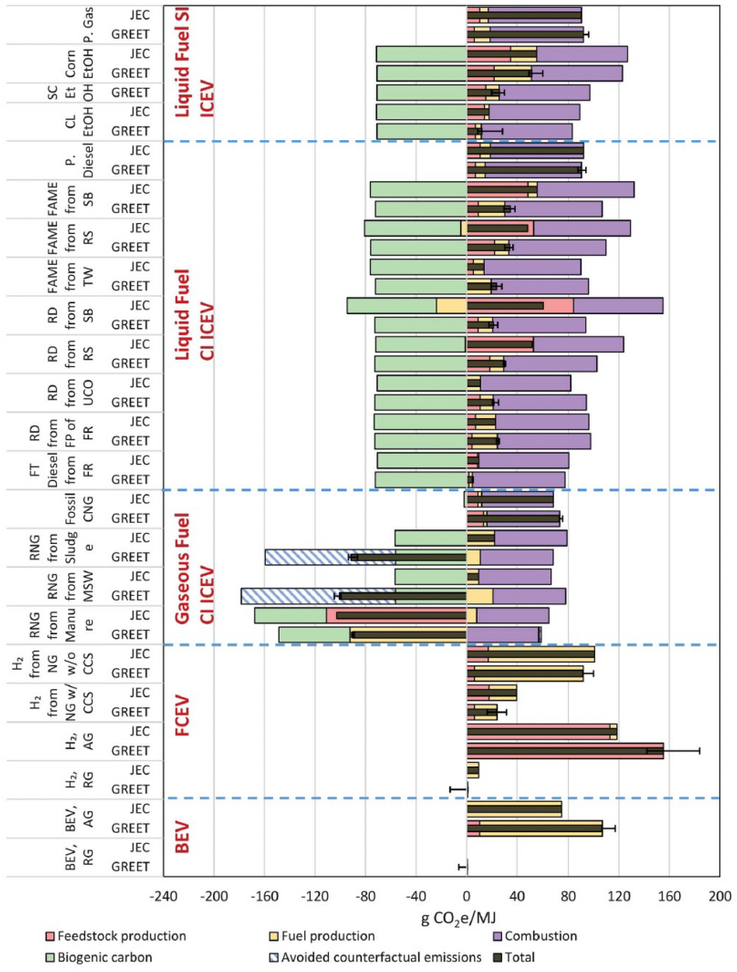
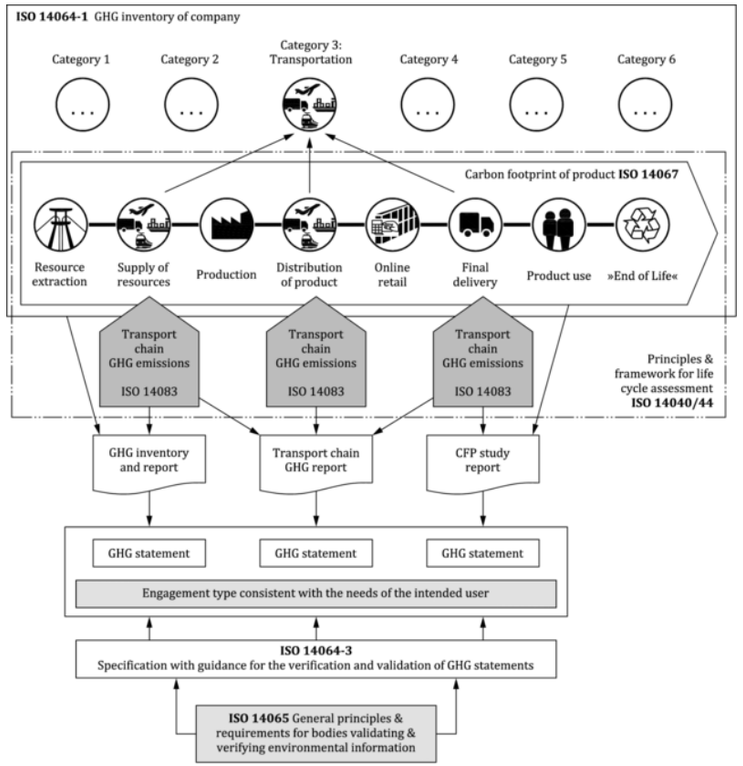


