Hybrid Electric Vehicles

Engine Lubrication Challenges

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Content

- Emission regulations
- Passenger car electrification status and forecast
- Hybrid electric vehicles engines operational conditions and lubrication challenges
- OEMs specifications and concerns around Hybrid Vehicles engine Lubrication
- Hybrid vehicles engine oil performance tests

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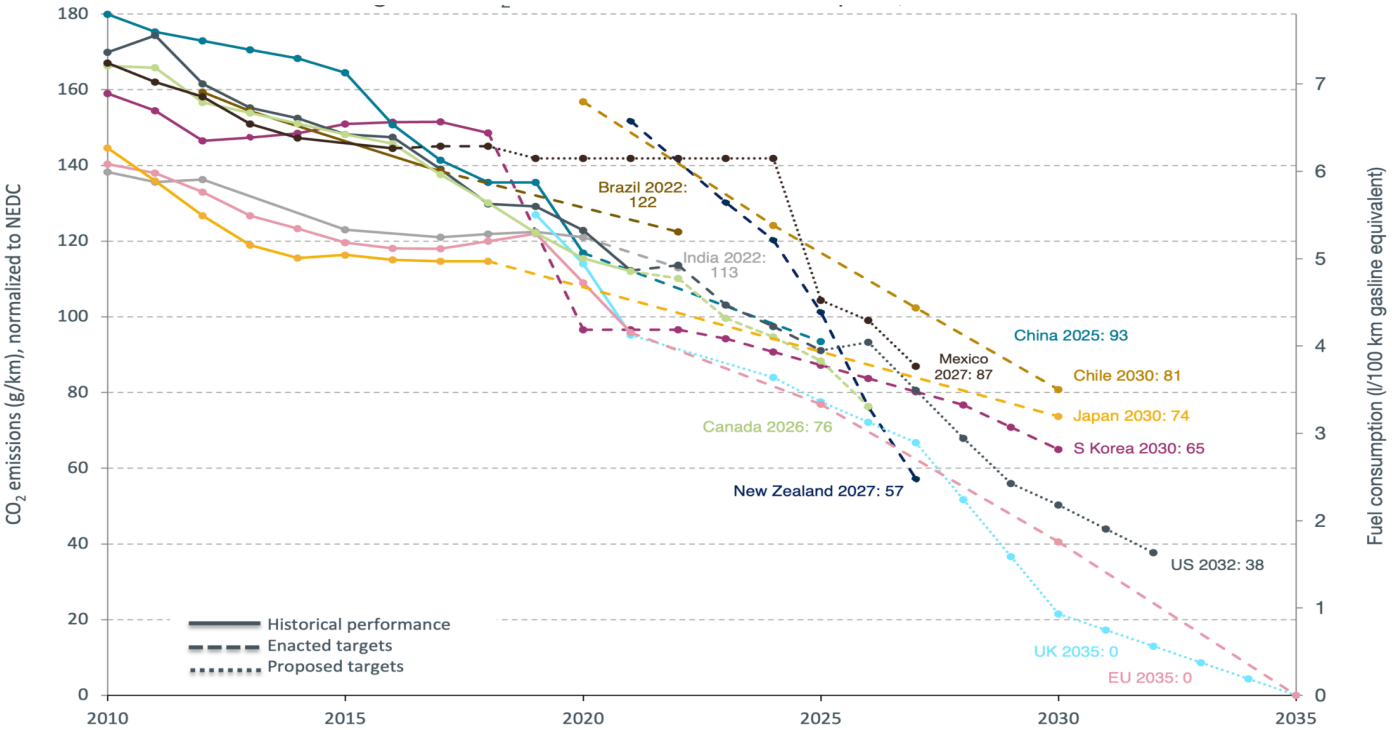
Fuel Economy Standards & Emissions Limits

