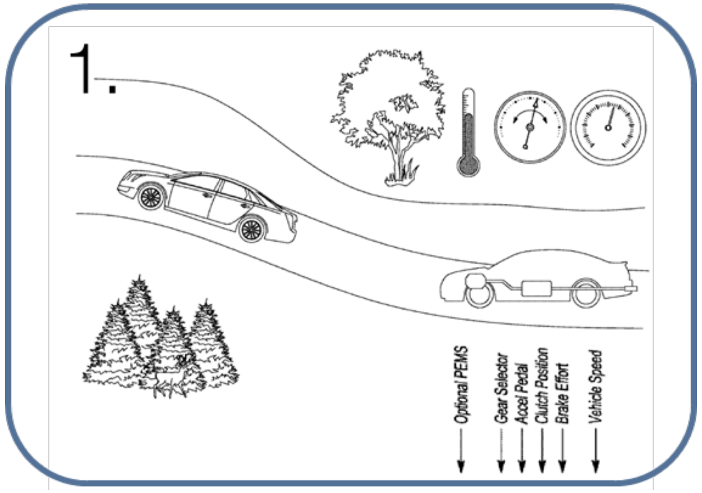
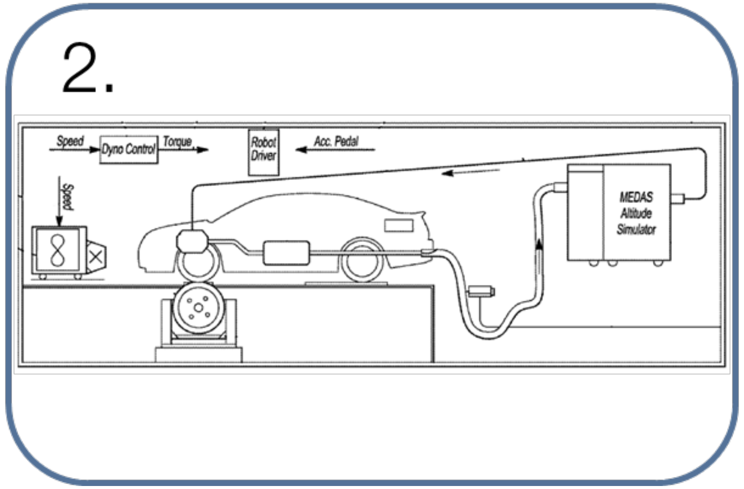
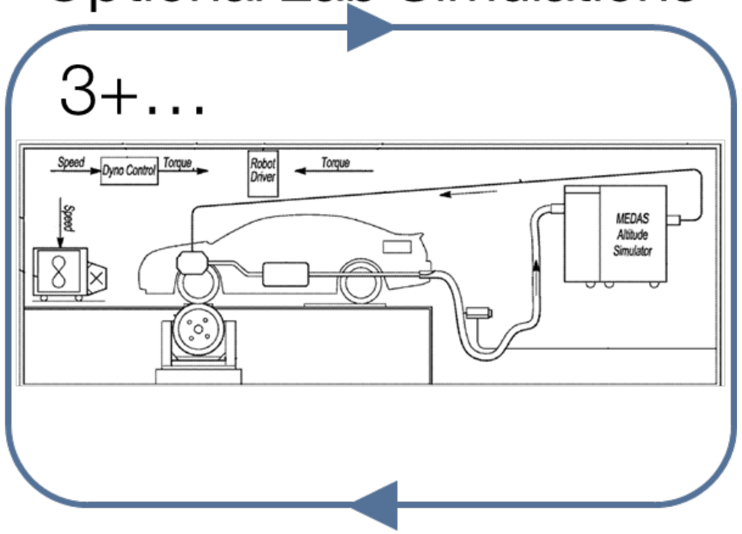
Road Test



Lab Replication/Validation



Optional Lab Simulations



HORIBA TORQUE MATCHING (HTM)

Improved Road to Rig Testing and An Alternative to Mini PEMS for Difficult Applications

UC Riverside OSAR/PEMS Conference - March 30, 2023

Leo Breton, HORIBA Automotive (US)

HORIBA Automotive

EPA ROVER PEMS Started Regulatory Transition (1995)

