After-Treatment Catalysts for Gasoline Hybrid Vehicles

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CO_2 Reduction – Potential Challenges for Emissions

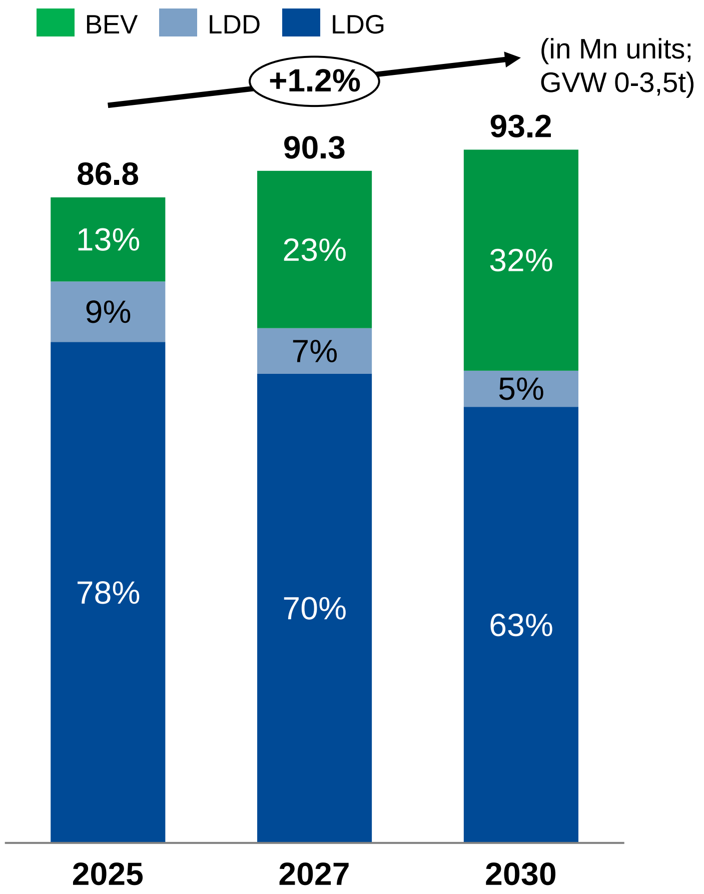
Challenge	CO_2 impact	Potential impact of concept	Potential solutions	Market feedback
Engine efficiency increases*	~10%	Reduction in engine temperature and limitation of heating measures	**New catalyst material concepts** Increase in PGM Calibration tuning	Need fast light-off and durable catalysts for lower exhaust temps.
Lean GDI*	~10-20%	NO_x emission challenge in lean mode	Usage of LNT and SCR components	**CO_2 benefit but NOx is costly to control; most OEMs dropped lean-burn**
CNG*	~20-30%	Methane conversion challenge Lower particulate emissions	**New catalyst material concepts** Increase in PGM	Good CO_2/PM benefit, but methane slip limits wider adoption.
Mild Hybrids (48V)	~10%	Synergies with electric drive might impact temperatures and emissions	General as ICEV	Popular for fuel savings; no extra emission-control demands.
Plug-in Hybrids	~70-80%**	Extended engine-off periods create additional operational challenges	Calibration improvement PGM can be lower	Catalyst cools during engine-off; OEMs split on severity.

*) combinations with mild hybrid (48V) possible
**) related to WLTC certification procedure, real CO_2 depends on interval of re-charging batteries