Emissions Legislation Forces Electrification

CO2 regulations



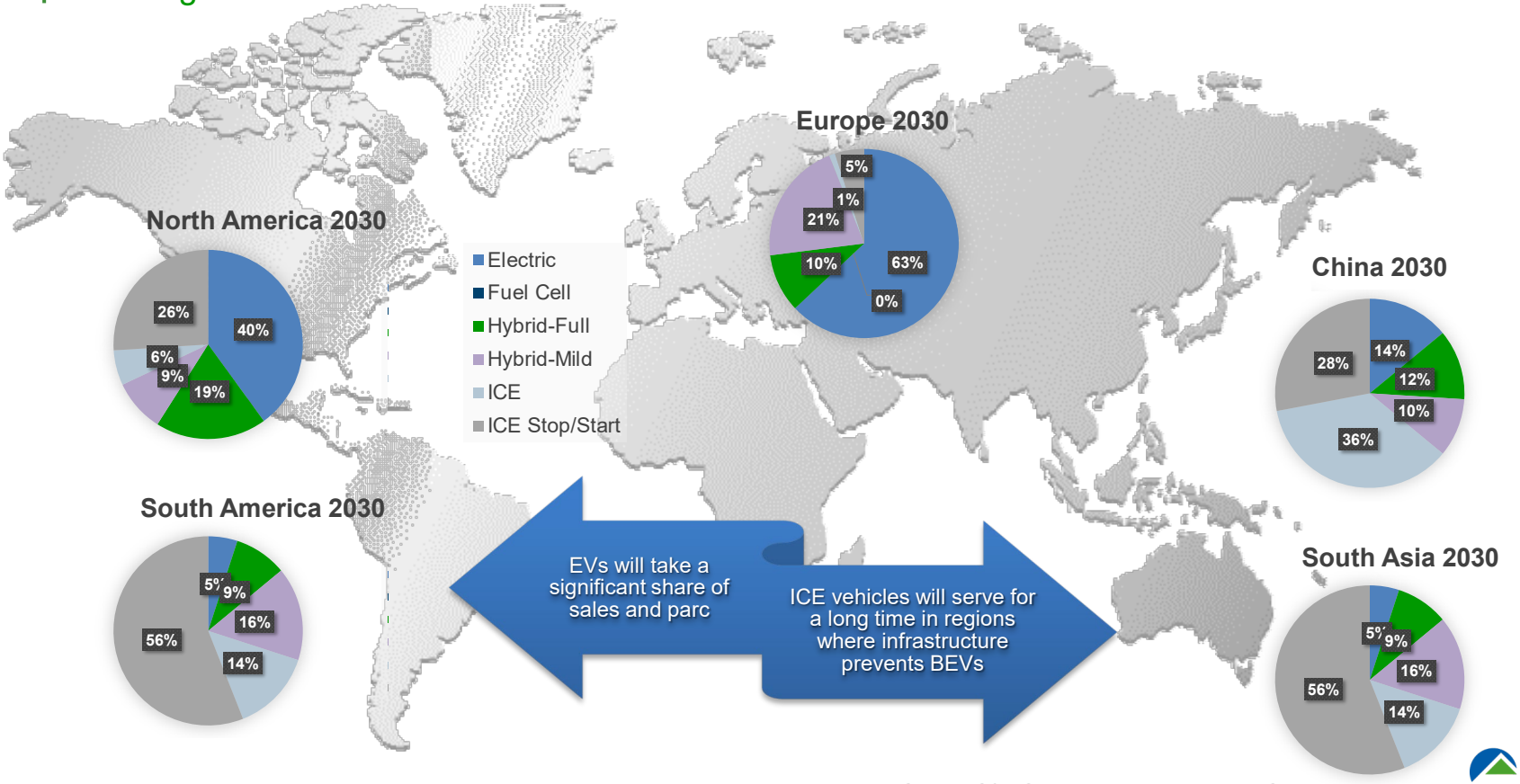
Source: ICCT Passenger Vehicle Greenhouse Gas Emissions and Fuel Consumption, 2023

