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E-mobility and electrification

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E-Mobility and electrification

Vehicle electrification

- From simple engine start/stop to full battery electric – how they operate.
- Mild vs. Full Hybrid – *Watt's* the difference?
- Transmissions, and their fluids, have a key role to play.

E-fluid formulation

- New fluid requirements include motor cooling, compatibility and electrical insulation
- All must be balanced with transmission performance and durability.

Electrification outlook

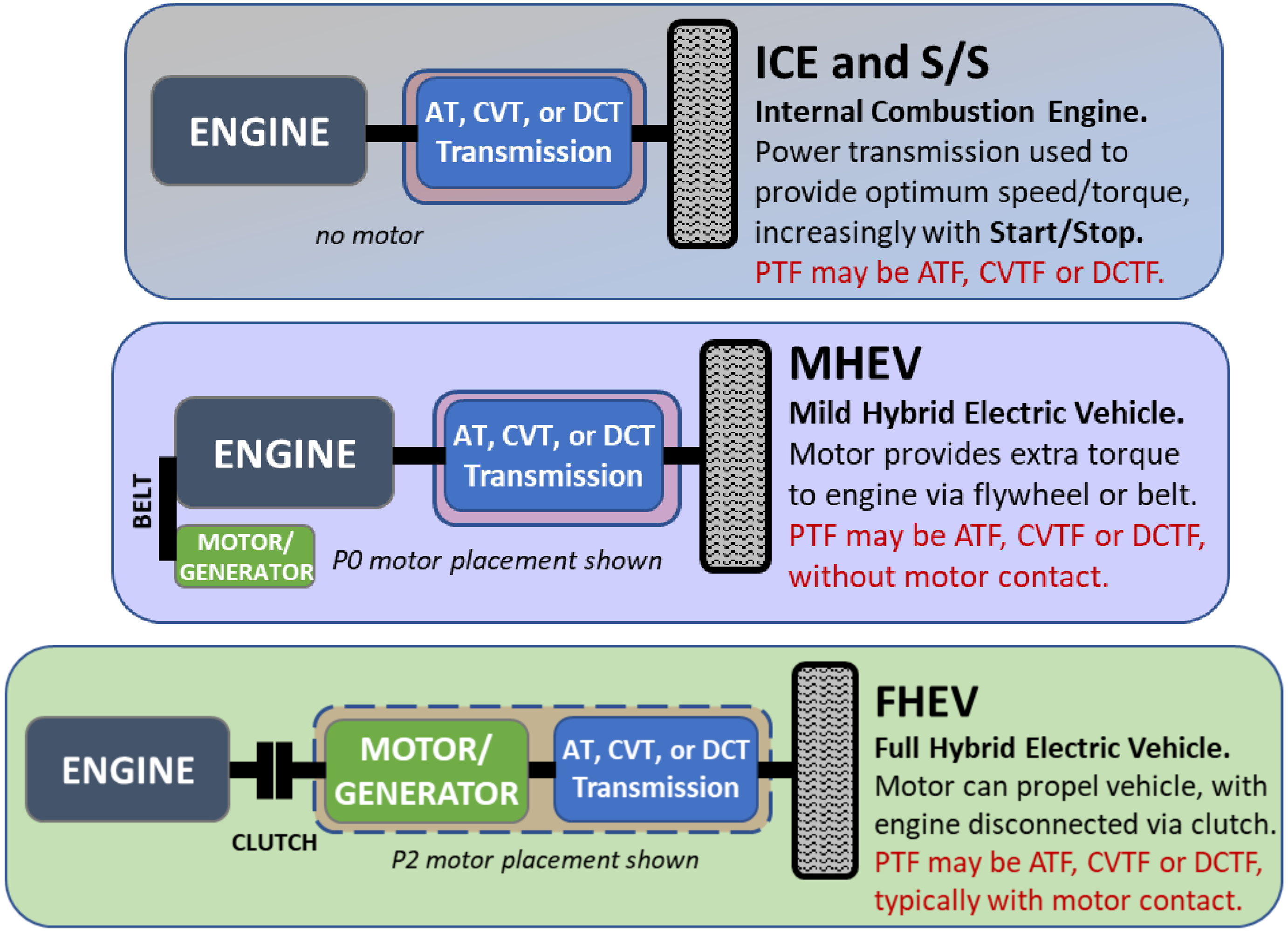
- Conventional engine and start-stop installations drop to ~50% by 2026.
- FHEV and BEV could reach 30% 2030
- Global parc exceeds 1.4 billion and is slow to change.
- Service Fill CAGR ~6%, with new fluids

Performance you can rely on.

Vehicle electrification

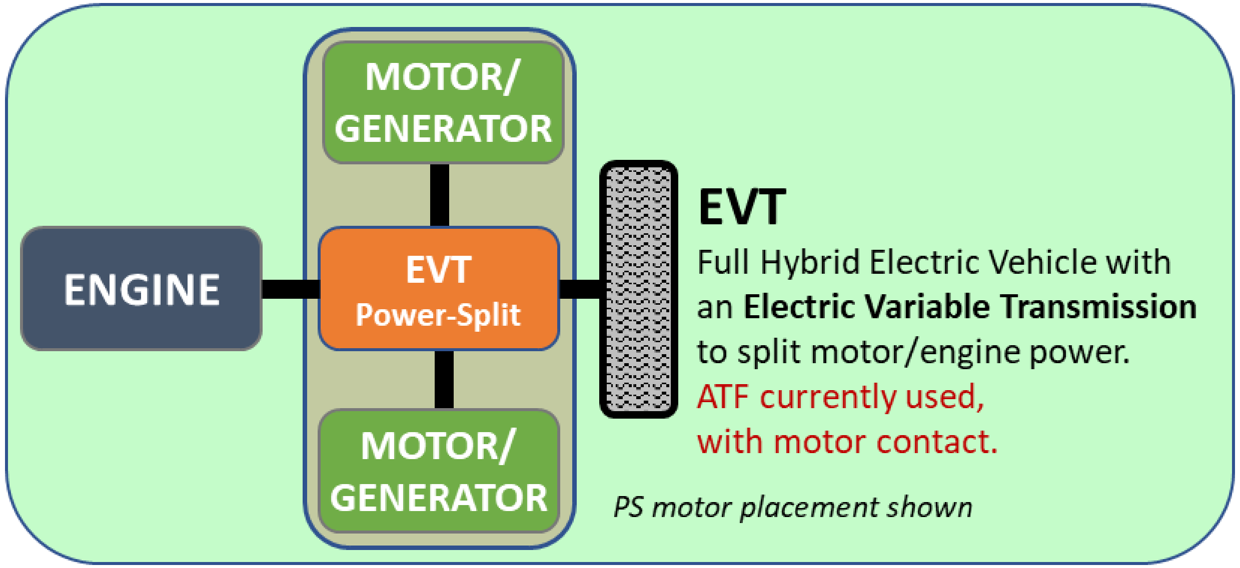
Electrification trends – design and PTF impact

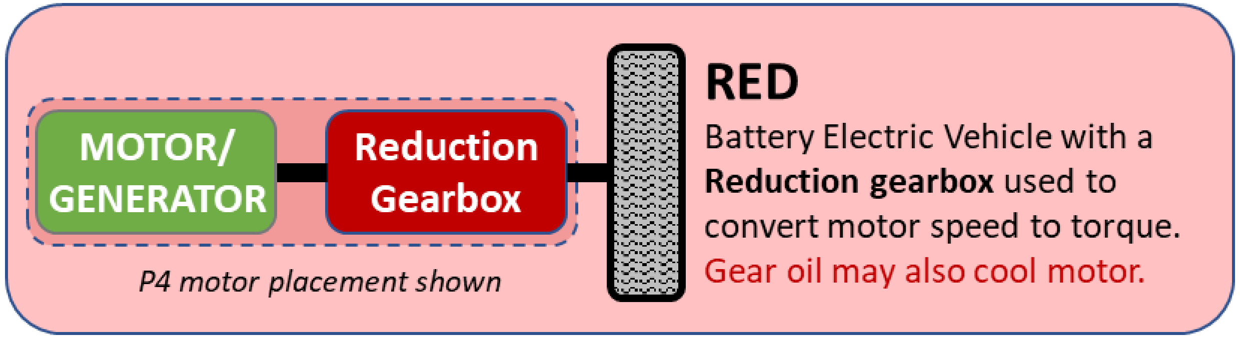
- **Mild Hybrid Electric Vehicles [MHEV]** use conventional transmissions.
  - Motor is placed either before [P0] or after [P1]
  - Standard ATF, CVTF or DCTF used, as transmission and motor are separate.
- **Full Hybrid Electric Vehicles [FHEV]** typically house the motor within the transmission casing.
  - Motor can be placed before [P2], or after [P3]
  - ATF, CVTF or DCTF is used to cool and insulate motor, while providing friction performance and gear protection



Electrification trends – design and PTF impact

- FHEVs may also use an **Electric variable transmission [EVT]** where a planetary gearset or set of clutches manage the power split [PS] between the engine and motor
  - Shifting clutches are eliminated.
  - Transmission fluid used to cool and insulate the motor, and protect the gears.
- Battery Electric Vehicles [BEV] employ a **Reduction [RED] gearbox**.
  - Motor is connected to drive shaft, typically using a simple two-gear design.
  - Motor and gears may be housed together, so transmission fluid may cool and insulates the motor, while protecting the gears.