Source: ICCT, IEA, SAE

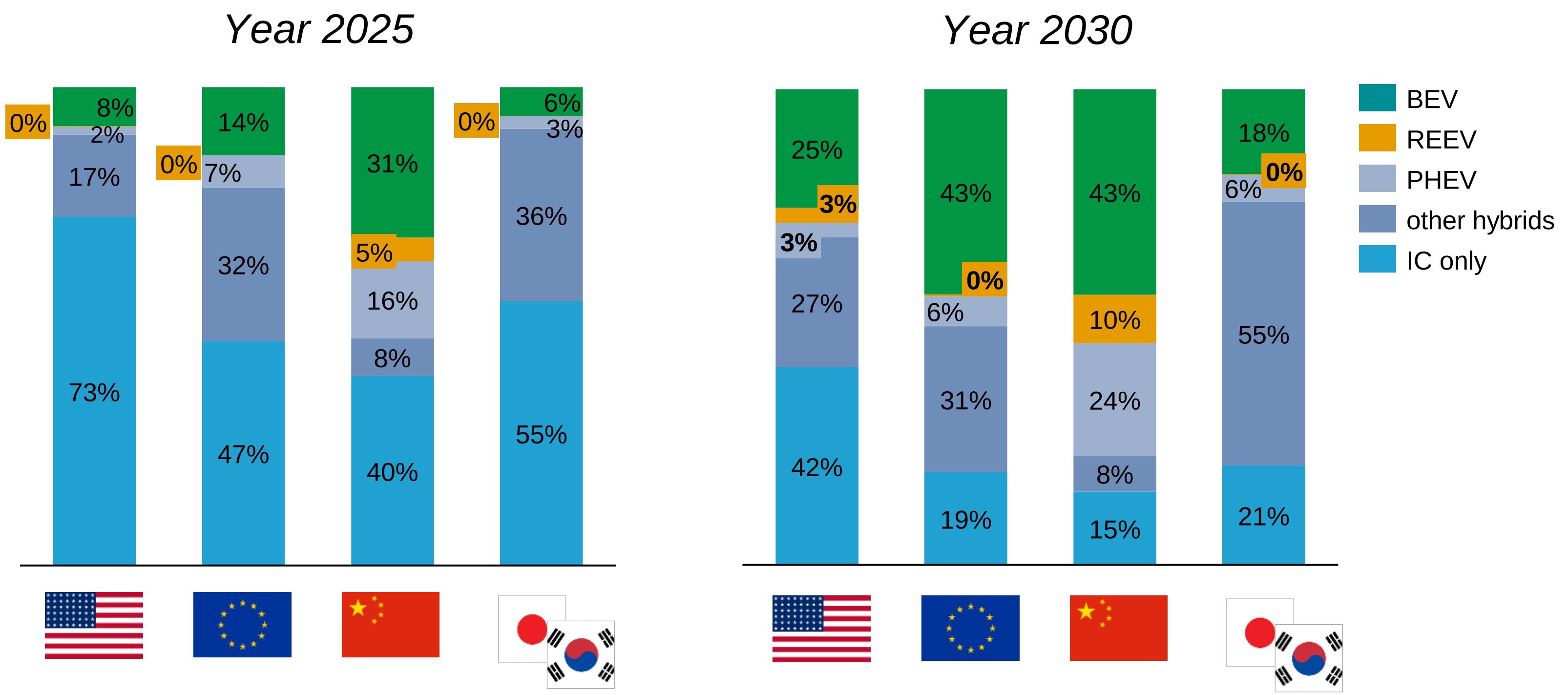
Global LD Electrification Trends

Global view (IHS)



Global BEV growth outlook got again reduced by 2 p.p. to 32% in 2030

Electrification by Production Region



IC-only remaining main powertrain in short term in all regions

High BEV penetration, REEV share increasing but projected to remain a niche outside China

*Source: IHS Global Light Vehicle Engine Forecast 04/2025

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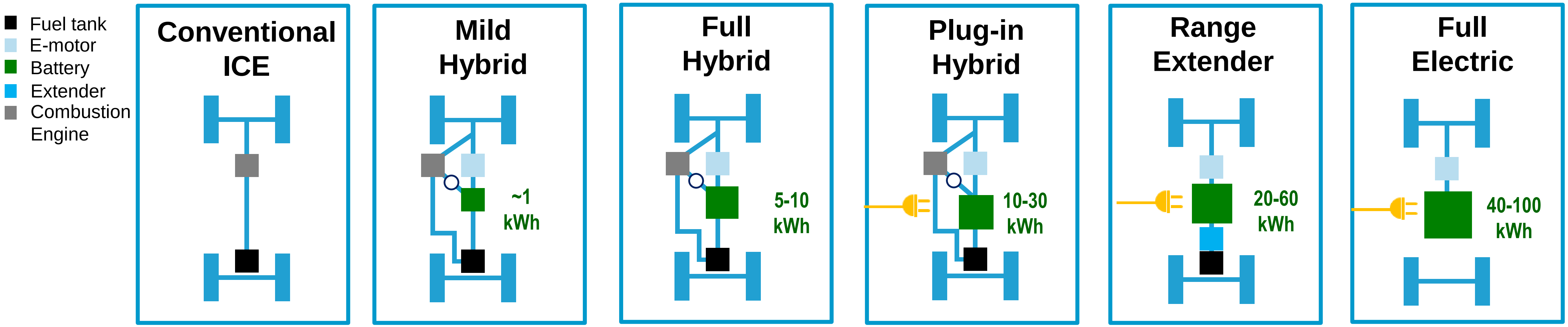
Types of Hybrid



	Conventional ICE	Mild Hybrid	Full Hybrid	Plug-in Hybrid	Range Extender	Full Electric
Driving Mode	Engine only	Engine drive + assist, no EV-only	Engine or motor or both	Long EV-only range + engine backup	EV, engine as generator	100% electric
Fuel Economy	+3–5%	+10–15%	+25 - 40%	+50–70% (if charged)	Very high (near EV)	>90% efficiency
Advantages	Cheap	Cheap, moderate fuel benefit	Good fuel economy, low emissions	Good fuel economy, extended range	Simple system, good range, lower emissions	Simple system with no tailpipe emissions
Catalyst Temp	Always hot	Stable	Risk of cooling → requires management	Low temp → needs good light-off strategy & calibration	Low temp → requires strong light-off strategy & calibration	NA

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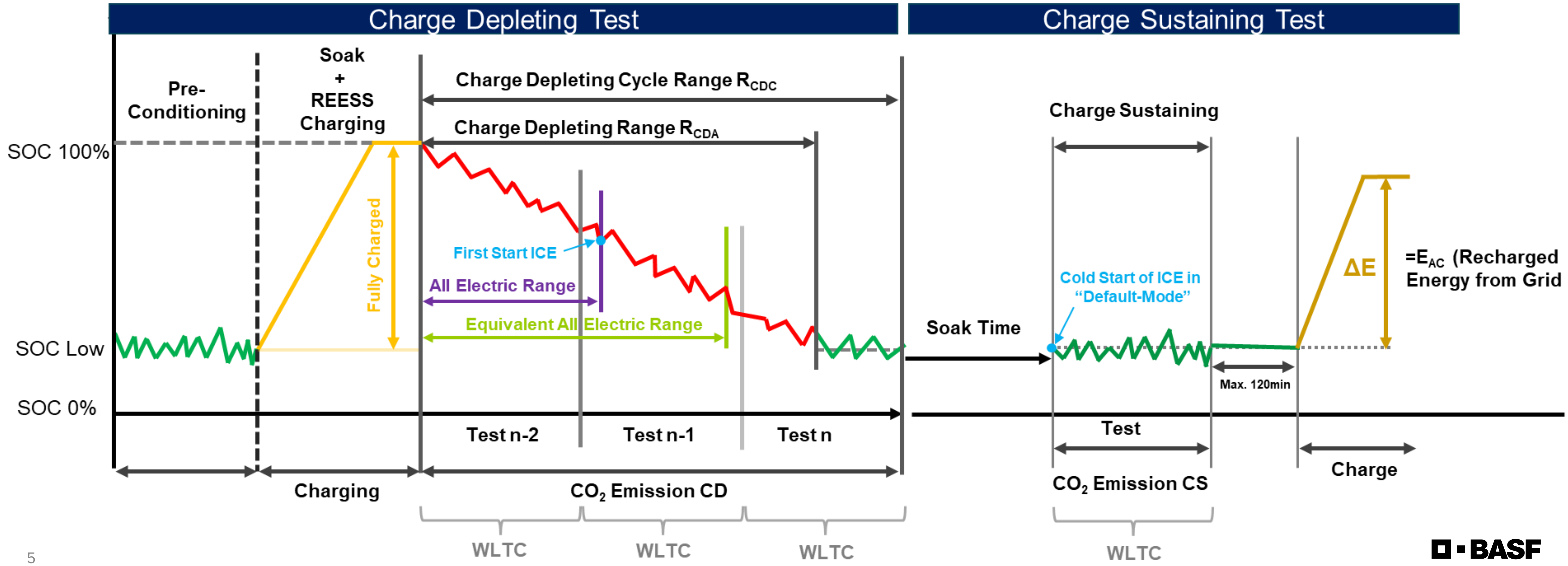
PHEV/REEV Emission Tests Procedure