To avoid major fines, OEMs must electrify

AftonChemical.com

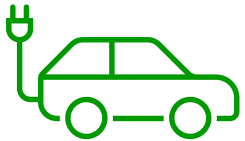
Global Forecast 2030

Growing sales and share of EVs across the Globe



Source: S&P Global Powertrain Forecast September 2022

Emissions Legislation Forces Electrification



Electric Vehicles

Over **14 million** sold during 2023

Approximately **40 million** on the roads worldwide

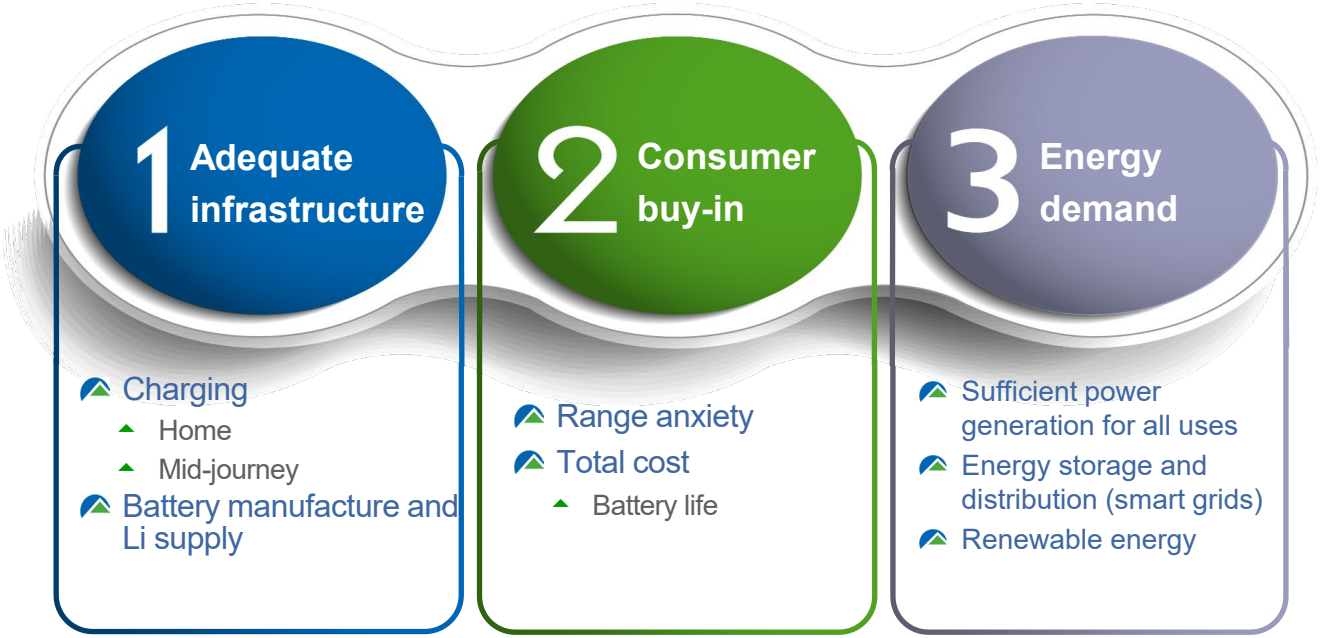
Around **70%** of the Electric Vehicles (EVs) Parc are Battery Electric (BEV)

China is the biggest EV market

Is this the end of the Internal Combustion Engines (ICEs)?

Note: Only considers BEV/PHEV

Key barriers still exist



Barriers will slow transition to full electric

A slower transition will
increase the interest on Hybrid Vehicles

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Exploring other option for Reach Carbon-Neutral goal

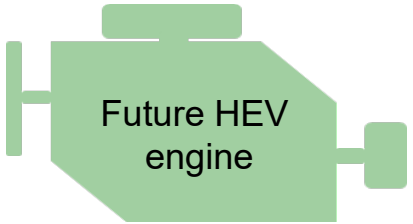
Developing new internal combustion engines

May 28, 2024

Subaru, Toyota, and Mazda Commit to New Engine Development for the Electrification Era, Toward Carbon Neutrality

Beyond Zero News Release Presentation Hydrogen BEV HEV PHEV Fuel Carbon Neutrality

Smaller engines compatible with carbon-neutral fuels including synthetic fuels, biofuels and liquid hydrogen.

