Powertrain Outlook

Electrification,
Engines & Transmissions

2017-2025

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Detroit Assn. of Business Economists/Wards Intelligence Conference

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United States Fuel-Economy Regulations Summary

Fuel Economy Regulations - Overview

- Under the 2012 NHTSA-EPA fuel-economy standards for model years 2017 - 2025, each OEM has a unique fuel-economy target for cars and light trucks, based on the makeup of its fleet
  - Every model has its own MPG target based on vehicle type and size (footprint)
  - Not every model needs to meet in target - compliance is based on the average (CAFE)

- Targets for cars are more stringent than for light trucks, and within each vehicle type, larger vehicles have less stringent targets

- Standards become more stringent every model year

Fuel Economy Regulations - Vehicle Type

All vehicles under 8,500lbs GVW, and passenger vehicles (excl. pickups and cargo vans) up to 10,000lbs

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Light Truck qualification:

At least one:

Transport more than 10 people

Temporary living quarters

Open bed

Greater cargo-carrying than passenger-carrying volume

3-row seating with seats that can be removed or stowed to create flat cargo-carrying surface

OR

At least one:

4-wheel drive

Gross vehicle weight greater than 6000 pounds

AND

Four:

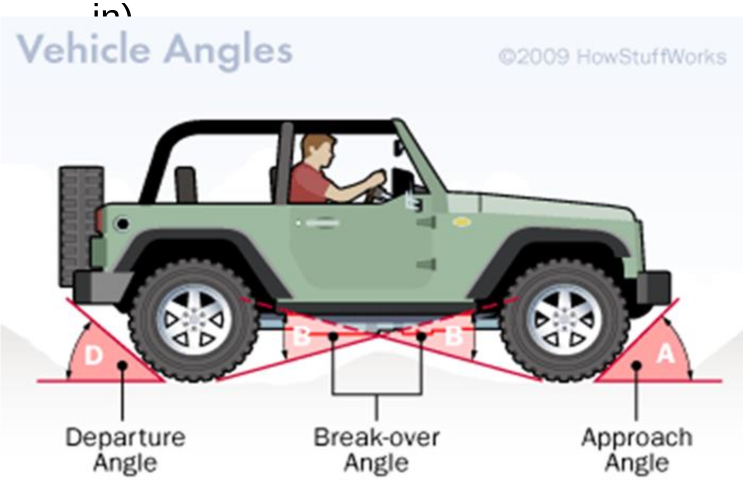
Approach angle ≥ 28°

Ramp break-over angle ≥ 14°

Departure angle ≥ 20°

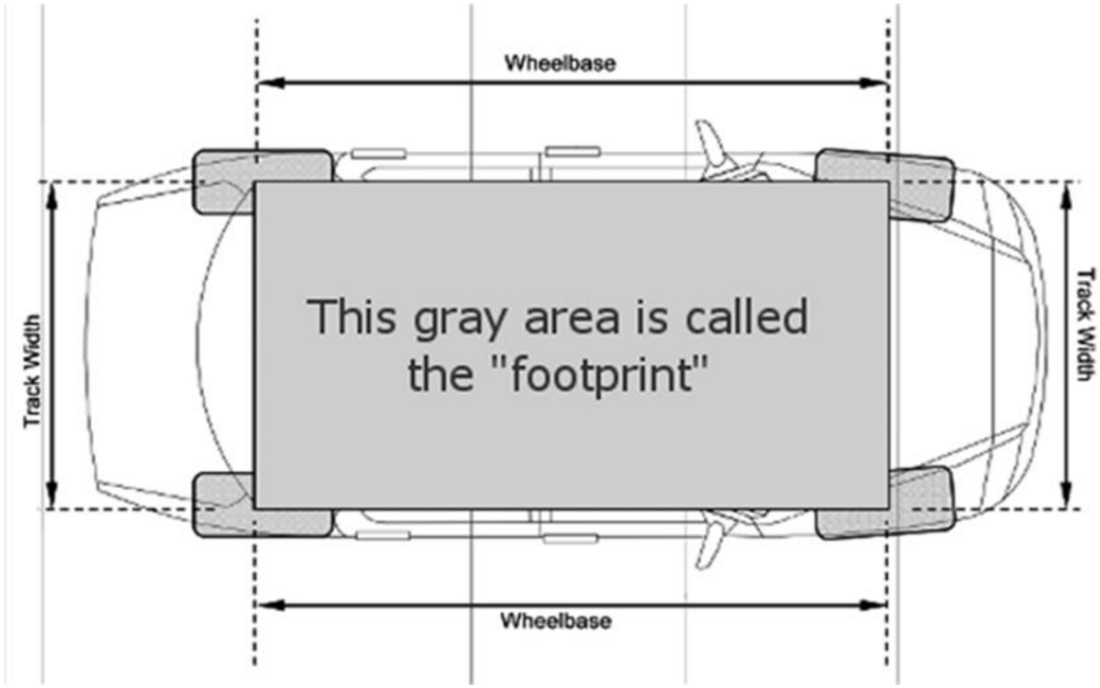
Running clearance ≥ 20 cm (7.9 in)

Front & rear axle clearance 18 cm (7.1 in)



Fuel Economy Regulations - Vehicle Footprint

- Vehicle footprint is the area shaped by the Wheelbase and Track Width



Fuel Economy Regulations - Targets

- Flexible and dynamic targets

Projections for MY 2025				
		AEO 2015 Fuel Price Case*		
	2012 Final Rule	Low (1)	Reference (2)	High (3)
Car/truck mix	67/33%	48/52%	52/48%	62/38%
CAFE (mpg)	48.7	45.7	46.3	47.7
GHG CO2 (g/mi)	163	178	175	169
GHG mpg equiv.	54.5	50.0	50.8	52.6

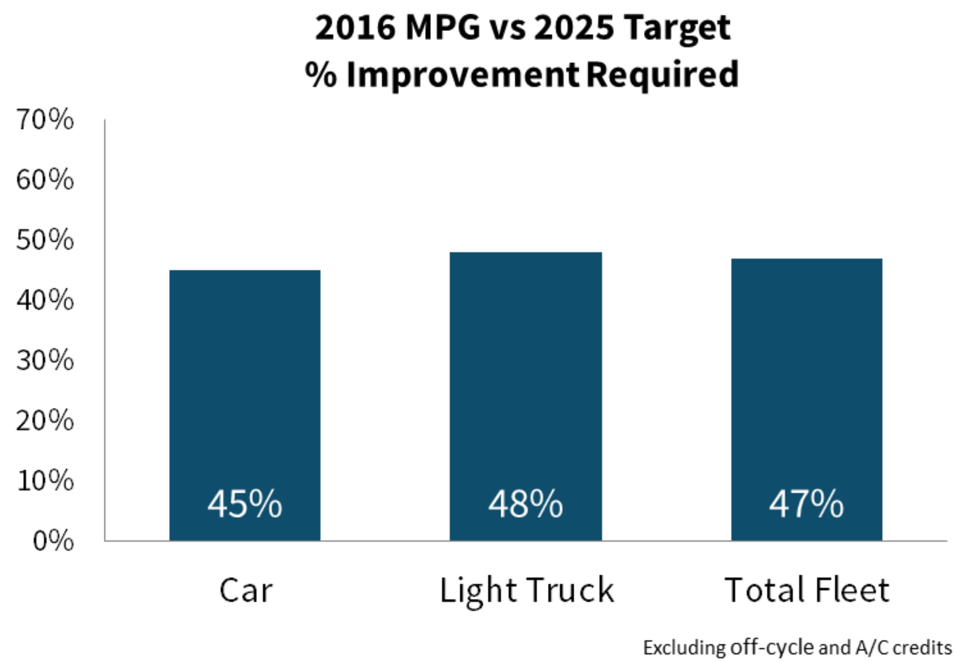
*Annual Energy Outlook: Fuel price trends to (1) $2.60, (2) $3.90, or (3) $6.33 per gallon in 2040

Source: Draft Technical Assessment Report, EPA, NHTSA, and CARB, July 2016

- New projections are 3.5-8.3% less stringent than 2012 estimate

Improvement Required from MY 2016

- **Light Vehicle**
  - Fuel economy: 31.1 mpg
  - Target: 45.6 mpg
  - Required PT improvement: 47%
- **Cars**
  - Share of '16 Sales: 43%
  - Fuel economy: 37.6 mpg
  - Target: 54.6 mpg
  - Required PT improvement: 45%
- **Light Trucks**
  - Share of '16 Sales: 57%
  - Fuel economy: 27.6 mpg
  - Target: 40.7 mpg
  - Required PT improvement: 48%



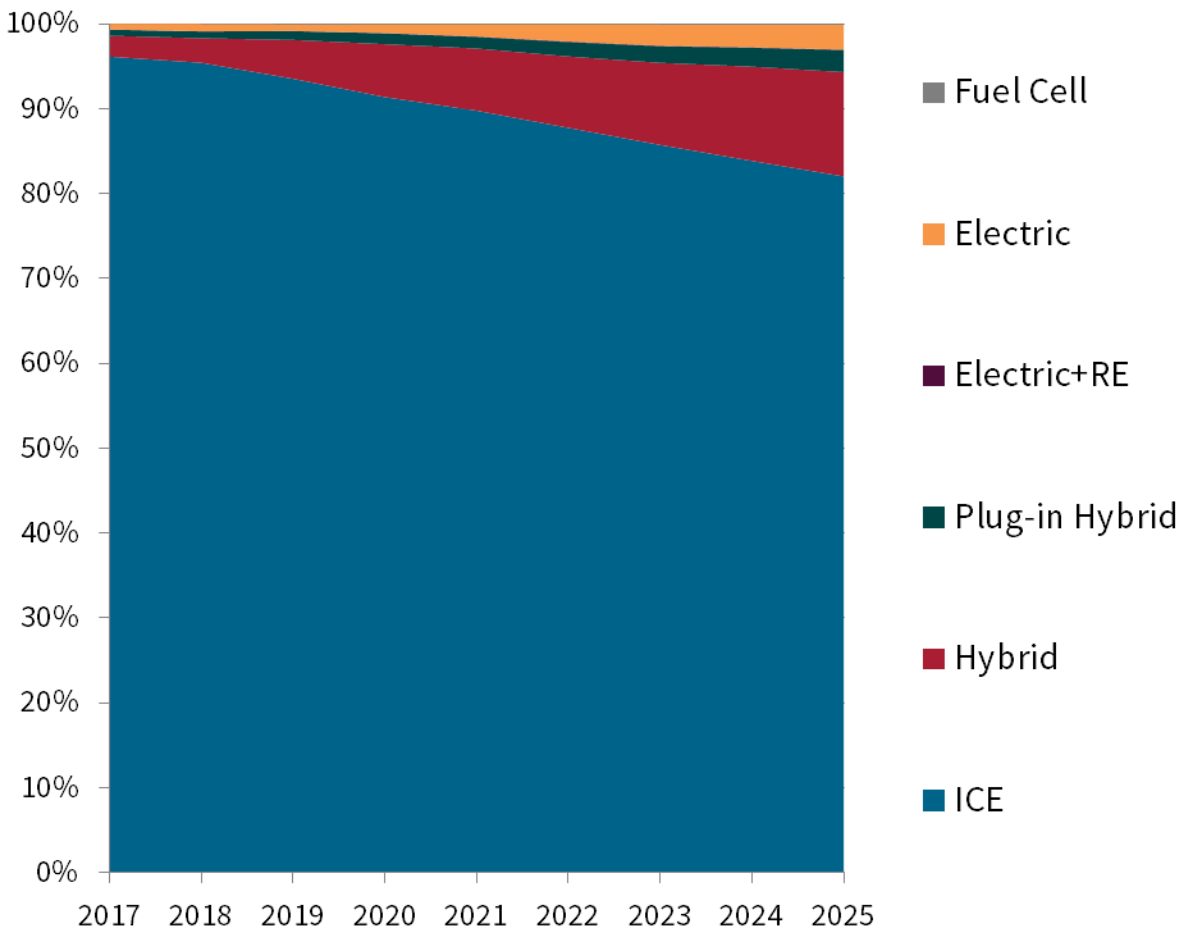
Required improvement ranges:
(with, without maximum OC/AC credits)

Car	36%-45%
Light Truck	40%-48%
Total	38%-47%

U.S. Sales:
Powertrain Trends

Green Powertrain Strategies
Overview

Powertrain by Type

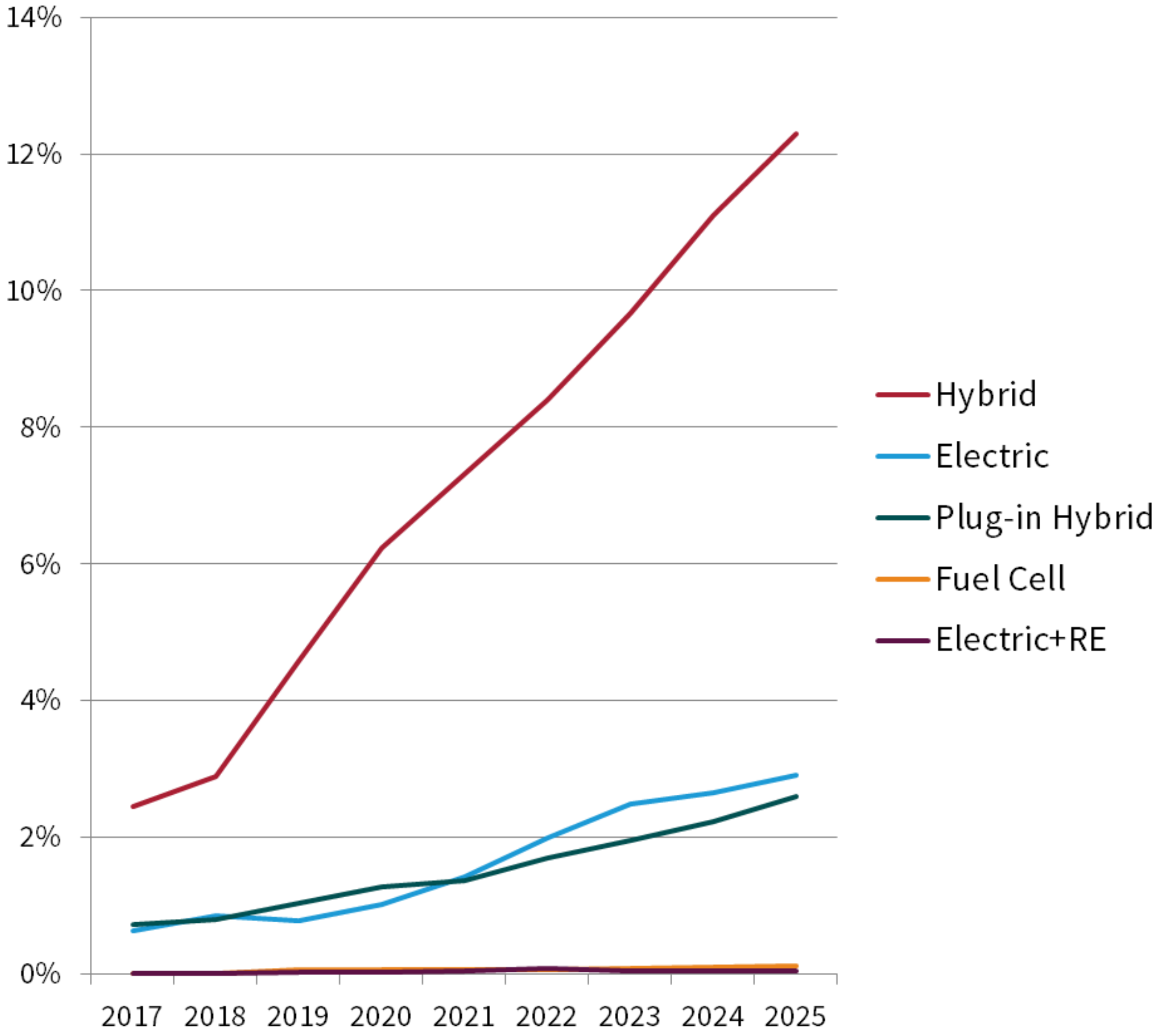


- Green vehicles to make up 18% of the industry mix in 2025
- Hybrids will account for two-thirds of green vehicles
- EVs & PHEVs each near 3%
- IC (internal-combustion) engines cede 14 share points but still make up 82% of vehicles sold in 2025

Electrification

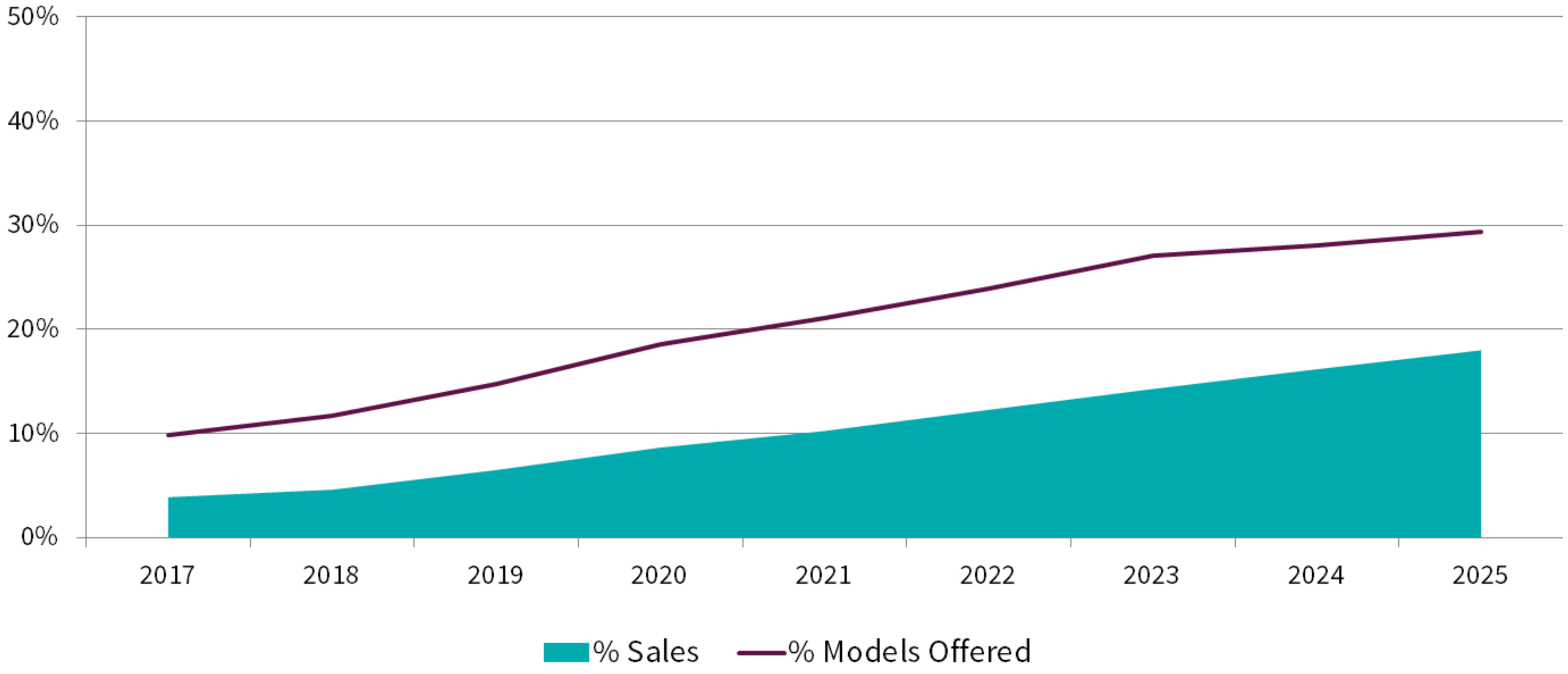
“Green Vehicles”

Electrified Powertrain by Type



- Hybrids currently the most common “green” solution for trucks in general
- Some automakers (mostly luxury) are focusing instead on PHEVs
- Fuel-cell vehicles remain a post-2025 solution for zero-emission vehicles

Green Vehicle Share vs. Availability



- At least 200 green vehicles are expected to be available in 2025
- Although the selection increases, there is still a gap from consumers preferring ICE-powered vehicles

