GLOBAL COMMERCIAL VEHICLE DRIVE TO ZERO™ | A PROGRAM OF CALSTART

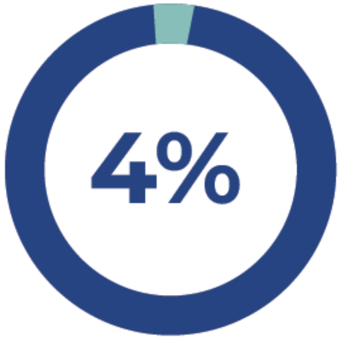
Heavy Duty Vehicle Charging: What is needed and where?

Global progress

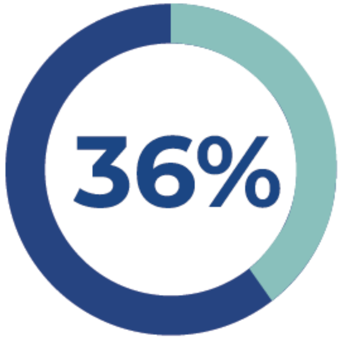
September 2024

WHY MEDIUM- AND HEAVY-DUTY VEHICLES?

Medium- and Heavy-Duty Vehicles (MHDVs) represent a small share of the global fleet, yet contribute disproportionately to fuel consumption and emissions