Fig. 3 Comparison of per km WTW results of various light-duty fuel and vehicle systems from GREET and JEC modeling. Key: SI: spark ignition; CI: compression ignition; ICEV: internal combustion engine vehicles; FCEV: fuel cell electric vehicles; BEV: battery electric vehicles; LEPG: low-ethanol petroleum gasoline; CL: cellulosic; FAME: fatty acid methyl ester; E100: pure ethanol; E10: a mixture of 10% ethanol and 90% gasoline; E85: a mixture of 85% ethanol and 15% gasoline FT: Fischer–Tropsch; FP: fast pyrolysis; FR: forest residue; RD: renewable diesel; UCO: used cooking oil; SB: soybean; B7: a mixture of 7% FAME and 93% diesel; P. diesel: petroleum diesel; CNG: compressed natural gas; MSW: municipal solid waste; RG: renewable electricity grid mix, AG: U.S./EU average electricity grid mix;; LR: long range; SR: short range; CCS: carbon capture and storage.

Alternative Fuels – ISO 14083

ISO 14083:2023(en)
Greenhouse gases — Quantification and reporting of greenhouse gas emissions arising from transport chain operations
Refers to JEC WTT/WTW Report V5, GREET



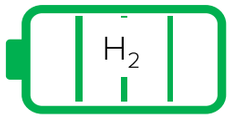
/w.iso.org/obp/ui/en/#iso:std:iso:14083:ed-1:v1:en

https://smart-freight-centre-media.s3.amazonaws.com/documents/Explanation_on_EU_and_US_emission_factors__ISO_14083_July_2023.pdf

Alternative Pathways Needed to Decarbonise

Conventional ICE
- Continued development of Ultra-Low NOx, Low CO_2 engines

8.8m 2022
9.7m 2030 Base (L)
8.2m 2030 IPCC 1.5 (H)
(November xEV scenarios)

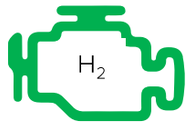


10k 2022
240k 2030 L
475k 2030 H

Fuel Cell
- Operates best at part loads
- Limited in NRMM due to durability

563k 2022
1.4m 2030 L
2.1m 2030 H

BEV
- Application very cycle dependent
- May be expensive, limiting for OH/NRMM applications



0 2022
6k 2030 L
73k 2030 H

H_2 ICE
- Potential mild recession in Q4
- Significant order backlog prioritises CL. 8 over 4-7
- Weakness appears limited at present
- Positive impact of IIJA and IRA

Renewable Diesel/Natural Gas
- Conventional/Low NOx Diesel/NG
- Fuel Availability may be limitation
- KGP currently investigating 20+ fuels with major NRMM OEMs