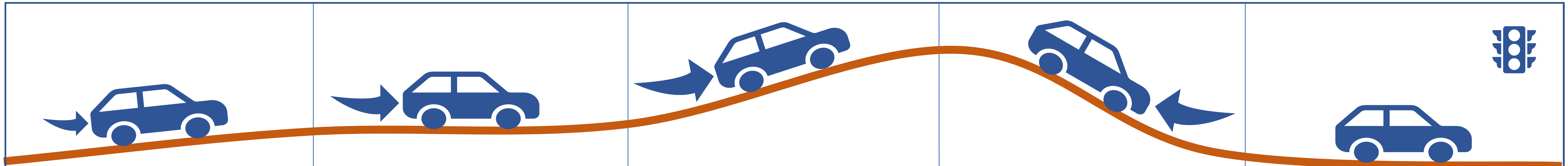


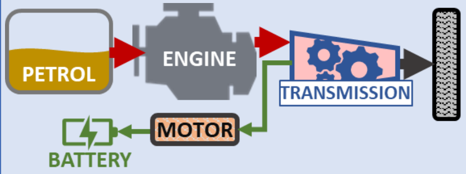
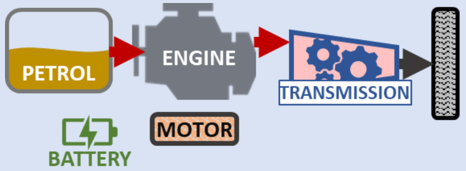
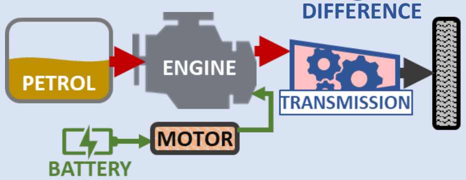
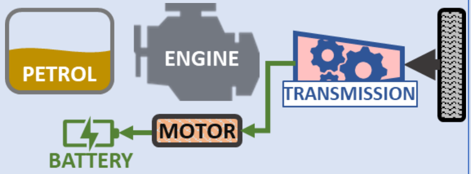
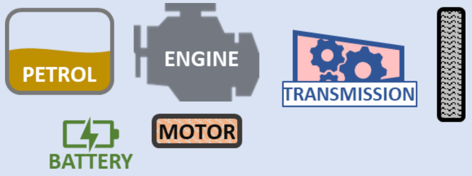
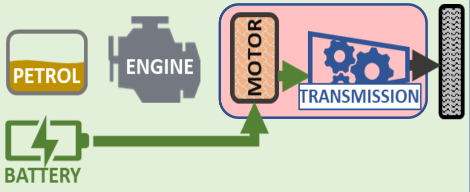
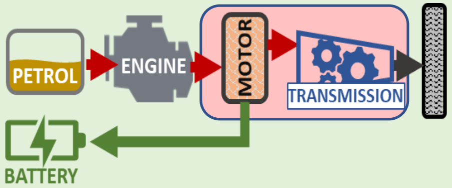
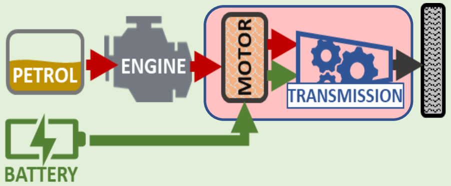
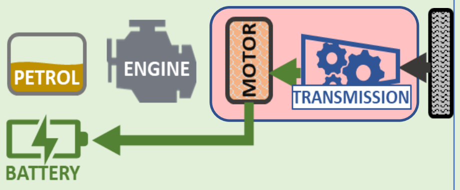
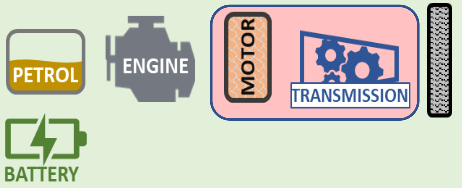


Vehicle electrification
Varying degrees and transmission impact

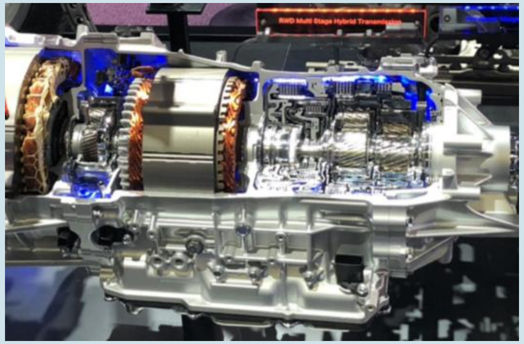
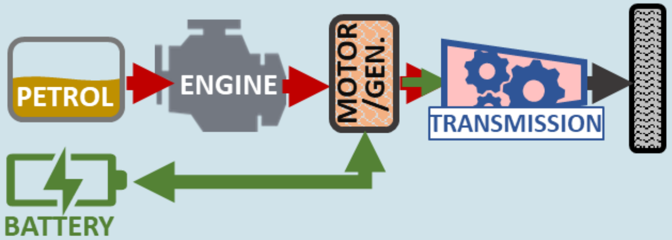
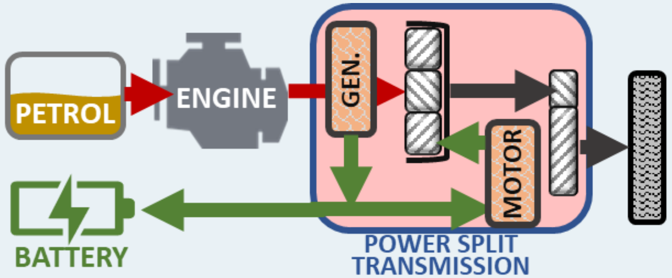
Electrification Type	Start/Stop [S/S]	Mild Hybrid [MHEV]	Full Hybrid [FHEV]		Plug-In Hybrid [PHEV]	Extended Range [EREV]	Battery Electric [BEV]
Basic Schematic							
Approx. Energy Efficiency	+2% to 4%	+8% to 11%	+20% to 35%	+30% to 50%	+50% to 60%	+60% to 70%	+70% to 80%
Energy Saving Operations	**Engine can shut-off when stopped** (S/S to EREV)						
		Engine assisted by motor for extra torque and can shut-off when coasting with motor restart. (MHEV to EREV)					
		Braking energy recovered (MHEV to BEV)					
			Motor can propel vehicle with engine off (FHEV to BEV)				
					Plug-in recharge (PHEV to BEV)		
						Motor only propulsion [no engine] (EREV to BEV)	
Motor Placement	n/a	Before **Engine** [**P0**] or After [**P1**]	Before [**P2**] or After [**P3**] **Transmission**	Before & After **Trans.**[**P13** or **P23**]	[**P2**],[**P3**], [**P13**] or [**P23**]	[**P4**] on **Axle**[s]	
Transmission Type	Standard **MT**, **AT**, **CVT** or **DCT**		Modified **AT**, **CVT** or **DCT**	Electronically Variable [**EVT**]	Modified **AT**, **CVT** or **DCT**; or **EVT**	Reduction Gear Box [**RED**]	
Transmission Fluid	**ATF**, **CVTF**, **DCTF** or **MTF**	**ATF**, **CVTF**, **DCTF** or **MTF**	**ATF**, **CVTF** or **DCTF**	**ATF**	**ATF**, **CVTF** or **DCTF**	**GEAR OIL** or **ATF**	
Motor Contact	n/a	no	typical	yes	typical	possible, with motor cooling	

Vehicle electrification
Operation of mild hybrid vs. full hybrid designs



GENTLE ACCELERATION	CRUISE	FULL ACCELERATION	DECELERATION	STOP
MILD HYBRID Engine drives vehicle. Motor captures any extra engine power to charge battery. 	**MILD HYBRID** Engine drives vehicle. Motor is on standby. 	**MILD HYBRID** Engine drives vehicle while **Motor only assists engine.** KEY DIFFERENCE 	**MILD HYBRID** Engine off. Motor regenerates braking energy to charge battery. 	**MILD HYBRID** Engine and Motor off. Battery provides energy to run accessories, such as A/C. 
FULL HYBRID **Motor drives vehicle** Engine is on standby. KEY DIFFERENCE . 	**FULL HYBRID** Engine drives vehicle. Motor captures any extra engine power to charge battery. 	**FULL HYBRID** Engine and Motor both provide power to drive the vehicle. 	**FULL HYBRID** Engine off. Motor regenerates braking energy to charge battery. 	**FULL HYBRID** Engine and Motor off. Battery provides energy to run accessories, such as A/C. 