of global on-road fleet are MHDVs



of on-road fuel consumption by MHDVs

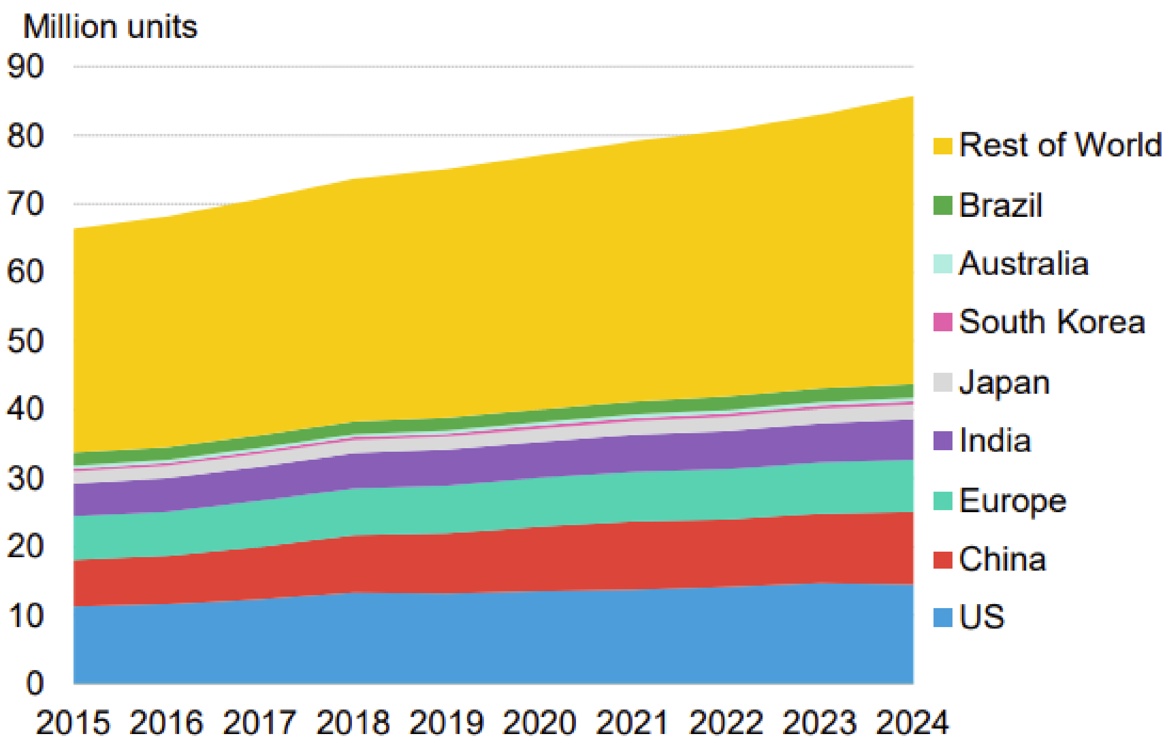
of on-road NOx by MHDVs

Source: CALSTART, 2020

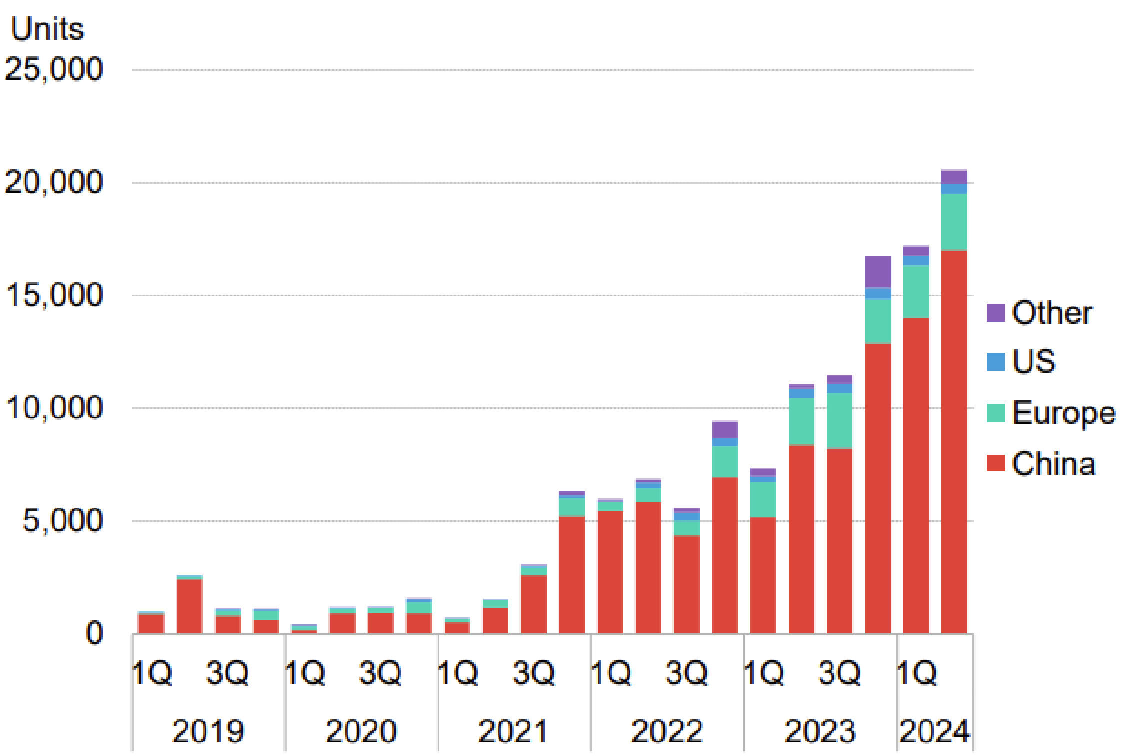
CURRENT STATUS

~83 million MHDVs operate globally; **~50 thousand ZE-MHDVs** were sold in 2023

Global MHDV fleet by region



Global ZE-MHDV sales by region



Source: BNEF, 2024

SIGNS OF PROGRESS

1

Technological maturity

2

Costs & access to finance

3

Targets and policy

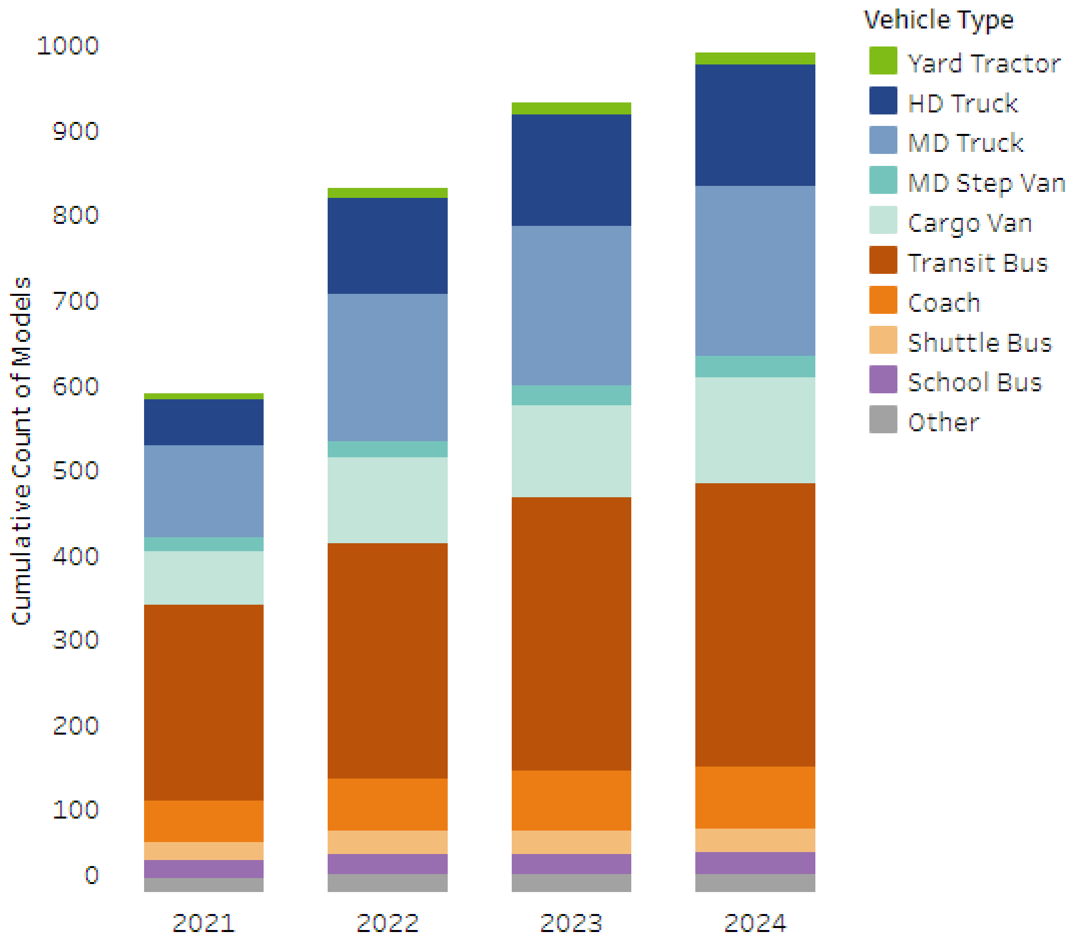
4

Infrastructure planning

TECHNOLOGICAL MATURITY

Almost **1,000 ZE-MHDV models** commercially available worldwide

ZE-MHDV models available by vehicle type

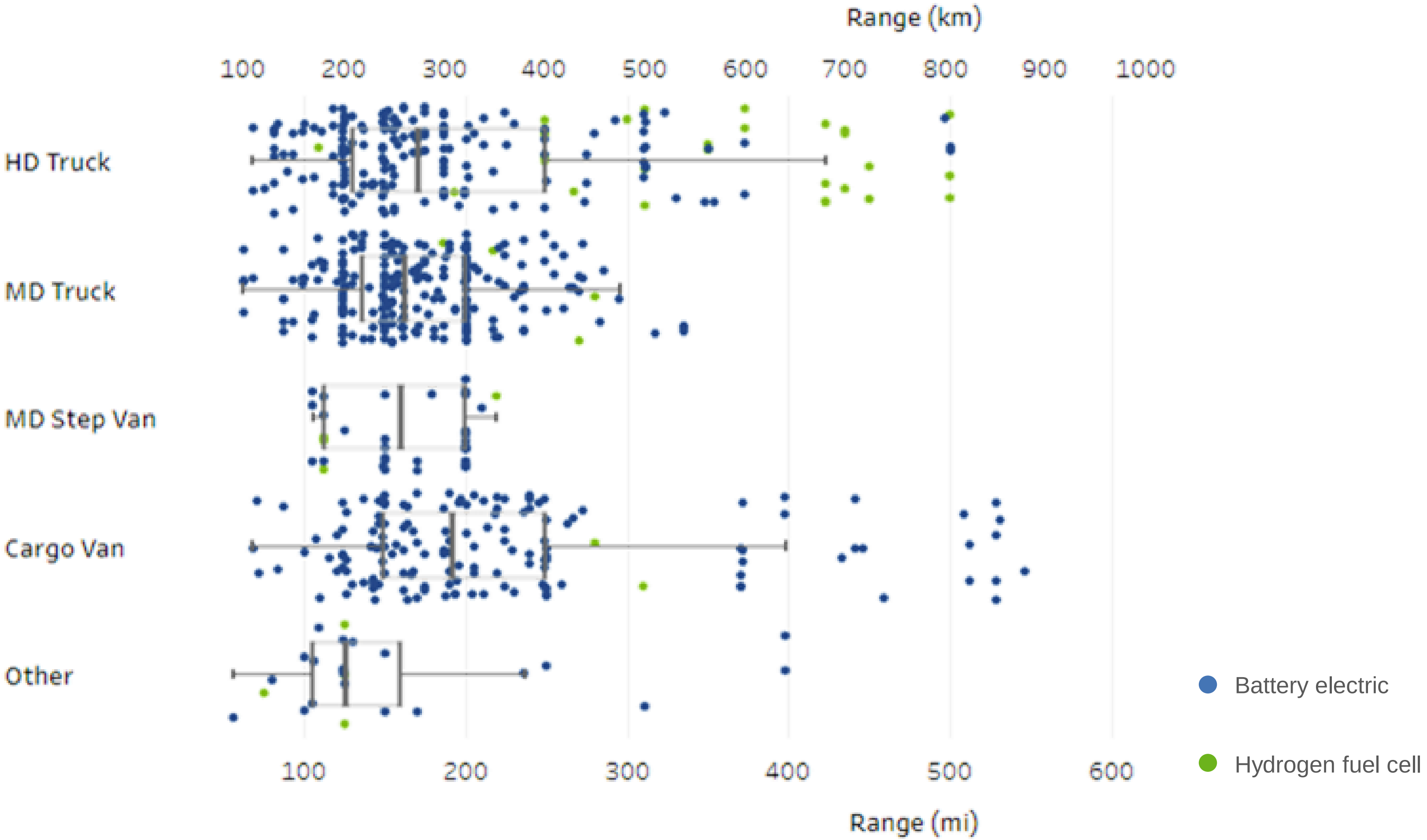


Source: CALSTART, ZETI & ZETI Data Explorer, 2024

TECHNOLOGICAL MATURITY

Average ranges of 200-400km already **satisfy the vast majority of use cases**

Truck range by vehicle type

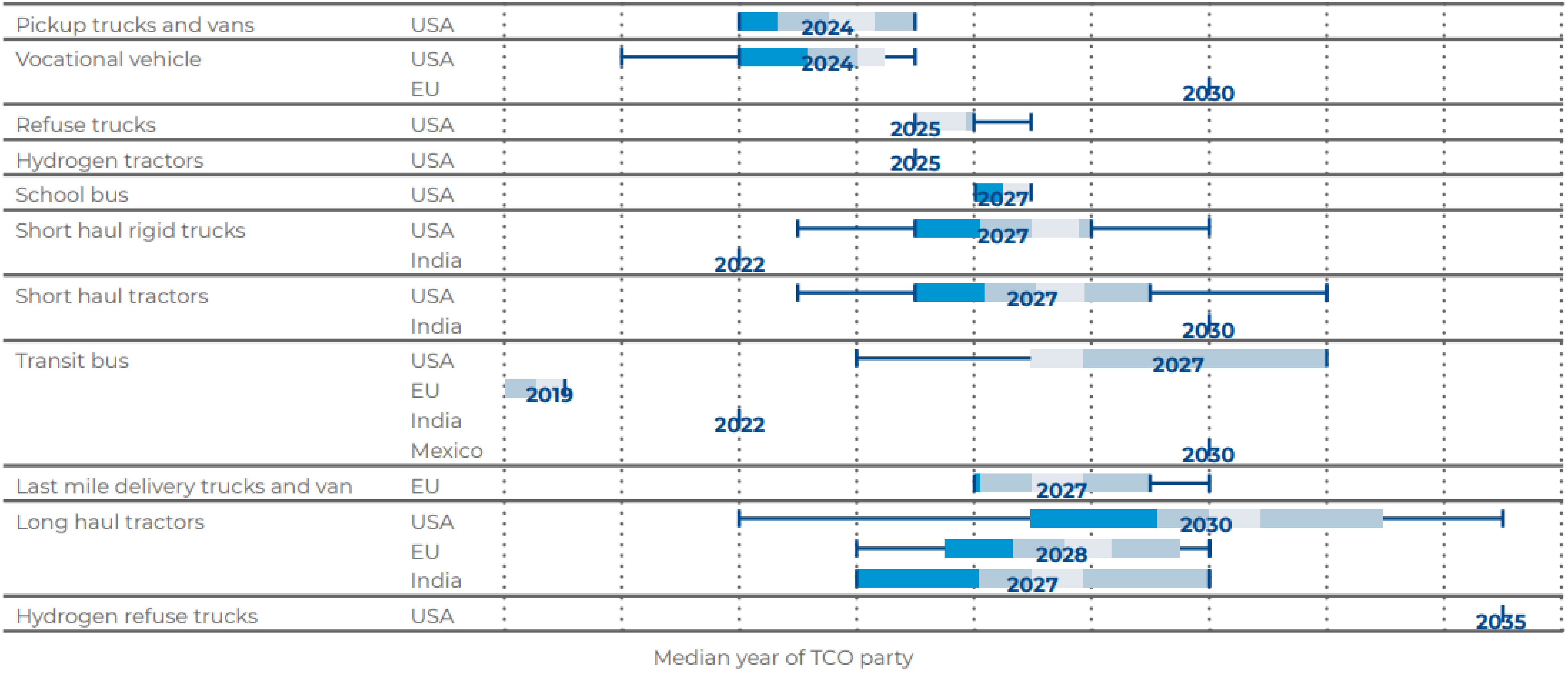


Source: CALSTART, ZETI & ZETI Data Explorer, 2024

COSTS & ACCESS TO FINANCE

Total cost of ownership already being achieved

Median year of TCO parity between ZEV and ICE HDVs



Source: ICCT, 2023

Grupo Bimbo

+2,500 ZEVs in Mexico
2023

Photo credit: Grupo Bimbo

Zoomlion + ZeroNox

1,000 retrofitted electric refuse trucks
2024

Photo credit: Zoomlion

Government of Bermuda

30 electric buses
2022

Photo credit: Xiamen Golden Dragon Bus

COSTS & ACCESS TO FINANCE

Government programs and business models are making the technologies accessible to **small owner operators**