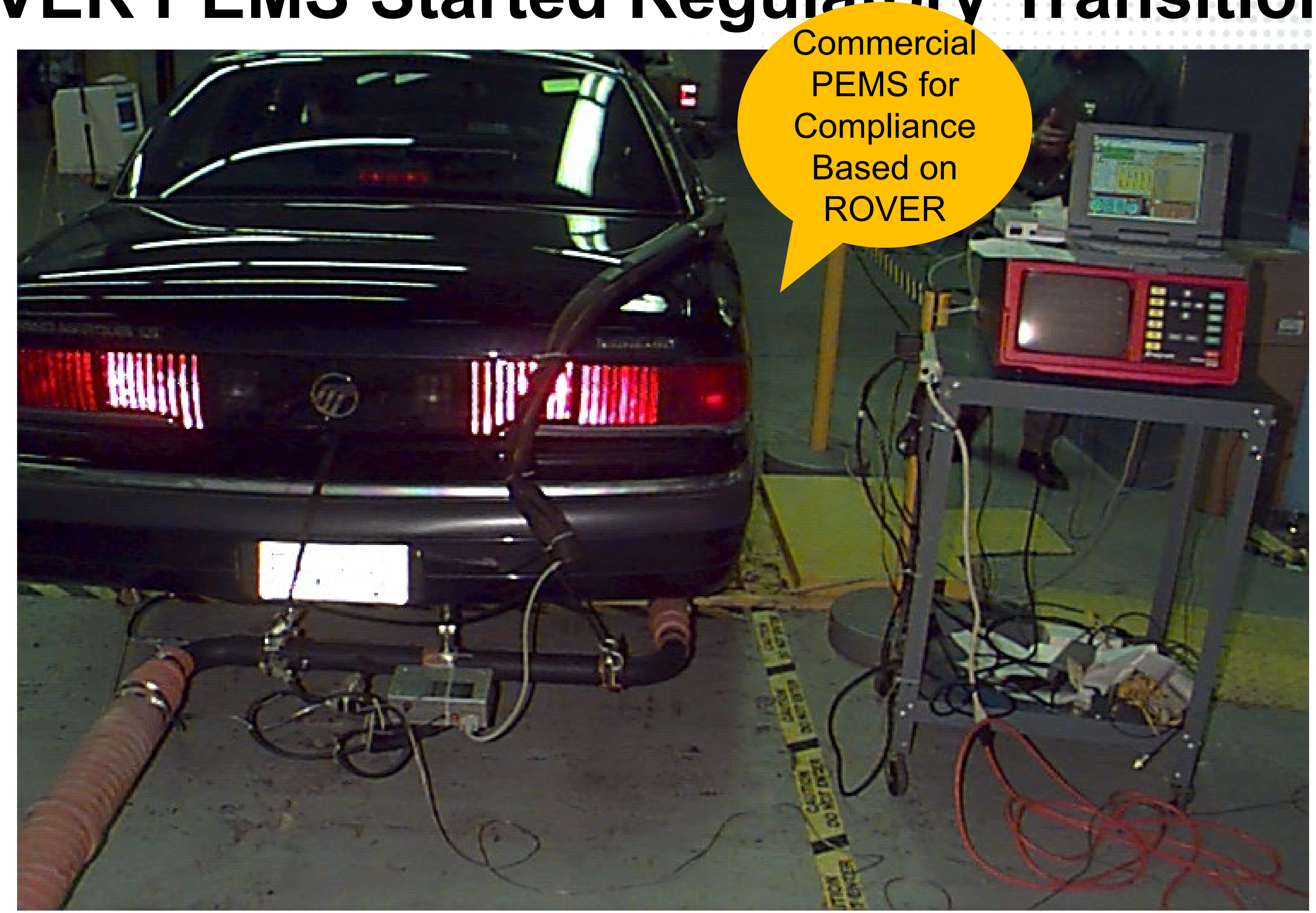
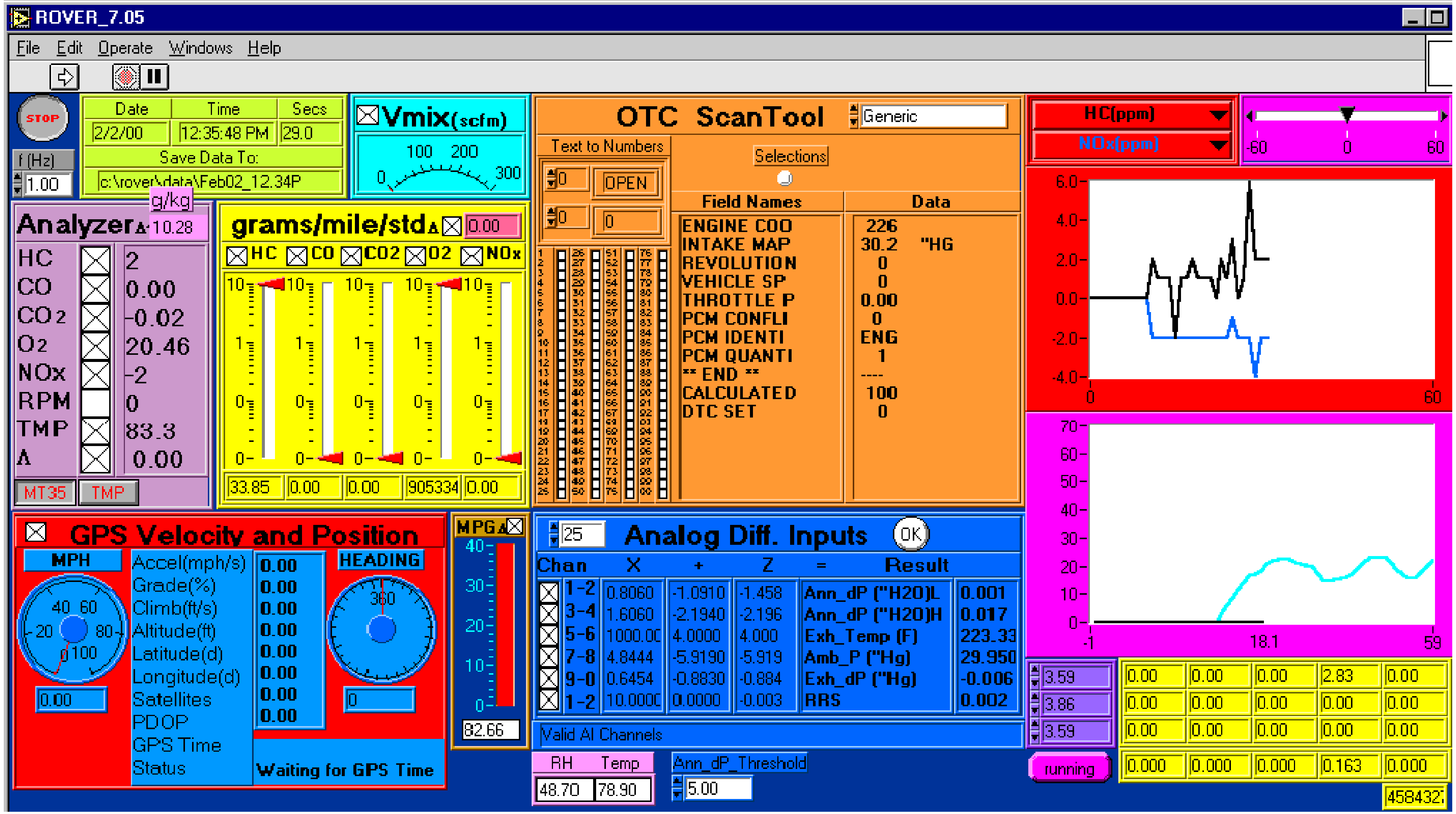