Vehicle electrification
Two full hybrid transmission approaches

Type	Design	Advantage	Examples	Operation
Modified AT, CVT or DCT	Motor placed within conventional hardware.	Manufacturing integration, often using same transmission casing	BMW X5, Jeep Wrangler 	The motor propels the vehicle, with or without the engine, or acts as a generator to charge battery with the engine. 
Electronically Variable [EVT]	New designs to manage the power split between engine and motor.	Engine operates in higher efficiency range.	Toyota Prius, Ford Fusion 	A separate generator captures any extra engine power to drive the motor and/or charge the battery. 

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E-fluid formulation

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E-fluid formulation
Conventional fluids, up to now…

- **Conventional transmission fluids are commonly used for FHEVs and BEVs**
  - Due to limited production
  - Providing adequate motor protection
- **Tailored e-fluids are currently being developed**
  - Designs are becoming more demanding on fluid
  - Increasing installations justify a bespoke fluid

Transmission		Manufacturer	FHEV / BEV (Placement)	Total Sales* (millions)	Top Models	Fluid Type (brand name)
EVT		**Toyota**	FHEV (P23)	17.2	Toyota Prius	**ATF** (Toyota WS)
		Honda	FHEV (P13)	1.2	Honda Accord	**ATF** (Honda DW-1)
AT		**Hyundai**	FHEV (P2)	0.6	Hyundai Sonata	**ATF** (Hyundai SP-IV)
		ZF Group	FHEV (P2)	0.5	BMW 5-Series	**ATF** (ZF Lifeguard 8)
CVT		**Subaru**	FHEV (P2)	0.1	Subaru Forester	**CVTF** (Subaru CVTF)
		Jatco	FHEV (P2)	0.1	Nissan X-Trail	**CVTF** (Nissan NS-3)
DCT	Dry	**Honda**	FHEV (P2)	1.2	Honda Fit	**ATF** (Honda DW-1)
	Wet	**VW**	FHEV (P2)	0.4	VW Passat	**DCTF** (EG 52529)
RED		**Nissan**	BEV (P4)	1.6	Nissan Leaf	**ATF** (Nissan Matic-S)
		Tesla Motors	BEV (P4)	1.3	Tesla Model 3	**ATF** (Tesla High Perf.)
		GM	BEV (P4)	0.2	Chevy Bolt	**ATF** (DEXRON® HP)

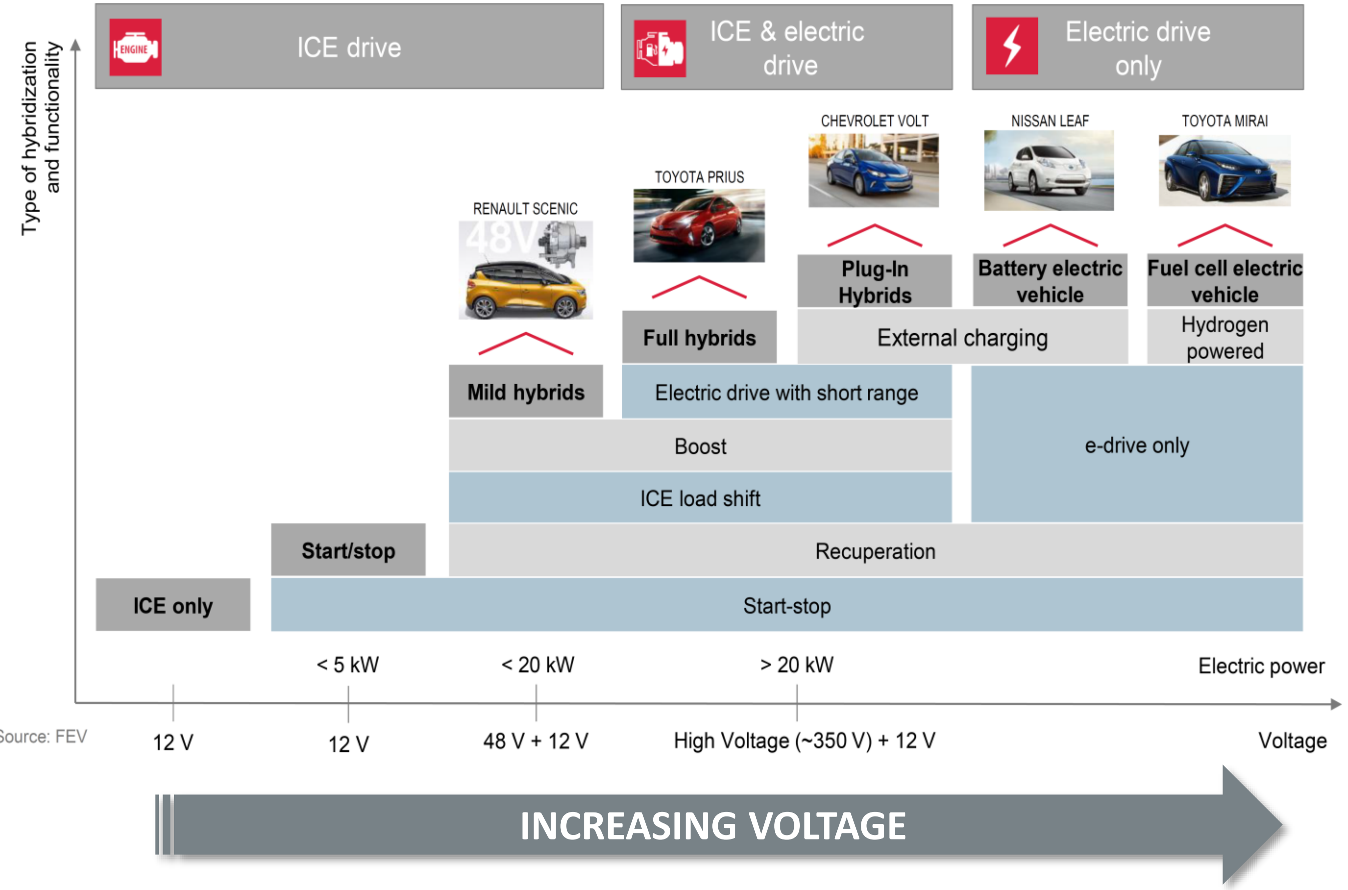
* Cumulative sales of all vehicle models through model year 2020

E-fluid formulation electrification platform development

OEM optimized e-motor designs will result in new fluid requirements:

- Increased power density to meet stricter packaging and performance requirements
  - Motor cooling via direct oil contact optimal
    - More efficient than water jacket
    - Reduces complexity and casing size
  - Direct oil cooling drives other critical E-Fluid requirements
    - Insulating current via volume resistivity
    - Specialized material compatibility