nacional financiera

Sustainable Transport Finance Program

Concessional loan + scrappage incentive

CALIFORNIA AIR RESOURCES BOARD

Zero Emission Truck Loan Pilot Project

Loan loss credit guarantee

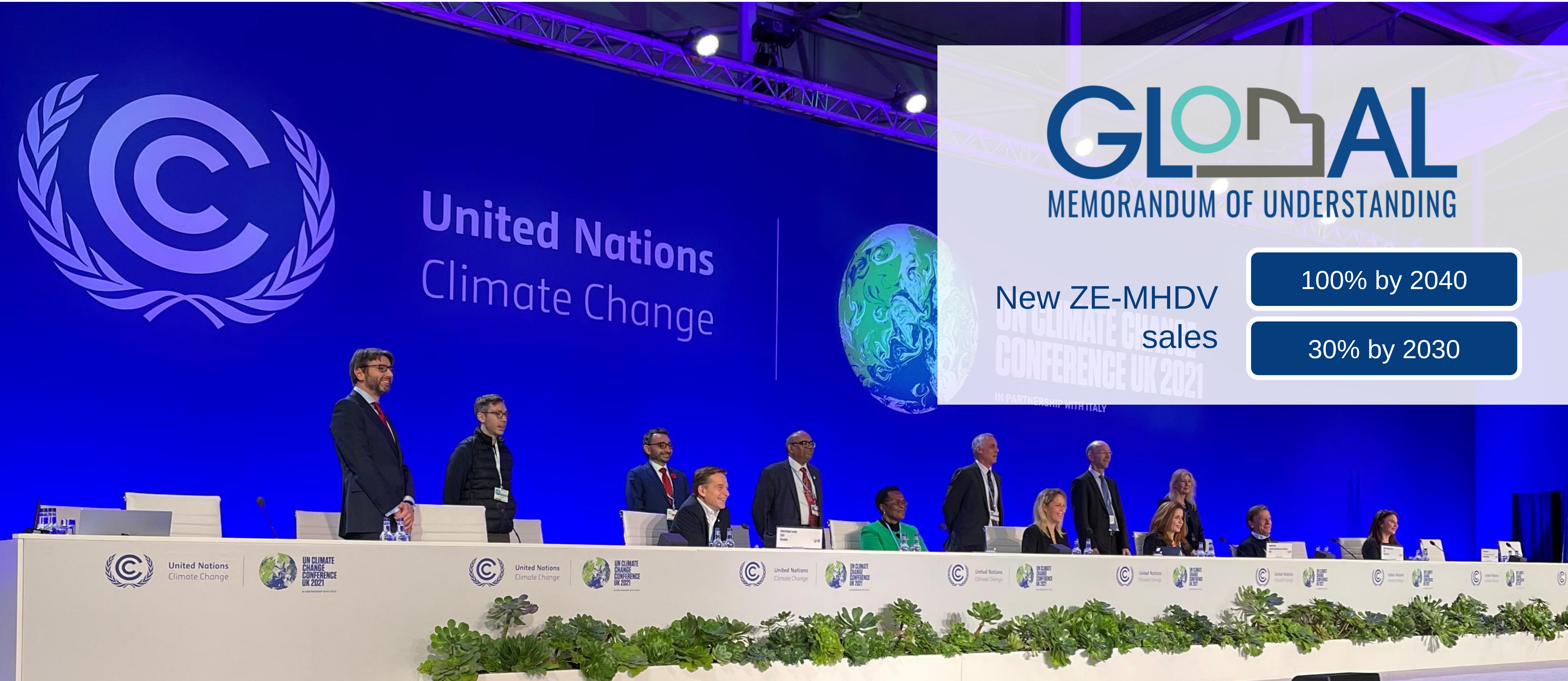
ZEEM SOLUTIONS

Fully bundled leasing

Shared depots

TARGETS & POLICIES

Net zero by 2050 will require all new MHDVs sold to be zero emission by 2040: **Global MOU**



GLOBAL MEMORANDUM OF UNDERSTANDING

New ZE-MHDV sales

- 100% by 2040
- 30% by 2030

TARGETS & POLICIES

The Global MOU has been signed by **38 nations**

TARGETS & POLICIES

The Global MOU has been endorsed by **+180 subnational governments, companies and partners**