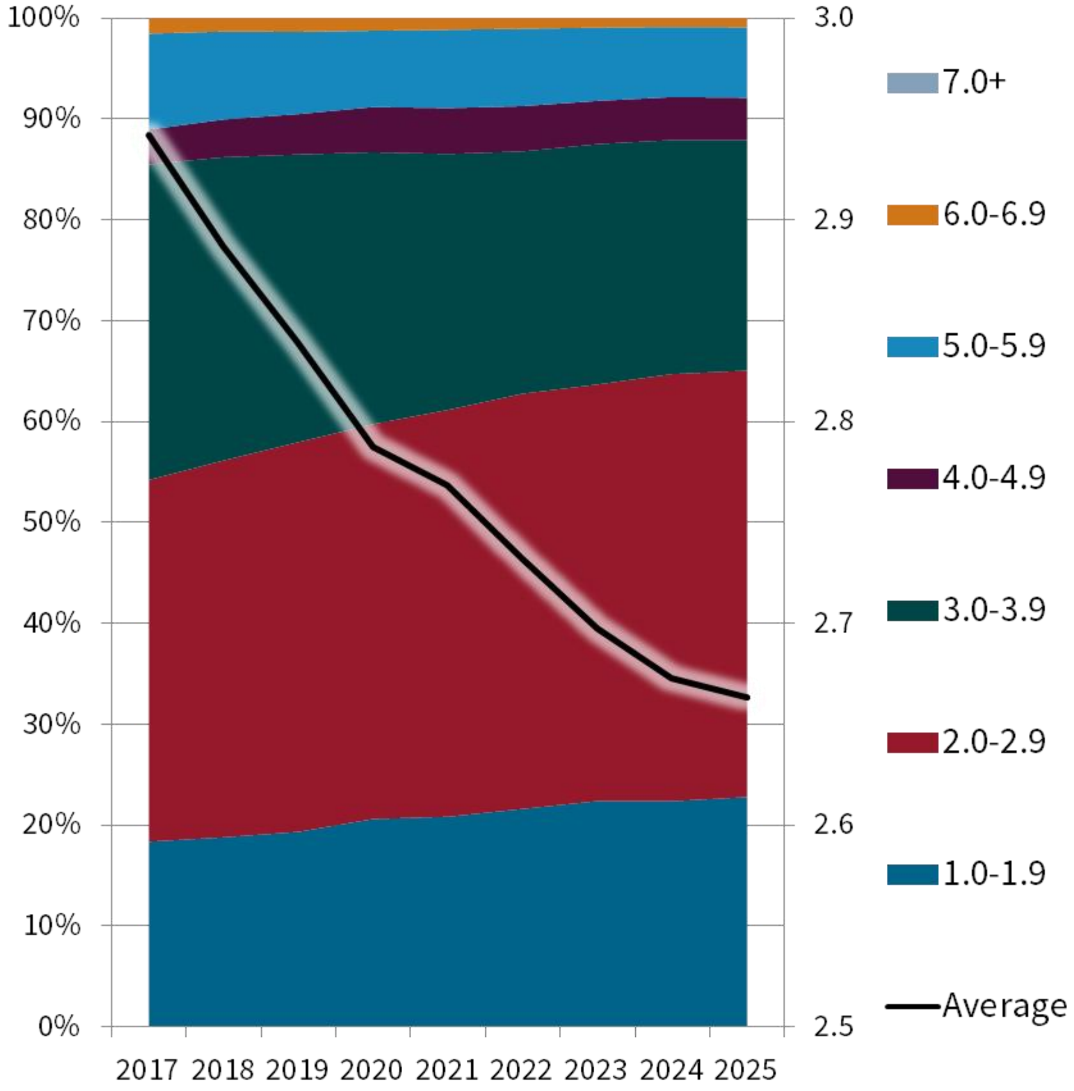
Internal-Combustion Engines

- **Downsizing & Boosting**
- **Direct Injection**
- **Valve Train**
- **Diesel**

Engine Downsizing

- To varying degrees, nearly every manufacturer is downsizing its stable of engines by replacing bigger engines with smaller versions, or increasing the mix of existing smaller displacements without consolidating engine offerings
- Among the top-volume companies with vehicles competing in most or all segments, reduction in the average displacement in trucks also is occurring through an increase in their mix of CUVs
- CUVs, even though they already have smaller displacements relative to other truck groups, on average will undergo the most downsizing among trucks – along with significant increases in turbochargers

Gasoline ICE Displacement



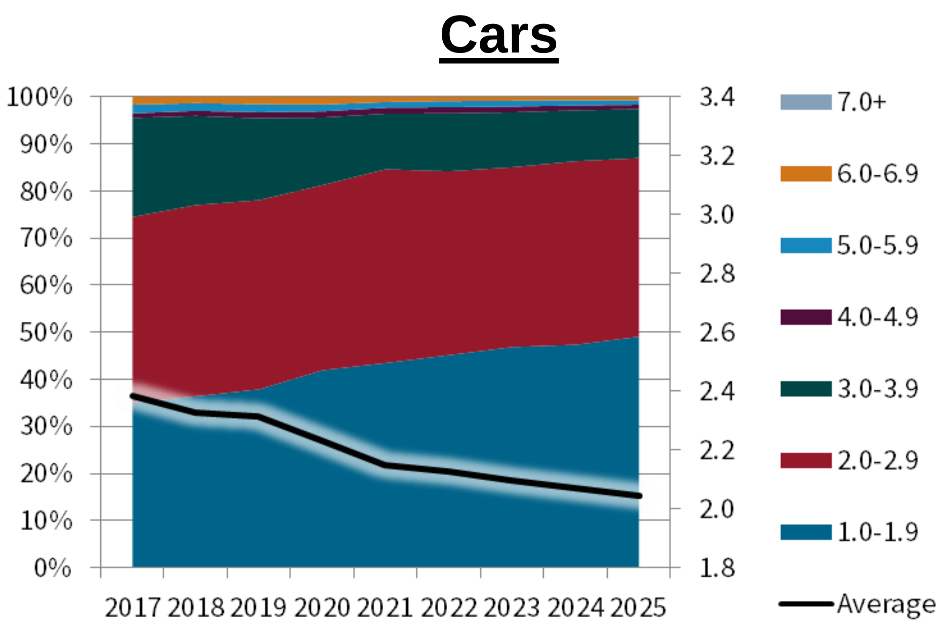
2.0-2.9L engines remain the top-seller, gaining some share from downsizing

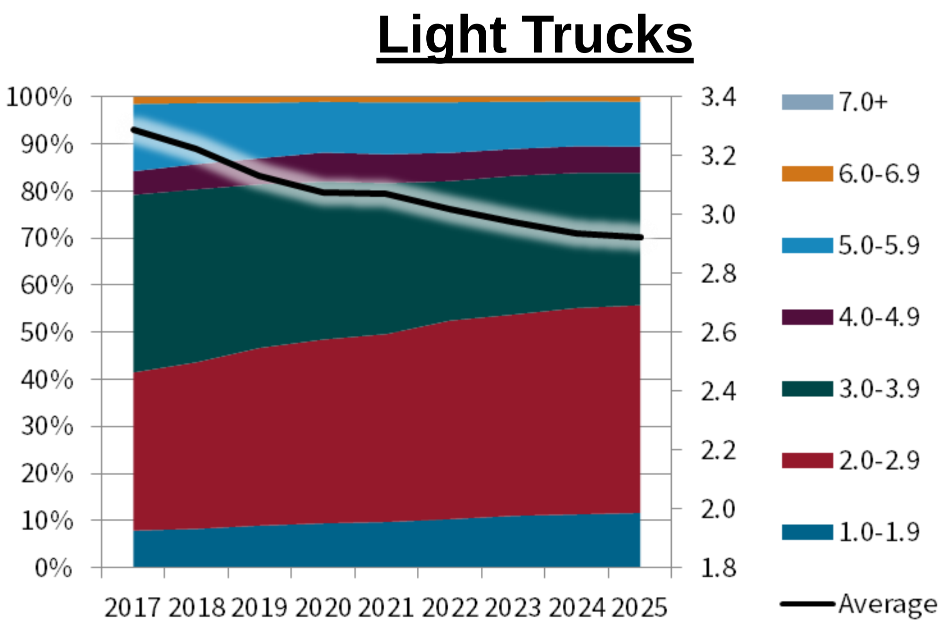
4.0-4.9L shows a small bump from large-truck engine advancements (all higher ranges lose share)

1.0-1.9L grows to be on-par with 3.0-3.9L

Industry average declines from 2.9L to 2.7L

Gasoline ICE Displacement by Vehicle Type

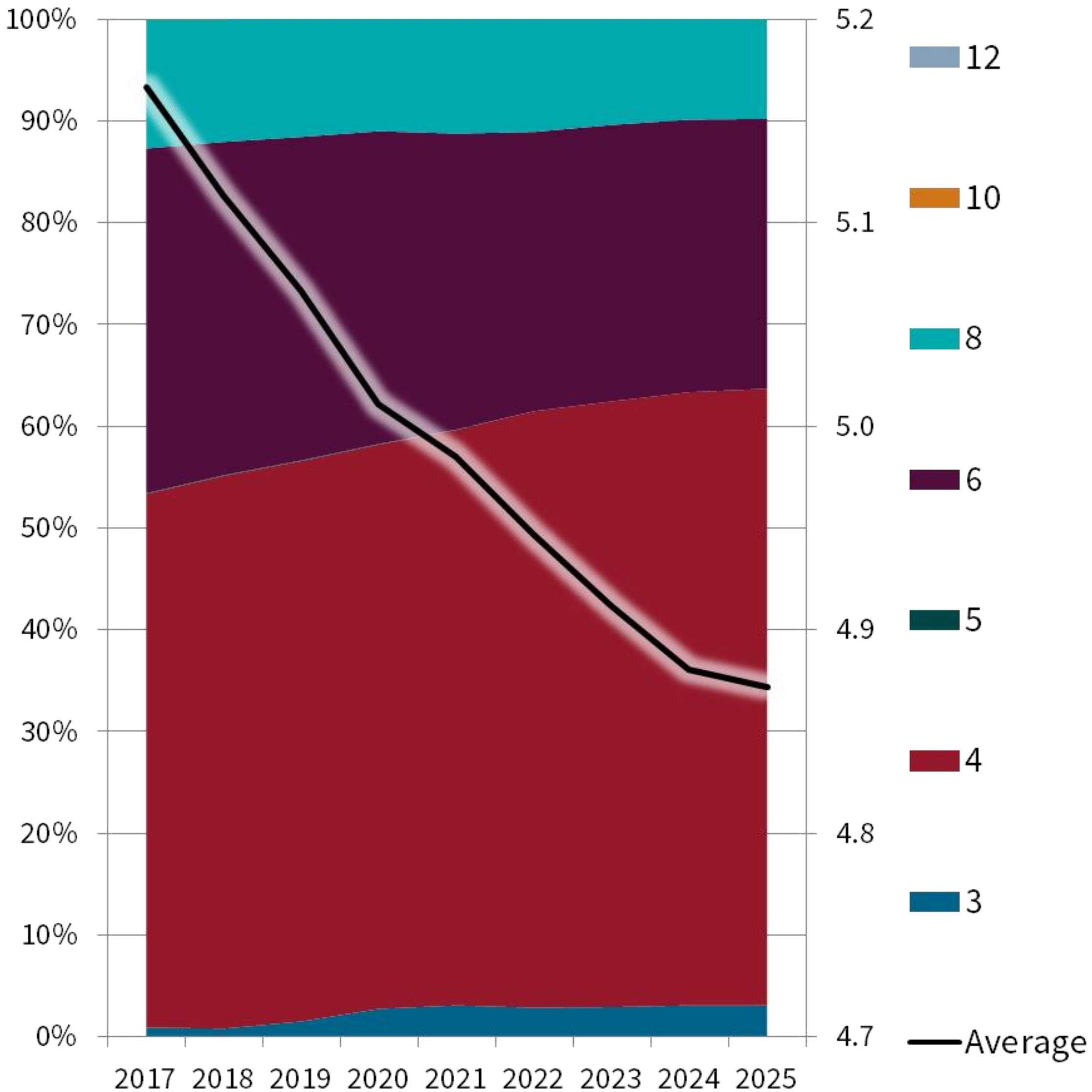




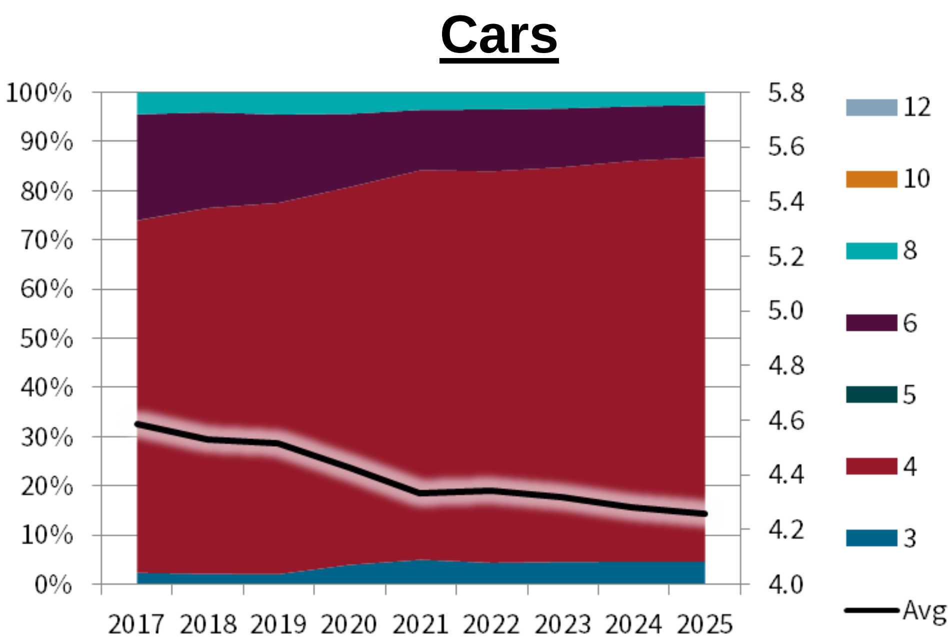
- 1.0-1.9L: much more prominent in cars (49.1%) vs trucks (11.6%)
- 2.0-2.9L: strong in both categories
- 4.0L+: continues in trucks to power the larger bodies

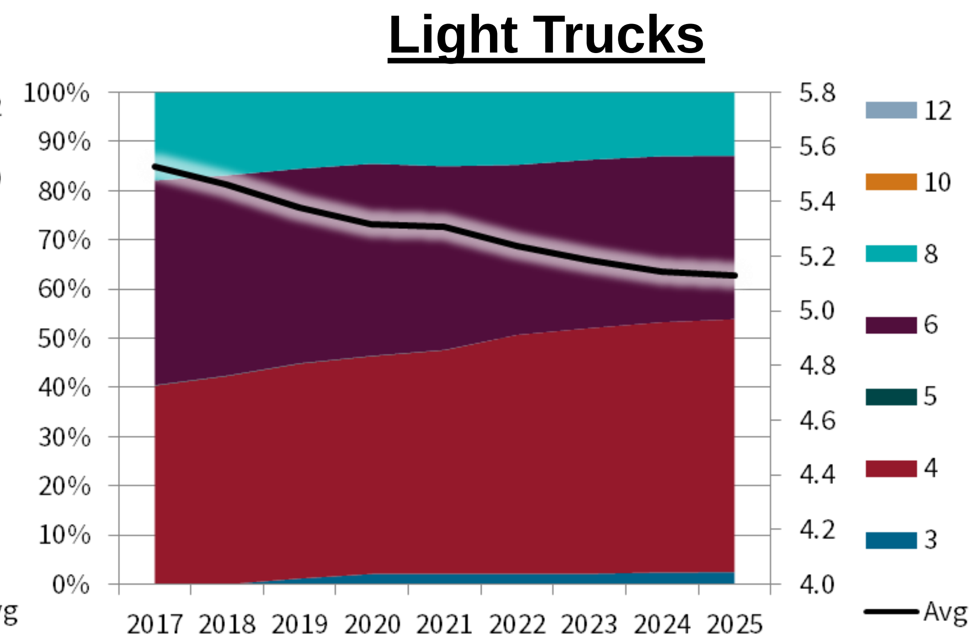
Gasoline ICE Cylinder Count

- 10- and 12-cyl (and 5's) engines virtually disappear - remaining on select luxury models
- Main trend: 6's down to 4's
- 3-cyl. penetration grows, but used by few brands: Ford, Fiat, Mini, Mitsubishi
- Industry average declines from 5.2 to 4.9 cylinders



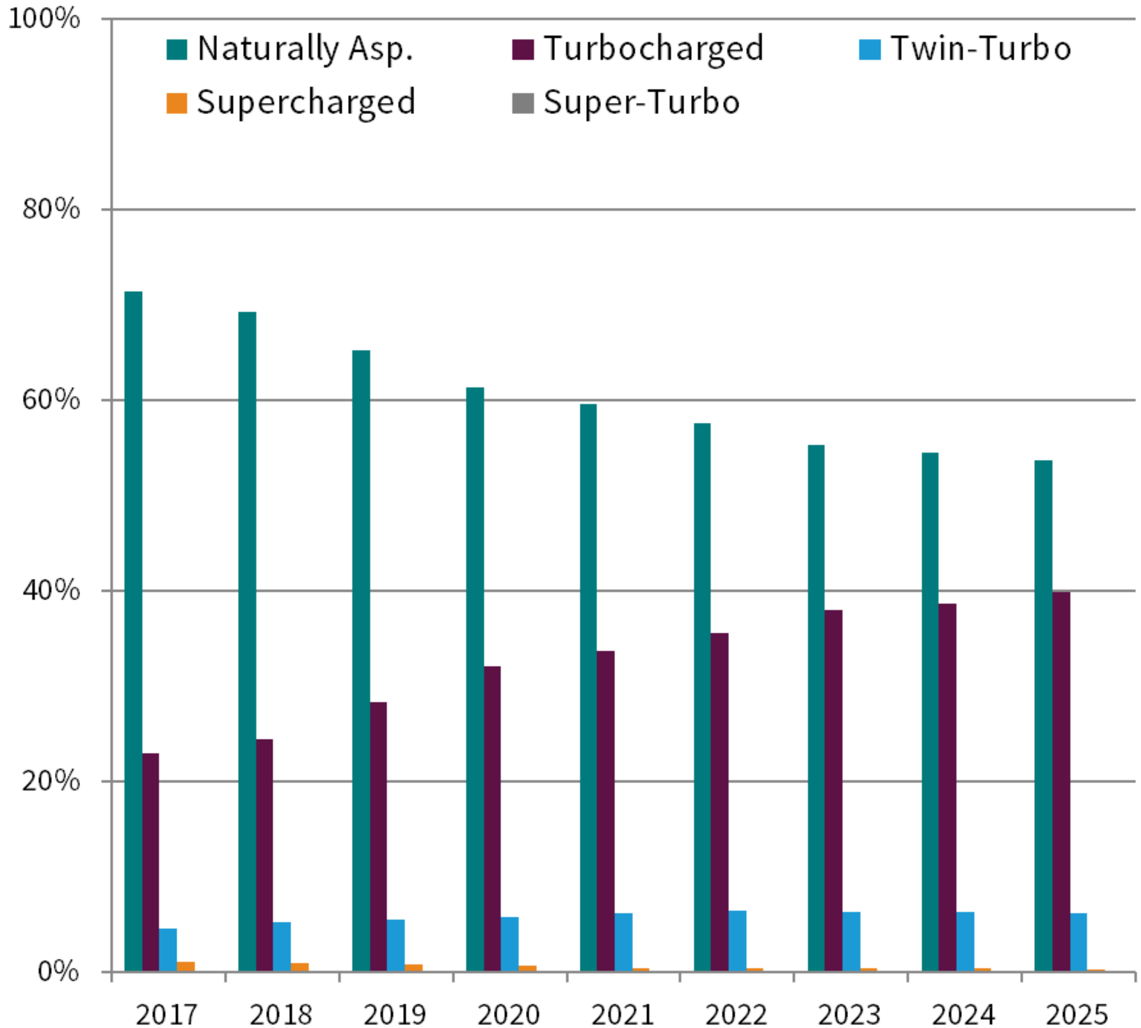
Gasoline ICE Cylinder Count by Vehicle Type





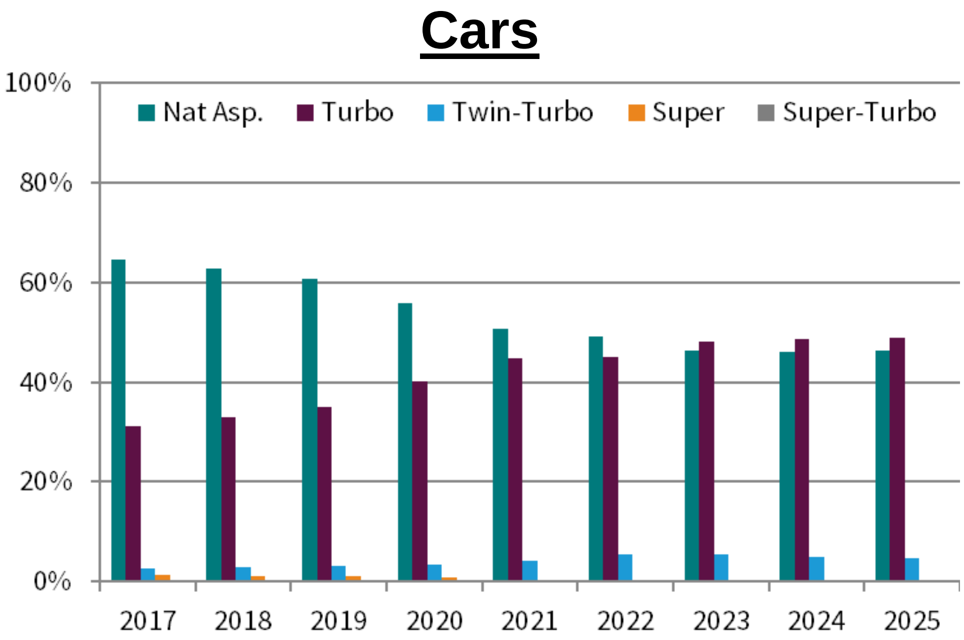
- 4-cyl: Strong majority in cars (82%), just over half (51%) in trucks
- CUVs put 3-cyl. in truck fleet