Photo courtesy USEPA
Washington, DC

Real World Test Experience - EPA

Photos courtesy USEPA, Washington, DC

EPA ROVER PEMS Real Time Mass Emissions



Courtesy USEPA
Washington, DC

Listening to the Customer – Motorcycle Example

Hearing “need mini PEMS”

- Lower cost
- Reduced capabilities OK
- Reduced accuracy OK
- Low weight
- Small footprint
- Installable on an arbitrary motorcycle
- Presumably installed external to vehicle

Can we say “need best m/c data possible” instead?

- Lower cost desirable, e.g. minimum equipment purchase
- Increased capabilities desirable
- Increased accuracy/representativeness desirable
- No interference with operation of m/c
- Data can be obtained from an arbitrary m/c

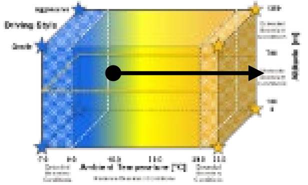
Agenda

1. Brief Introduction to the HORIBA Torque Matching (HTM) Method
2. HTM for ICE / BEV / PHEV
3. HTM Alternative to Mini PEMS
4. Summary and Potential Applications

Real-World Emissions (RWE) Testing Definitions

Replication

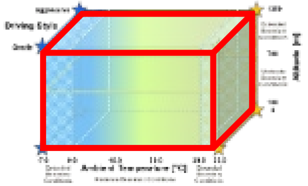
Reproduction of the on-road drive on Chassis, Engine or Powertrain dynos




Emulation

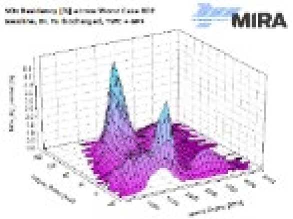
Reproduction of an on-road drive, except for intentional differences for precision calibration, development & validation





Simulation

Virtual simulation of real-world driving environment connected to chassis, engine and powertrain dynos (HiL)

Goals Remain Unchanged – Reproduce Road Drive in Lab

ROAD

Real World Measurement
of Weather and
Powertrain Torque/Speed
Using Instrumented Driveshaft