CD and CS Test of Light Duty Hybrid Electric Vehicles

- Charge depleting (CD): Vehicle starts from fully charged. Emission measured till SOC drop to default lowest. Required for OVC-HEVs.
- Charge sustaining (CS) test: Vehicle tests at lowest default SOC. Required for OVC- and NOVC-HEVs.



*Source: GB/T 19753-2021

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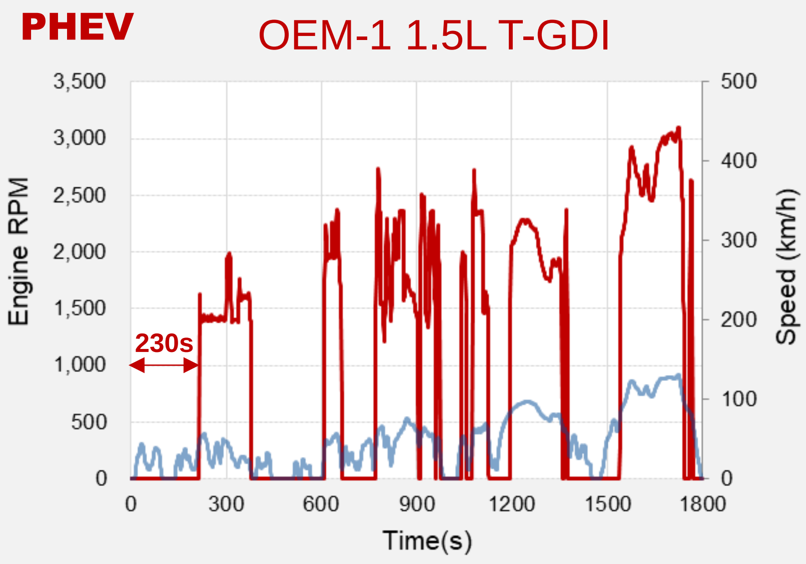
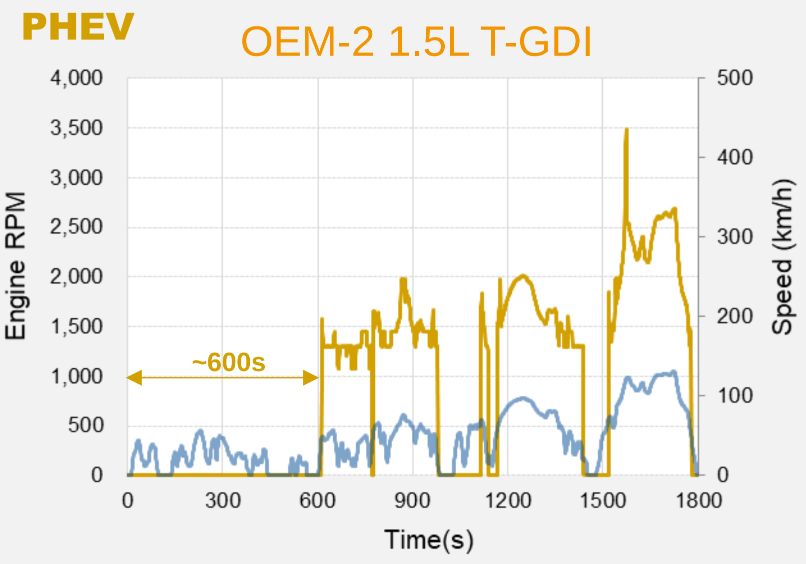
PHEV and REEV Emission Characteristics