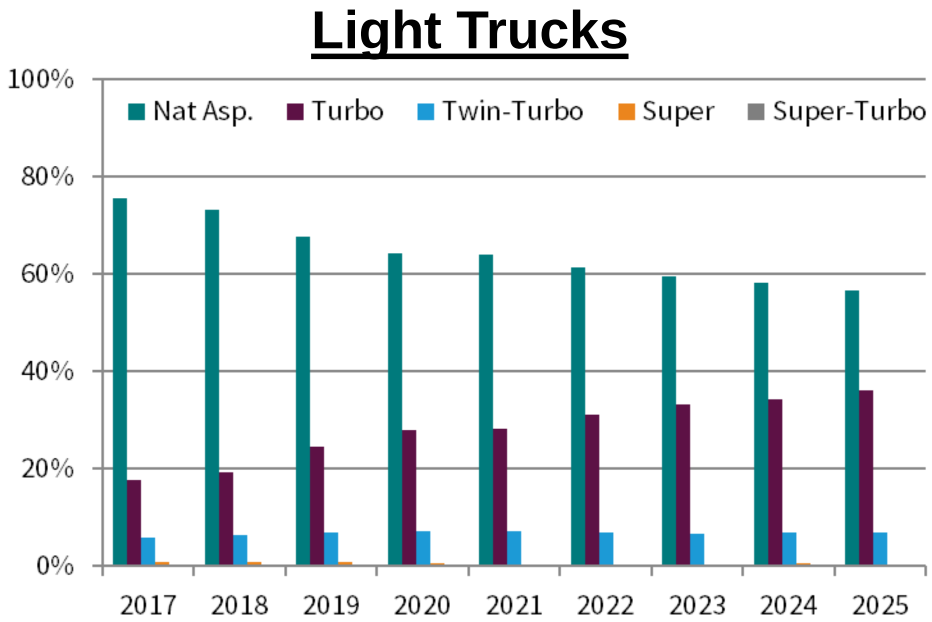
Gasoline ICE Aspiration Mix



- Forced induction (boosting) complements downsizing
- Almost half of all engines will be boosted heading to 2025
- Turbocharging is the primary choice at 40%
- Supercharging doesn't gain favor due to parasitic loss -- though this could change if e-boosting catches on

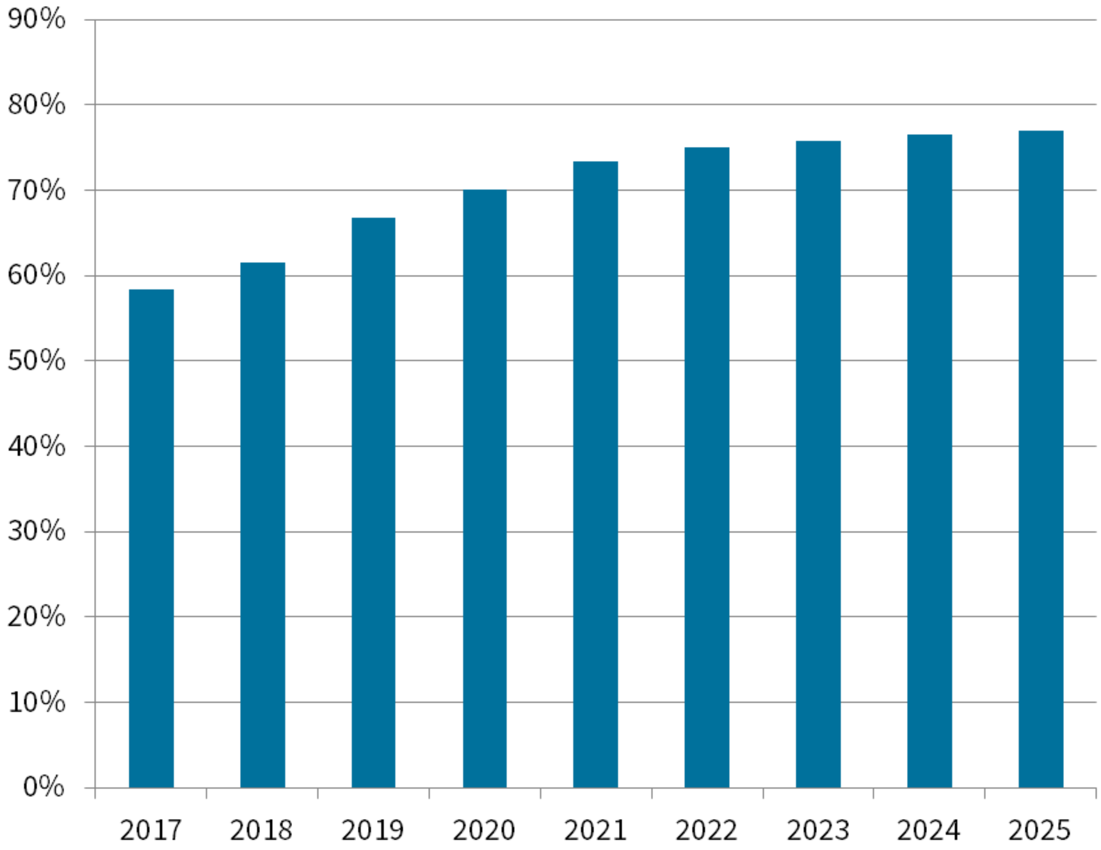
Gasoline ICE Aspiration Mix by Vehicle Type





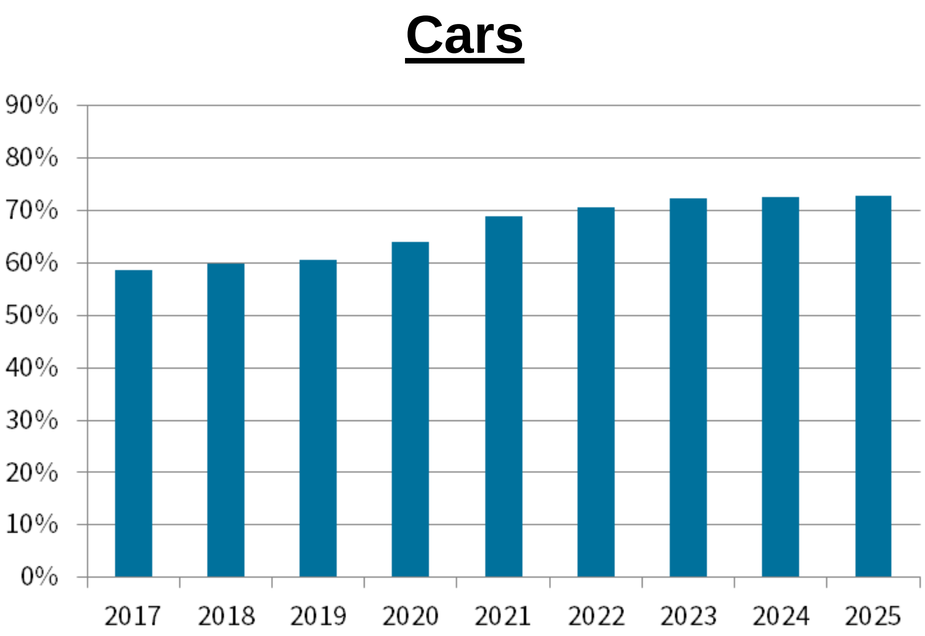
- Cars have an especially high penetration of turbocharging

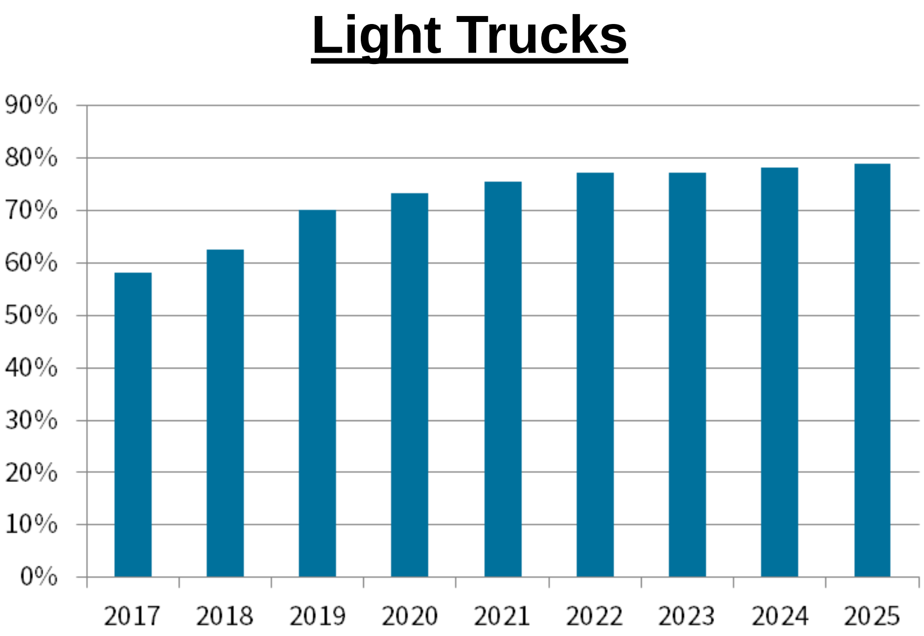
Fuel Delivery: Direct Injection



- Use of Port Fuel Injection cuts in half over the study period, allowing Direct Injection to near 80%
- Like many other technology upgrades, DI has strong near-term growth, with the trend flattening – though still rising – in the next decade

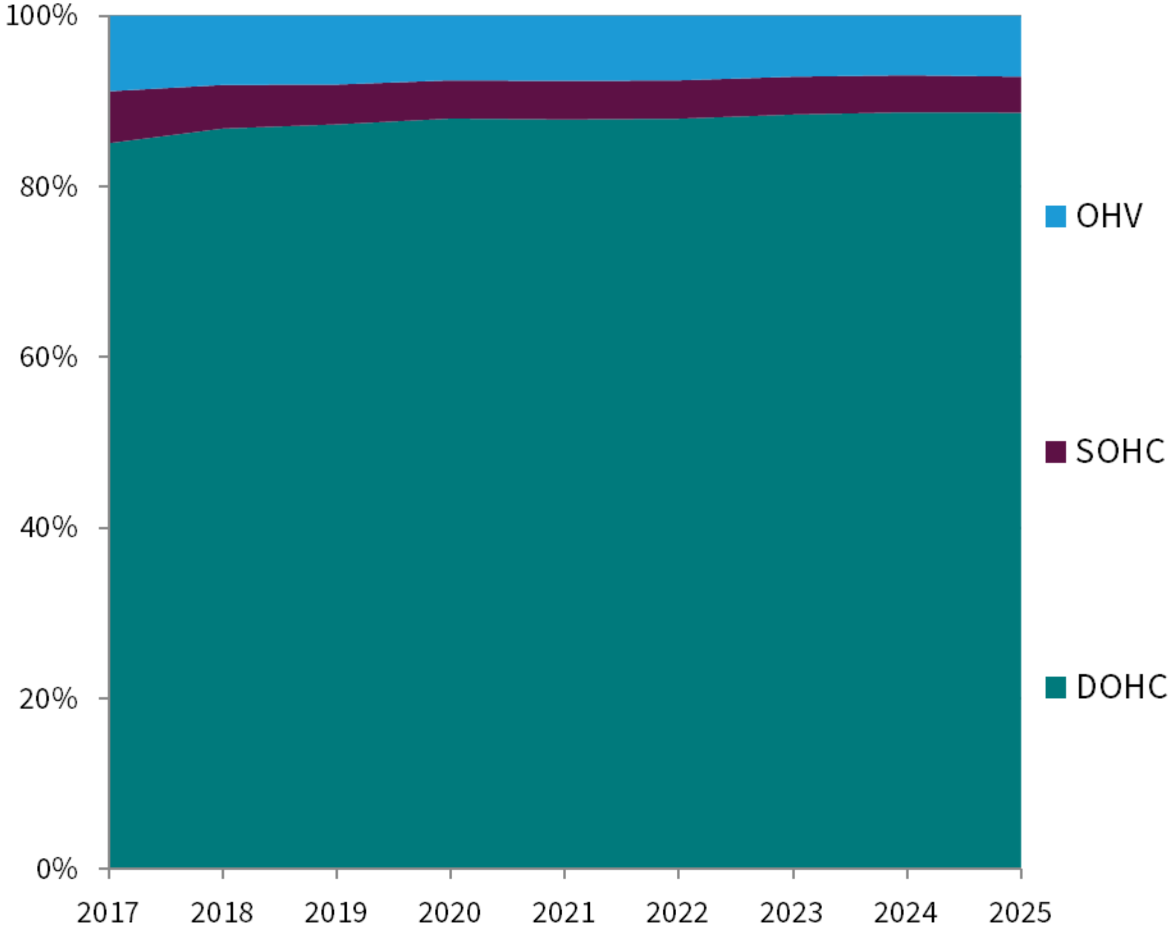
Direct Injection by Vehicle Type





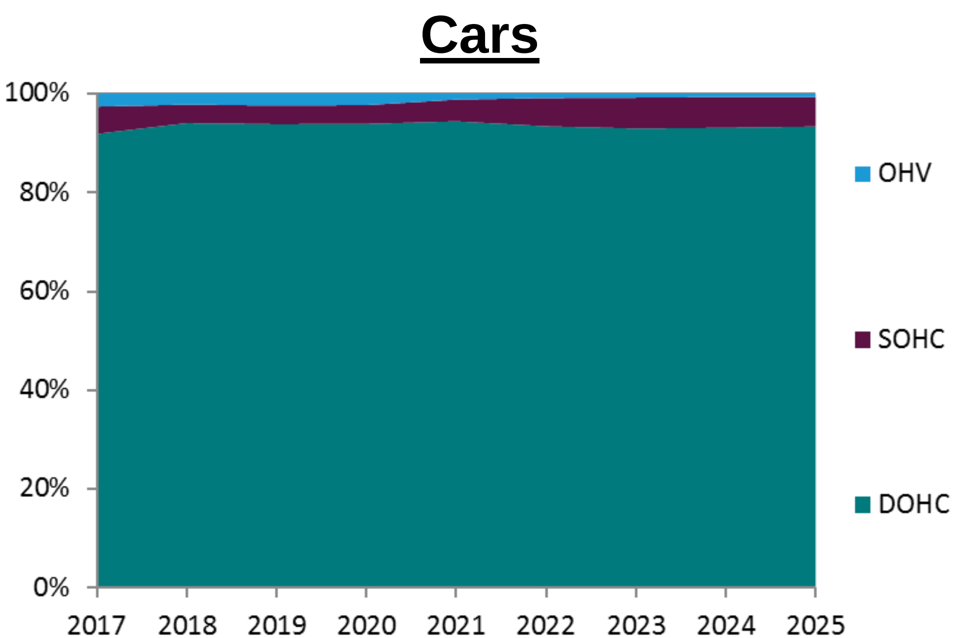
- Both vehicle types start at nearly the same point, but trucks pull ahead in 2025

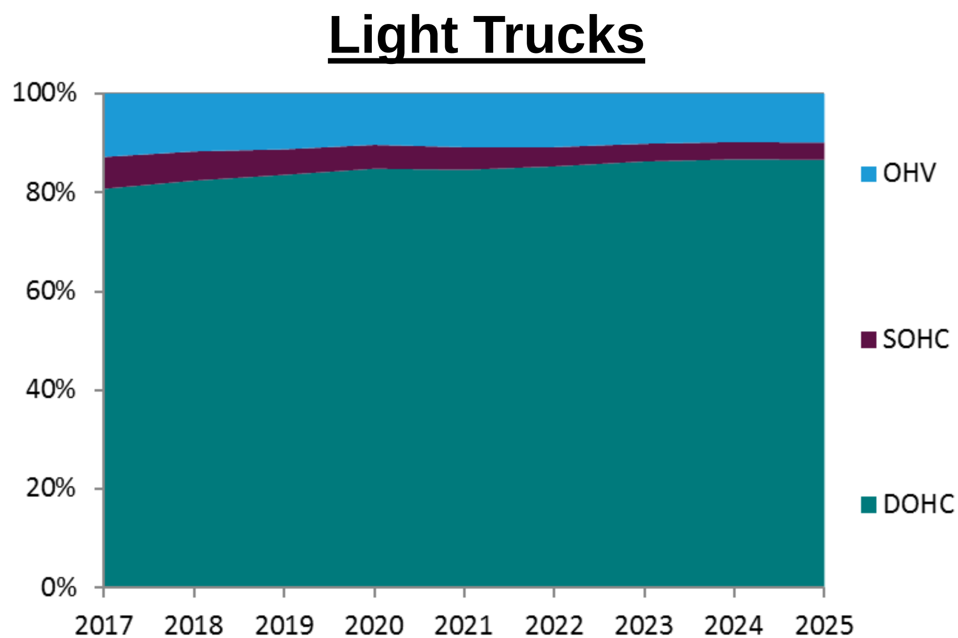
Valve Train



- Over 90% of IC engines have overhead-cam valve trains, with the combined penetration increasing slightly
- Double overhead cam (DOHC) remains the dominate design at 89%

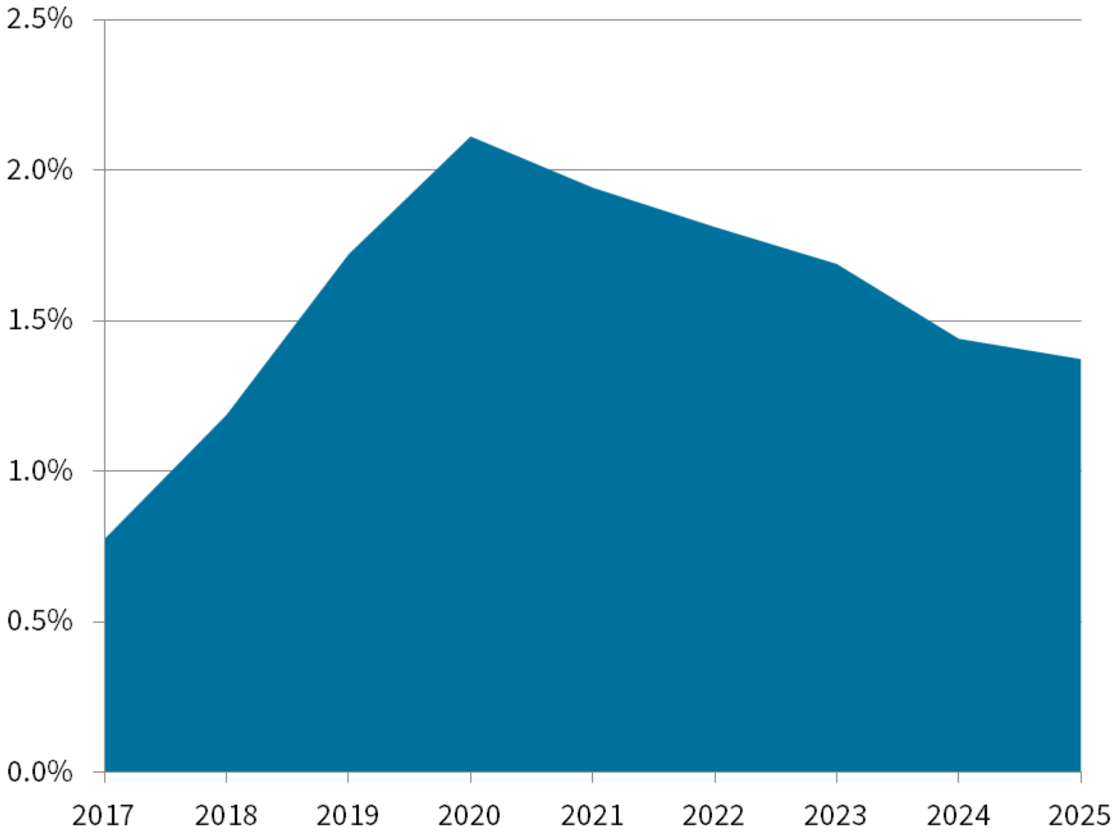
Valve Train by Vehicle Type





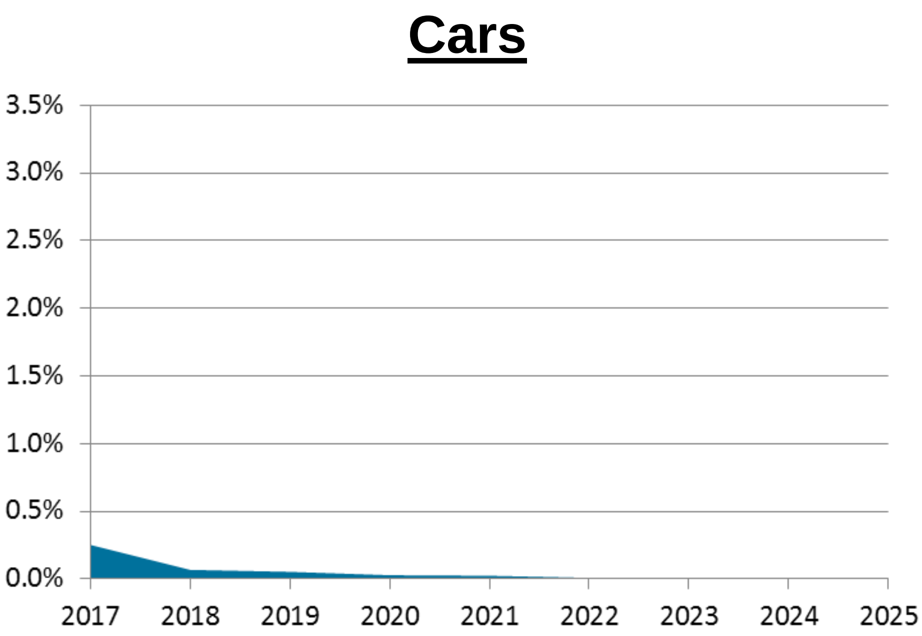
- OHV’s primarily continue in SUVs, pickups and vans from GM and FCA