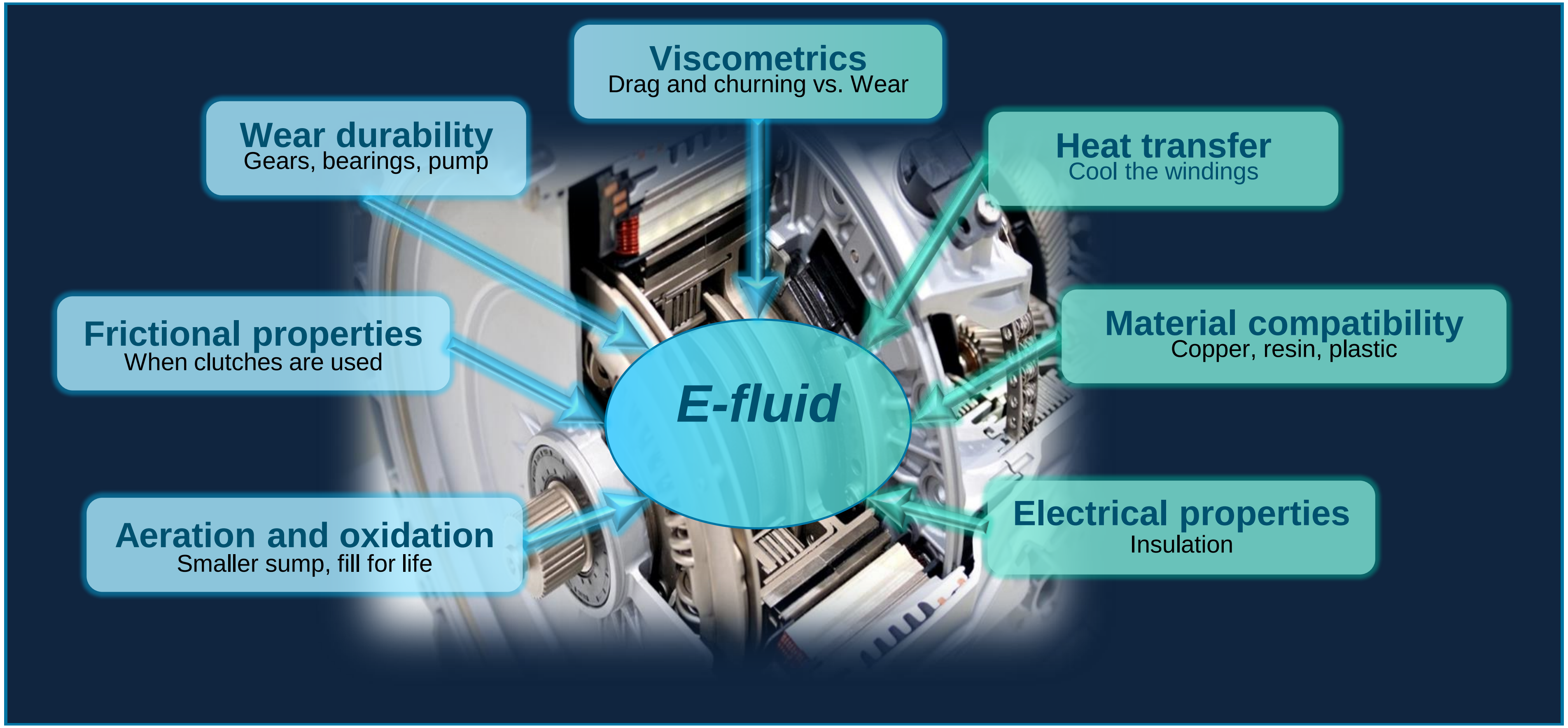
POWERTRAIN LANDSCAPE



Source: FEV

E-fluid formulation
Added electrification requirements

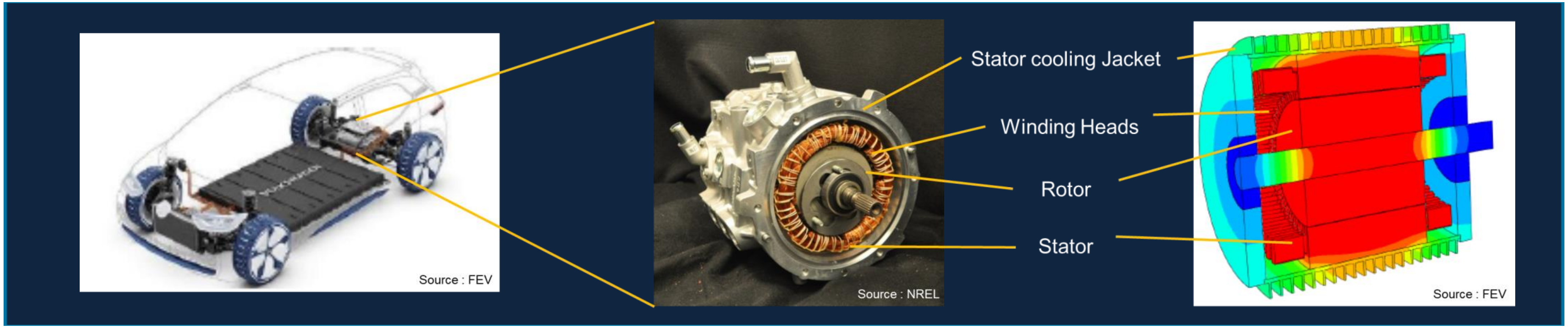
E-Fluid electrical properties must be considered, along with transmission performance and protection



E-fluid formulation
Heat Transfer Requirements

Heat transfer
Cool the windings

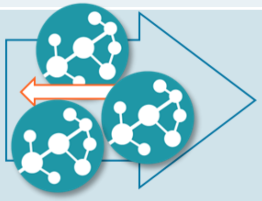
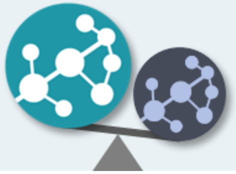
- **High temperature can lead to motor performance loss and demagnetization.**
  - Winding heads and magnetic rotors may be subject to localized hot spots at peak loads



- **Direct oil cooling is more efficient and less complex than water cooling jackets.**
  - Oil cooling can improve motor efficiency and enable smaller higher voltage motors.

E-fluid formulation
Fluid heat transfer properties

Heat transfer
Cool the windings

FLUID PROPERTY	MEASUREMENT	IMPACT ON HEAT TRANSFER
Thermal Conductivity (k) 	Molecular ability to conduct heat. [W/m·K]	Fluids with higher k have molecules that are better at transferring heat away from hot surfaces and between each other.
Specific Heat Capacity (c_p) 	Molecular amount of heat per unit mass required to raise the temperature by one degree Celsius. [kJ/(kg·K)]	Fluids with higher c_p have molecules that are better at absorbing heat with a lower rise in temperature.
Dynamic Viscosity (μ) 	Molecular resistance to flow. [cP]	Fluids with lower μ have molecules with less internal resistance to flow to hot surfaces and away with the heat.
Density (ρ) 	Molecular compactness. [kg/m^3]	Fluids with higher ρ have more molecules per given volume that can conduct heat between each other.

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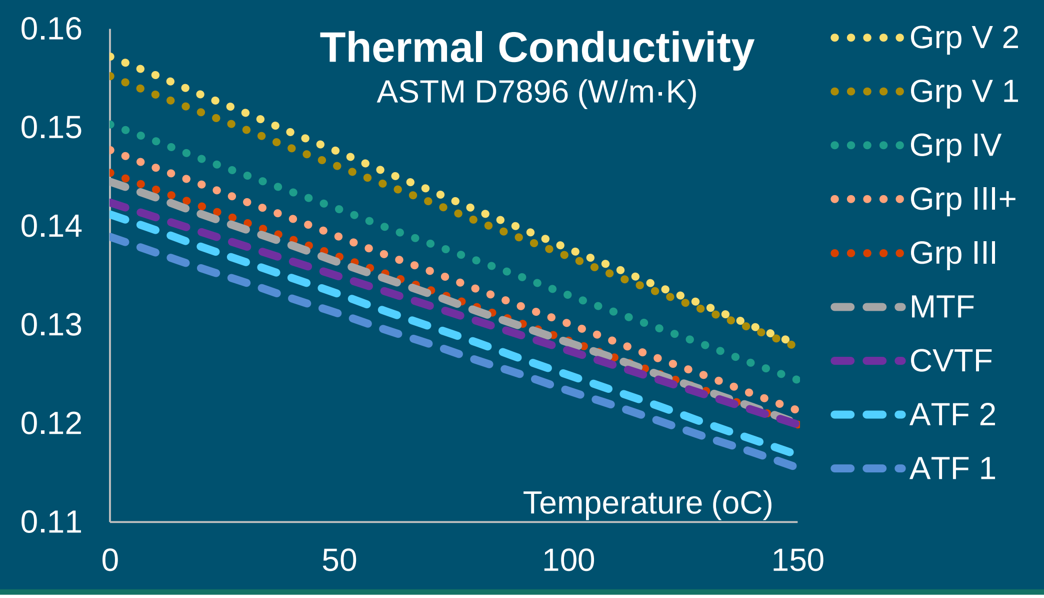
E-fluid formulation
Measuring heat transfer properties

Heat transfer
Cool the windings

- **ASTM D7896:** Standard test method for thermal conductivity, thermal diffusivity and volumetric heat capacity of engine fluids
  - Uses a transient hot wire liquid thermal conductivity method

- **The thermal conductivity of transmission fluids is largely a function of the base oil used.**
  - ↑ base oil quality → ↑ ***k***



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E-fluid formulation
Formulating for heat transfer

Heat transfer
Cool the windings

- **The *Mouromtseff* number [M_0] is used to compare the heat transfer capability of turbulent fluids**
  - e-fluids are subject to turbulent flow

- **Provides formulation guidance, largely on base oil selection**
  - ↑ **Increase fluid density**
    - Higher viscosity and quality - minor effect on oil density and M_0
  - ↑ **Increase fluid thermal conductivity**
    - Function of base oil purity [Grp IV > Grp III]– large effect on M_0
  - ↑ **Increase fluid specific heat capacity**
    - Non-conventional oils could have a large effect on M_0 , at high cost.
  - ↓ **Reduce fluid dynamic viscosity**
    - Lower viscosity oil – major low cost effect on M_0 [balance vs. wear]

Mouromtseff Number
for turbulent fluids

$$M_0 = \frac{\rho^{0.8} k^{0.67} c_p^{0.33}}{\mu^{0.47}}$$

Fluid properties:
- ρ = Density [kg/m^3]
- k = Thermal conductivity [W/(m·K)]
- C_p = Specific heat capacity [kJ/(kg·K)]
- μ = Dynamic viscosity [cP]