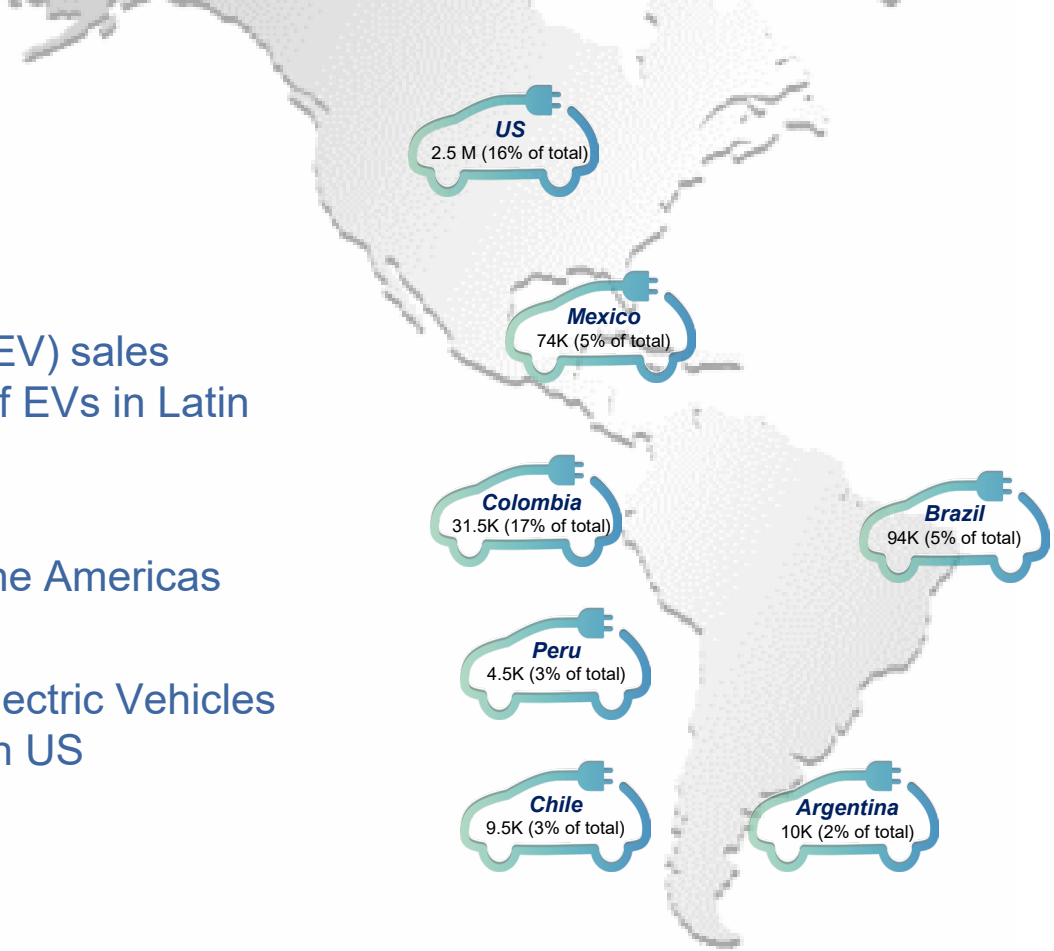


Hybrid Vehicles could be a good fit for consumers that want to reduce the CO2 emissions and avoid some disadvantage of the BEVs