Subnational governments

Manufacturers and suppliers

Fleet owners and operators

Utility and infrastructure providers

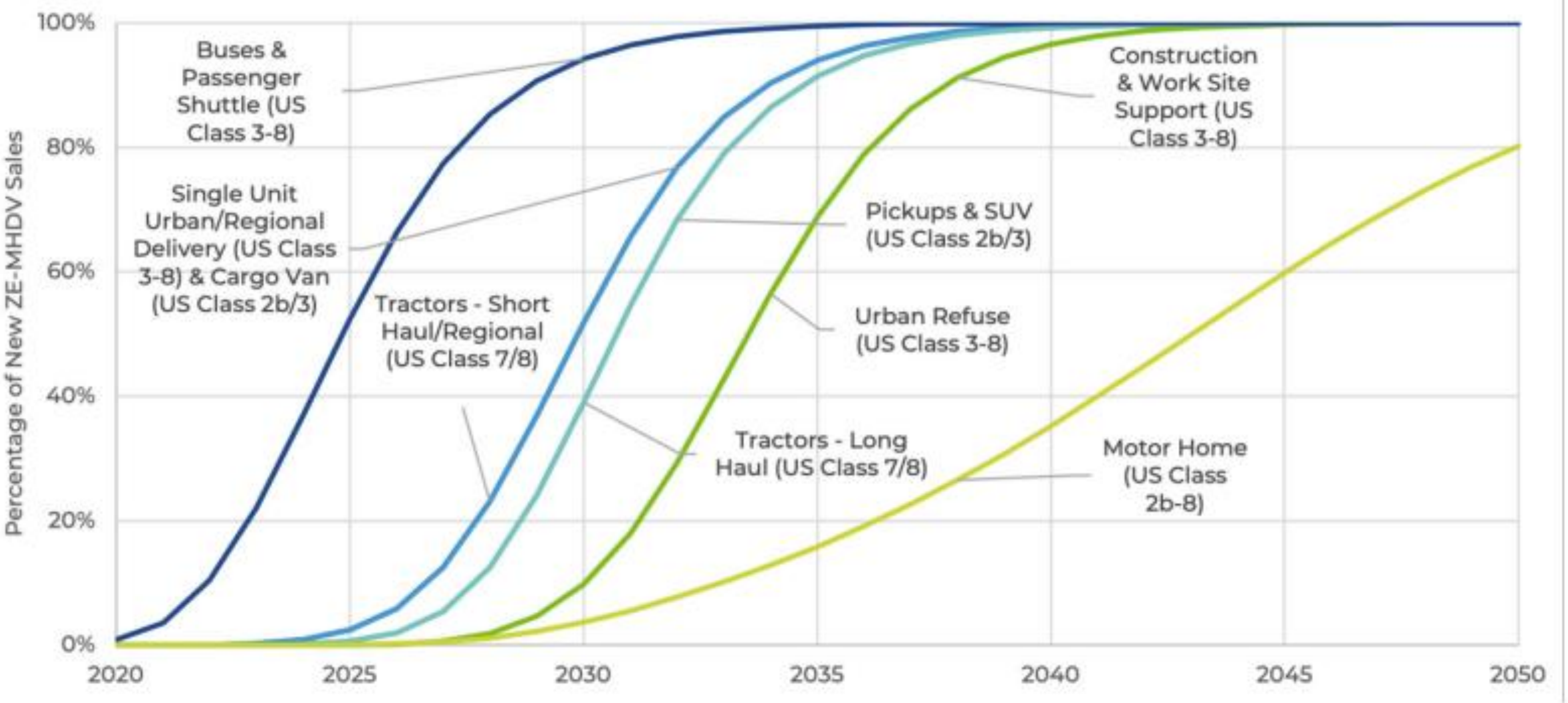
Finance institutions

Knowledge partners and other endorsers

TARGETS & POLICIES

The transition happens in **stages**, electrifying first best suited use cases

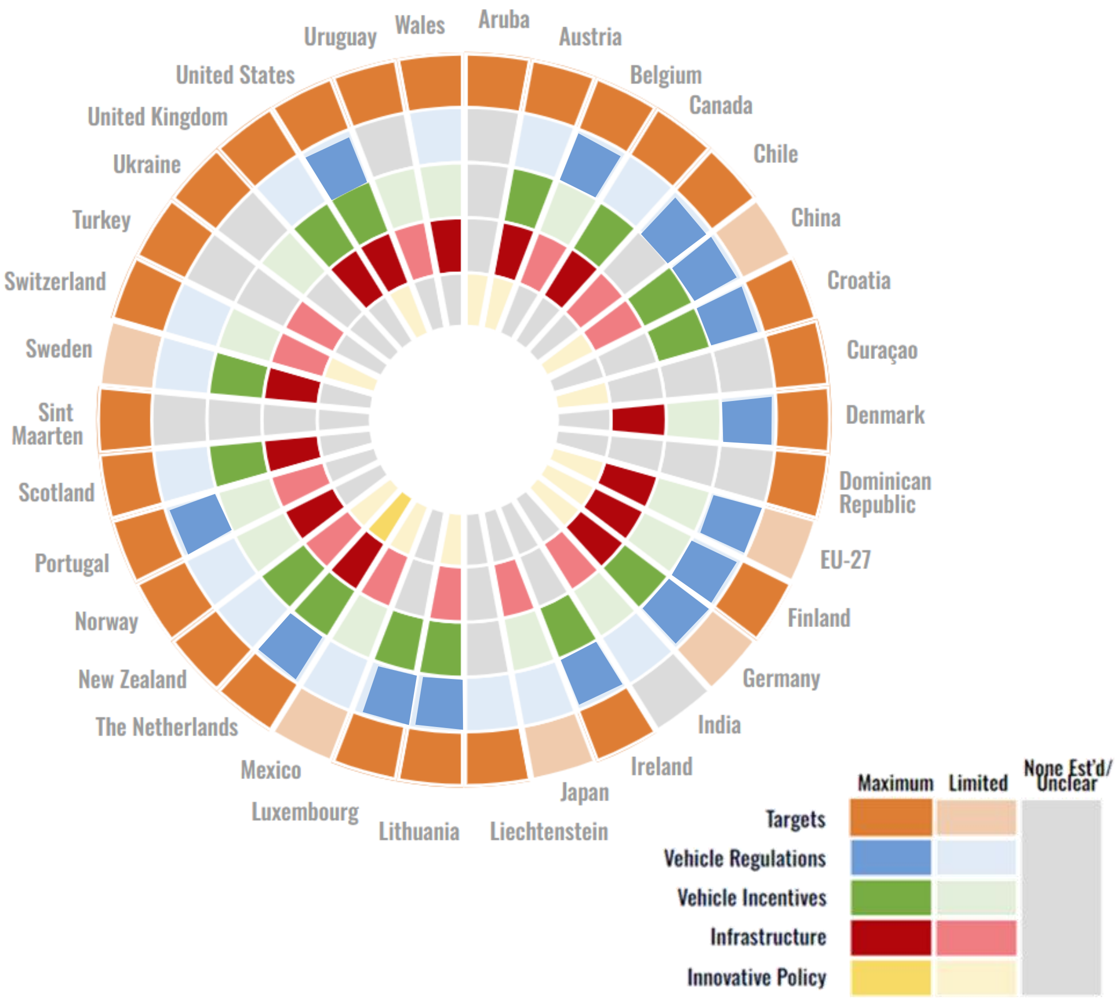
Projected sales targets to reach Global MOU targets



Source: CALSTART, 2023

TARGETS AND POLICIES

Governments are making their targets binding through **supply-side regulations**

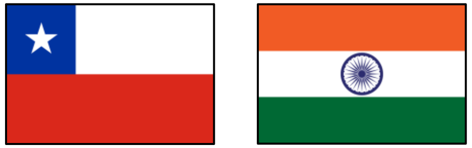


Source: Progress Dashboard, 2024

Sales mandates

Emission standards

Fuel economy standards

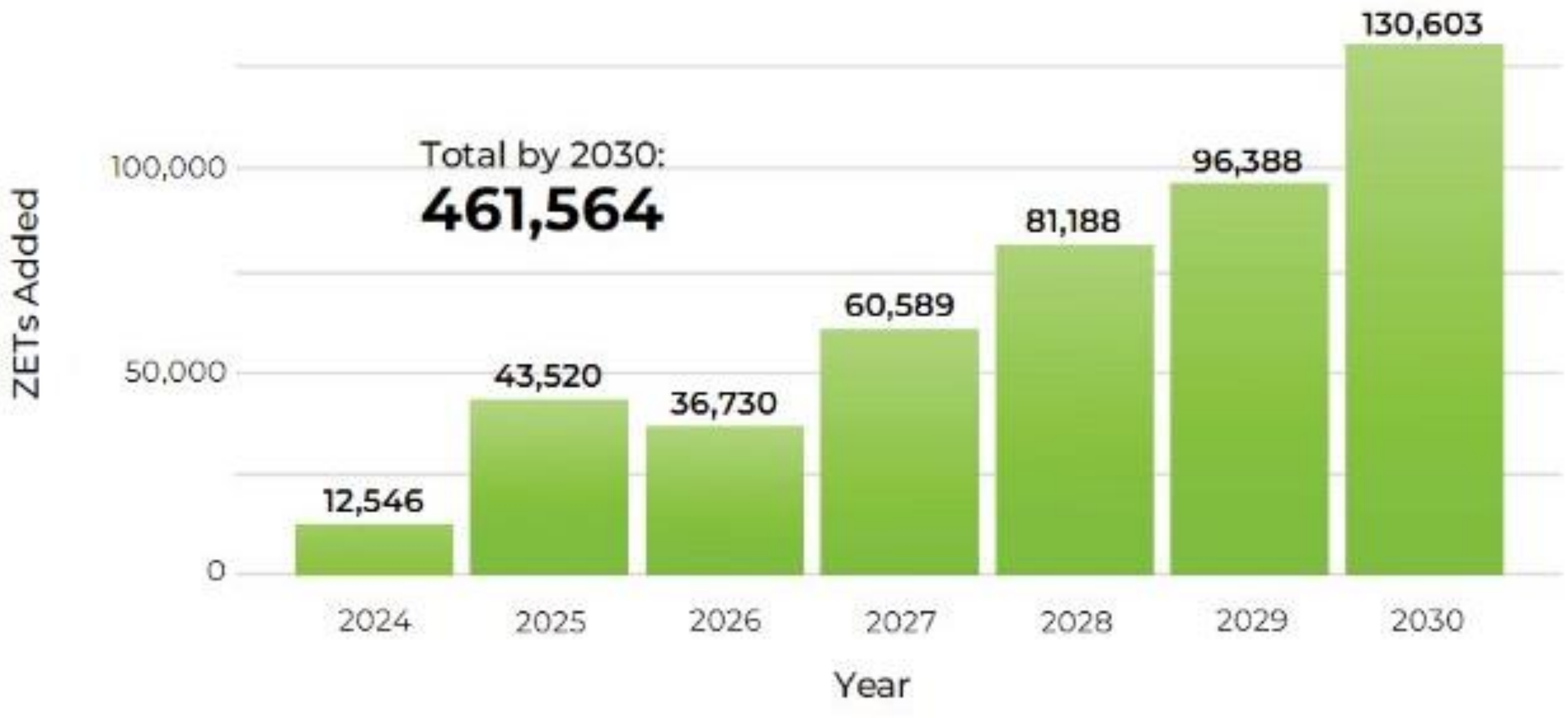


Import ban

TARGETS AND POLICIES

Regulation creates certainty that allows for production scale up and infrastructure planning

ZETs deployed yearly through 2030 under ACT and ACF



Source: CALSTART, 2024

INFRASTRUCTURE PLANNING

Long-term planning critical to provide investment guidance, avoid sunk costs, and ensure chargers will be available when needed

Alternative Fuels Infrastructure (AFIR) Regulation

National Zero-Emission Freight Corridor Strategy

TAKEAWAYS

1 **Technological maturity**

Technology is mature and available for most users

2 **Costs & access to finance**

TCO parity within reach, access to finance challenging

3 **Targets and policy**

Targets needed to set direction; binding regulation critical

4 **Infrastructure planning**

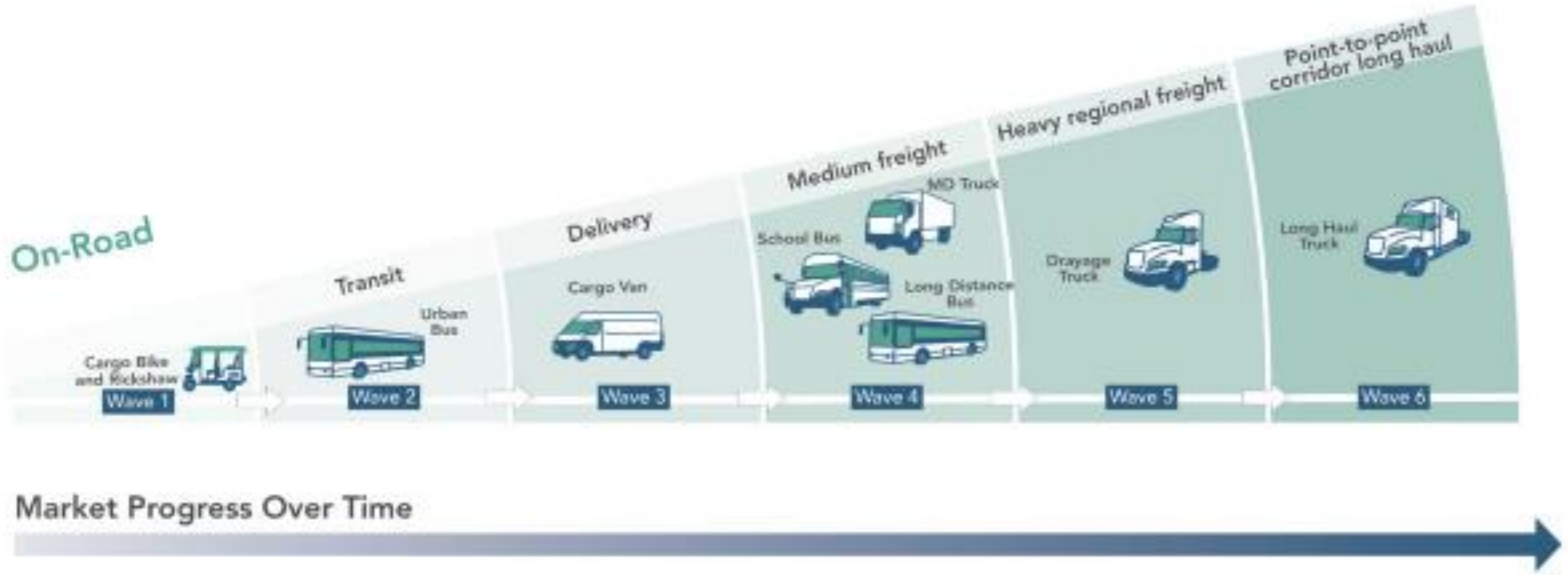
Countries getting started, long-term planning needed now

Heavy Duty Vehicle Charging: What is needed and where?