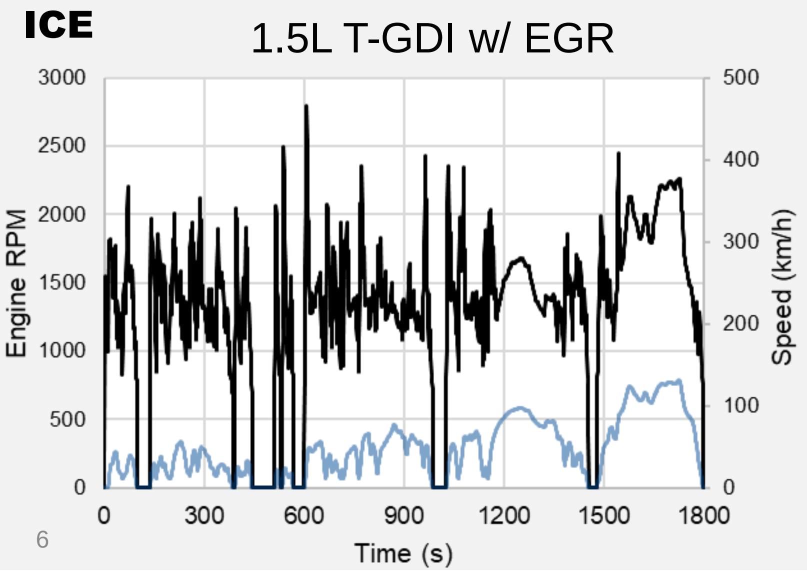
Engine RPM in CS Test

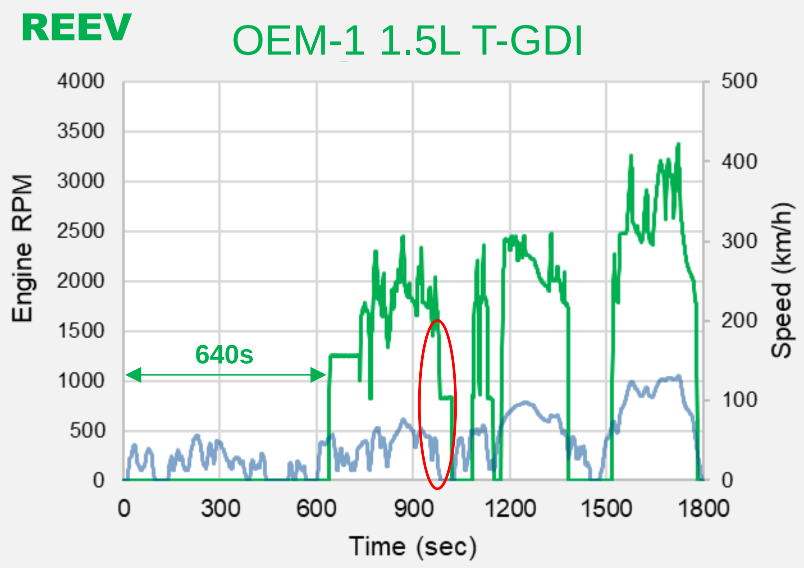
For PHEV and REEV:

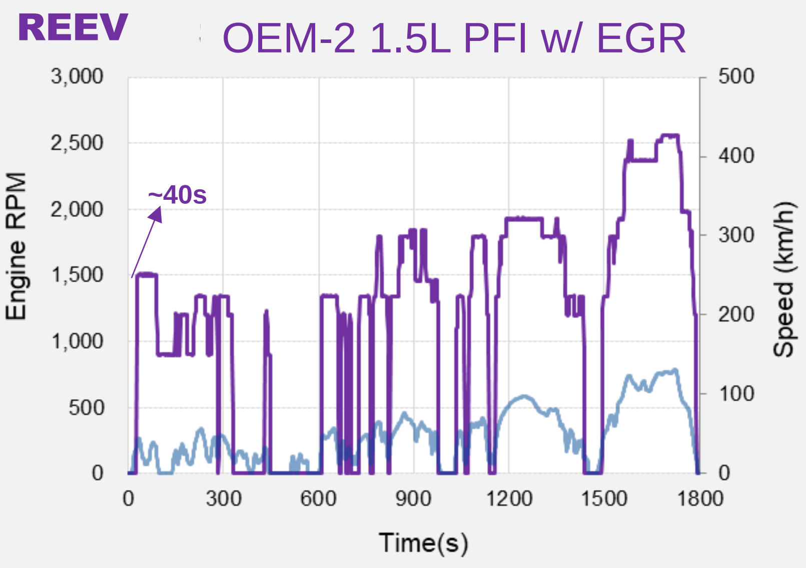
- Engine starts late.
- Engine works only part of the time, working area varies.
- Engine may still be running for battery charging when speed zeroes.
- Less rpm perturbation.