Electrification in the Americas

Key Countries - Sales 2023

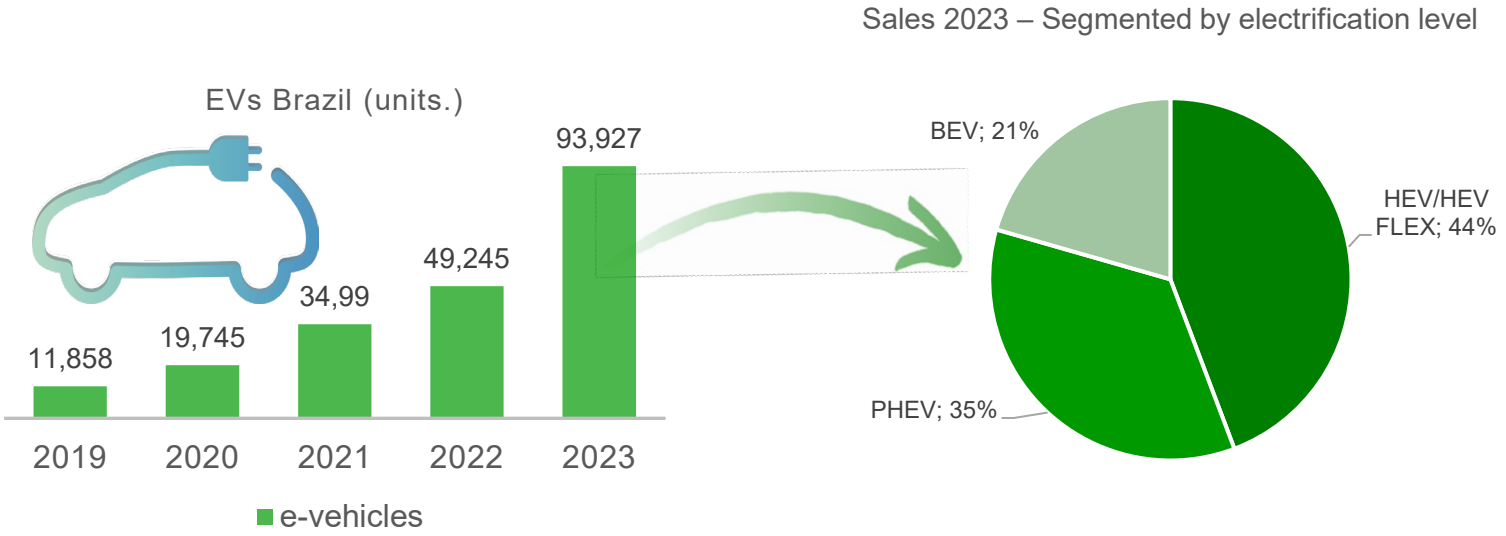
- EVs sales continue growing
- Hybrid Electric Vehicles (HEV/PHEV) sales represent over 80% of the sales of EVs in Latin America and over 50% in US
- Toyota leading of HEVs sales in the Americas
- Chinese brands leading Battery Electric Vehicles sales in Latin America and Tesla in US