Ricardo García Coyne, CALSTART/Drive to Zero

September 2024

BEACHHEAD STRATEGY

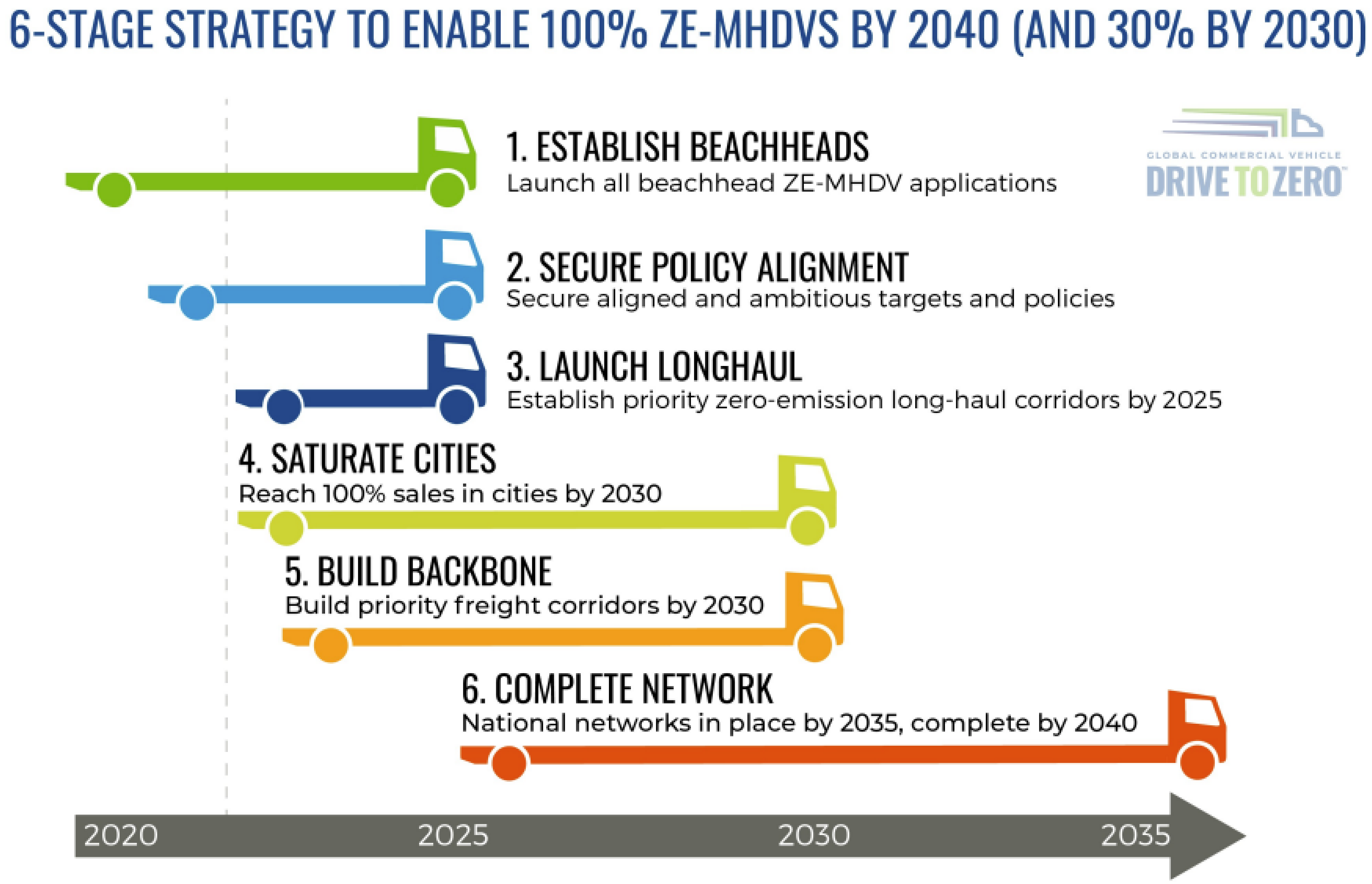


Similar drivetrain and component sizing can scale to early near applications

Expanded supply chain capabilities and price reductions enable additional applications

Steadily increasing volumes and infrastructure strengthen business case and performance confidence

DRIVE TO ZERO THEORY OF CHANGE



THE OPPORTUNITY

ZE-MHDVs offer substantial **economic** and **air pollution** benefits

~30% lower fuel and **~60%** lower maintenance costs compared to diesel

IADB, 2022

~$3.4 trillion USD in potential annual ZEV investments globally

McKinsey & Co, 2022

Brent crude oil barrel price
$14 low in 2020
$130 high in 2022

U.S. Energy Information Administration, 2023

Air pollution | ZE-MHDVs eliminate diesel tailpipe emissions, responsible for **180,000 premature deaths** annually.

ICCT, 2019

Karen Geekie

Heavy Duty Vehicle Charging: What is needed and where?

Scottish progress

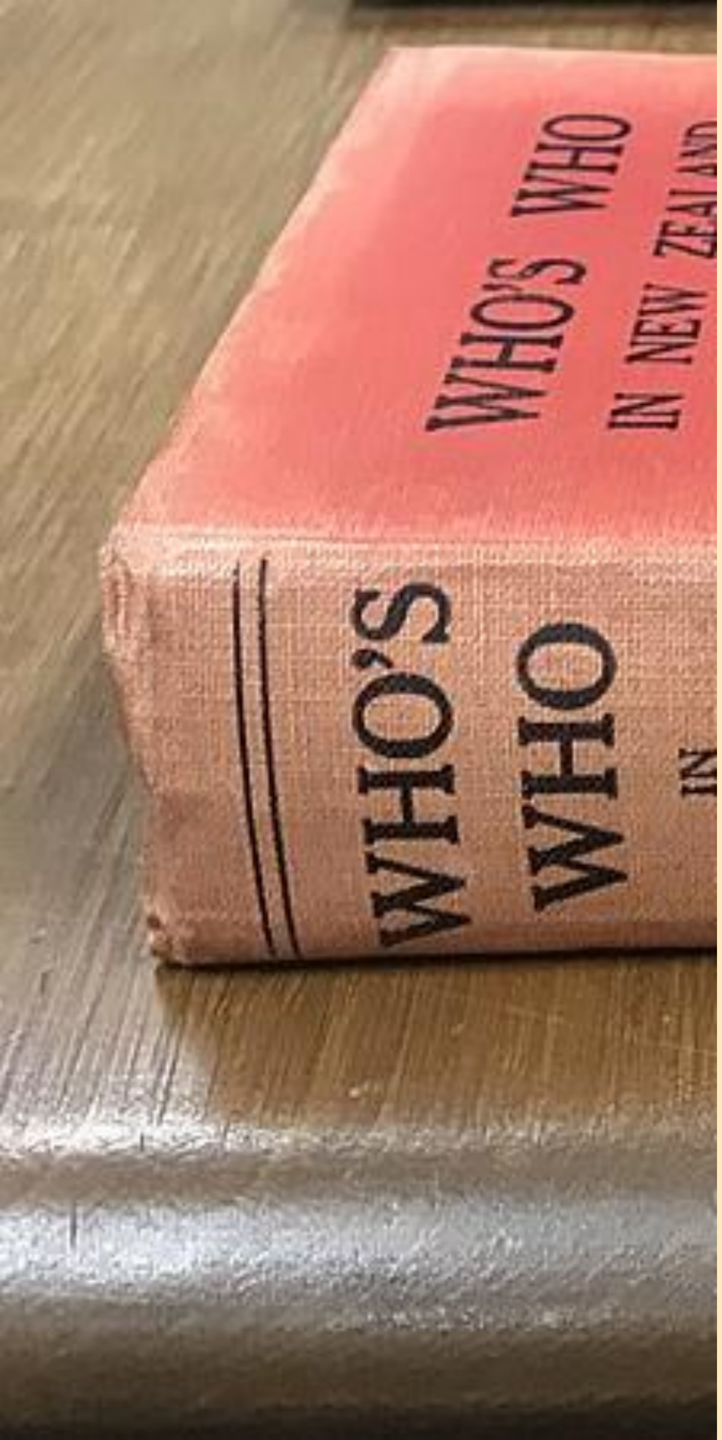
Scottish context

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

- Scotland has 8% of the UK population … but 32% of its landmass including 94 inhabited islands
- Ambitious and legally binding climate legislation, Net Zero 2045
- Around 37,000 HGVs across 5,500 fleets registered in Scotland
- 90% of Scottish HGV fleets have 10 vehicles or fewer
- Around 13,000 buses and coaches
- Collaborative approach to policy making

Decarbonising buses

- Since 2020, the Scottish Government has supported operators to acquire 800 zero emission buses.
- ScotZEB 2 challenge fund awarded £41.7 million to Zenobe Energy and their innovative consortium which will by 2026 deliver:
  - 252 new, zero emission buses and coaches
  - a pan-Scotland charging network for other commercial vehicle fleets
  - £3.20 of private investment for every £1 of public subsidy.
- No further public funding is envisaged as the market should now be self-sustaining.