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E-fluid formulation
Novel approaches for heat transfer

Heat transfer
Cool the windings

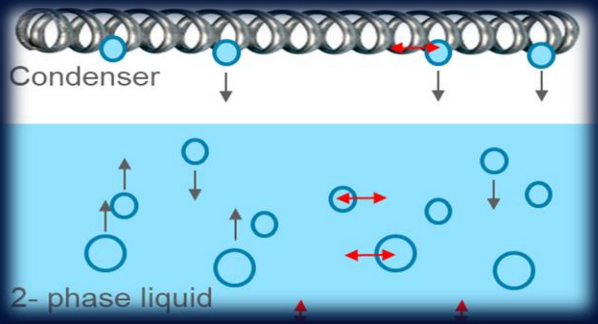
Novel Base Oils

- Provides high heat capacity, thermal conductivity and oxidative stability
  - E.g. polyol esters, silicones, heat transfer fluids and vegetable oils

Novel Additives

- Improves thermal conductivity and breakdown voltage (potentially)
  - E.g. boron nitride, aluminum oxide, titanium oxide, iron oxide nanoparticles

Two-Phase Liquids



- Uses latent heat of vaporization for heat transfer
  - E.g. hydrofluororethers, used in immersion cooling of batteries

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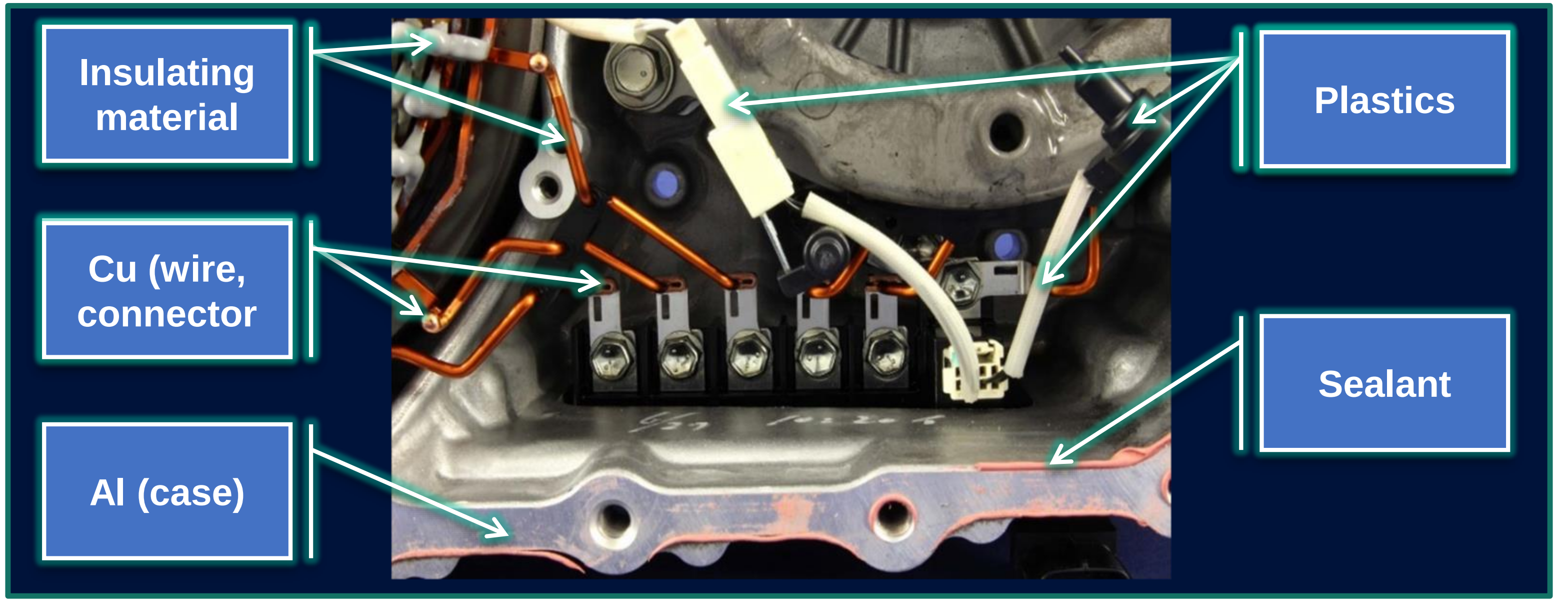
E-fluid formulation
Material compatibility requirement

Material compatibility
Copper, resin, plastic

- **Motors introduce new materials to the transmission**
  - Copper wire and connections, along with insulating materials, plastics, sealants, etc.



- **Material compatibility with transmission fluid is critical for e-fluids**
  - Insulation failure can lead to shortages, corrosion can erode connections and circuits

E-Fluid formulation
Formulating for material compatibility

Material compatibility
Copper, resin, plastic

- **Material compatibility must be considered for additive selection, e.g.:**
  - Extreme pressure additives used in typical gear oils will corrode copper.
  - Corrosion inhibitors may help mitigate.

- **Additive components used in e-fluids must be screened for compatibility:**
  - Soak tests, at elevated temperature
  - Energized circuit board tests

Copper Compatibility	Current Fluid	Improved E-Fluid
Cu Dissolution, ppm *168 hrs @ 150 C*	182 ppm	20 ppm
Cu Strip 168 hrs @ 150 C		
Circuit Board Test		

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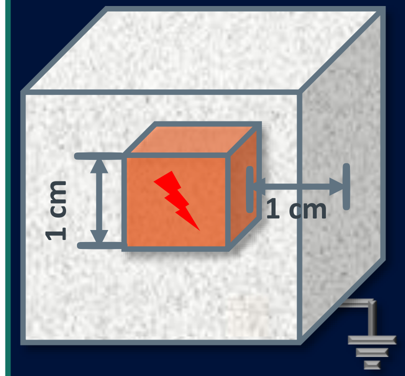
E-fluid formulation
Electrical property requirement

Electrical properties
Insulation

- **Motors rely on insulating material to isolate high voltage components.**
  - When oil cooled, the e-fluid's resistance to current flow must be considered.



Volume Resistivity [VR] is the oil resistivity [1/conductivity] multiplied by the separation and divided by the area.

EXAMPLE:
Consider a 1 cm^2 conductor immersed in oil and separated from ground by 1 cm.
- *Oil with conductivity 1x10-9 S/cm at 100 °C would present 1 GΩ resistance.*
- *If driven by 500 V, a 0.5 μA leakage current would occur.*

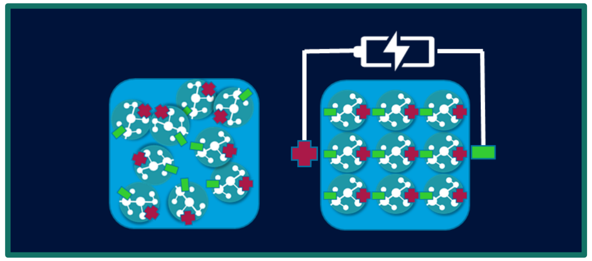
- **The optimum e-fluid VR to electric current is being investigated.**
  - Higher VR can allow for increased motor voltage and smaller casing, but can lead to static build-up and arcing.

E-fluid formulation
Fluid volume resistivity properties

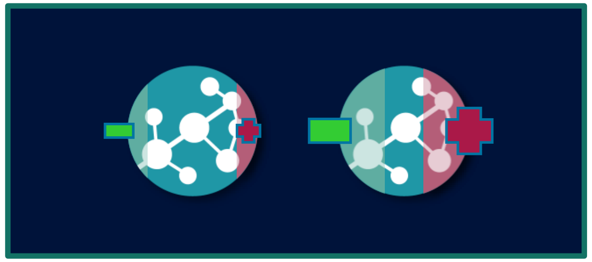
Electrical properties
Insulation

Relationship between molecular electronic properties and measured resistivity

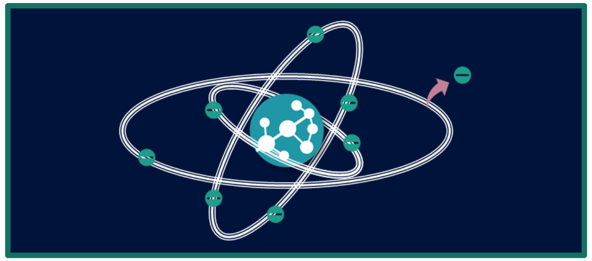
- **Dipole Moment** (Debye): measures the difference in electrical charge between a positive end and a negative end of a molecule.
  - Polar molecules, with higher ***Debye*** are less resistive.
    - Detergents



- **Polar Surface Area** (PSA): measures polarity based on the surface area (Å2) of oxygen and nitrogen atoms including attached hydrogen atoms.
  - Molecules with higher ***PSA*** are less resistive.
    - Different Friction Modifiers