Note: Considers BEV/HEV/PHEV

Electrification in Brazil

Vehicle Sales 2023

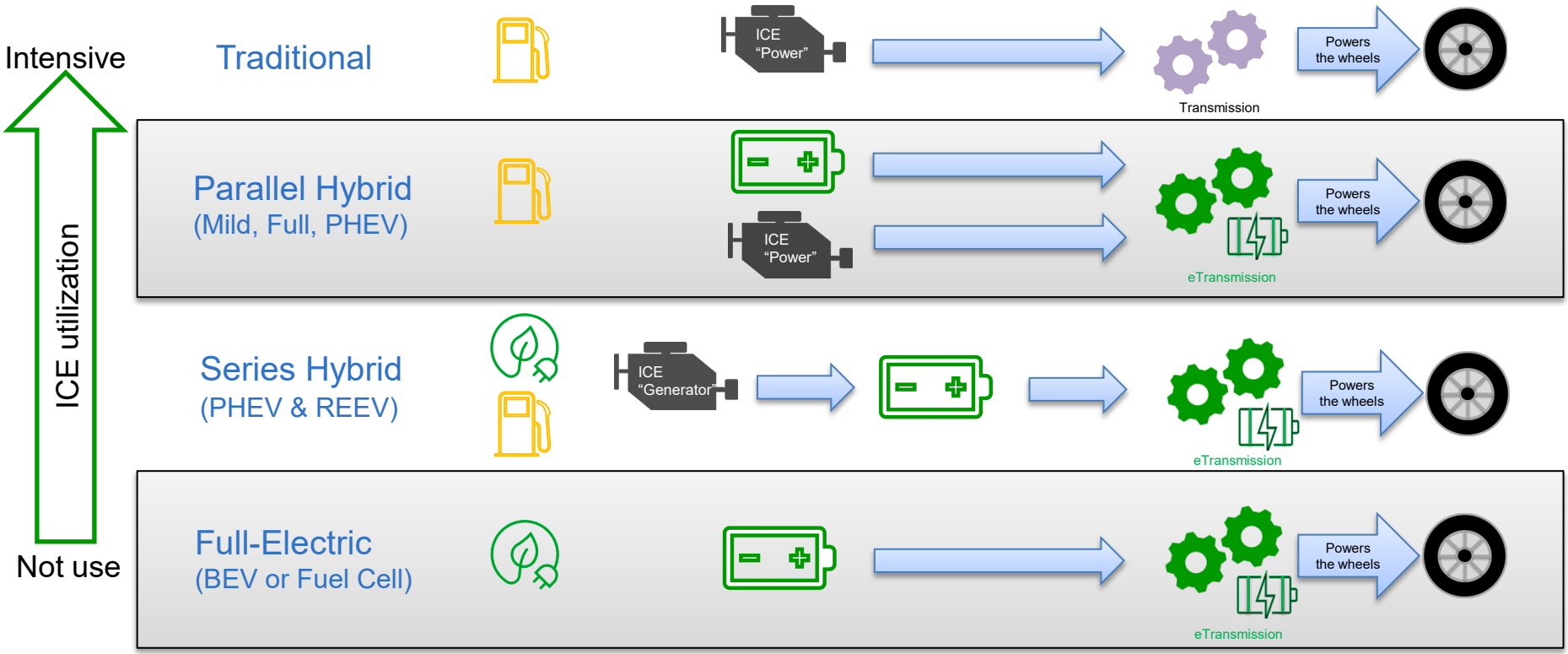


Source : ABVE

EV's sales are growing and represented 5% of light duty vehicle sales in 2023

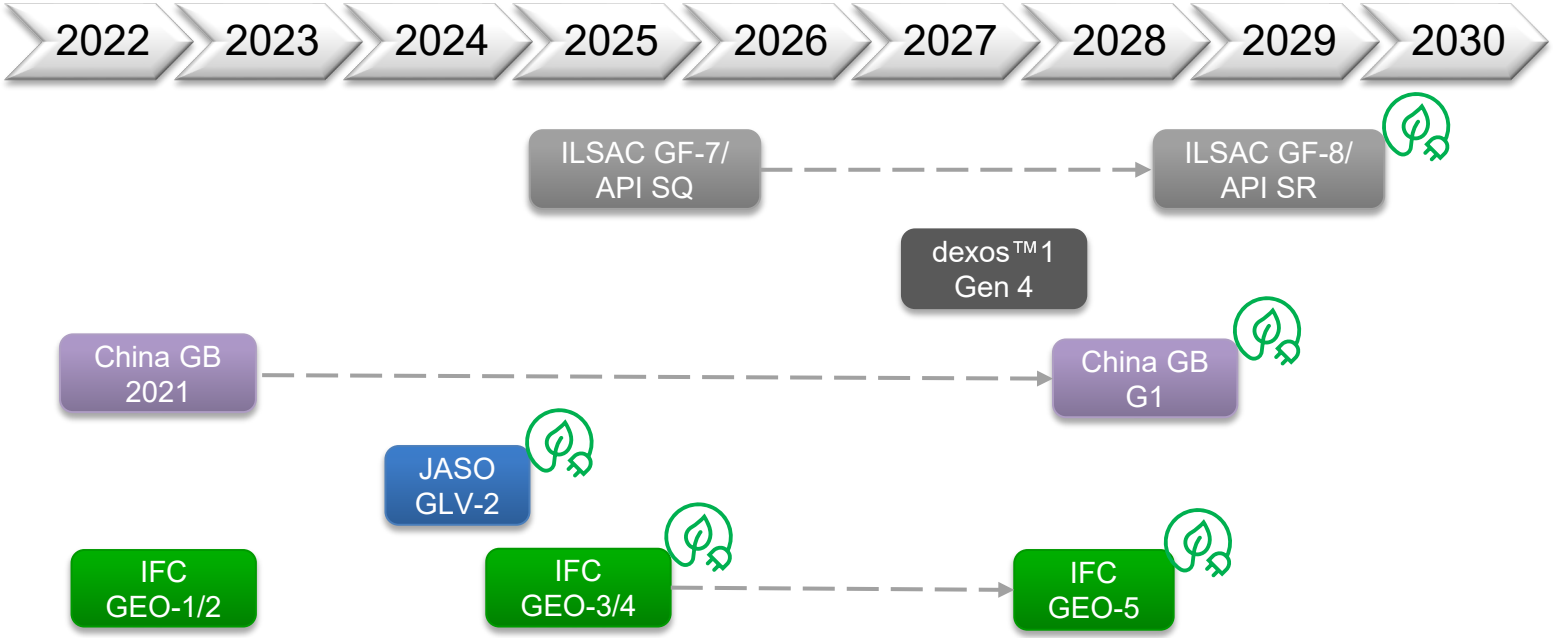
Automobile Transition

Hybridization changes the ICE operational conditions



Industry and OEM Specification Potential Outlook to 2030

Potentially will or includes tests for Hybrids Vehicles engine



Japanese and Chinese OEMs incorporate Low Viscosities Lubes performance under lower temperature for Hybrid Vehicles Engines

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OEM Specifications for Hybrid Vehicles

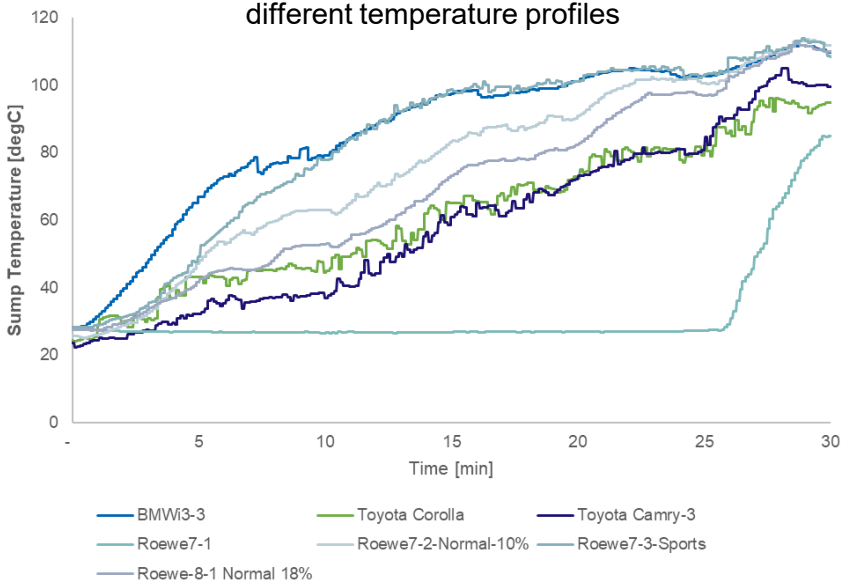
- No specific hybrid engine oil specification defined by the industry for the NA market
- GF-8 will include requirements for Hybrid Engine particular operational conditions (corrosion, water resistance, etc.)
- JASO GLV-1, 2 include performance engine tests at lower temperature to cover Hybrids
- IFC GEO-3/4 align with JASO with the addition of low ash and lower viscosities lubricants
- China OEMs prefer to include in the own specifications, performance tests for HEV/PHEV engine oils for better protection (Emulsion retention and anti-freezing, Sludge, fuel economy, etc.)

Engines in Hybrids Experience Different Conditions

Severity Can Be Higher

- Afton has extensively studied hybrid vehicle
  - Operating conditions of engines in hybrid vehicles
  - The impact of these conditions on the fluid
- Hybrid vehicles use their engines in a different way than traditional ICE vehicles
  - The greater the hybridization, the more different the engine operation.
- Hybrid engines experience different conditions at different temperatures
  - Temperature profiles of operation have greater variation vs conventional ICE
- Hybrid engines can run more severe than traditional ICE

Hybrid engines can exhibit very different temperature profiles



WLTC Temperature profile – various hybrid vehicles.
Source: Afton Chemical, Tsinghua University

Hybrid Engine Oil Challenges

Configuration & operation mode can increase lubricant severity in service

Cold commuter

110km/h (70mph) on the highway when engine first starts

→ Start-up wear from cold

→ Wear under fuel dilution

Runabout

Vehicle rarely leaves town & operates engine intermittently with battery in stop-go service.