Zero Emission Truck Taskforce

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

- Haulage operators/ trade bodies
- Energy infrastructure: electricity
  hydrogen
- Manufacturers
- Commercial finance
- Trade unions
- Scottish Government

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

The task at hand

- Identify hurdles and opportunities
- Co-design a pathway to a swift and just transition with clear actions
- Build confidence in partners

Key hurdles

- **Confidence and knowledge** – procurement, energy, financing, operation
- **Energy infrastructure** – depot, en route, destination
- **Commercial viability** – business models for the transport operator; for the energy infrastructure provider; for the financier

Overcoming the hurdles

Four challenges:

- **energy infrastructure**
- **financial models**
- **confidence in technological and commercial change**
- **workforce skills**

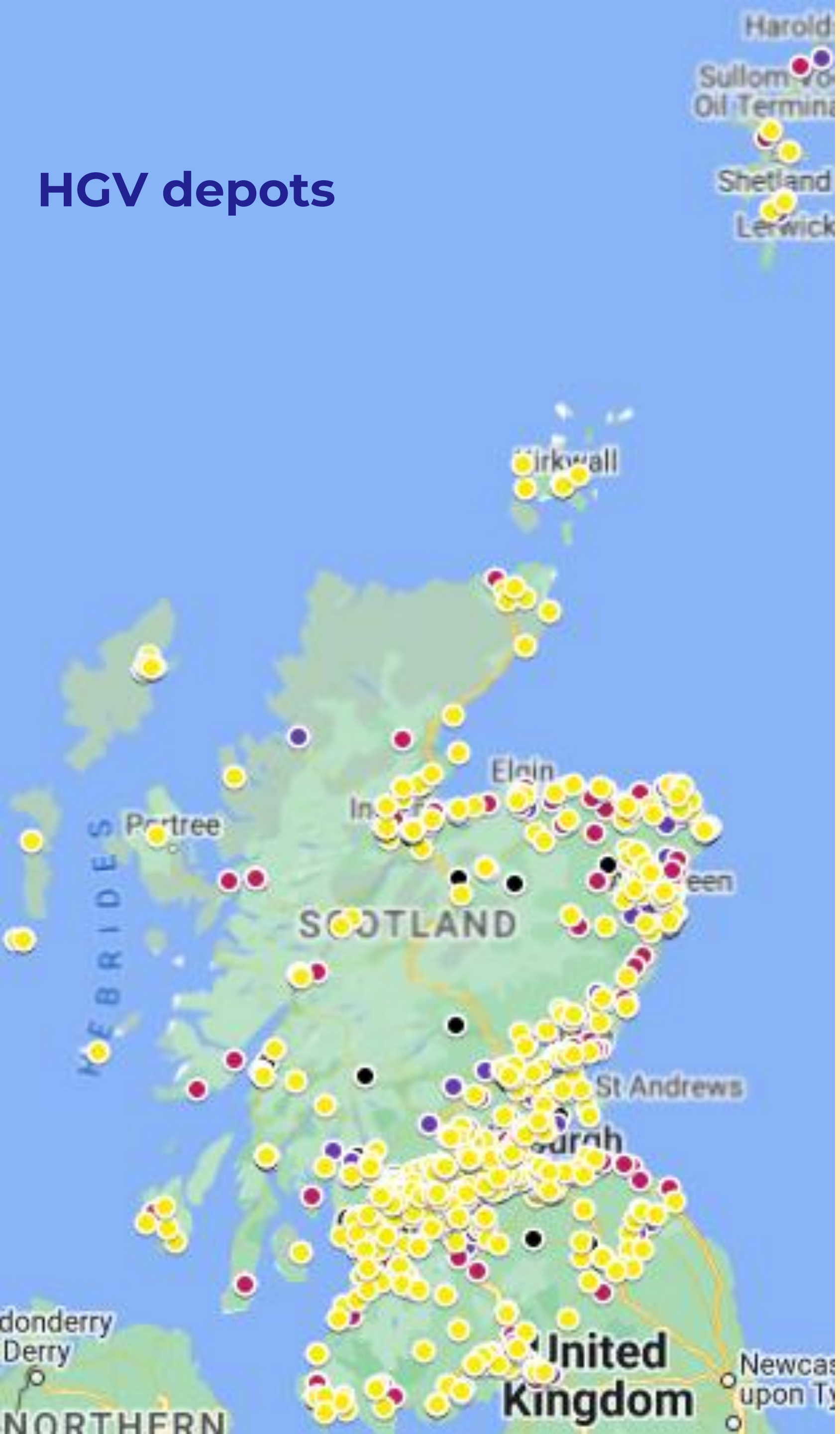
Simple distillation of what is already happening, vision for the future and concrete actions to be delivered by members

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

Scottish Government actions

- Research to understand where charging and fuelling is needed in Scotland
- A forum to bring together haulage operators and those able to finance or deliver transition projects
- A commitment that any investment into heavy vehicle decarbonisation will support wider transition, not just recipient fleets

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA



HGV charging and hydrogen fuelling

- Good understanding of where depots are
- Electricity networks need to know en route locations well in advance to reinforce the Grid
- Sites will need sufficient demand to become investible propositions – likely to require commitment from multiple fleets
- Haulage operators need to understand what “good enough” looks like in order to commit
- Minimal information publicly available on how trucks travel due to commercial confidentiality

Purposes of research

- **To develop a shared understanding of where we need en-route charging and hydrogen fuelling in Scotland**
- To convene fleets, DNOs and commercial fleet energy providers in discussion around specific sites.
- To improve understanding of which sites will be commercially viable and which may require a different solution.

When will this infrastructure be needed?

TRANSPORT SCOTLAND
CÒMHDHAIL ALBA

Previous UK government committed to phase out dates for new sales of non-zero emission trucks:

- 2035 – trucks up to 26tonnes
- 2040 – all ICE trucks

Many major fleets already exploring transition.

Towards Zero Emission HGV Infrastructure in Scotland

Dr Dhanan Utomo

on Behalf of:

Philip Greening; Dhanan Utomo; Zoe O'Connor; Alan Logan; Andreas Elombo; Meg Bartholomew; Jane Andrews; Andrew Smith

About the Project

This project provides a proof of concept for a data-driven assessment of critical locations for charging and refuelling infrastructure for zero-emission Heavy Goods Vehicles (HGVs) across Scotland.

Aim

The project's aim is to aid government and other relevant stakeholders to facilitate a smooth transition to zero-emission freight fleets by offering an evidence-based analysis of the most likely critical en route, shared-use charging and hydrogen refuelling infrastructure needs across Scotland to support freight operations.

Scope

The scope of the project was freight transportation by Heavy Goods Vehicles (HGVs) within Scotland, for journeys ranging from the relatively short (2-4 hours) to more than 8 hours, including tramping operations.

Outcomes

a. Suggest where shared en route charging or refuelling facilities should be developed to allow efficient operation of battery electric (BEV) and hydrogen fuel cell electric (FCEV) HGVs. Provide an estimation of the demand at each corresponding location.

b. Provide recommendations on which locations should be prioritised and phased based on utilisation.

In addition, the project provides a proof of concept for evidence-based identification of critical locations for shared en route charging and refuelling infrastructure for BEVs and FCEVs.

As more data is added, the model will uncover further locations and will provide additional insight into resource usage. This will lead to more accurate recommendations for how locations should be prioritised and phased.

Methodology

1	Identify and engage with relevant stakeholders
2	Obtain telematics and scheduling data of existing diesel HGV routes
3	Analyse fleet routes using CSRF modelling (MILES) for electric and hydrogen vehicles
4	Feedback preliminary findings to stakeholders
5	Use stakeholder feedback to validate and refine model and assumptions
6	Engage with Electricity Distribution Network Operators (DNOs), obtain network data
7	Report findings and continue engagement with Industry and DNOs

CSRF Modelling Approach

Analyses existing diesel HGV routes for electrification & hydrogen viability, pinpointing refuelling/recharging needs. Details on CSRF modelling in step 3 below.