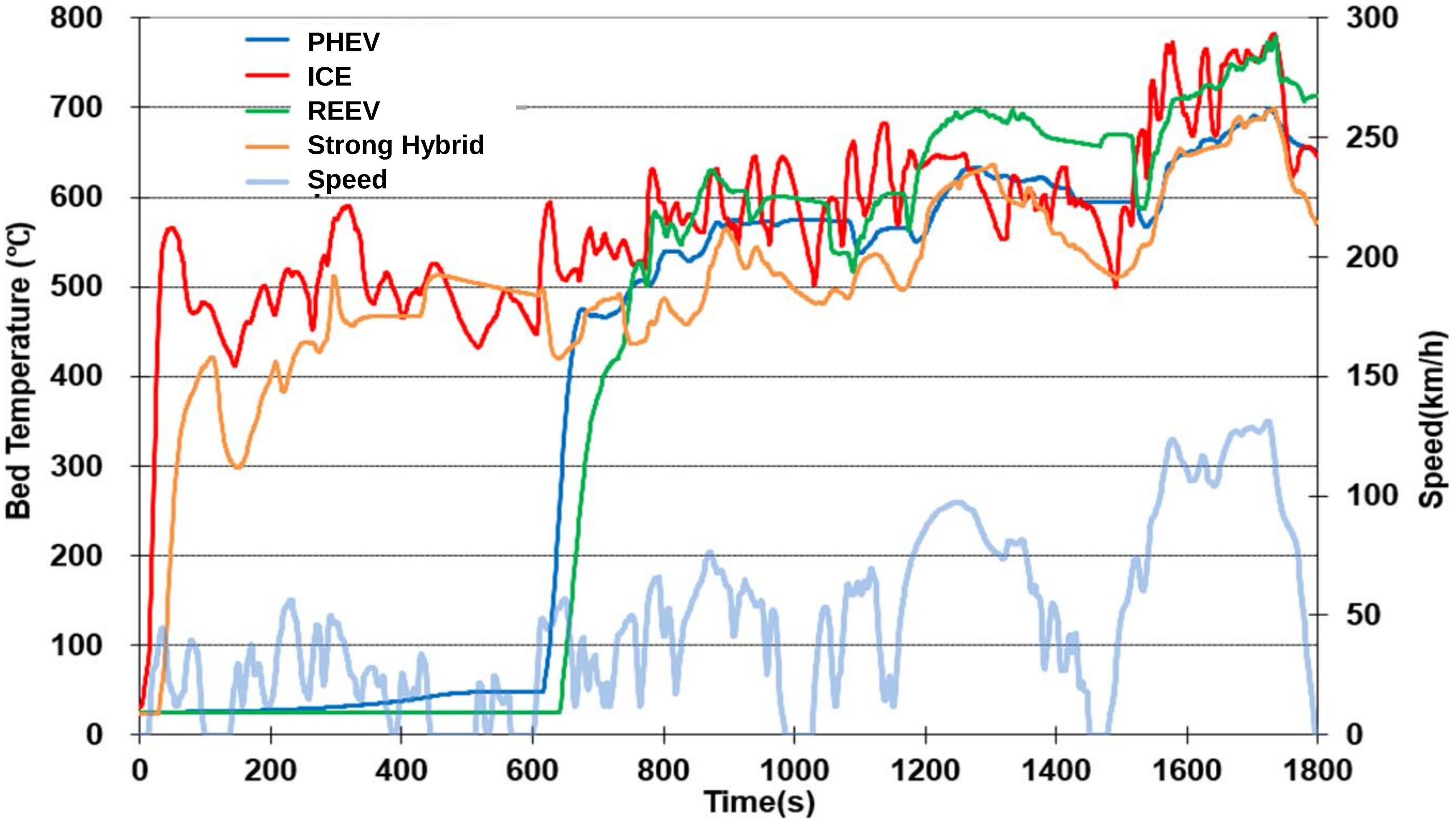








ICE/HEV: EO Temperature Under WLTC Cycle



- PHEV and REEV at CS model
- For REEV, engine usually start late, and in WLTC low-speed phase 1, electromotor drives the vehicle, causing lower overall exhaust temperature and shorter aging time (depending on the specific case).

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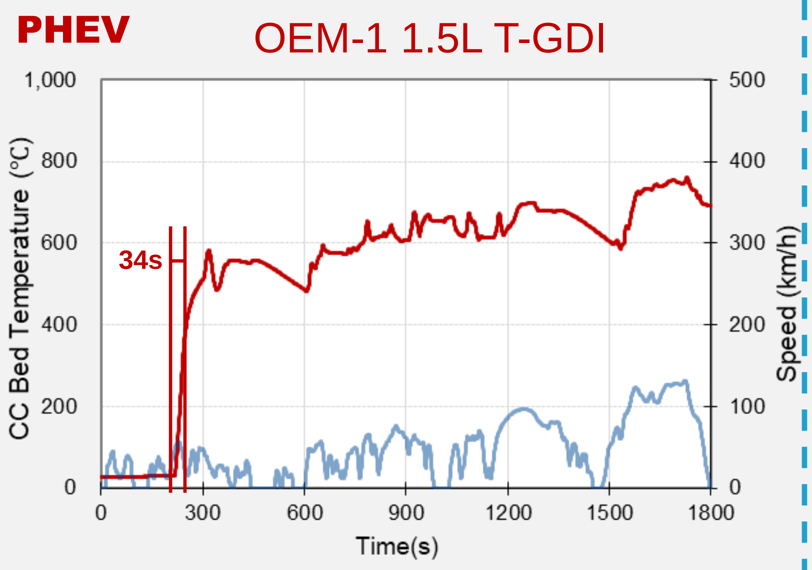
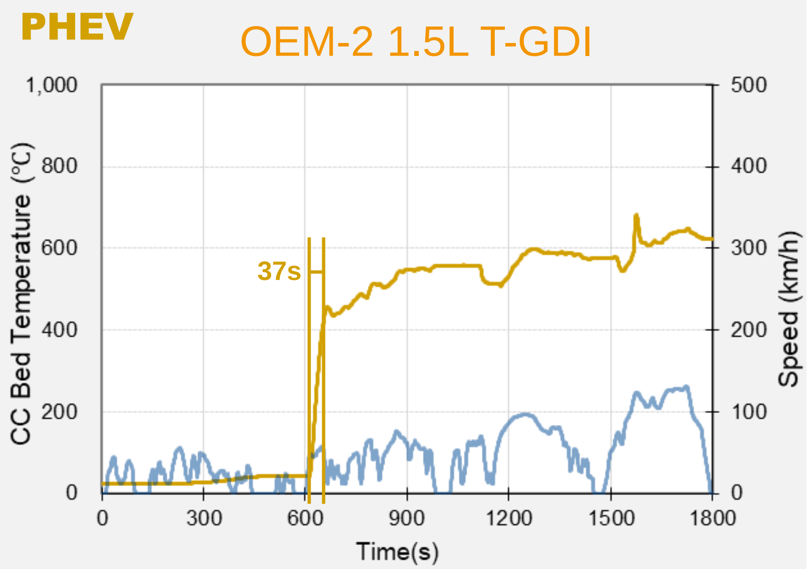
PHEV and REEV Emission Characteristics