Replication Thought Experiment

same weather

Replication

same powertrain

same drive

LAB

HORIBA
Automotive

Predict Real World Emissions From Lab Test

ROAD

Real World Measurement
of Weather and
Powertrain Torque/Speed
Using Instrumented Driveshaft

Emulation Thought Experiment

different

LAB

Emulation

Different P/T or Emiss Control

same drive

But Traditional Dyno RLC Model Is Not Robust for R2R (and nobody wants to instrument drive shafts)

Driver Control of Speed With Throttle Can Vary Widely

- Replicating real driving in the lab can be complicated:
- Traditional road to chassis dynamometer model (assumption):

$$F(t) = (A + B * v(t) + C * v(t)^2) + M * \frac{dv(t)}{dt}$$

A,B,C's Depend on Roads and Tires

- But the real world has variable road gradient:

$$F(t) = (A + B * v(t) + C * v(t)^2) + M * \frac{dv(t)}{dt} + M * g * \sin(\alpha)\, t$$

Road Grade is Difficult to Measure Precisely

- But the real world has variable wind:

$$F(t) = (A + B * v_g(t) + C * v_a(t)^2) + M * \frac{dv_g(t)}{dt} + M * g * \sin(\alpha)\, t$$

Air Speed and Ground Speed Can Vary Widely

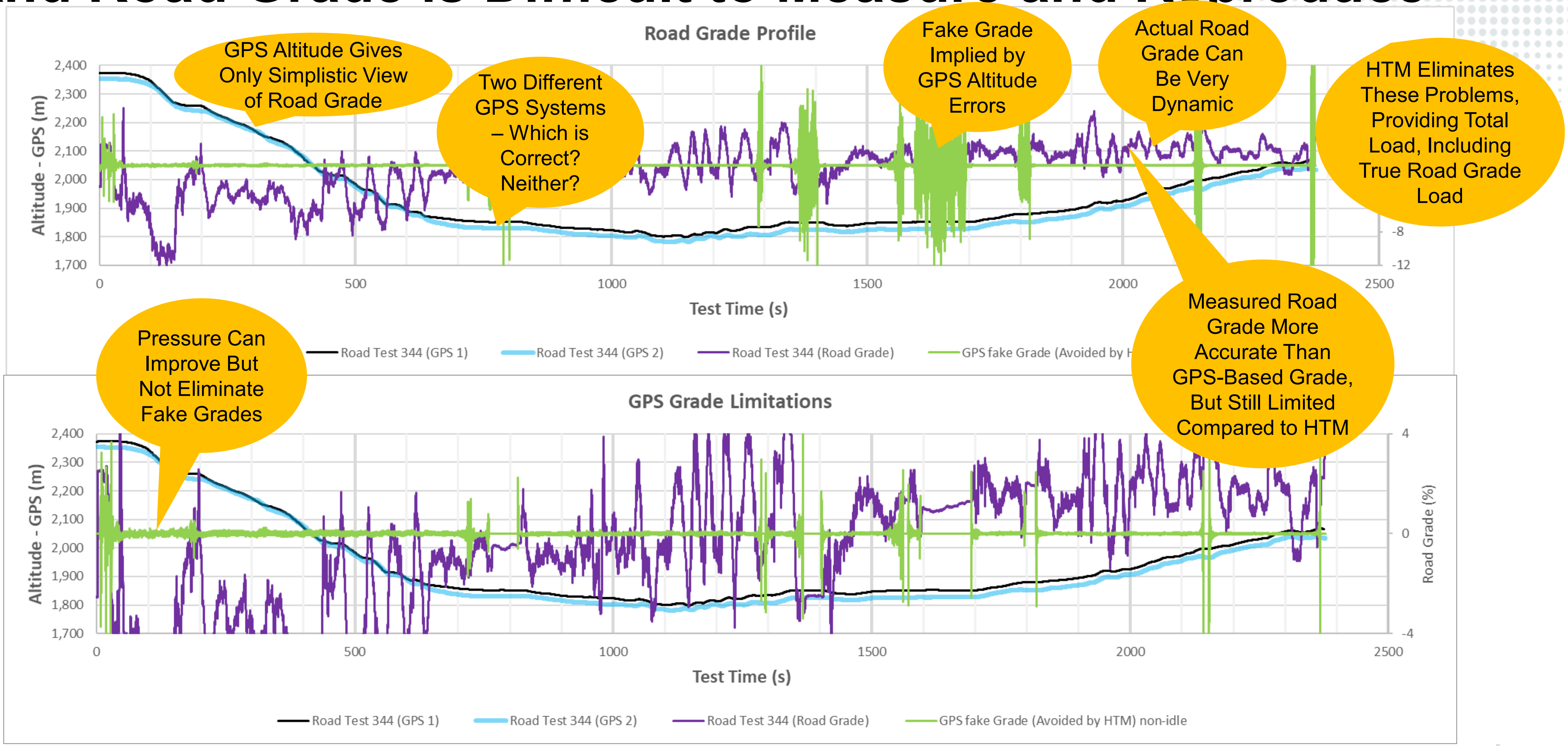
- But the real world has variable air densities:

$$F(t)? = (A + B * v_g(t) + \frac{\rho(t)}{\rho_o} * C_0 * v_a(t)^2) + M * \frac{dv_g(t)}{dt} + M * g * \sin(\alpha)\, t$$