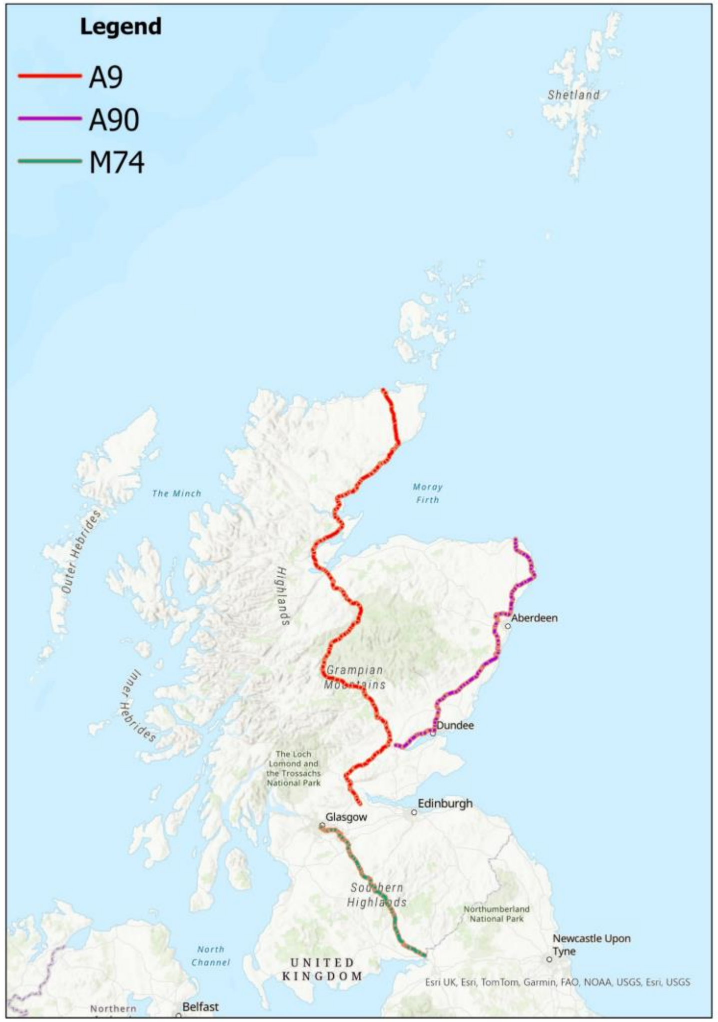
- *Create a network of HGV charging or refuelling locations based on existing suitable potential host infrastructure e.g. truck stops facilities like toilets and cafes.*
- *The existing diesel truck routes are overlayed over this network. A route "starts" when the truck leaves the home depot, and "finishes" when it returns there.*
- *A simulation is created to investigate how electric or hydrogen HGVs would complete each route. Each vehicle chooses from the given network list where the optimal location is to recharge or refuel.*
- *Truck routes are analysed for changes to accommodate charging or refuelling.*
- *Charging or refuelling locations are analysed to determine utilisation.*

Popular HGV Routes in the study

The analysis of the available data (1% of the total HGV population in Scotland) identified several key freight corridors experiencing high HGV traffic volumes.

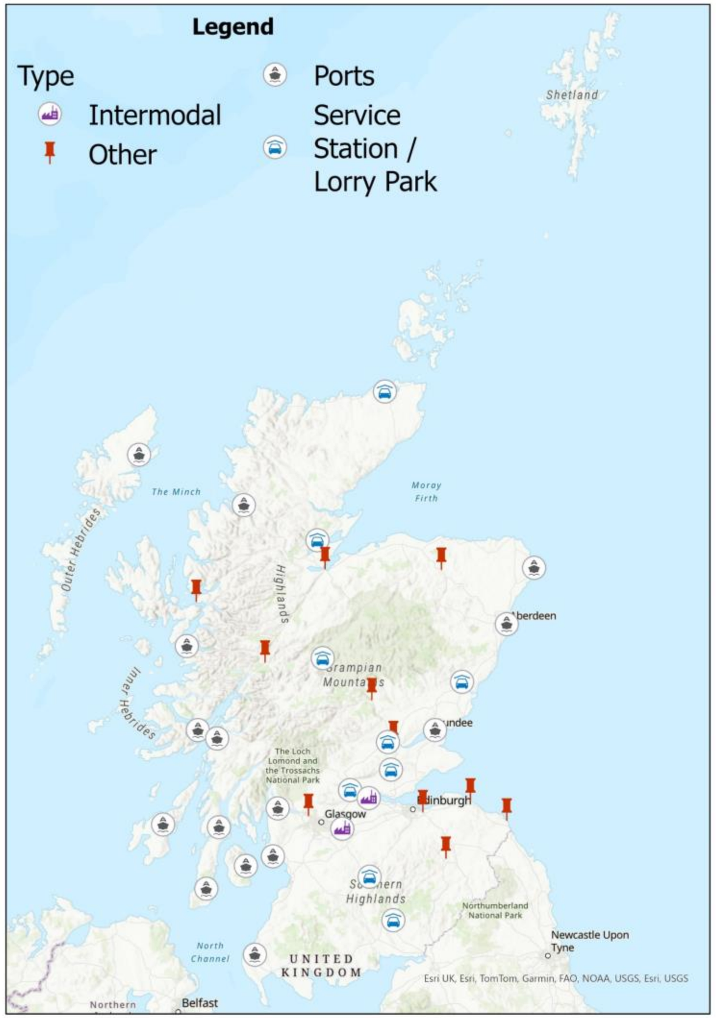
These corridors primarily connect major population centres, industrial zones, and ports across Scotland.

**some remote routes require further analysis in the future*



Suggested Charging and Refuelling Stations

- The model, combined with stakeholder feedback, has suggested specific locations as a priority for en route chargers and refuelling stations.
- These are based on existing locations such as truck stops, lorry parks, intermodal hubs and ports.
- **Adding new en route chargers in strategic locations (see Figure 2) will unlock the full potential of electric fleets.**
- **Future work will include confirmed charging sites.**



Battery Electric Vehicles (BEVs)

Assuming all HGV fleets to be electric, Battery size 500KWh and charger power of 500kW at each location. We tested three charging scenarios:

A. Home depot charging only.

B. En route charging only.

C. Home depot and en route charging.

The results from each scenario, including any additional stops compared to current diesel HGV journeys, are summarised in Table 1. The best scenario is C, where both depot and en route charging are available – all routes* can be completed, although some may require additional stops for charging.

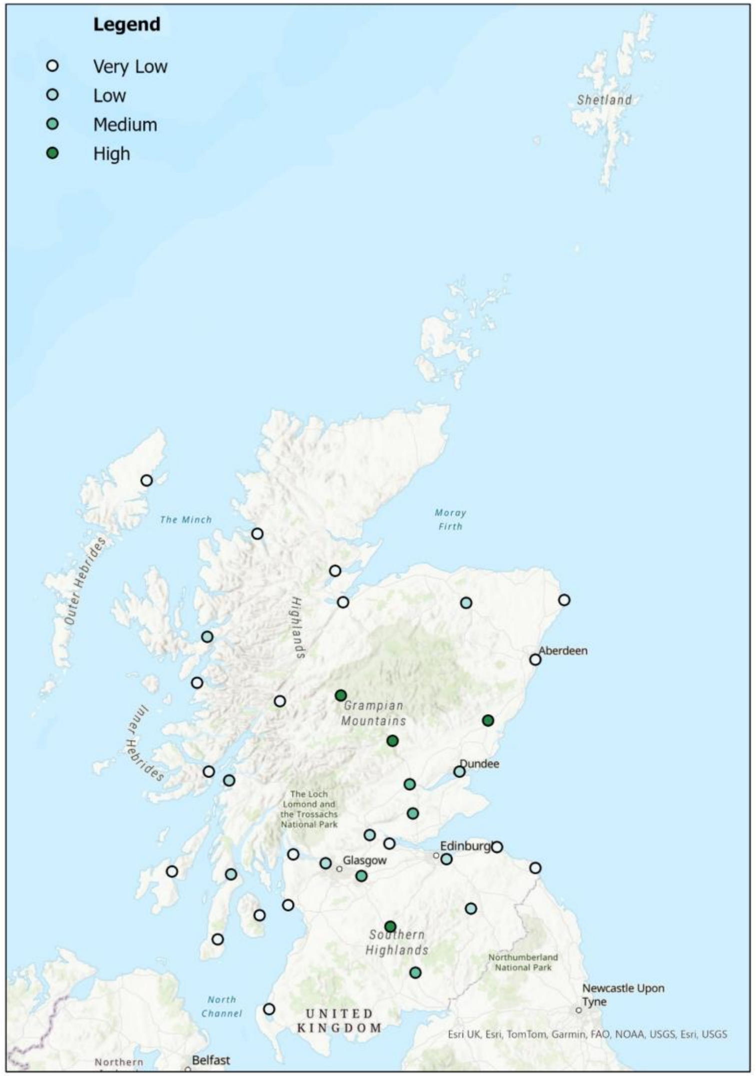
	Scenario A (depot charging only)	**Scenario B** (en route charging only)	**Scenario C** (both)
% routes unable to complete	33%	2%	~0%
% complete with no extra stop	65%*	59%	61%
% complete with +1 stop	2%	12%	12%
% complete with +2-3 stops	0%	20%	20%
% complete with 4+ stops	0%	7%	7%

Charging Hotspots

Analysis of journey data revealed heavy usage of specific routes, particularly along **the A9 (Stirling-Perth-Inverness), A90 (Perth-Aberdeen), and M74 (Glasgow-Carlisle) corridors. These critical corridors for freight movement within Scotland would benefit significantly from strategically placed en route charging stations to support BEV journeys.**

The high utilisation hot spots are marked in Figure 3 and outlined in Table 2. The longest distance on the mainland between these potential charging locations is 106 km to Cairnryan. The median distance between charge points is 43km.