→High water/fuel contamination

→Increased emulsion & corrosion

Cold start-up and water/fuel contamination can increase wear in Hybrid Vehicle engines

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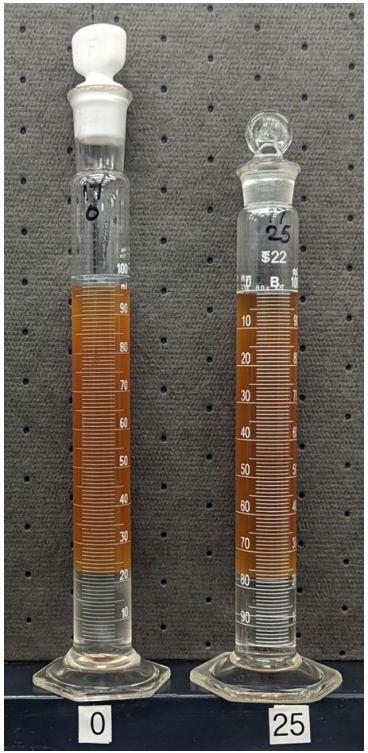
Emulsion Test Photos

ASTM D7563 in an industry test to look at an oils ability to hold an emulsification of oil and contaminants – water and fuel (E85) is blended and monitored at 2 temperatures (0 C and 25C) for 24 hours.

Poor results



Good results

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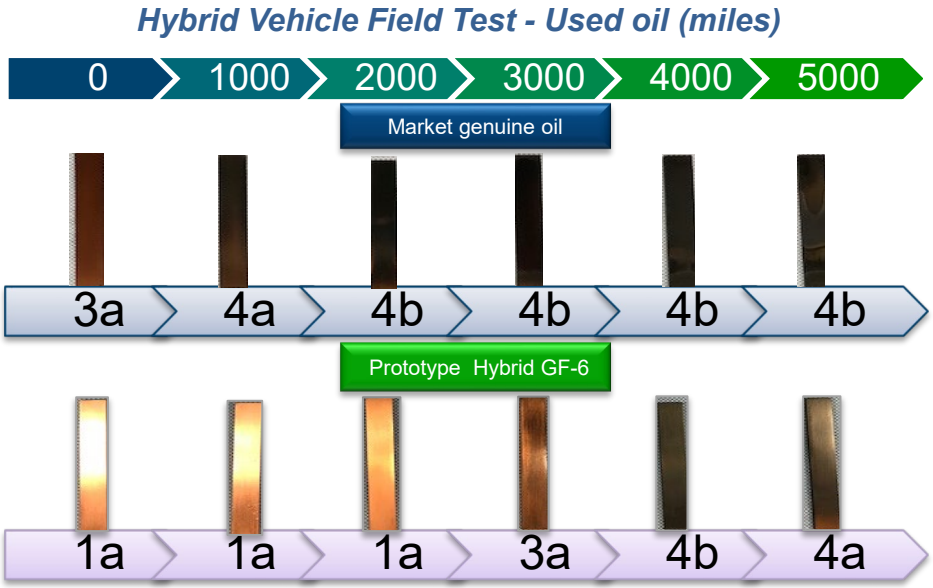
Emulsion and Water Contamination Control

Engine Oil	Standard ASTM D7563	15-day Extended ASTM D7563
Prototype Hybrid Oil	☑	☑
Commercial Hybrid Oil 1	☒	☒
Commercial Hybrid Oil 2	☑	☒
Commercial Hybrid Oil 3	☒	☒
Commercial Oil 1	☒	☒
Commercial Oil 2	☑	☒
Factory Field Oil	☑	☒

A good emulsion property is a key performance attribute for engine oils and more important for Hybrid vehicles.

Corrosion Protection

Corrosion protection is an important attribute in a lubricant for Hybrid Vehicle engine



Cu corrosion (ASTM D130) with sampled oil at mileage intervals

Summary

- Global Electric Vehicles Sales are growing but customers remain concern around charging infrastructure, charging time, range and car cost.
- Share of hybrid vehicles sales is growing due to transition to EVs barriers
- Hybrid vehicles use their engines in a different way than a traditional ICE vehicle and the combined drive cycle can result in a more severe operation
- Japanese and Chinese OEMs are taking the lead in the development of HEV/PHEV engine lubricant specifications
- Not all lubricants have the appropriate emulsion and corrosion performance needed by HEV engines.