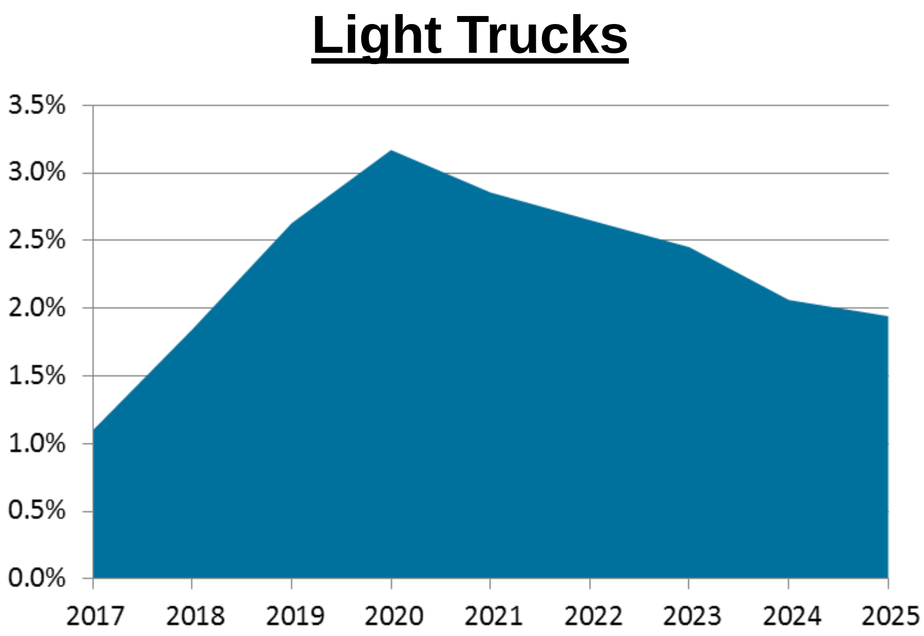
Diesel Engines - Share of ICEs



- Volkswagen diesel scandal has increased government scrutiny, making certification a longer process, and causing some automakers to pare back plans
- Diesel engines top out at 2.1% of all (regulated light-vehicle) ICEs in 2020.

Diesel Engines - Share of ICEs by Vehicle Type



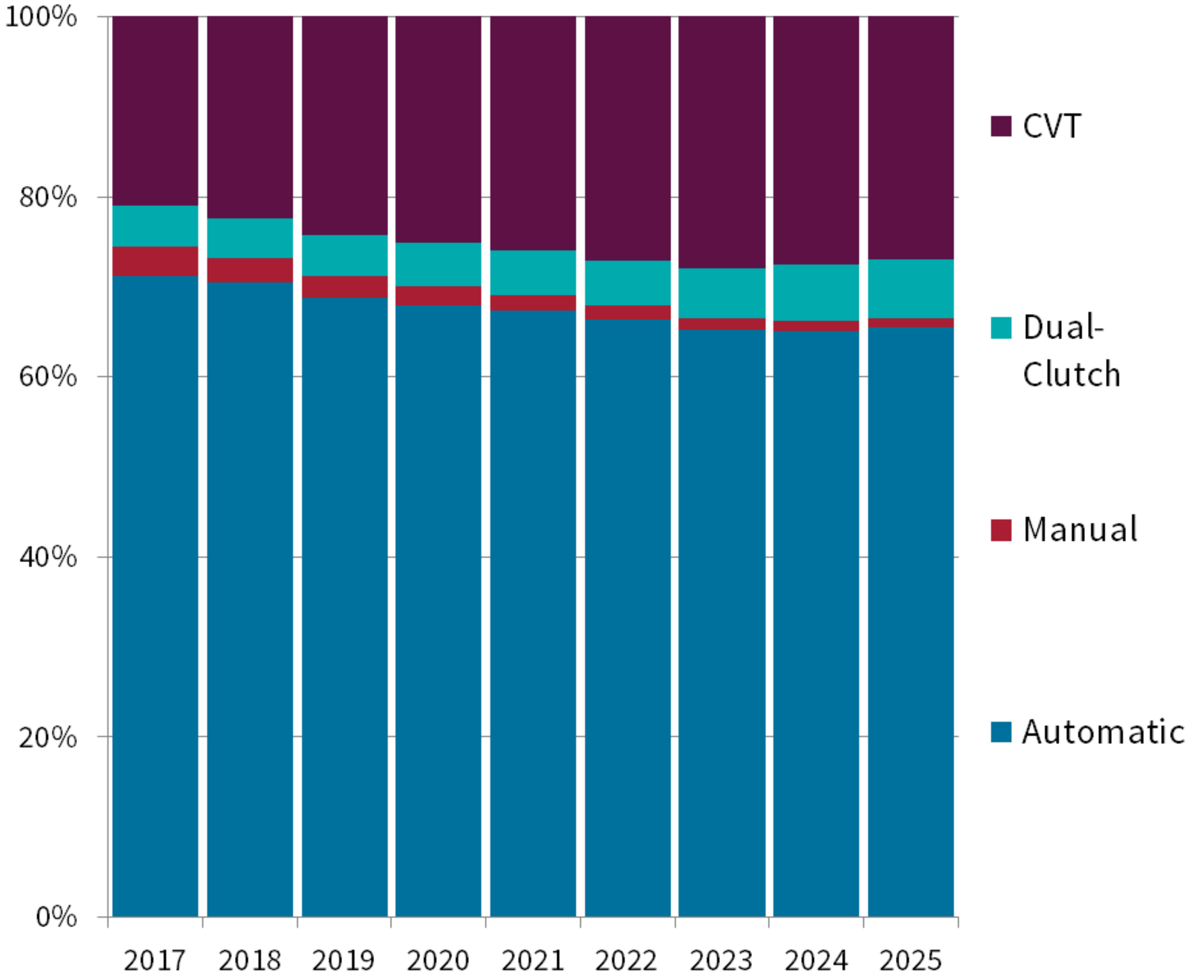


- Among cars, offered to fill consumer demand niche rather than improve CAFE results
- Mostly in pickup segment of trucks (note: 8,501-10,000 GVW pickups excluded from light-vehicle CAFE)

Transmissions

Automatic
Manual
Continuously Variable (CVT)
Dual-Clutch (DCT)

Transmission Mix

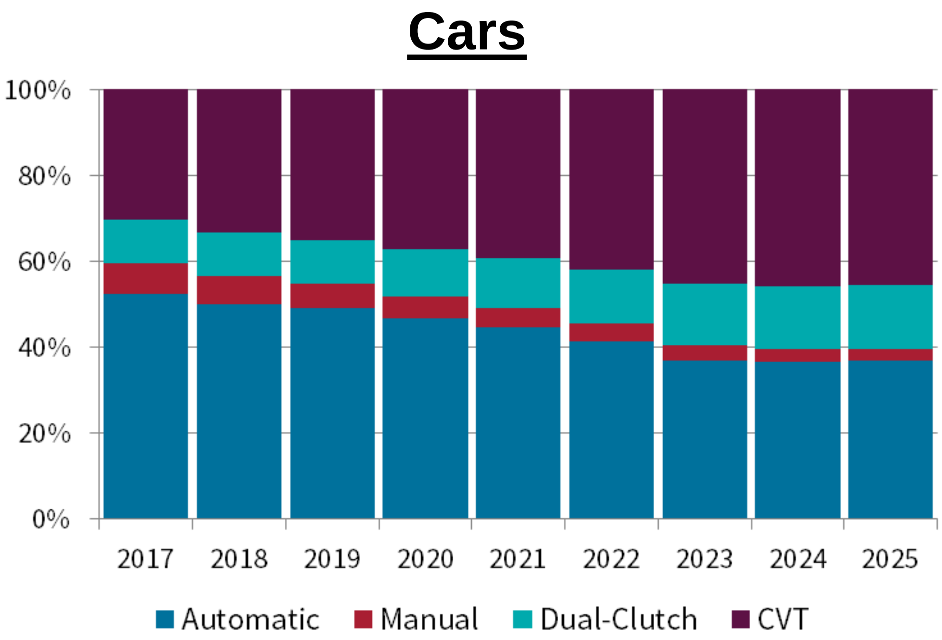


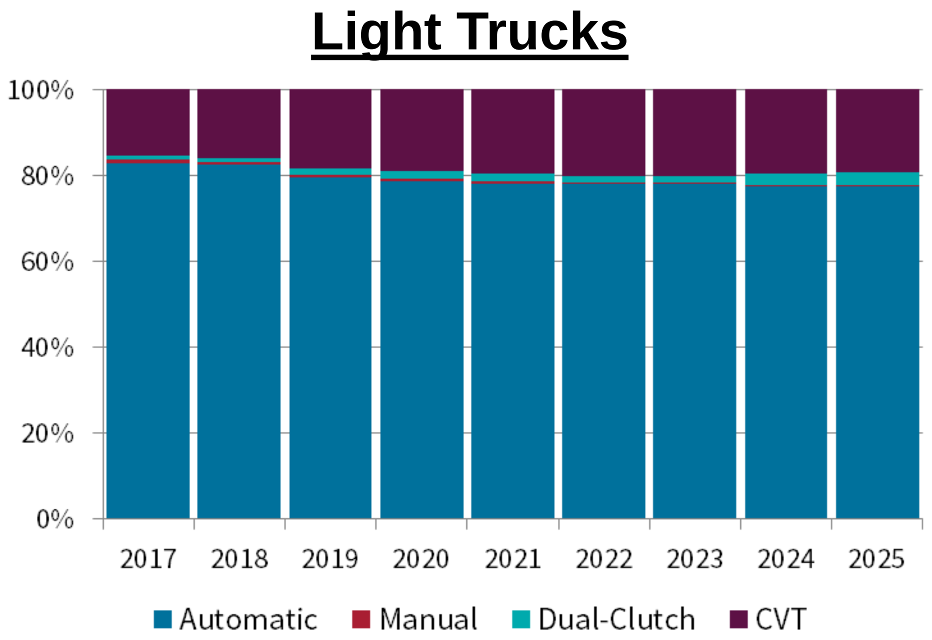
- Automatics remain the favorite, declining slightly, but two-thirds of the market in 2025
- Manuals fade
- Dual-clutch shows small uptick, mostly in sporty applications
- CVTs gain, mated to small engines

Includes only transmissions mated to ICEs

WARDS INTELLIGENCE

Transmission Mix by Vehicle Type

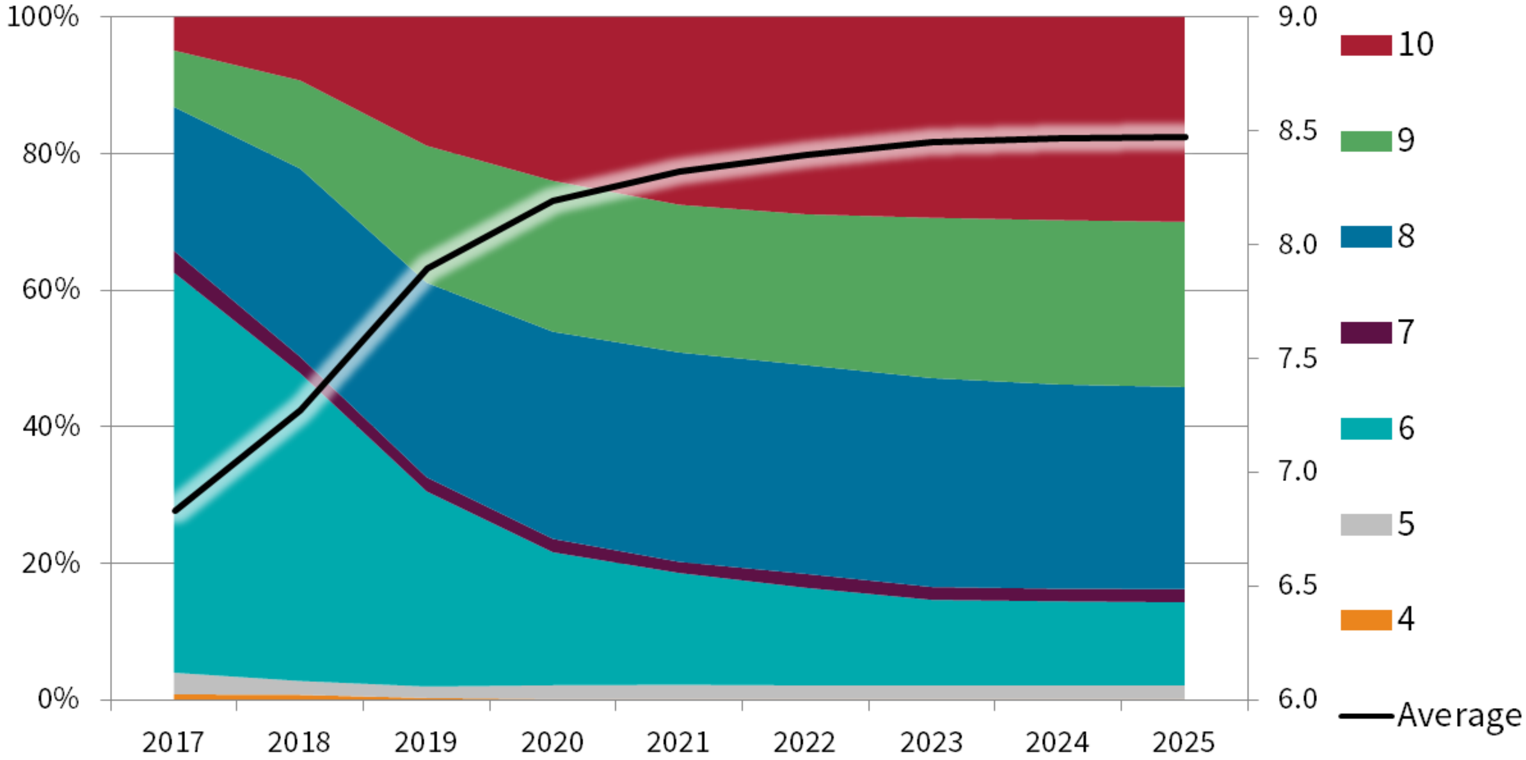




- Thanks to truck applications, automatics remain the dominant transmission in the U.S. (75% penetration in LTs)
- CVTs have growth, mostly in cars (45%) where automatics fall to 37% penetration

Includes only transmissions mated to ICEs

Automatic Transmission Forward Gear Count

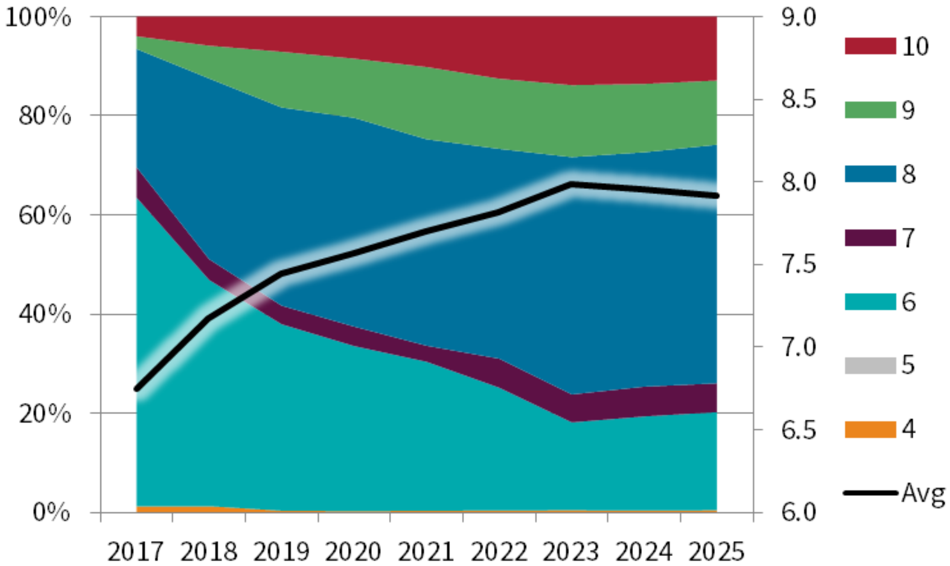


- 6-speed automatics, the top seller in 2017, lose share fast over the period
- The share of 8- to 10-speed will increase from a combined 34% in 2017 to 84% in 2025

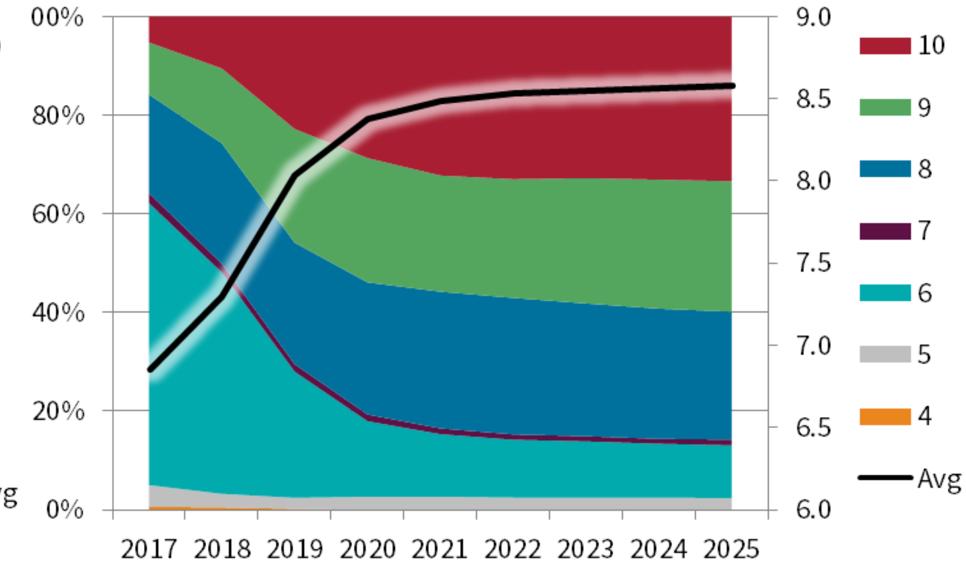
Includes only transmissions mated to ICEs

Automatic Transmission Forward Gears by Vehicle Type

Cars



Light Trucks



- 8-speeds cover almost half of cars in 2025
- Trucks mostly 8- to 10-speed, with 10 gears on top in 2025

Includes only transmissions mated to ICEs

2017 to 2025 Snapshot

	2017	2025
% Car	40	33
% Light Truck	60	67
Green Vehicle Forecast Share	4	18
Availability (% Models offered)	10	29
Average Cylinders/Engine	5.2	5.1
Average Displacement (L)	2.9	2.9
% Forced Induction	29	47
Primary Transmission Type	Auto (71%)	Auto (66%)
Avg. Automatic Gears	6.8	8.5

Cars

	2017	2025
Green Vehicle Share	7	27
Availability	12	31
Average Cyl./Engine	4.6	4.5
Average Disp. (L)	2.4	2.3
% Forced Induction	36	54
Primary Transmission	Auto (52%)	CVT (45%)
Avg. Automatic Gears	6.7	7.9