Aerodynamic Drag Depends on Atmospheric Conditions

- Road load is still an idealization; road surface effects, cornering forces, imprecise road grade measurement, throttle movement differences between drivers and tests
- There must be a better way to eliminate the need for vehicle load instrumentation as well as the inaccuracy and imprecision of traditional road load control for road to rig testing ....

And Road Grade is Difficult to Measure and Reproduce



Desirable Attributes for R2R Method Are Embodied in HTM

HORIBA has developed a robust "Road to Rig" test method known as HORIBA Torque Matching that enables blind testing vehicles on a chassis dynamometer to replicate real-world vehicle operation performed virtually anywhere

- Robustness results from meticulously replicating individual controlled powertrain parameters
- Blind testing is ensured by requiring only parameters that are easily measured in the field - no specific technical information related to the test vehicle is required
- HTM allows a centralised testing location to replicate tests from other road test locations for all types of road vehicles

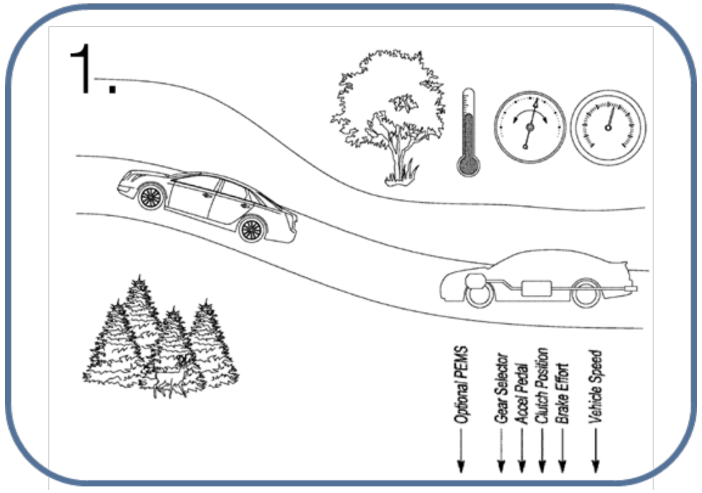
HORIBA's Torque Matching (HTM) method has several, additional and valuable benefits:

- Road grade knowledge is not required but is implicitly accounted for because the total road load is replicated
- Coastdowns and coastdown coefficients are not used because the load is not based on a road load model, but on load replication whereby all road load and changing road surfaces are implicitly accounted for
- Real-world wind conditions are also implicitly replicated
- Conventional test cell hardware, with the addition of MEDAS and HORIBA software can be used
- Matching road load while emulating different ambient conditions, or after component substitutions can help diagnose vehicle failure modes

HORIBA Torque Matching (HTM) Method in General

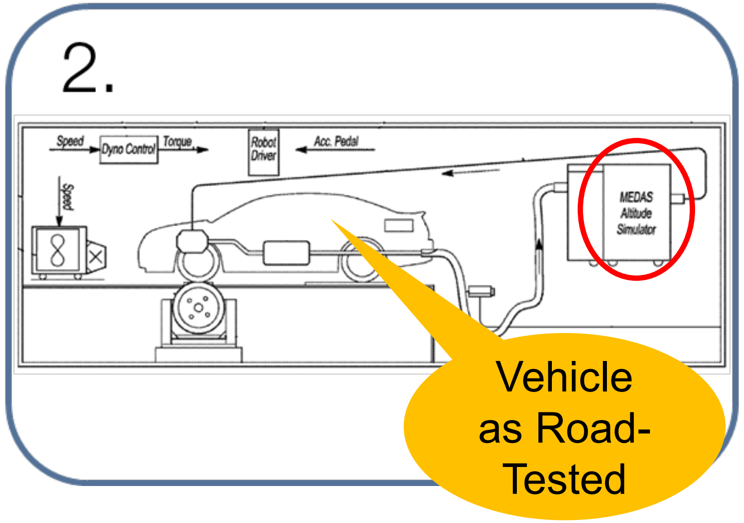
3 Steps to Precision Real-World Testing in the Laboratory Under Any Real-World Conditions