- **Band Gap (eV):** measures the energy required to move an electron from the valence band to the conduction band in the outermost orbit of a molecule.
  - Molecules with lower eV are less resistive.
    - Example: Zinc phosphide [eV ~ 1.5] < Zinc oxide [eV ~ 3.4]



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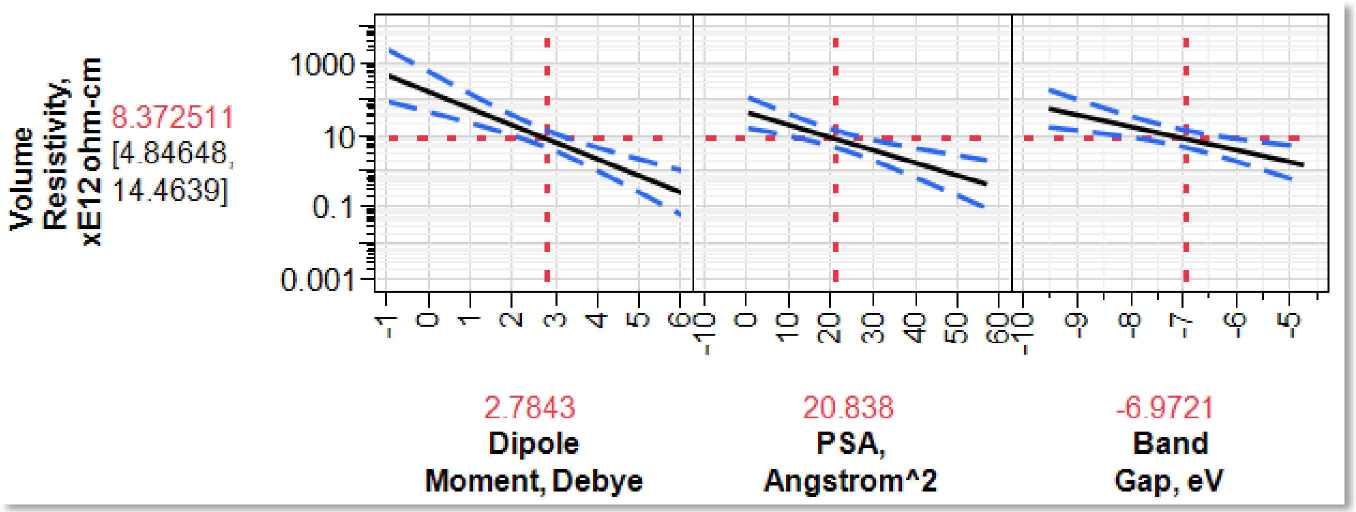
E-fluid formulation
Measuring volume resistivity

Electrical properties
Insulation

- **ASTM D1169 -** covers the determination of specific resistance (resistivity)
  - applied to new electrical insulating liquids, as well as to liquids in service, or subsequent to service, in electrical apparatus.

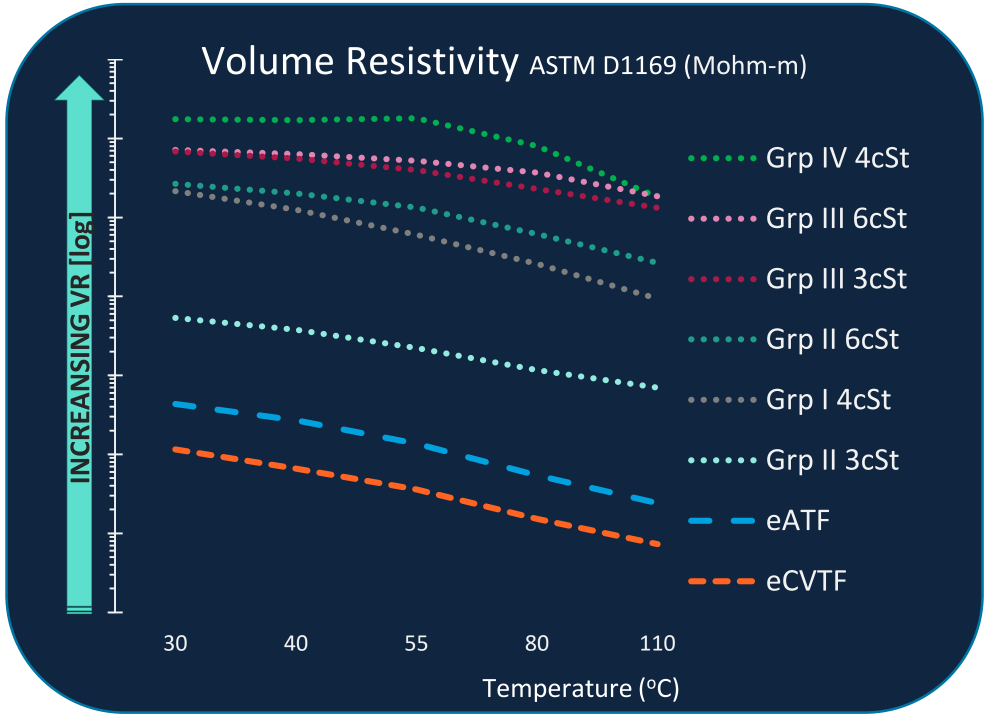
- **VR decreases as molecular polarity increases:**
  - ⇧Debye → ⇩VR
  - ⇧PSA → ⇩VR
  - ⇩eV → ⇩VR

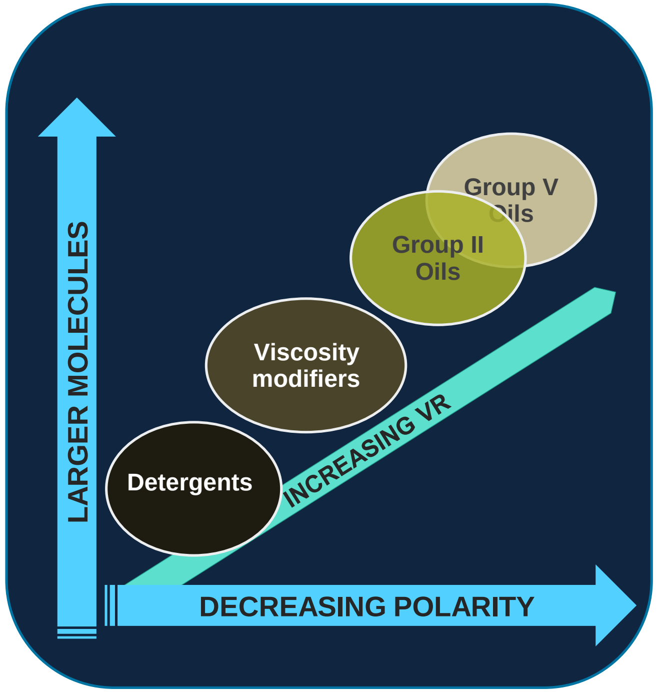


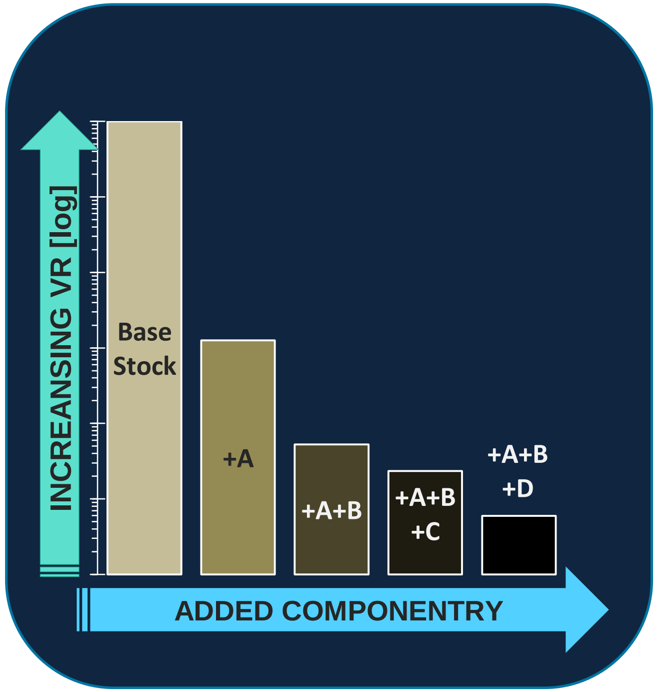
E-fluid formulation
Formulating for volume resistivity

Electrical properties
Insulation

- **Maximum e-fluid VR is dictated by base oil:**
  - Higher quality reduces polarity and increases VR.
  - Higher viscosity increases molecule size and VR.
- **Additives lower VR as:**
  - Molecular polarity increases
  - Molecules are smaller
  - Treat rate increases