Light Trucks

	2017	2025
Green Vehicle Share	2	14
Availability	6	27
Average Cyl./Engine	5.5	5.5
Average Disp. (L)	3.3	3.2
% Forced Induction	25	44
Primary Transmission	Auto (83%)	Auto (77%)
Avg. Automatic Gears	6.9	8.6

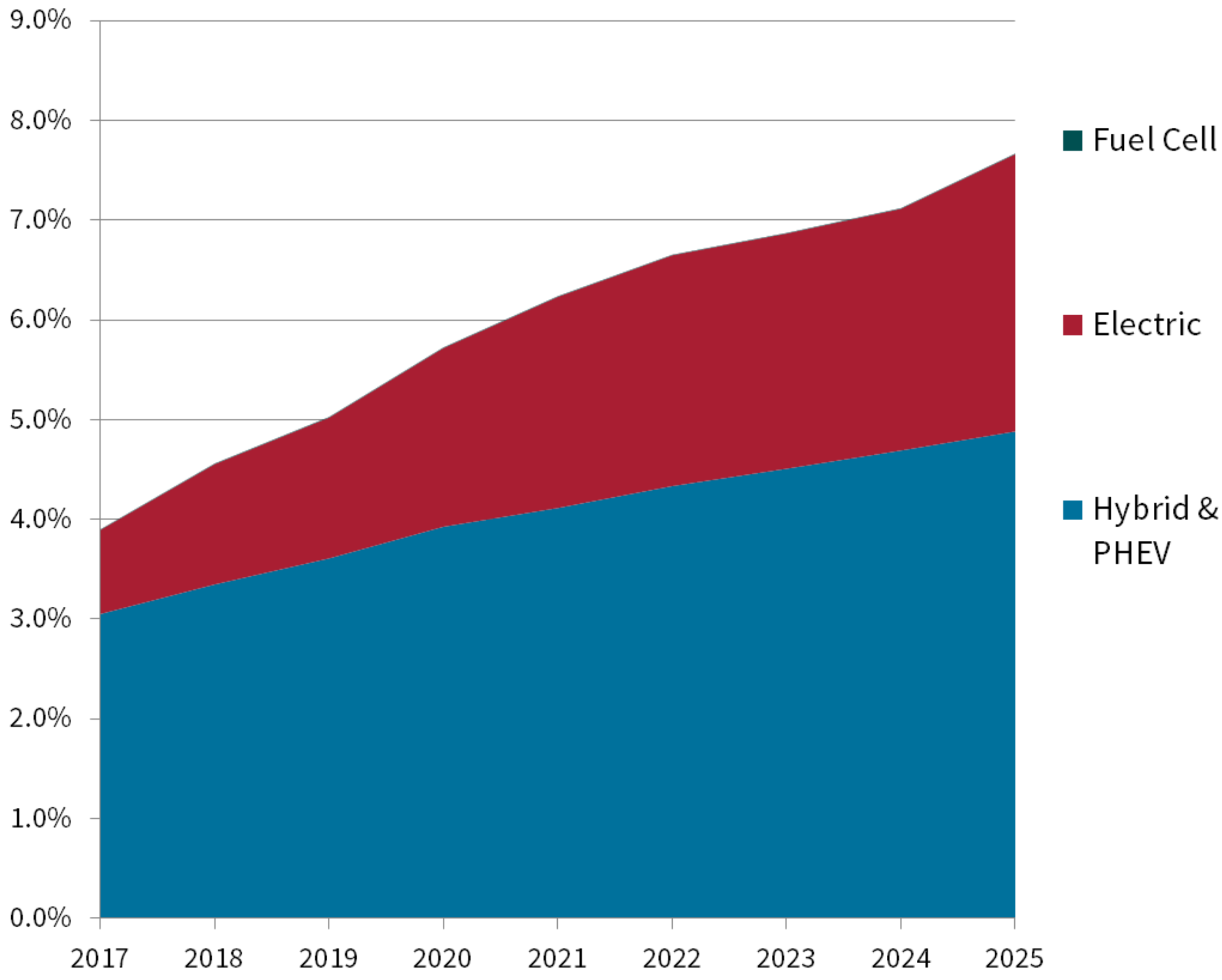
Global Production: Powertrain Trends

Wards Intelligence & AutoForecast Solutions

Electrification

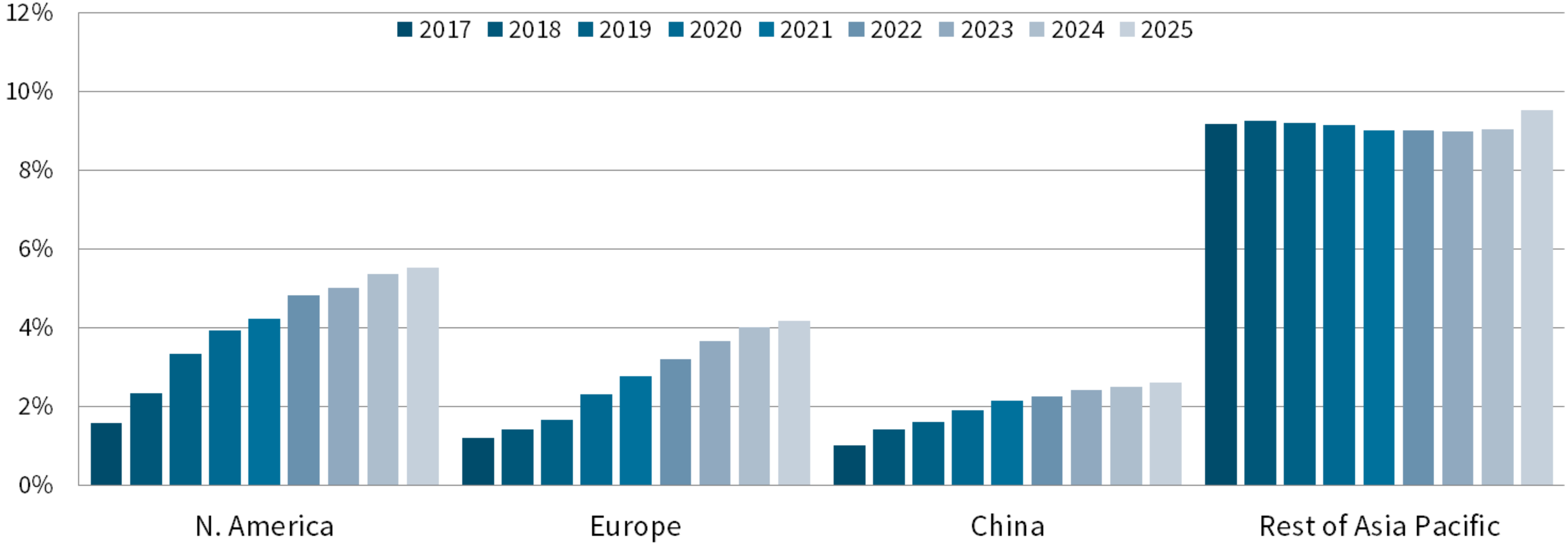
“Green Vehicles”

Green Vehicle Market Share



- Penetration rises steadily through 2025
- Hybrid vehicles remain the dominant green powertrain
- EV rate triples
- Although some automakers still view fuel-cell as a long-term solution, they remain virtually non-existent in the forecast timeframe

Hybrid & Plug-in Hybrid Market Share by Region



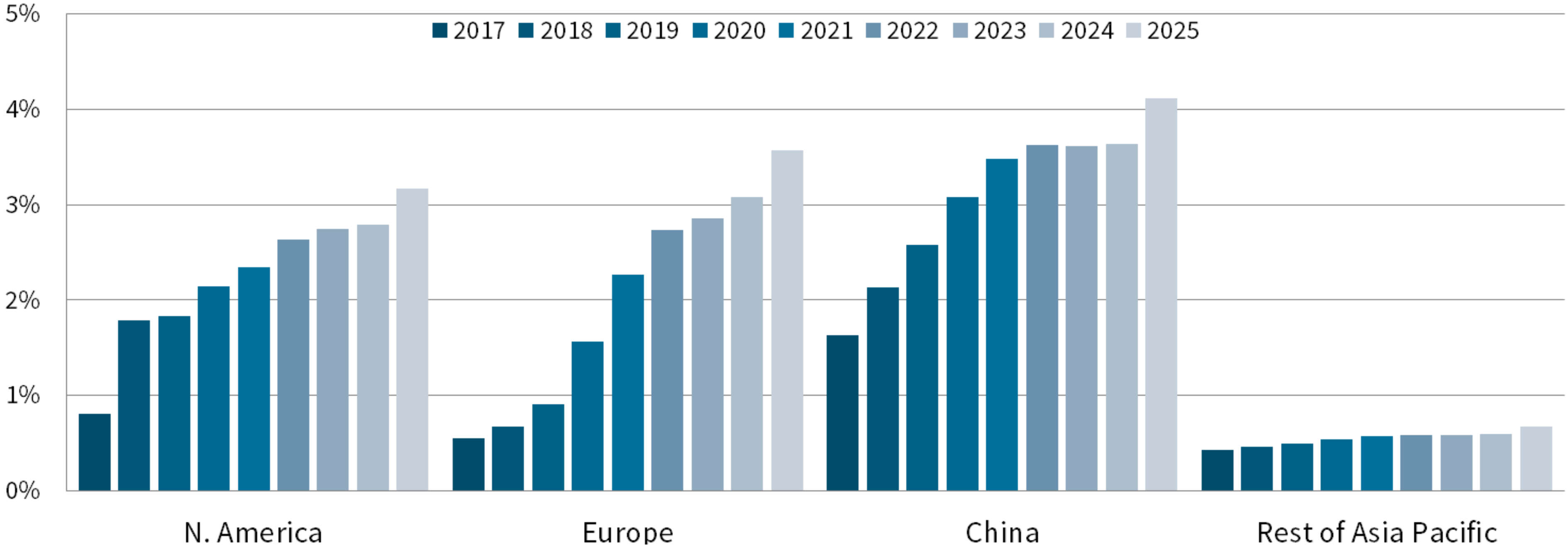
North America shows rapid growth as more applications enter the U.S. market

Europe's near-term growth will not be as rapid

China maintains steady growth as emissions regulations get stricter for certain urban areas, but penetration remains small due to the huge volume of total vehicle production

Rest-of-Asia, where hybrid output is dominated by Japan and South Korea, is already relatively high and holds mostly steady

Electric Vehicle Market Share by Region



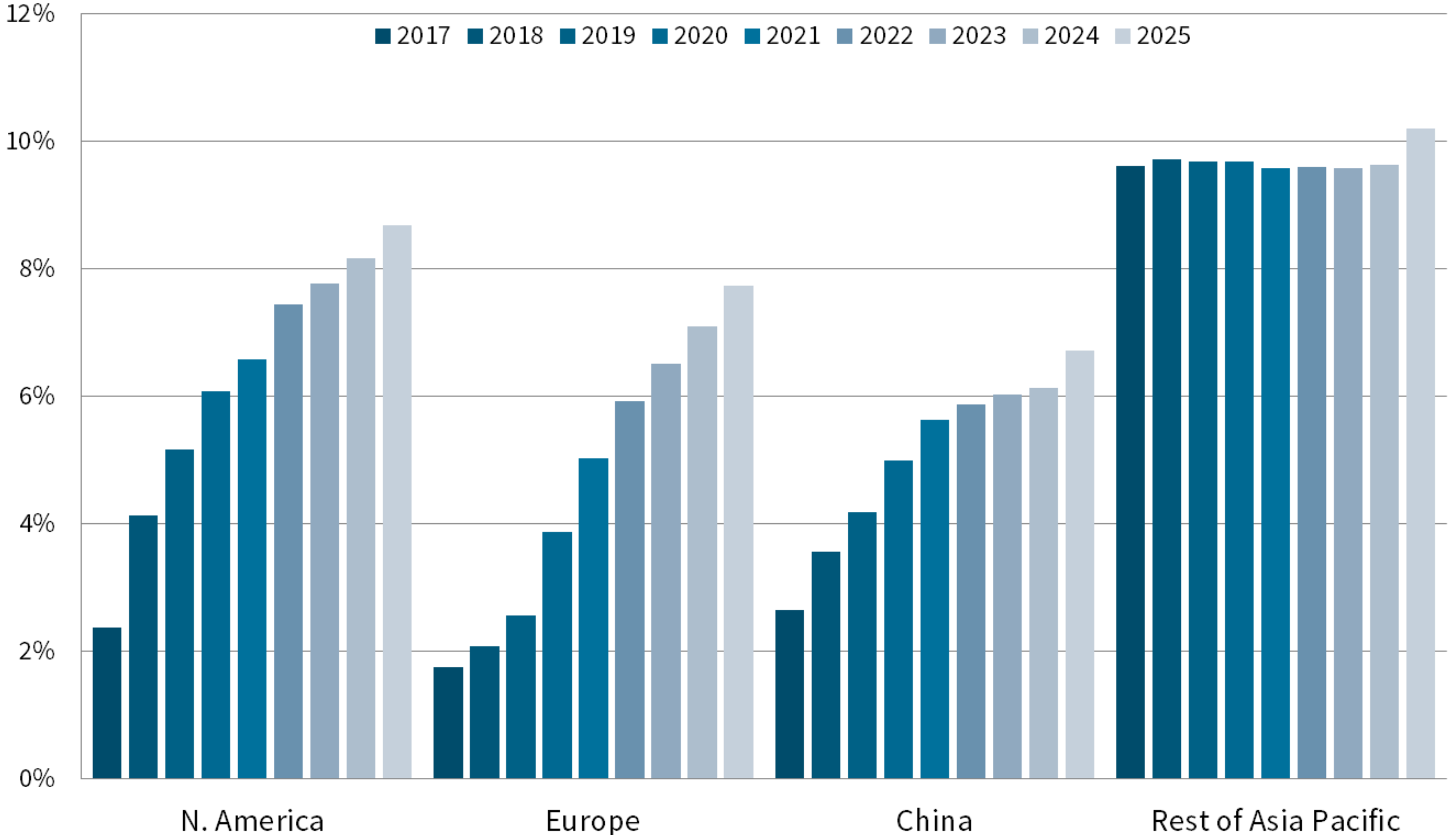
North America's EV production majorly comes from Tesla. Future figures depend on Tesla's potential transition to China-based production.

Europe, China and North America roughly follow the same upward trend, but Europe starts at the lowest point (of the three) and comes in second by 2025.

China's penetration will accelerate as more global-based manufacturers expand their production mix into the country, and local manufacturers gain the technology to make electric vehicles.
ZEV policy still uncertain.

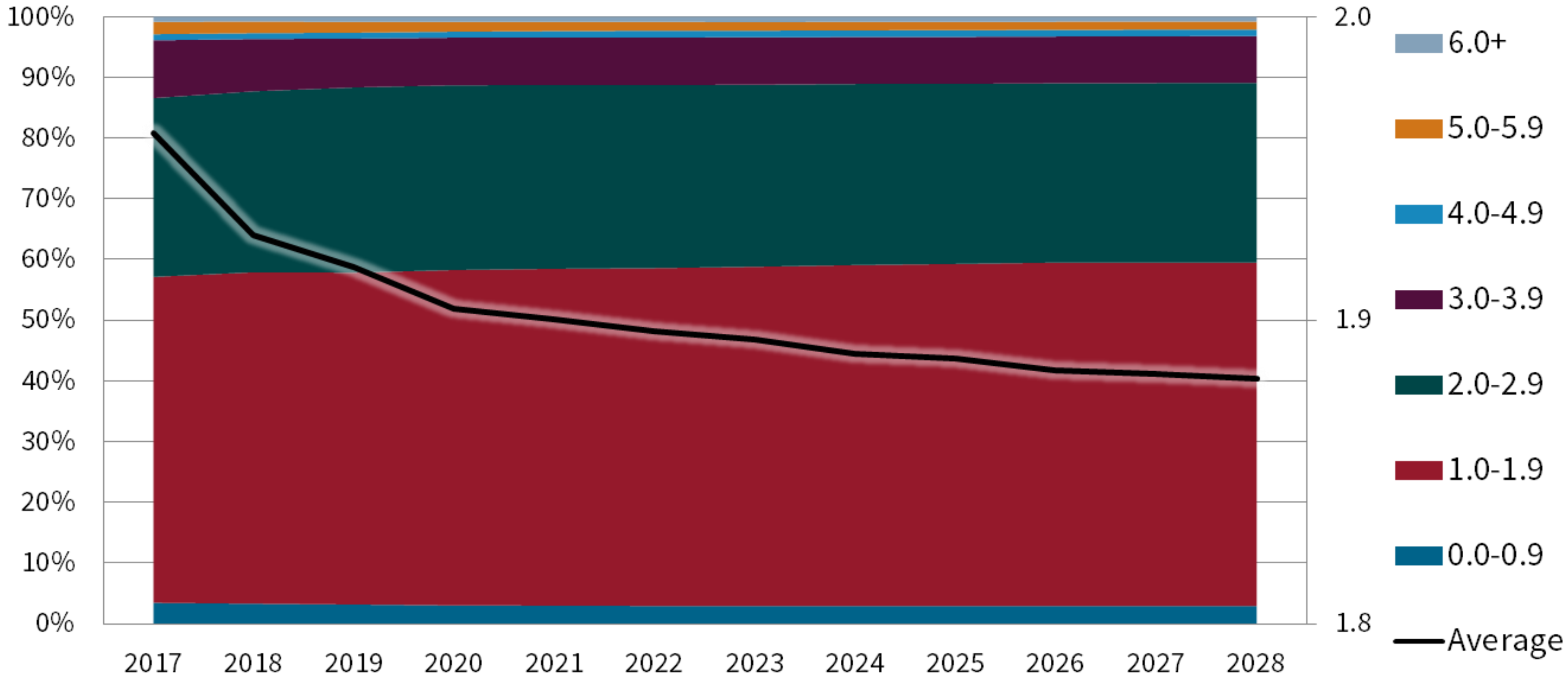
Rest-of-Asia is behind in penetration rates as some manufacturers in the region (until recently) abstained from heavy investment for battery-electric vehicles.