Road Test



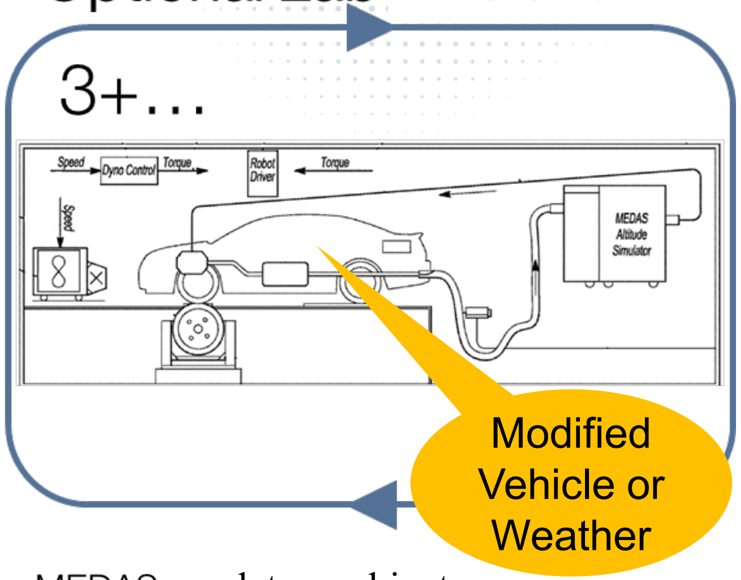
- Record speed, pedals, ambient conditions
- Any grade, surface, weather, altitude, and cornering
- Optionally measure emissions for validation (concentrations only – 5 gas analyzer)

Lab Replication/Validation



- MEDAS replicates ambient
- Dyno replicates speed
- Robot driver replicates pedal or throttle
- Dyno torque *recorded*
- Emissions and load match road test

Optional Lab Emulation



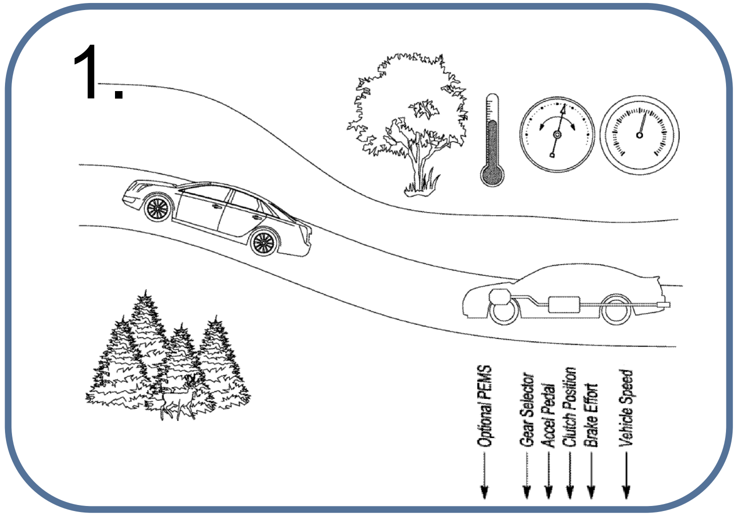
- MEDAS emulates ambient
- Dyno replicates speed
- Robot driver replicates *dyno torque*
- Change engine calibration or emission controls as desired and repeat test for comparison
- Emissions and load would match road test if run