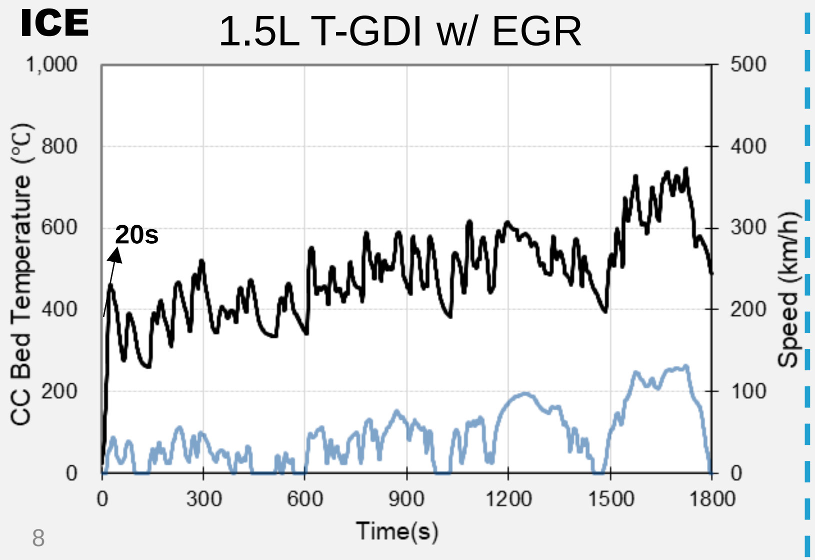
CC Bed Temperature in CS Test

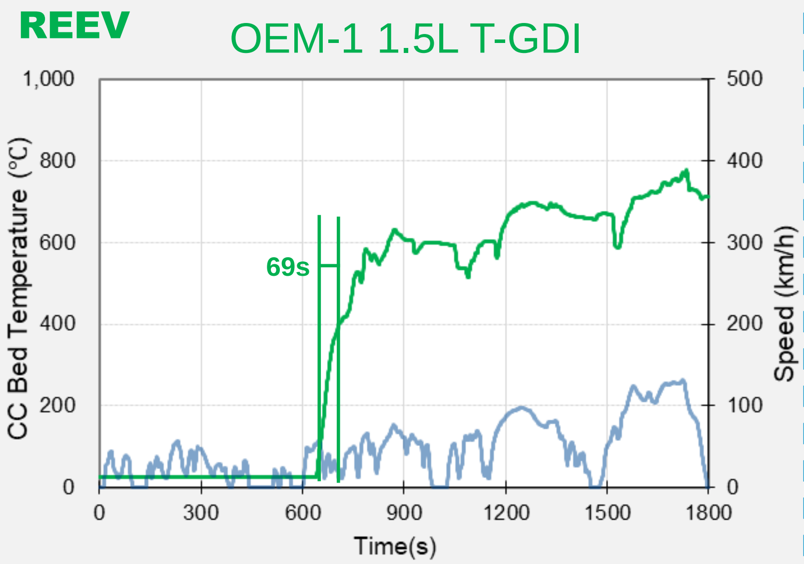
For PHEV and REEV:

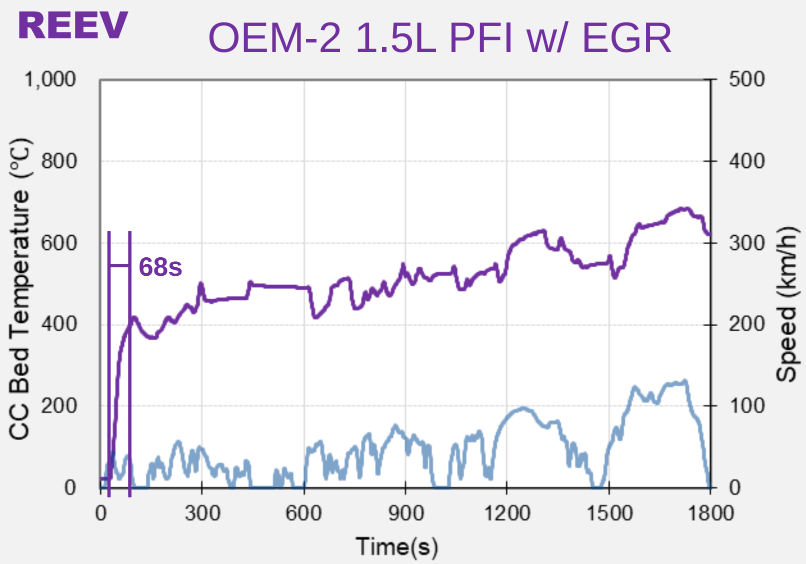
- Slower temperature ramp-up. Challenge for cold-start emissions.
- Less perturbation after light-off. Bed temperature >400ºC, good window for catalyst operation.











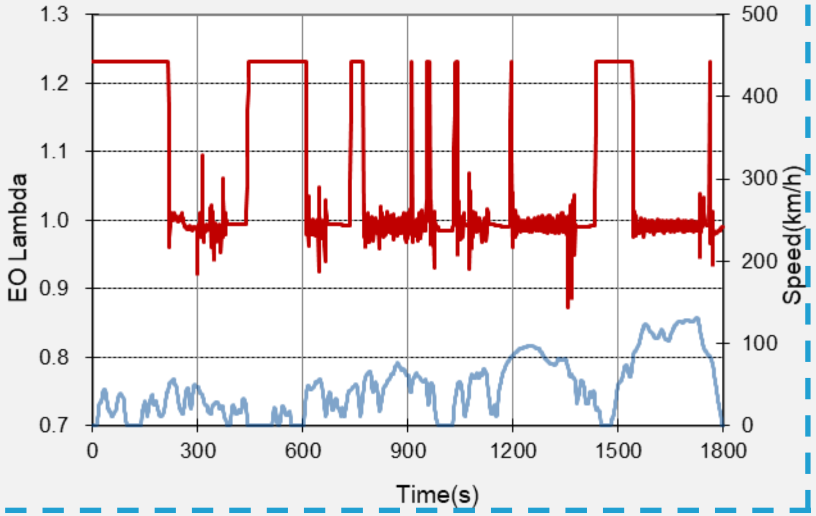
PHEV and REEV Emission Characteristics

EO Lambda in CS Test

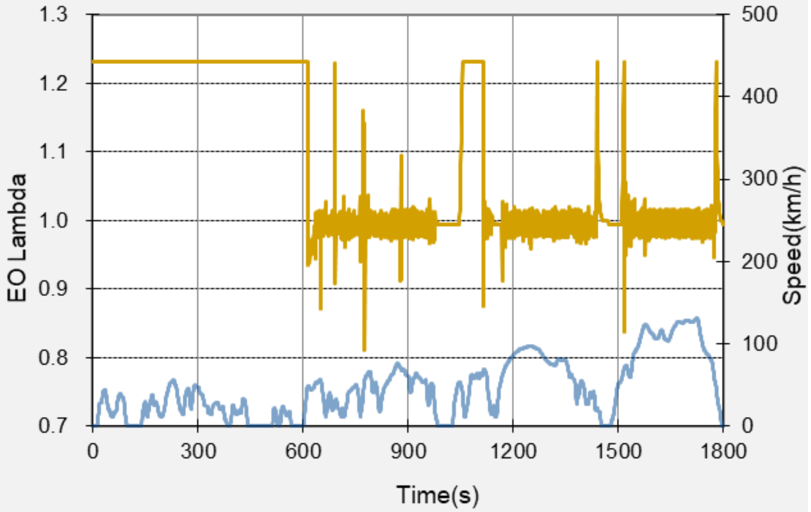
For PHEV and REEV:

- Less lambda perturbation than ICE but behaves differently among vehicles.
- Milder perturbation for PHEV OEM-2 (more lambda 1).
- More fuel cut and rich bias for REEV OEM-2.