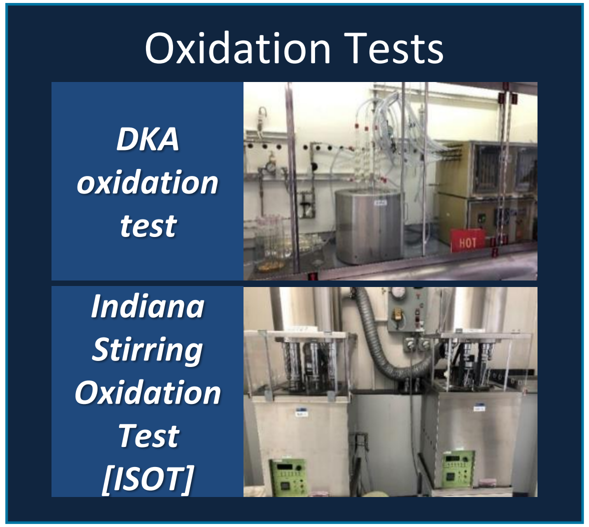


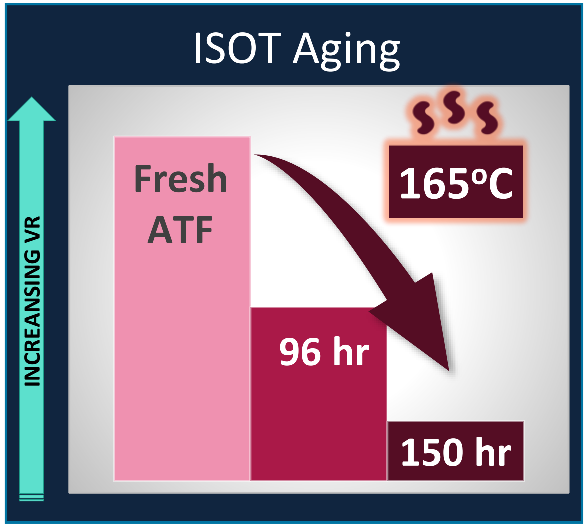


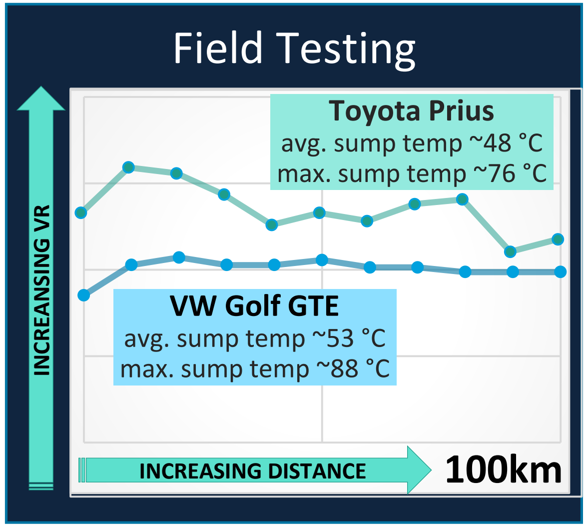
E-fluid formulation
Volume resistivity of aged fluid

Electrical properties
Insulation

- **Oxidation lowers the volume resistivity of aged fluids**
  - OEMs have introduced oxidation tests to evaluate electrical properties…
    - including ISOT and DKA, but these approaches may be too severe.
  - VR remains relatively unchanged after field aging in cooler hybrid transmissions.
    - Battery electric vehicles may have even lower overall sump temperature.



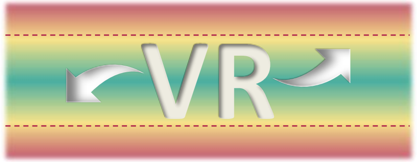




E-fluid formulation
Volume resistivity considerations

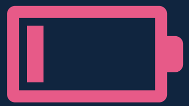
Electrical properties
Insulation

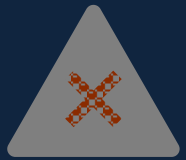
What may define the upper and lower limits for volume resistivity?



- **SAFETY**
  - **ISO6469-3 Part 3**: *Protection of persons against electric hazards*
  - (DC) Isolation resistance minimum value 100 ohm/volt (10mA)
  - (AC) Isolation resistance minimum value 500 ohm/volt (2mA)

- **OTHER PARAMETERS TO CONSIDER**
  - Electrical arcing with high VR?
  - Potential current leakage with low VR?
  - Electrically induced corrosion with low VR?

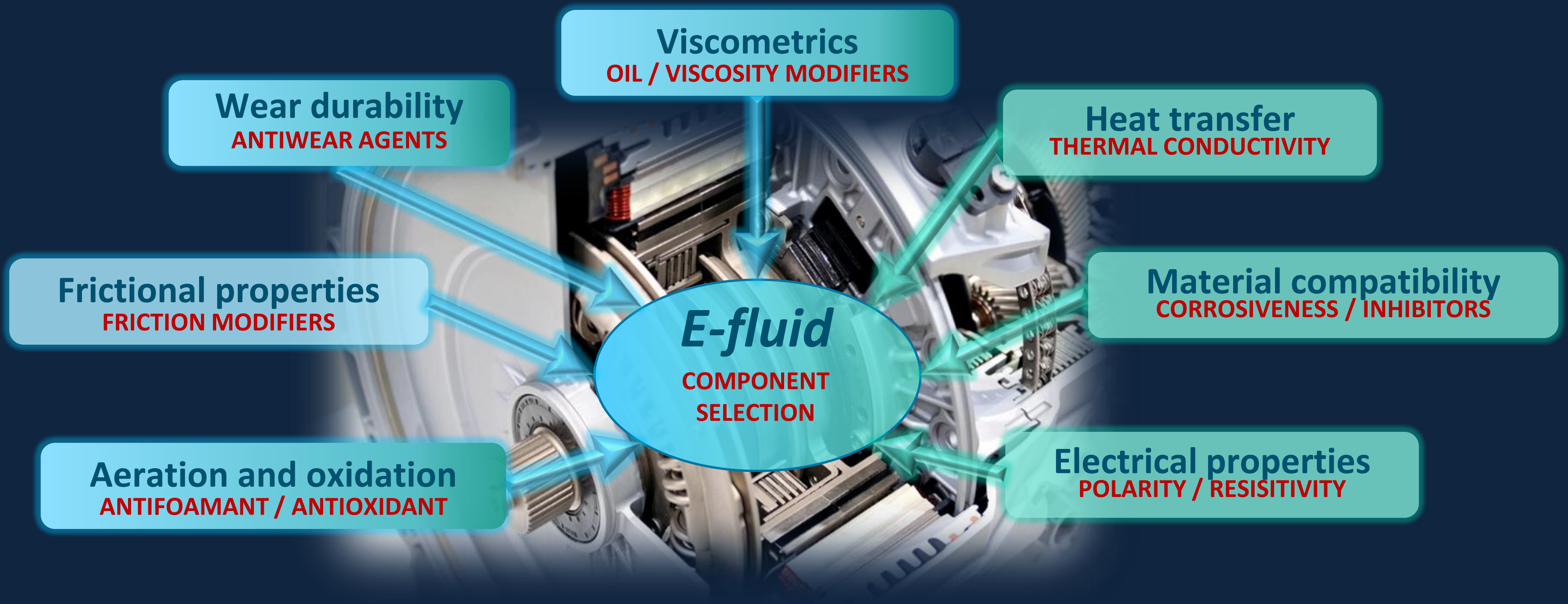




E-fluid formulation
Formulation map

- **Balance of transmission performance and protection with electrical properties**

New considerations are needed for component selection, e.g. antiwear and antioxidant



Performance you can rely on.