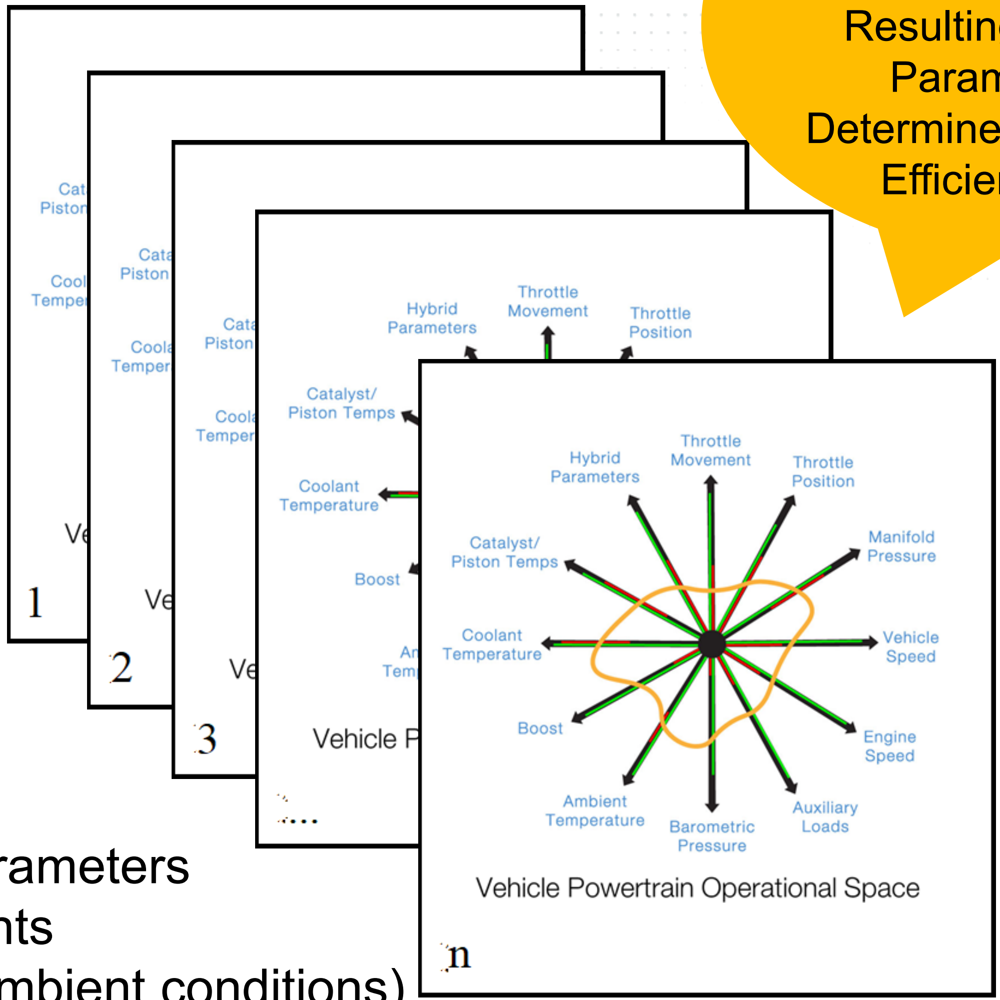
HORIBA Automotive

HTM Method – Road Test (Step 1)

Road Test Creates a Sequence of Controlled Parameters and Resulting Operational Parameters That Determine Emissions and Efficiency Results

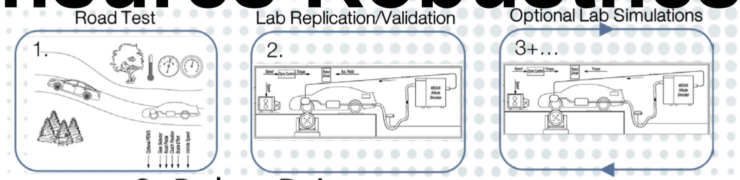
Road Test



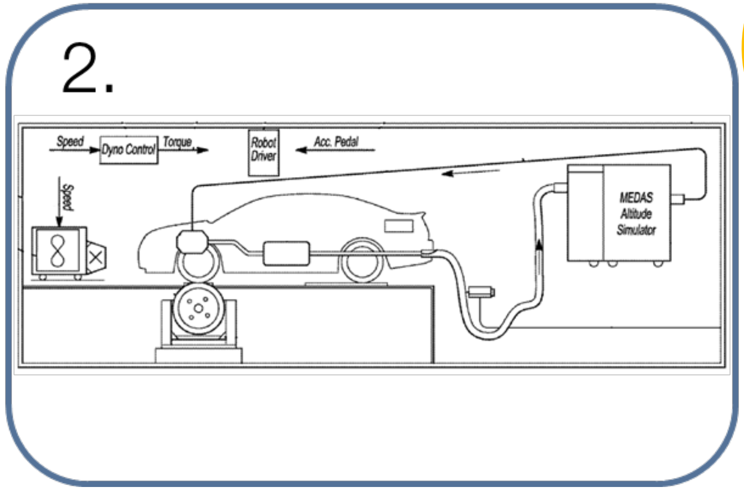


Log Simple Controlled Parameters
Over Small Time Increments
(speed, pedal positions, ambient conditions)