Green Vehicle Market Share by Region



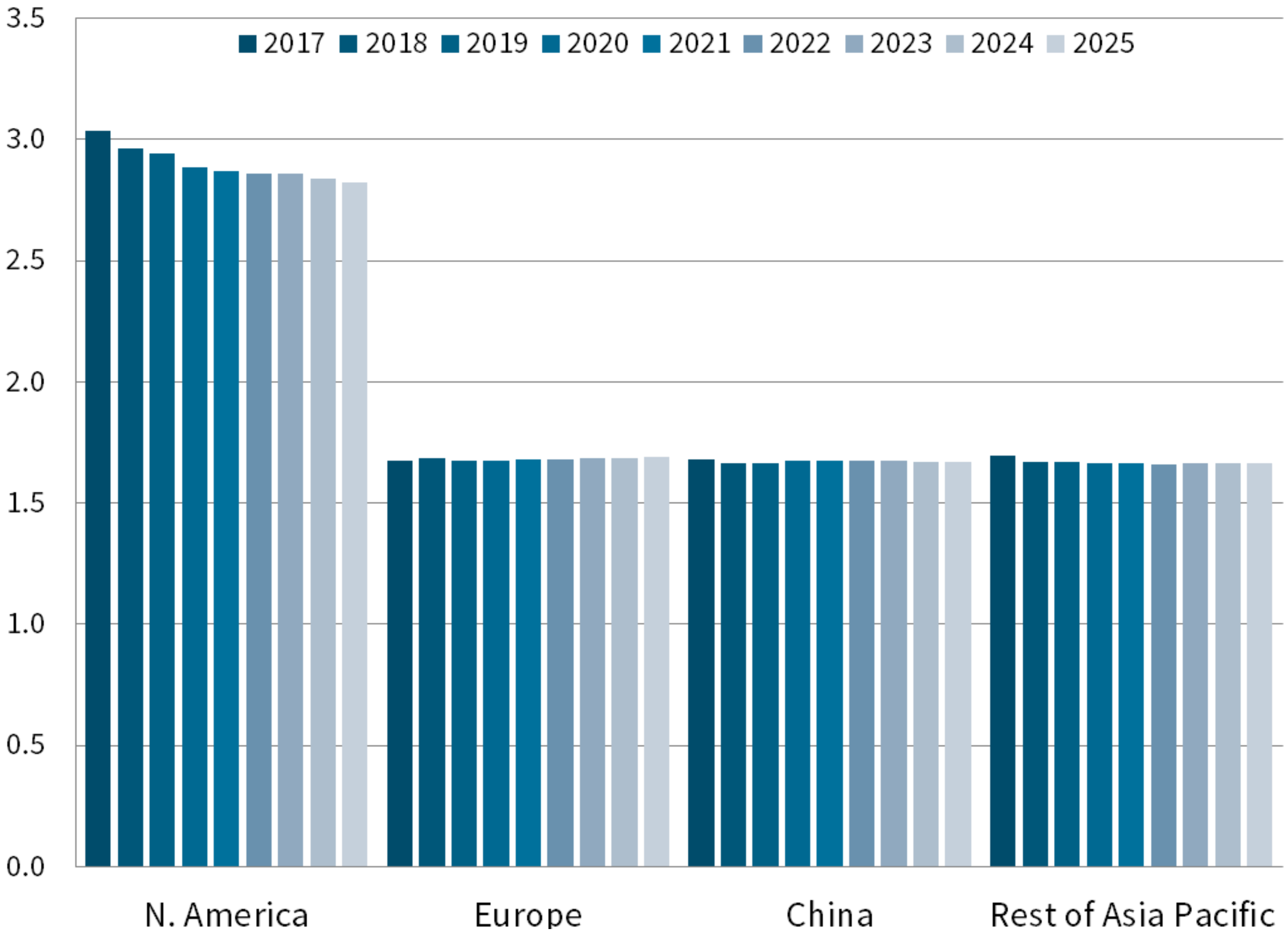
Internal-Combustion Engines

Gasoline ICE Displacement



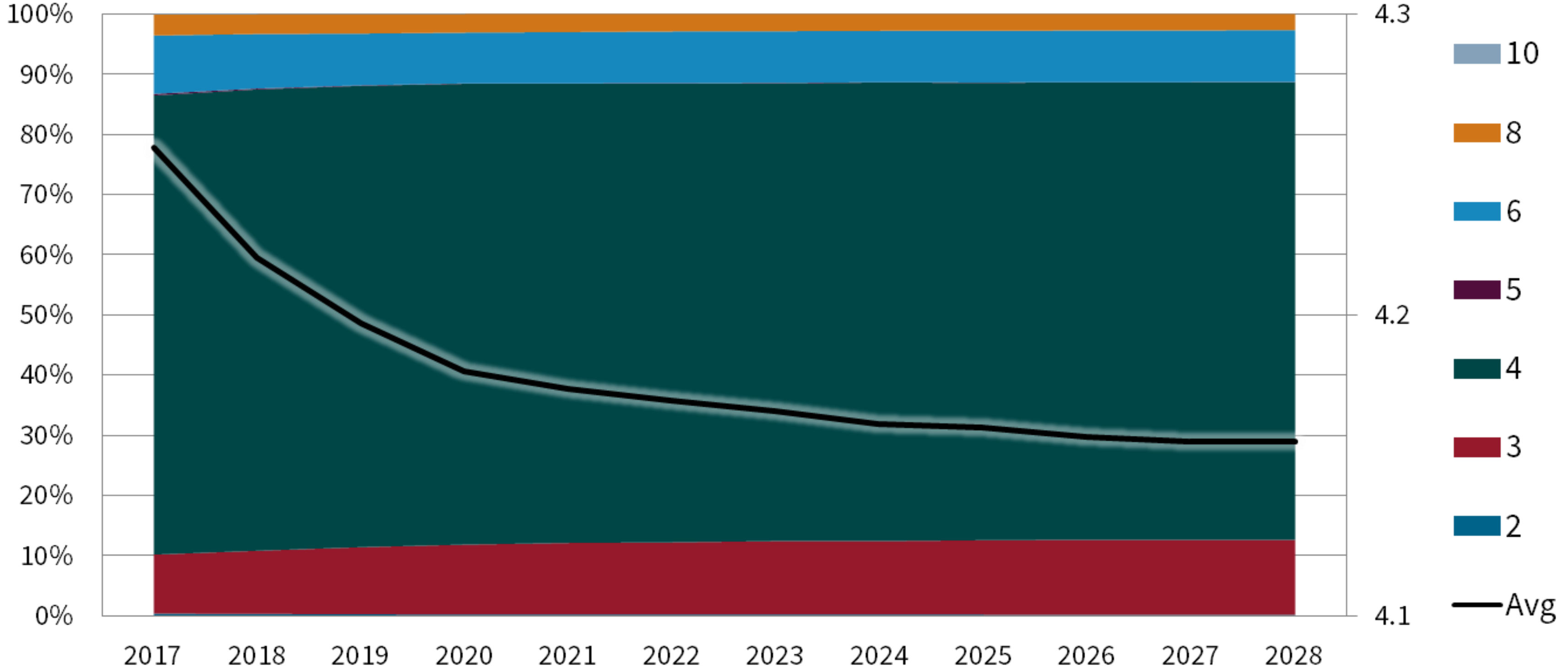
- Average displacement declines fast in the near-term, then largely levels off – though some decline continues
- 1.0-1.9L engines account for over half the global market

Gasoline ICE Displacement By Region



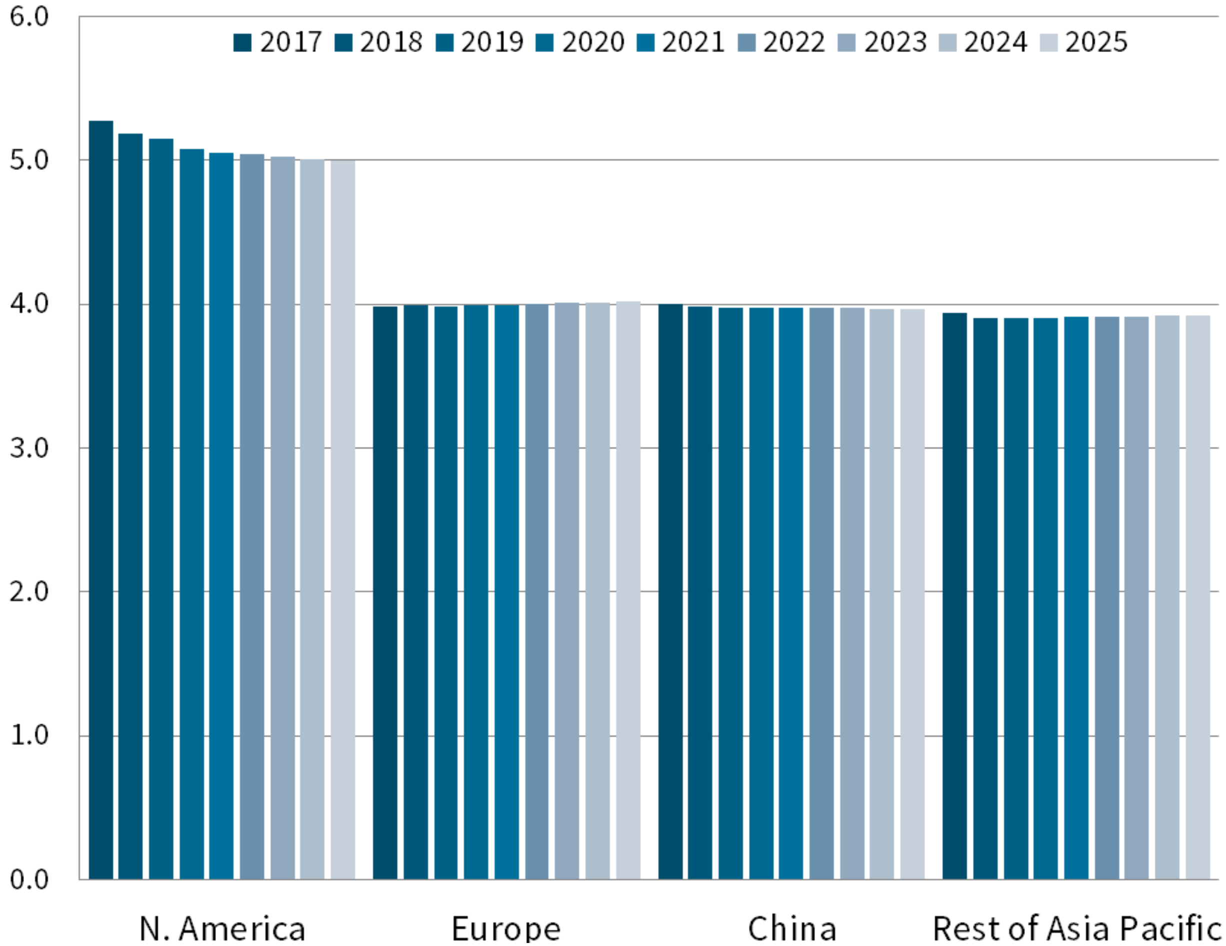
- Displacement (and cylinder) trends are closely tied to vehicle-type demand
- North America will fall to 2.8L and hold steady
- Asia and Europe have already downsized to 1.7L on average, and are unlikely to show significant decline over the tracked period

Gasoline ICE Cylinder Count



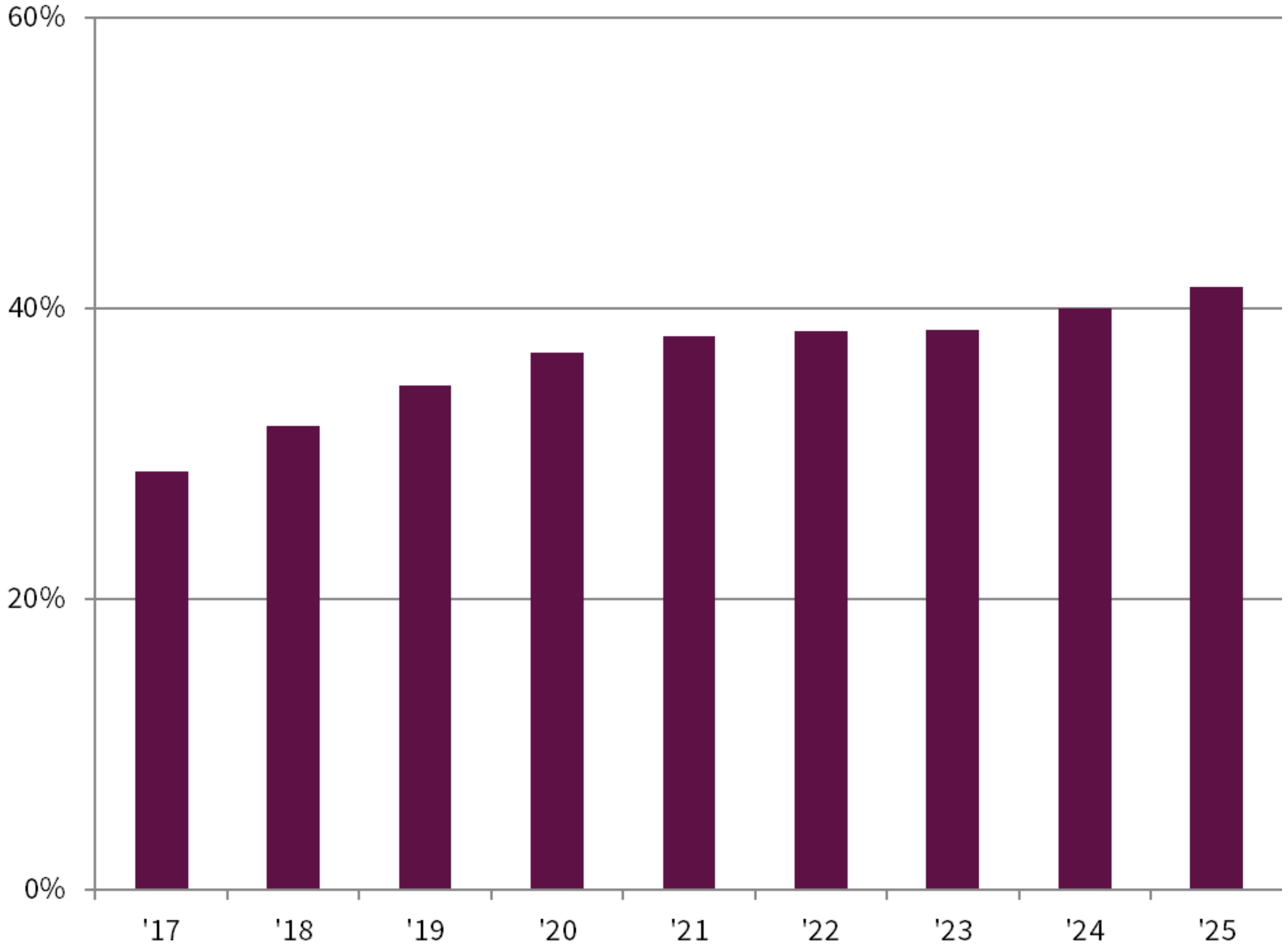
- Average cylinder count declines quickly through 2021 before leveling off as most automakers will have powertrain plans set in place by then for most of the next decade.

Gasoline ICE Cylinder Count



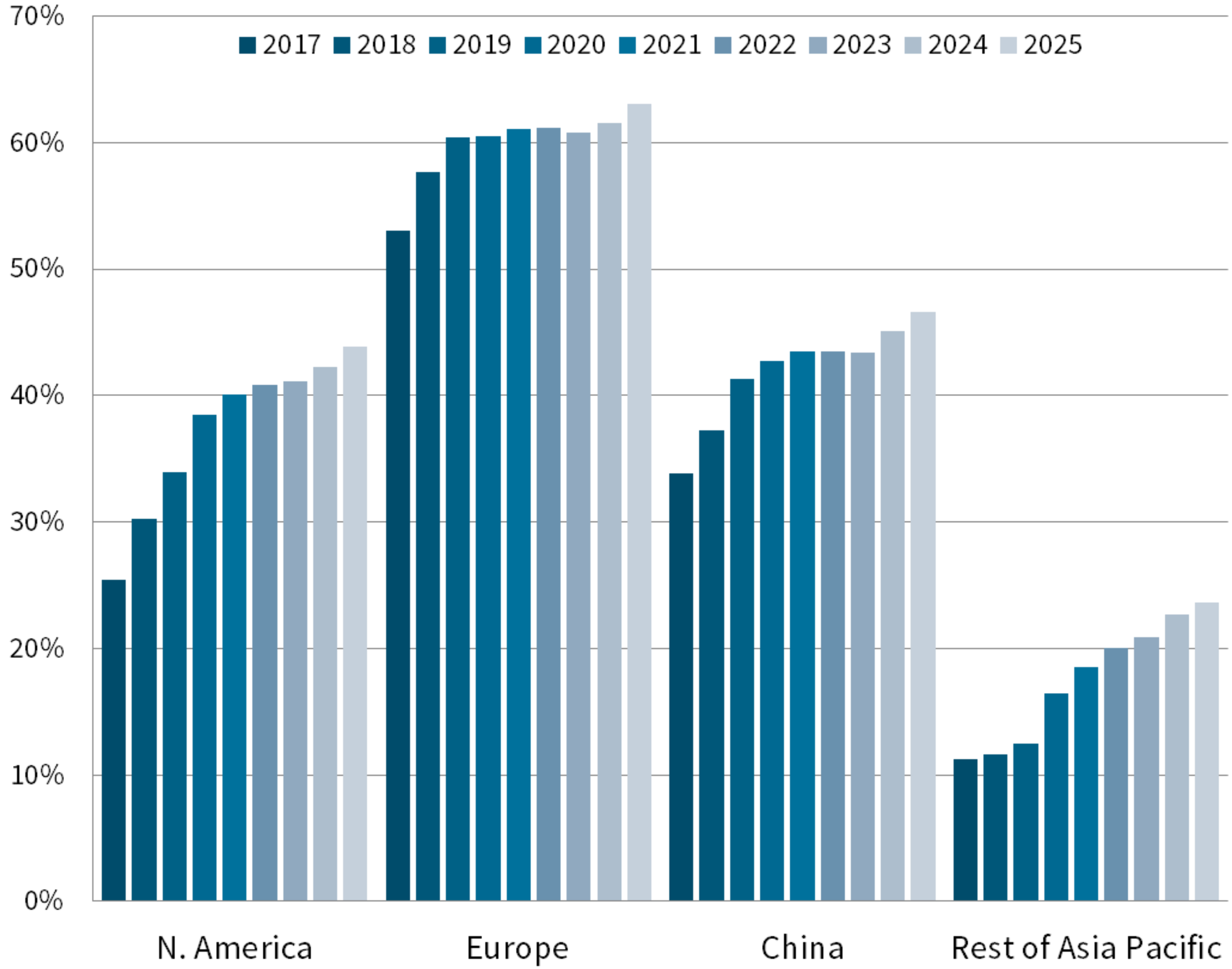
- North America will trend downward through 2021, after which the average will rest at 5 cyl. High mix of big trucks – not popular in other regions – hinders further movement
- Asia and Europe embraced downsizing before the study period. Barring wide adoption of 3-cyl. options, the 4-cyl. average will continue forward

Gasoline ICE Forced Induction



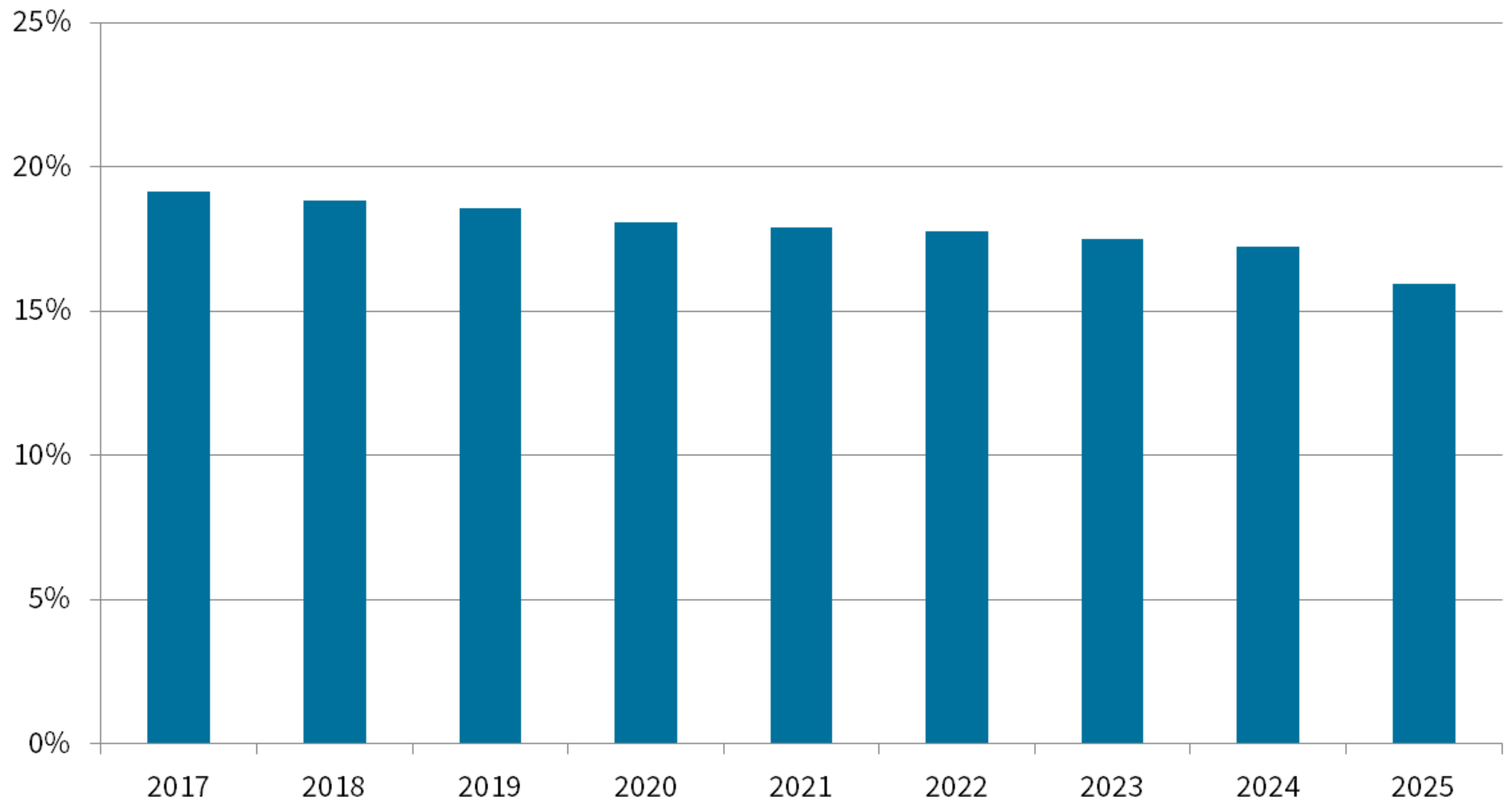
- More rapid movement in early years
- Mostly single-turbo applications (37% of industry)