Electrification outlook

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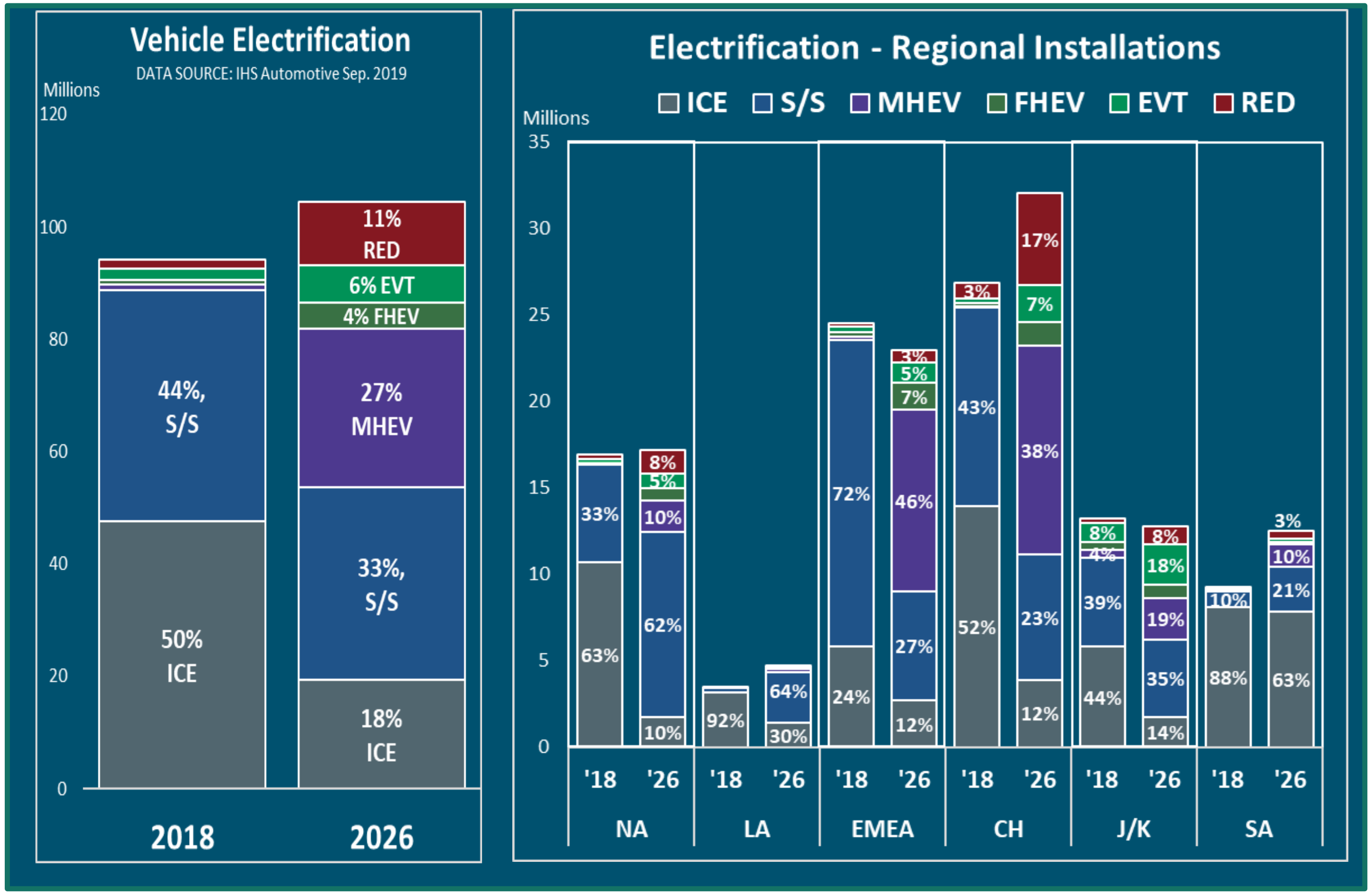
Electrification outlook
Passenger car installations

- **ICE and S/S installations drop to ~50% by 2026.**
  - Most growth in MHEV, with integration into ICE platforms.
  - FHEV and BEV growth expected to accelerate by 2030, with battery advances.
- **Largest ICE and S/S declines in Europe and China.**
  - Driven by government regulations and incentives
  - RED growth highest in China with new BEV OEM start-ups



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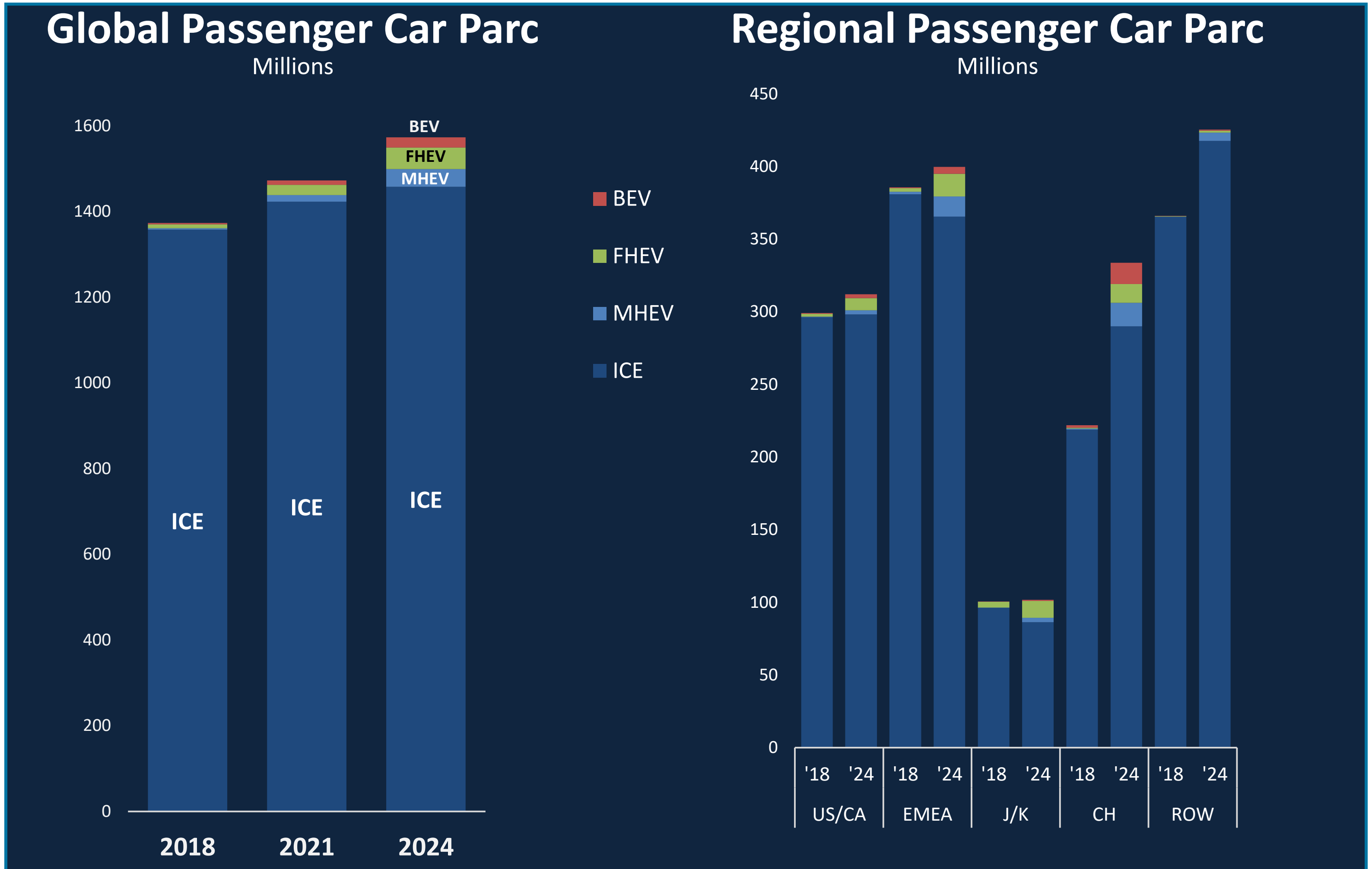
Electrification outlook
Passenger car electrification

- **Growing fleet of hybrid and electric vehicles by 2024**

TYPE	PARC CAGR
ICE & S/S	1%
MHEV	50%
FHEV	35%
BEV	40%

  - Even with high FHEV and BEV growth, the fleet is expected to be <5% total
  - Beyond 2024, as battery technology improves:
    - FHEVs will displace MHEVs
    - BEVs will then displace FHEVs
  - Rate of light duty electrification may exceed that of passenger cars.
    - Driven by heightened inner city emission concerns, facilitated by a return-to-base operation.



Infineum projections are based on IHS and RBC data

Performance you can rely on.

Summary/ recap

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E-mobility and electrification

Vehicle electrification

- Electrification efficiency varies from simple engine start/stop [~2-4%] to full battery electric [~70-80%]
- Motors only assist the engine in Mild Hybrids, but Full Hybrid motors propel the vehicle without the engine
- Full Hybrid motors are often placed within the transmission, so the fluid must take care of it!

E-fluid formulation

- FHEV and BEV transmissions currently use conventional PTF and Gear Oil, but are now being improved.
- New fluid requirements include motor cooling, compatibility and electrical insulation
- These new requirements must be balanced with transmission performance and durability.
- The right combination of base oils and additive componentry is required

Electrification outlook

- Conventional engine and start-stop installations drop to ~50% by 2026.
- FHEV and BEV installations could reach 30% 2030 as battery technology improves
- Global vehicle parc exceeds 1.4 billion and is slow to change.
- Service Fill e-PTF CAGR ~20%, although will represent ~1% PTF demand by 2024

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Electrification fluid drivers

Consumer demands

- Satisfying driving experience
- More usable passenger & cargo space
- Longer driving range & reduced power consumption

Design response

- Increased motor power & torque
- Tighter packaging constraints

> Higher power density

- Eliminate parasitic losses – Lower fluid viscosity & decreased sump volume

Fluid requirements

- Better cooling capability
- Higher volume resistivity
- Increased oxidation resistance
- Maintain gear protection at lower viscosity

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