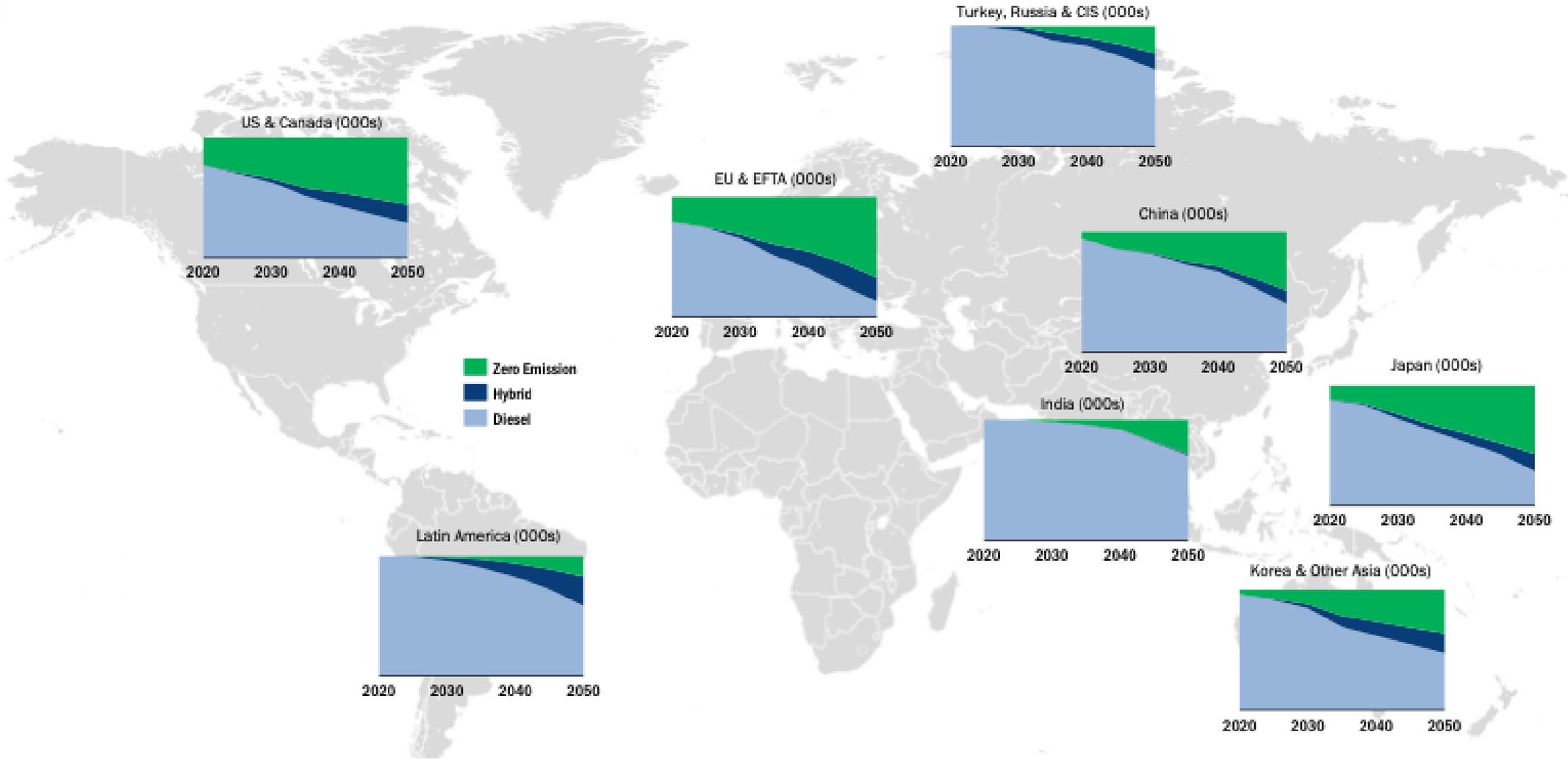
10k 2022
111k 2030 L
445k 2030 H

Hybrid
- Less likely in On-Highway
- Opportunity in NRMM, Marine, PowerGen
- Downsized conventional, low NOx ICE

TIV
9.4m 2022
11.3m 2030

Base Scenario – NRMM (AG, CE, MH)

xEV Penetration Forecast by Region



Contacts

CALL OR EMAIL US

- For a discussion about your company's requirements call or email us

  To receive regular free updates send your email address to subscribe@kgpauto.com

KGP AUTOMOTIVE INTELLIGENCE

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

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

www.kgpauto.com

KGP AUTOMOTIVE INTELLIGENCE

James Dorling
Senior Consultant - NRMM
jamesdorling@kgpauto.com
+44 (0)1332 856 301
+44 (0)7525 052 009

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

www.kgpauto.com

KGP AUTOMOTIVE INTELLIGENCE

Paris Kiernan
Senior Consultant - CV
pariskiernan@kgpauto.com
+44 (0)1332 856 301
+44 (0)7453 239 605

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

www.kgpauto.com

Or for our free newsletter use:
www.tinyurl.com/KGPPowertrainNews

Acronyms

AG - Agricultural Equipment
APU - Auxiliary 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