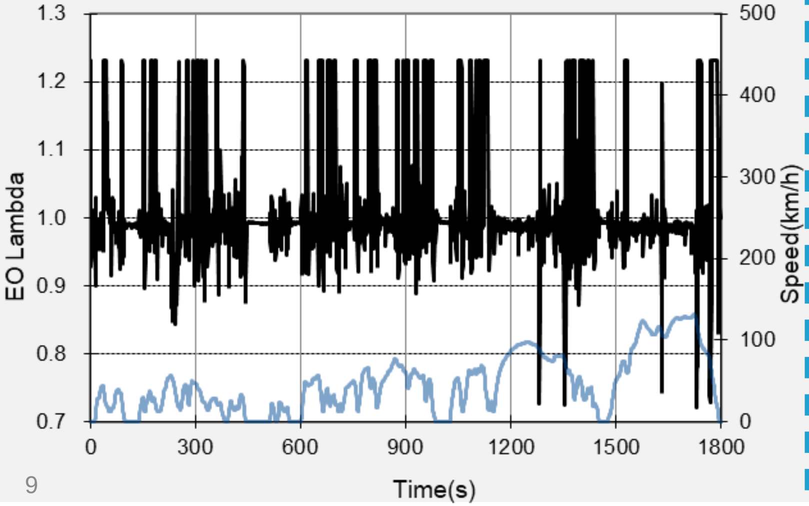
PHEV OEM-1 1.5L T-GDI



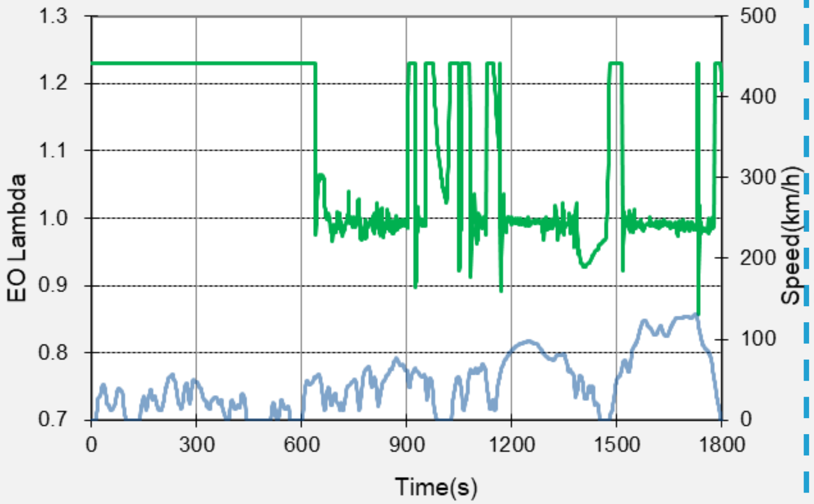
PHEV OEM-2 1.5L T-GDI



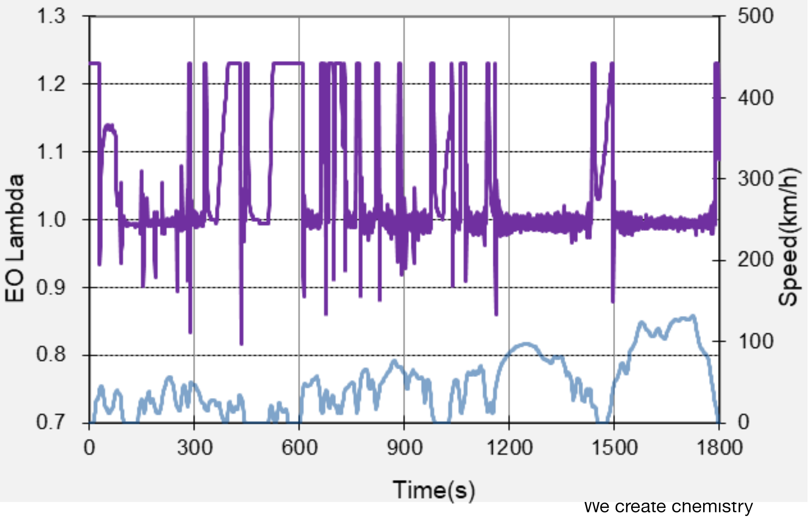
ICE 1.5L T-GDI w/ EGR



REEV OEM-1 1.5L T-GDI



REEV OEM-2 1.5L PFI w/ EGR



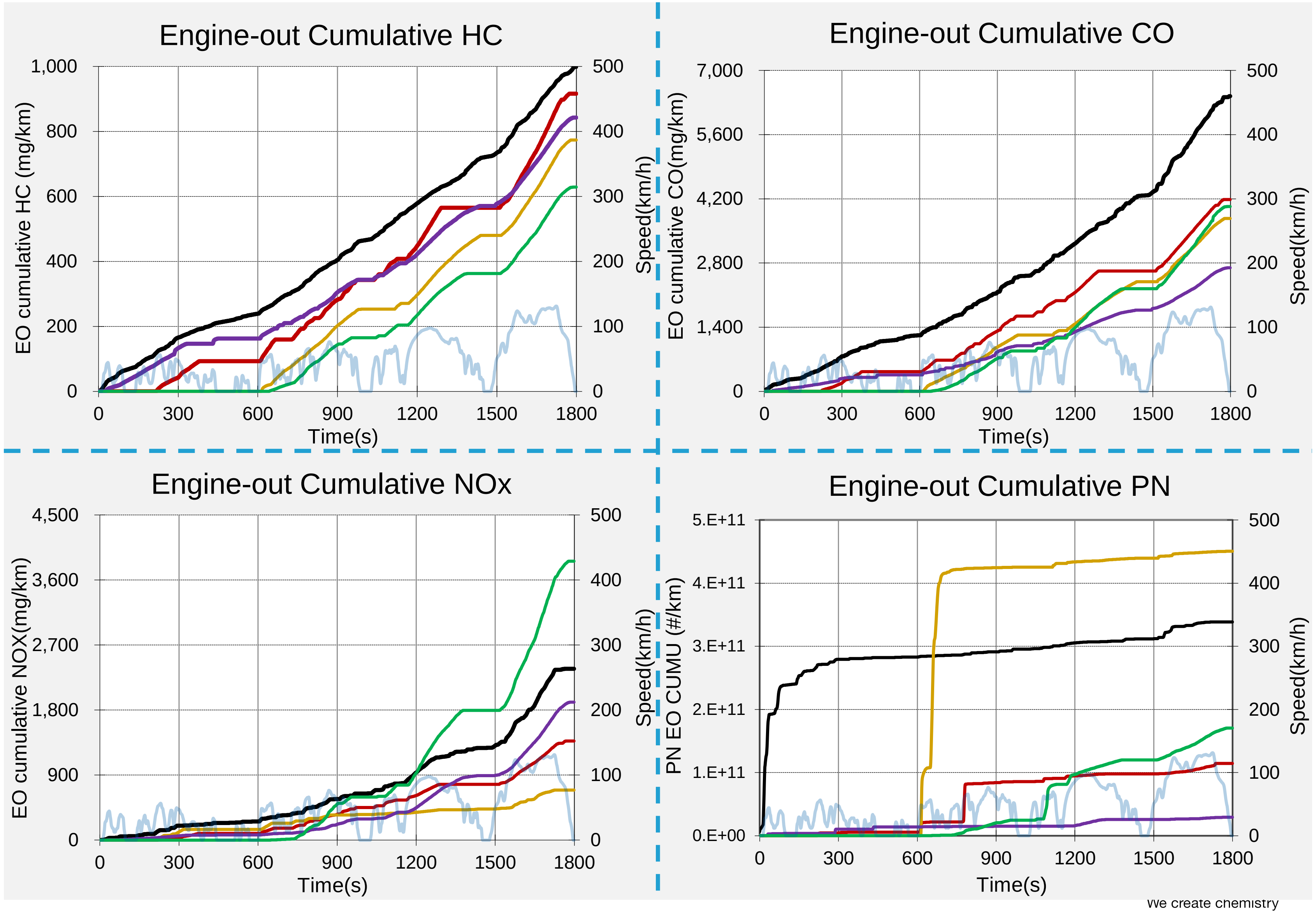
PHEV and REEV Emission Characteristics

EO Cumulative in CS Test

For PHEV and REEV:

- Engine starts late. For some of the vehicles even no emission at Phase1 (first 600sec).
- Engine-out emission behaves differently among vehicles.
- Very low EO PN for REEV OEM-2.

— 1.5T GDI w/ EGR
— PHEV OEM-1 1.5L T-GDI
— PHEV OEM-2 1.5L T-GDI
— REEV OEM-1 1.5L T-GDI
— REEV OEM-2 1.5L PFI w/ EGR



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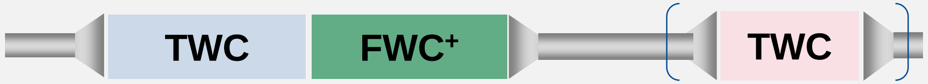
Catalyst Solution for Various LD Powertrain

Pure ICE/Mild Hybrid

Features :
- Quick temperature ramp-up during cold-start
  Heavy engine load in cold-start and high speed
- Challenge 1: long aging duration
- Challenge 2: cold-start and high-speed emissions and particles

Catalyst system :
- Thermal stable TWC for fast light-off
- FWC$^+$ for particles and high-speed emissions
  Optional, uf-TWC for CO/NOx breakthrough



Strong Hybrid

Features :
- EV-only drive possible (engine OFF long periods)
- Frequent restart cycles