Location	Number of uses (annual)	Total charge delivered (MWh)
Dalwhinnie	11,180	2,357
Ballinluig	8,801	1,409
Stracathro	8,490	2,045
Abington	6,950	1,571
Kinross	4,662	945
Annadale Water	3,835	937
Broxden	3,625	822
Mossend	2,890	658
Clydebank	2,538	576
Dundee	2,152	476



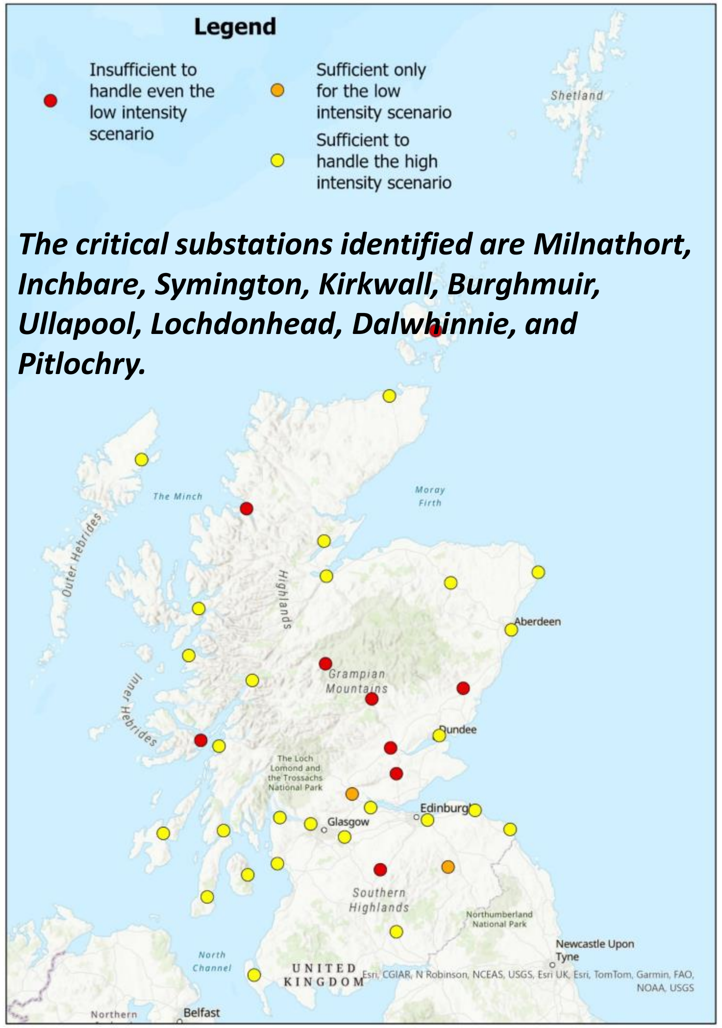
Grid Infrastructure

To determine whether there is sufficient energy infrastructure to support the identified optimal charging locations several primary substations were identified close to each proposed charging location. Data from Distribution Network Operators (DNOs) was used to understand expected headroom (unutilised grid capacity) based on 2025/26 forecast.

Two scenarios are tested: **high** i.e., charging event happen with two peaks during the day and **low** i.e., charging event happen with four peaks during the day.

Substations are colour-coded based on their current headroom availability :

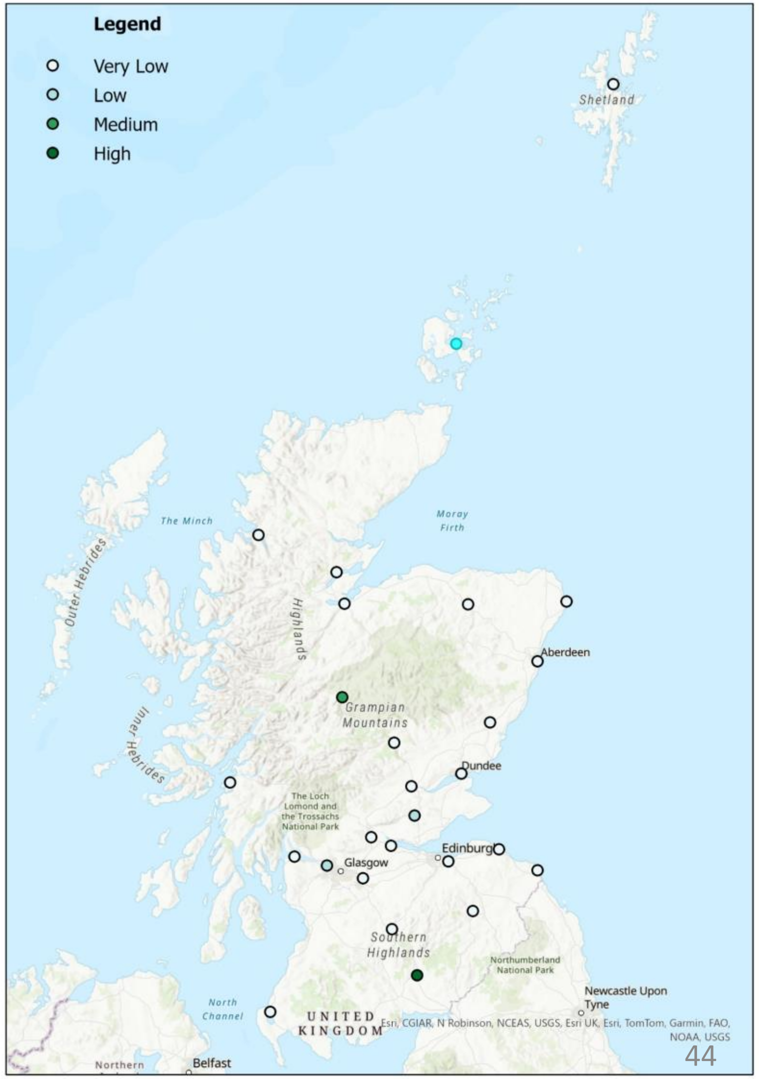
- **Yellow:** Sufficient headroom to handle even the high intensity scenario (68% of all substations based on available data).
- **Amber:** Headroom is sufficient only for the low intensity scenario. Upgrades might be necessary (5.2% of all substations based on available data).
- **Red:** Insufficient headroom to handle even the low intensity scenario. Upgrades are likely required (26.4% of all substations based on available data).



Hydrogen Vehicles (FCEV)

- Hydrogen (FCEV) model analysed for all routes. FCEV range is assumed to be 500 km, and they cannot be refuelled at the depot.
- High demand expected on A90 and M74 corridors, moderate in Central Belt, and lighter (potentially due to limited data) on A9. Siting complexities near hydrogen production noted.

Location	Number of uses (annual)	Total hydrogen delivered (kg)
Dalwhinnie	6205	140,722
Annadale Water	6166	290,291
Kinross	1675	46,780
Clydebank	631	18,651
Broxden	197	9,034
Ballinluig	155	8,502
Abington	133	5,658
Stirling	98	2,972
Stracathro	79	2,504
Dundee Port	64	2,040



Key Messages

1. Whole fleet Battery Electric HGV (BEV) operation is possible for current routes, provided depot and en route charging infrastructure is developed in key locations across Scotland.

2. Based on data included to date, prioritising shared charging on the A9, A90, and M74 corridors maximises the impact for these BEV operations.

3. Many HGV operations, especially short-haul operations, require no route changes to accommodate BEVs. Most modelled routes can be completed with no additional stops for charging and, in the worst case, travel an average of 15 km more than the existing diesel HGVs.

4. Even when considering only a small proportion of Scotland's HGV fleet, considerable mitigation for increased peak grid demand, such as reinforcement of grid connections, will likely be required.

5. Hydrogen fuel cell electric HGVs (FCEV) require refuelling facilities away from depots. Production of hydrogen is energy inefficient and operational and capital costs may be considerably more than BEVs.

! *Data from more operators will validate the proof of concept, ensuring identified charging or fuelling locations support all operations across Scotland, and creating confidence for investment.*

Future Work

- More data will enable an increasingly accurate understanding of what will be required and will build the evidence base required for investment in HGV charging and fuelling.
- Aggregated data, such as forestry data and traffic count data, may be used in future modelling. This data is low-quality by nature but could potentially make the modelling relevant to all heavy vehicle operations in Scotland.
- More data will also allow for a deeper analysis of low/medium/high charging demand scenarios. The distribution network operators (DNOs) emphasise that detailed scenarios combined with times of charging are crucial for planning future energy infrastructure.
- Outlying cases where there may still be insufficient existing host infrastructure (servicestations, truck stops, etc) for charging were identified on the A9 north of Invergordon and in Shetland. Stakeholders also suggest the A82 and A83, important freight routes for timber, aquaculture and access to the Western Isles, as well as the A77 to Cairnryan are in remote areas where potential gaps in charging infrastructure require further modelling. Transportation by ferry to the islands also needs to be accounted for in modelling. Once more data becomes available, these situations will be further investigated.