Gasoline ICE Forced Induction by Region



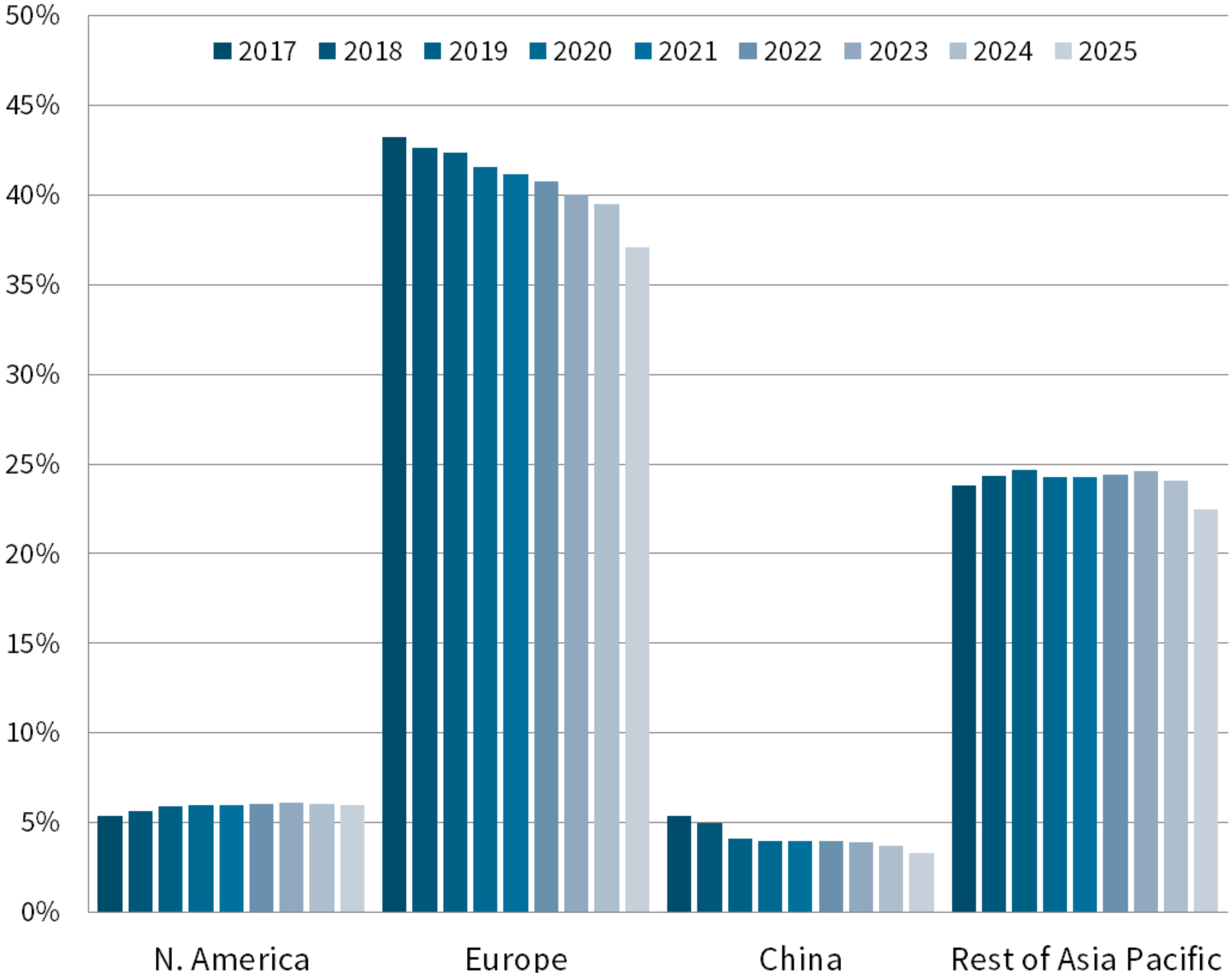
- Rates increase among all major regions
- Europe ends well ahead of the global average with already-strong penetration
- Due in part to the dominant mix of trucks, North America remains below China and Europe in penetration
- Small vehicles in Asia do not require as much boosting to be equipped with

Diesel Engines - Share of ICEs



- Diesel continues declines worldwide as pollutant-emission policies grow stricter
- Increasing awareness of actual emissions has created negative opinions

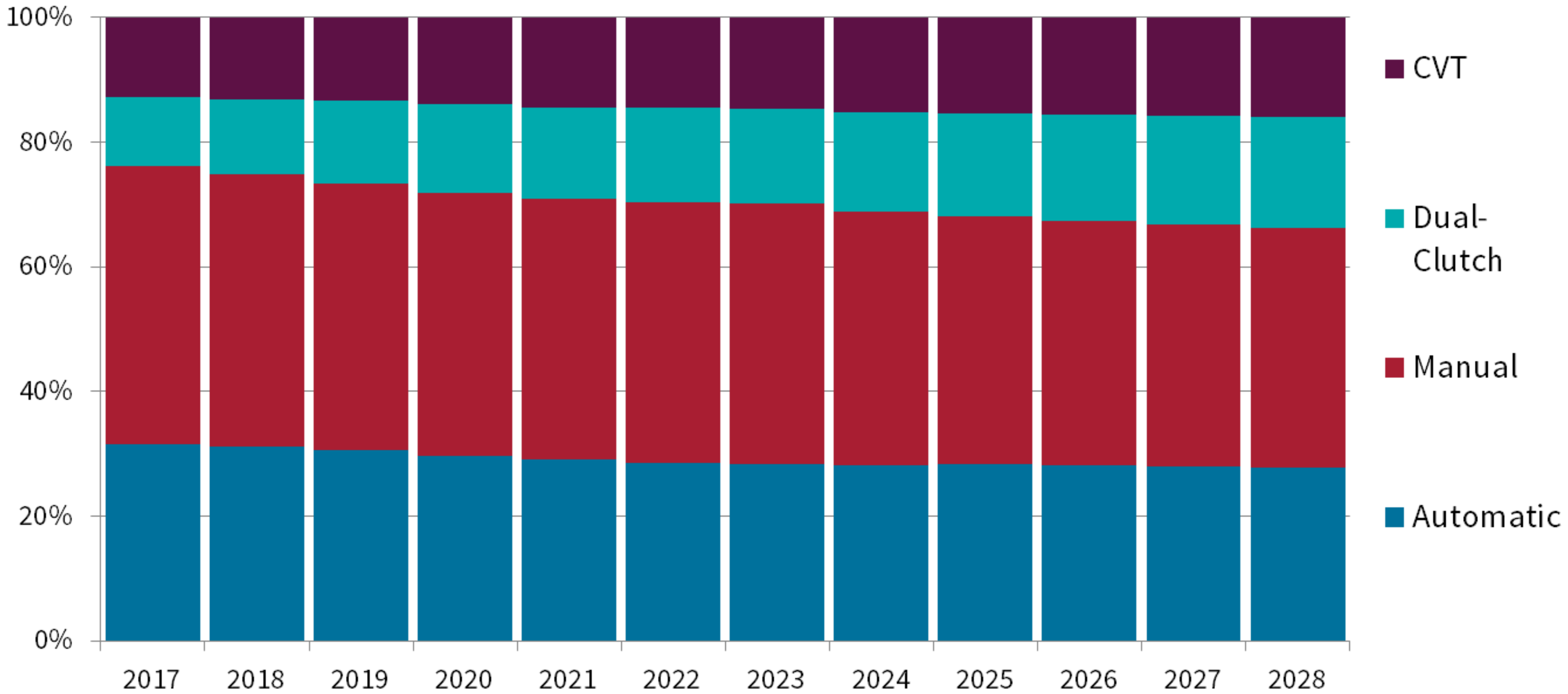
Diesel Engines - Share of ICEs by Region



- Diesel rate has been traditionally high in Europe, but will decline as the EU has become aware of high emissions and will become more strict in regulation compliance.
- In North America, diesel remains a viable niche on trucks.
- Overall, resources shift to other fuel-efficient technologies.

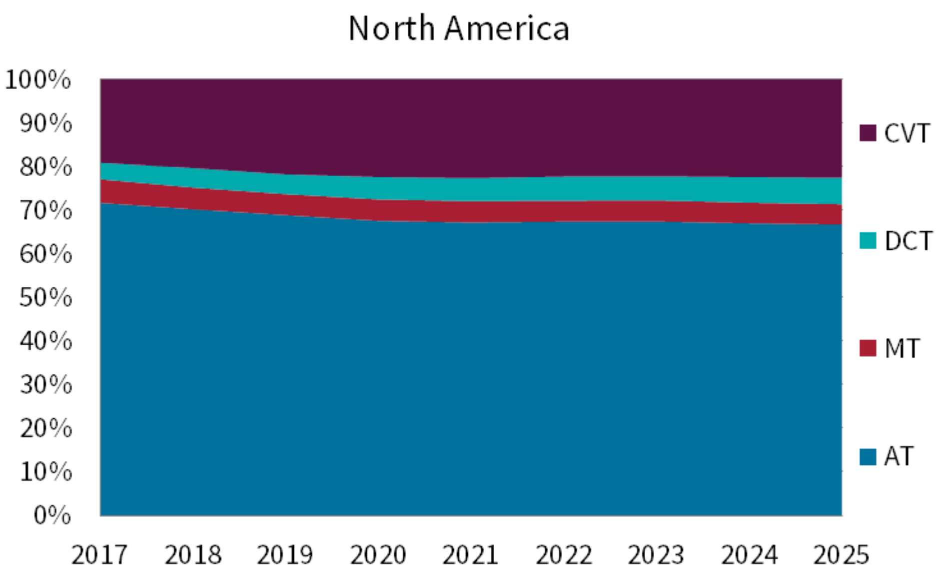
Transmissions

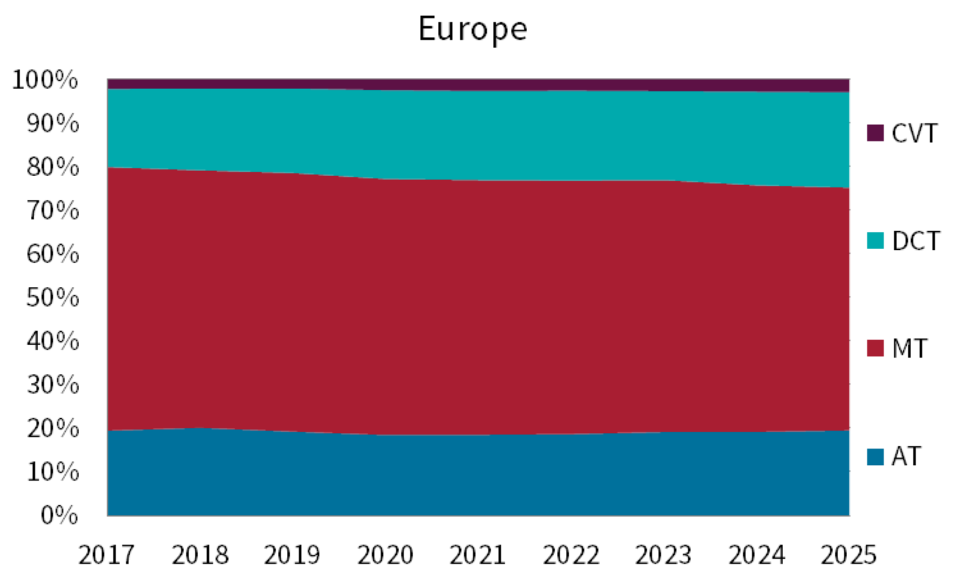
Transmission Mix

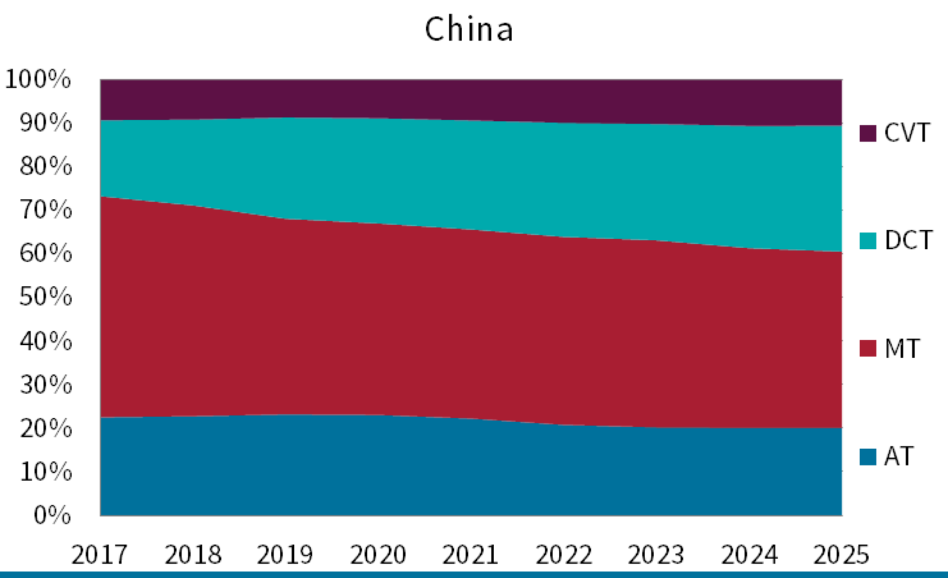


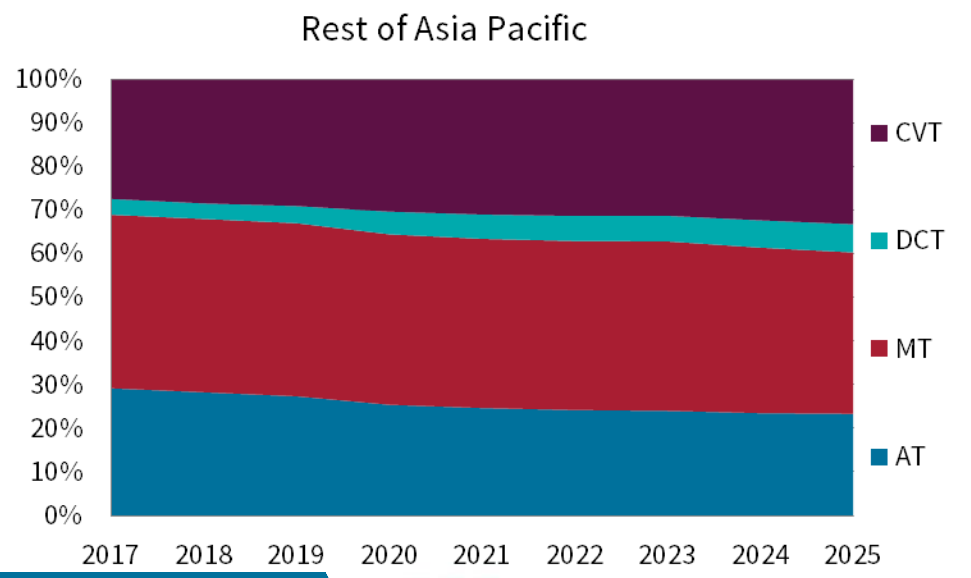
- DCTs gain favor, manuals decline
- Small downward shift for automatics, while CVTs tick up

Transmission Mix by Region

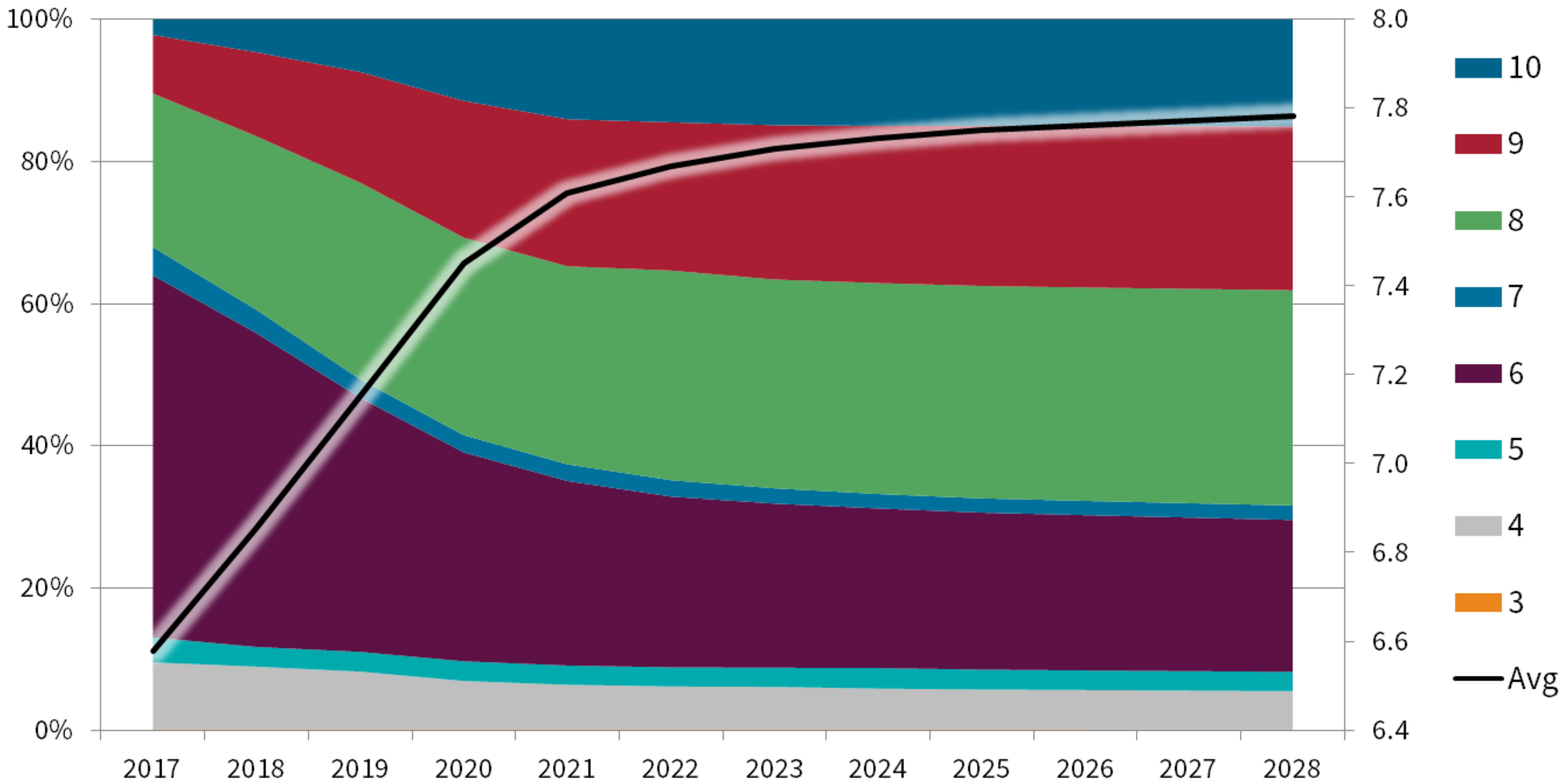






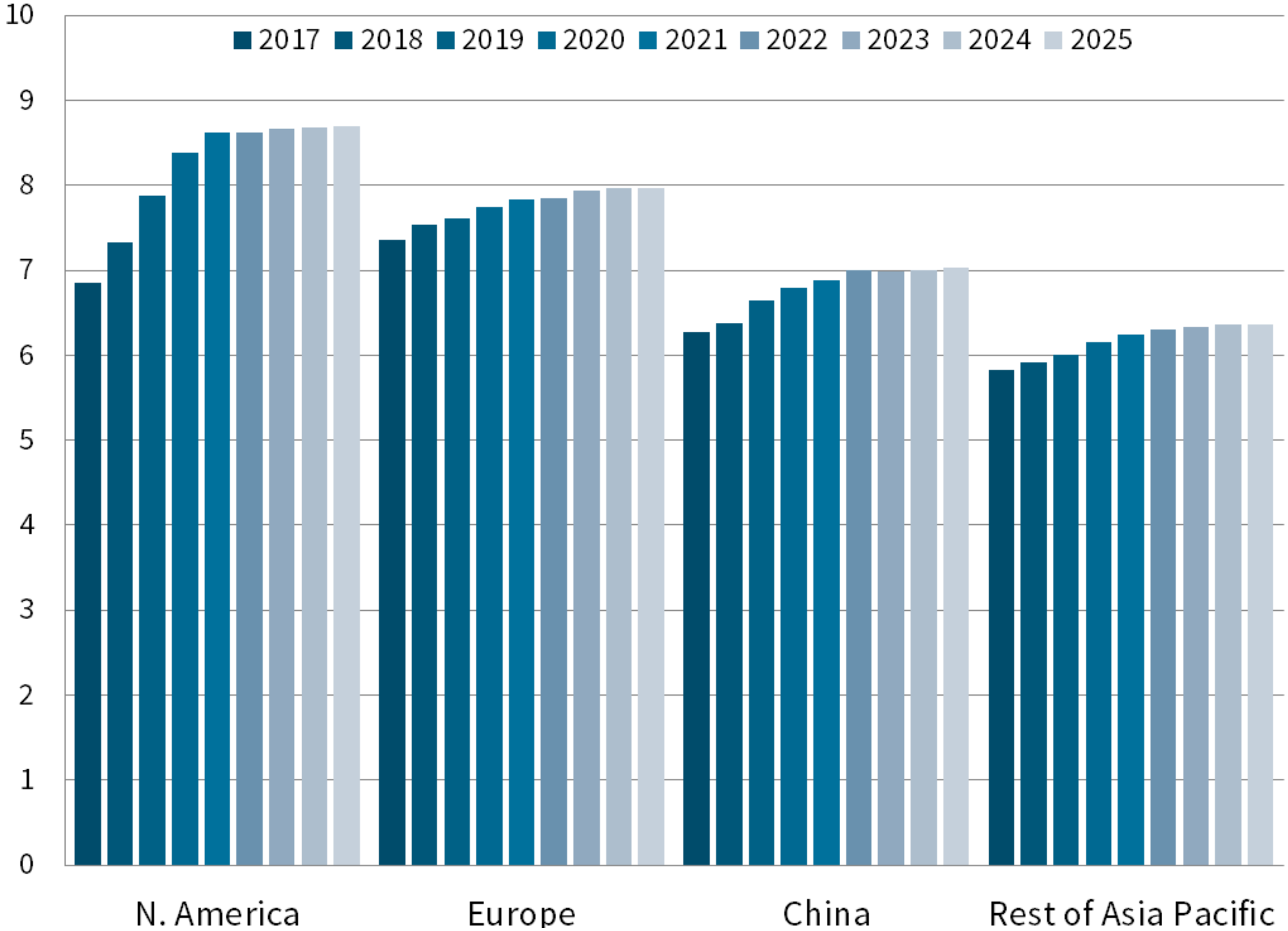


Automatic Transmission Forward Gear Count



- 8- to 10-speed jump from one-third to two-thirds of the market (at the expense of 6-speeds)
- Transition is fastest through 2021, then slows