- Challenge: Catalyst cooling during long EV phases

Catalyst system :
- Fast light-off TWC with improved thermal stability
- FWC$^+$ for particles and high-speed emissions

PHEV

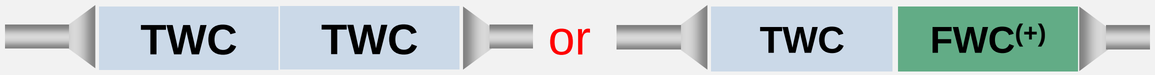
Features :
- Slow temperature ramp-up during cold-start
- Challenge: cold-start emissions and particles

Catalyst system :
- TWC for fast light-off
- FWC or FWC$^+$ for particles and high-speed emissions

REEV

Features :
- Short aging duration
  Slow temperature ramp-up during cold-start
- Challenge: cold-start emissions

Catalyst system :
- Low PGM loading TWC for fast light-off
- 2nd TWC for high-speed emissions, FWC$^+$ depending on PN emissions



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Conclusion

- **Hybridization of the powertrain is a powerful tool to reduce CO_2 emissions for passenger cars.**
- **Hybrid vehicles bring unique challenges for exhaust-gas after-treatment**
  - Delayed catalyst heat up
  - Frequent start and stop
  - Reduced available space
- **TWC and FWC remain the key components to enable cleaner exhaust-gas and to comply with current and future emission regulations for hybrid vehicles**
  - Tailor-made solutions for the divers powertrain conditions are available and continuously improved

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Classified as Internal