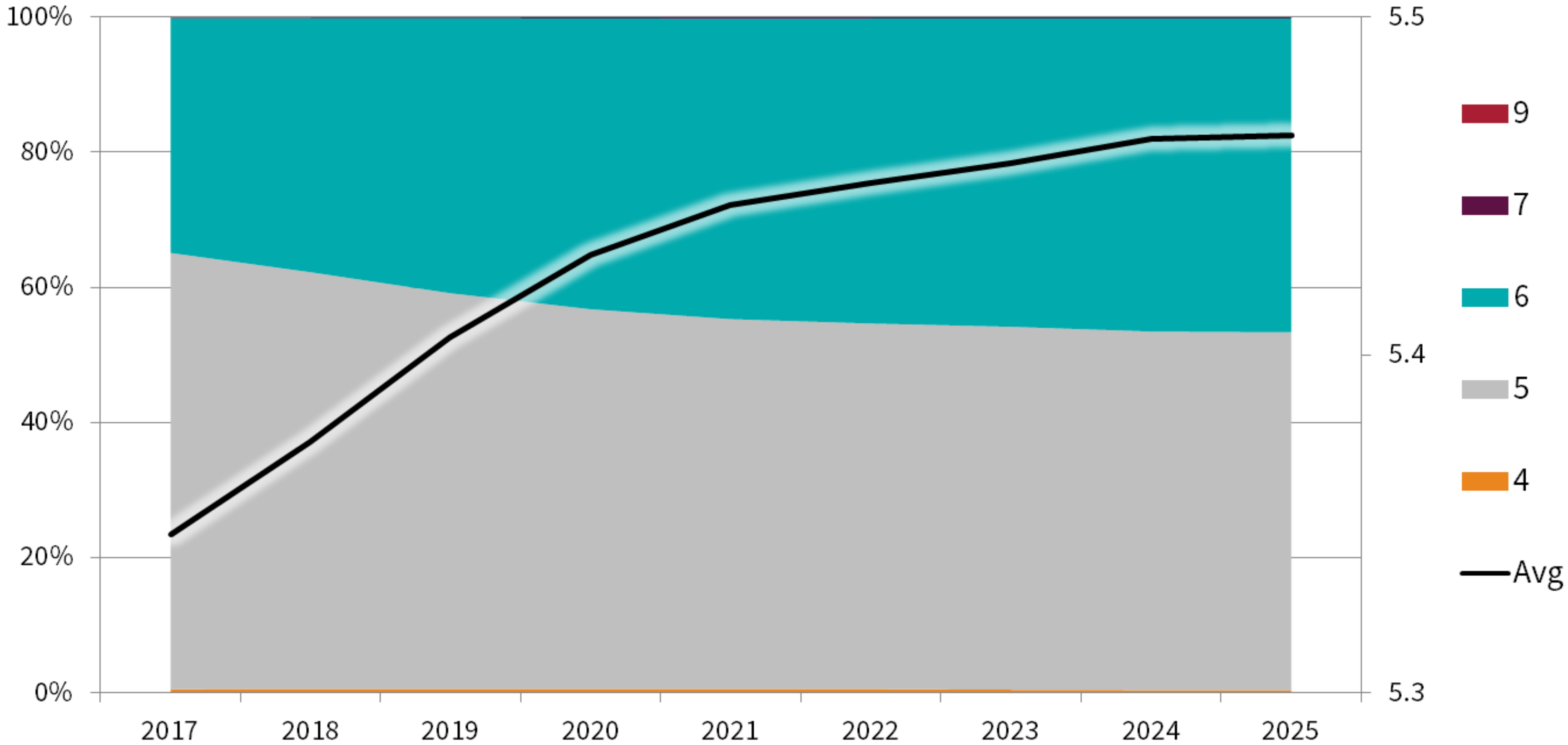
Automatic Transmission Forward Gear Count by Region



- North America has the highest AT penetration, and thus gets the most investment, leading to an 8.7 average gear count

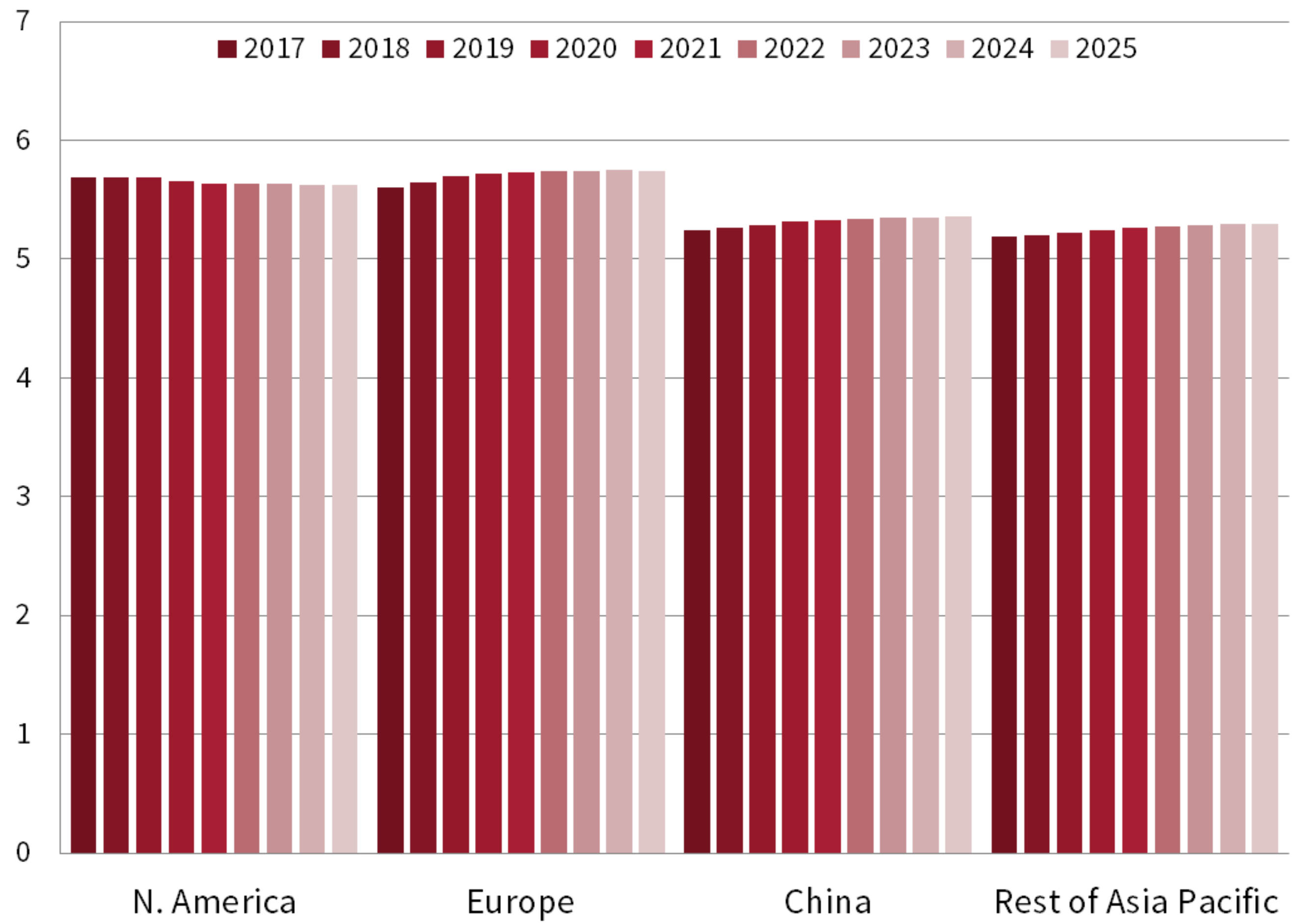
- Europe and Asia have similar rates of AT- vehicle output, but Europe stays a full gear count ahead over the period

Manual Transmission Forward Gear Count



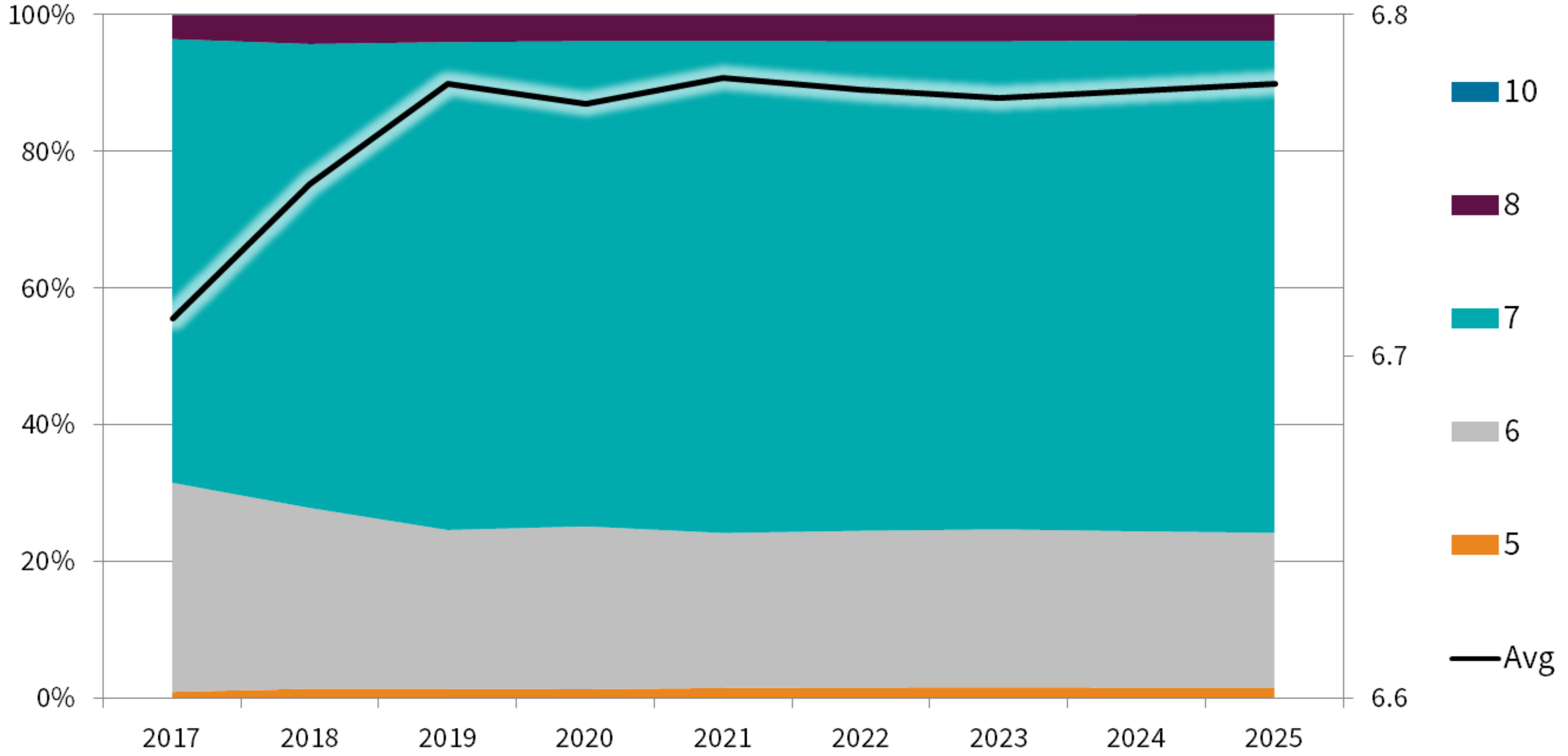
- Virtually only 5- and 6-speeds in the market
- Manuals show less movement in average gear count, compared with automatics

Manual Transmission Forward Gear Count by Region



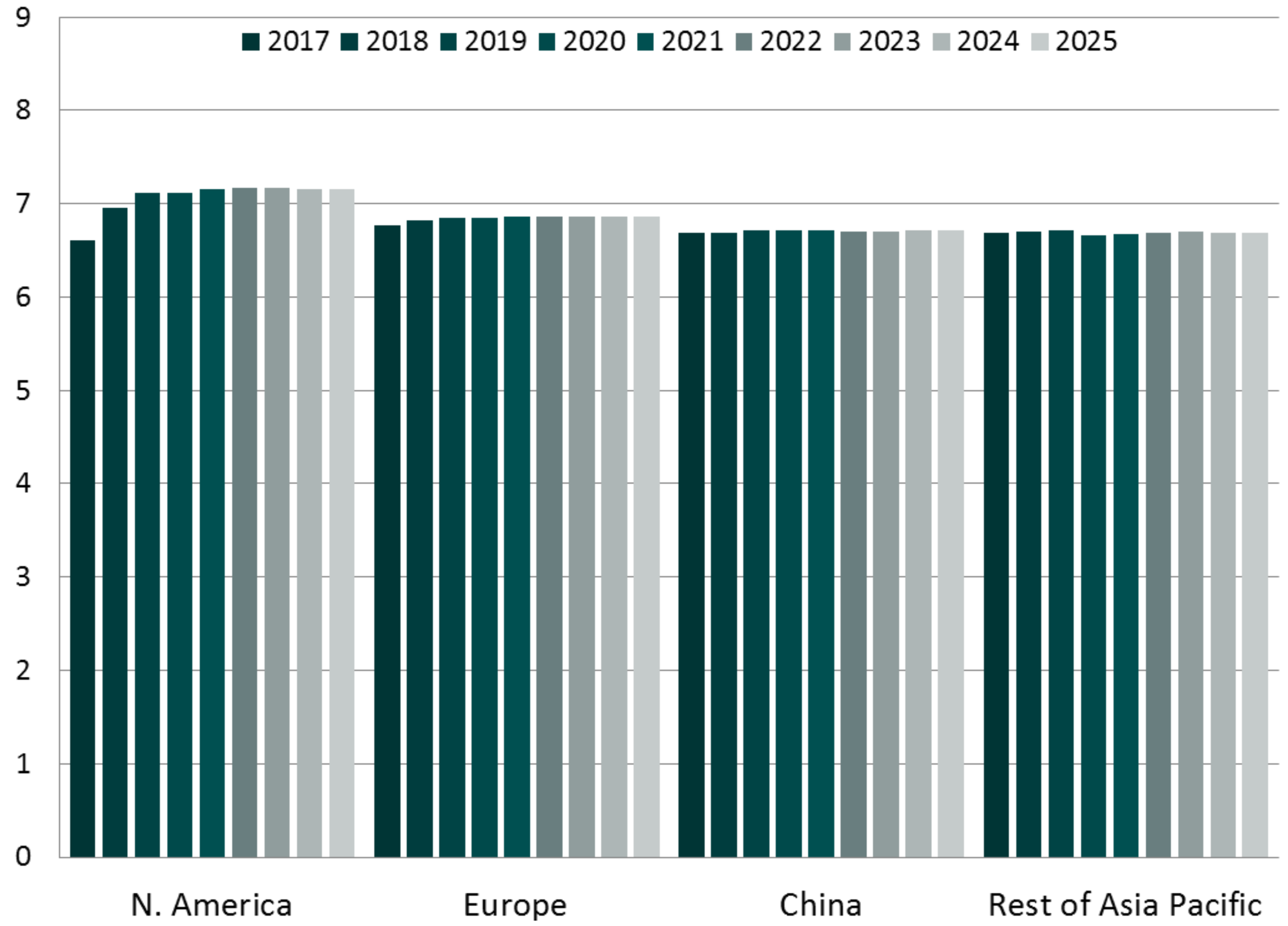
- Manuals, although globally declining in demand, show average gears counts rising (albeit slowly).
- The lone exception is North America, where production is especially low

Dual-Clutch Transmission Forward Gear Count



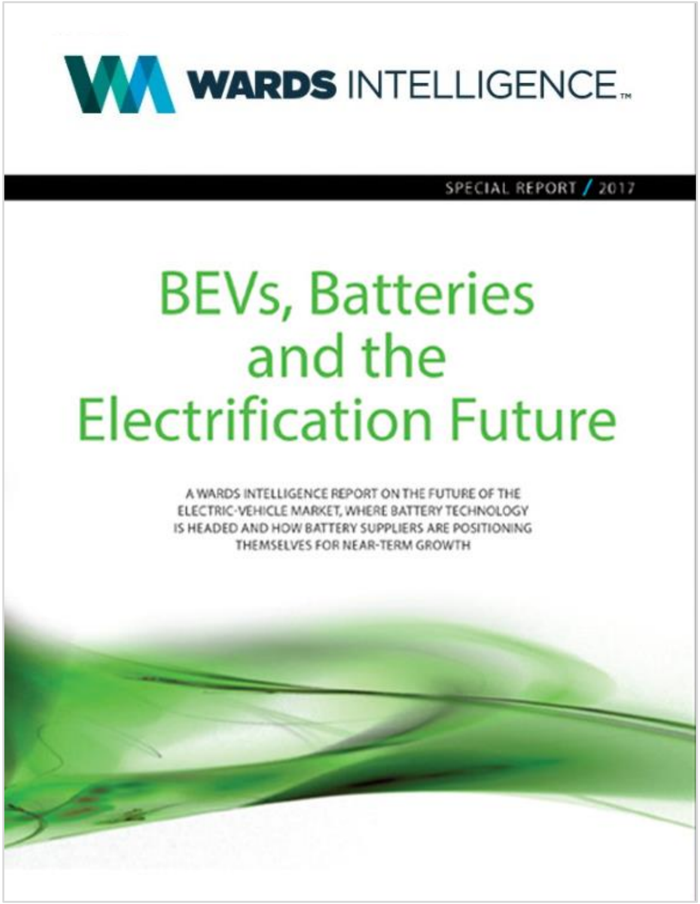
- Despite rising production in all regions, the average gear count moves up only slightly in the near-term.

Dual-Clutch Transmission Forward Gear Count by Region



- North America shows the highest gear count even though the region has the lowest output
- Higher market penetration of smaller vehicles keeps gear counts down in China, Europe and Rest-of-Asia.

REPORT: The Future of the Electric-Vehicle Market



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- The state of EV battery technology
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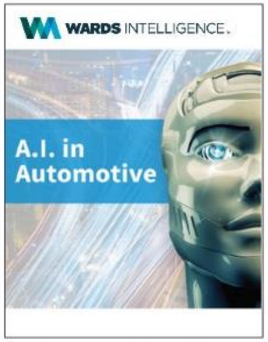

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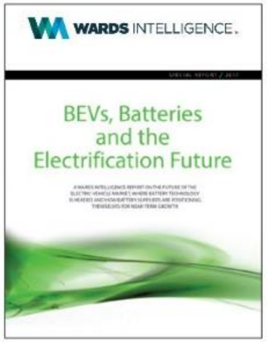

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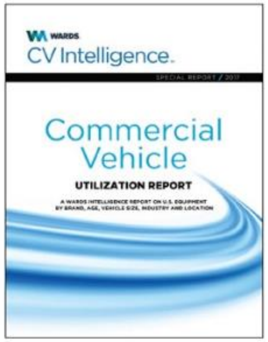

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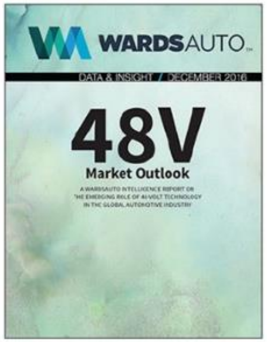

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