HTM Method–Lab Replication (Step 2) Ensures Robustness

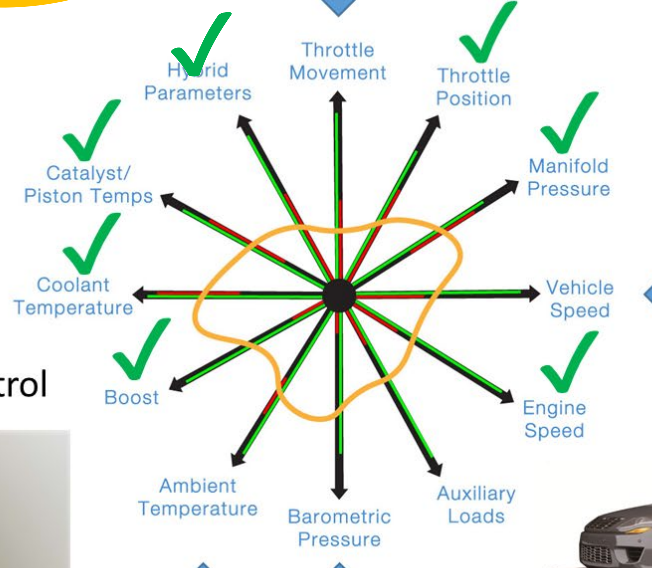


Lab Replication/Validation



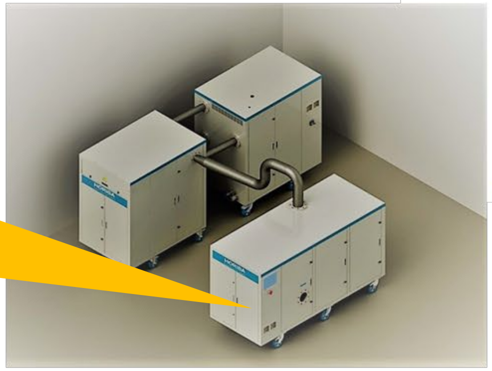
Centralized Lab Testing Can Replicate Test From Anywhere in the World

2. Robot Driver



… Other Parameters Follow

1. MEDAS Intake Air Control



Needed for Centralized Lab Replications Differing Significantly in Elevation

Powertrain Operating State

3. Chassis Dyno

Speed Mode Enables Replication and Eliminates Load Modeling

Road-to-Chassis Goal

Potential geographic diversity of testing locations for centralised laboratory testing

- Replicate a road test from anywhere in a central lab
- Emulate same test under different ambient or seasonal conditions, or evaluate failure modes
- Evaluate the effects of component substitution on emissions performance
- Evaluate the effects of alternative calibrations
- Evaluate the absolute effects of lubricant and fuel blends across well defined, fully controlled real-world driving scenarios.

Agenda

1. Introduction to the HORIBA Torque Matching (HTM) Method
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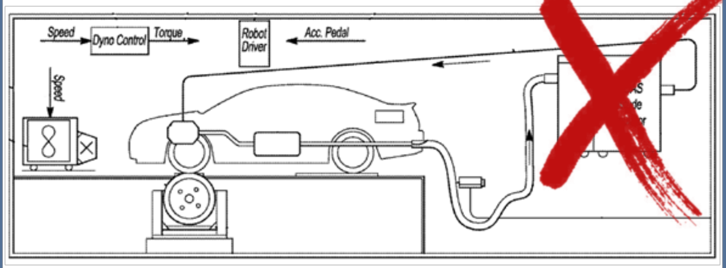
Replication of Pure EV is Simplest Application of HTM

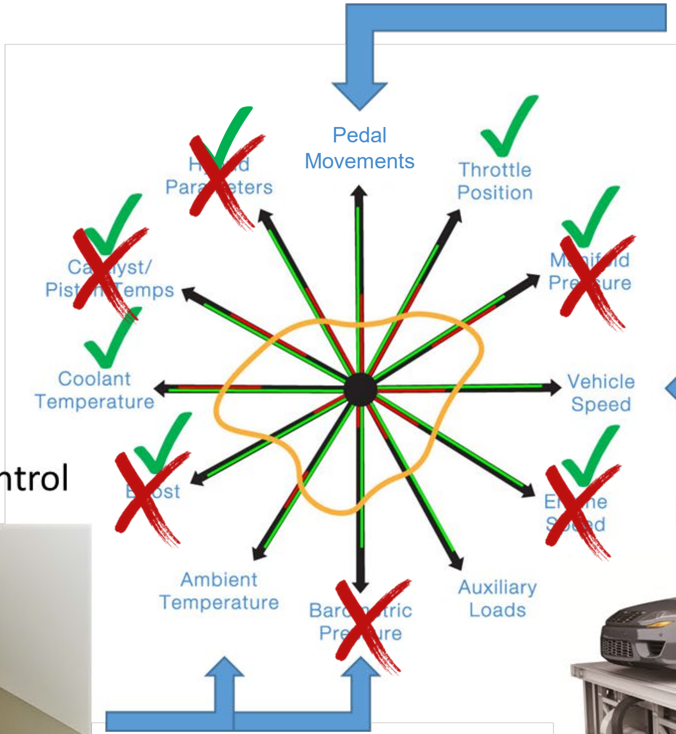
Lab Replication/Validation

2.



Optimization of Real-World Range and Energy Efficiency Using Replication of a Set of Road Tests in Lab

1. MEDAS Intake Air Control



Powertrain Operating State

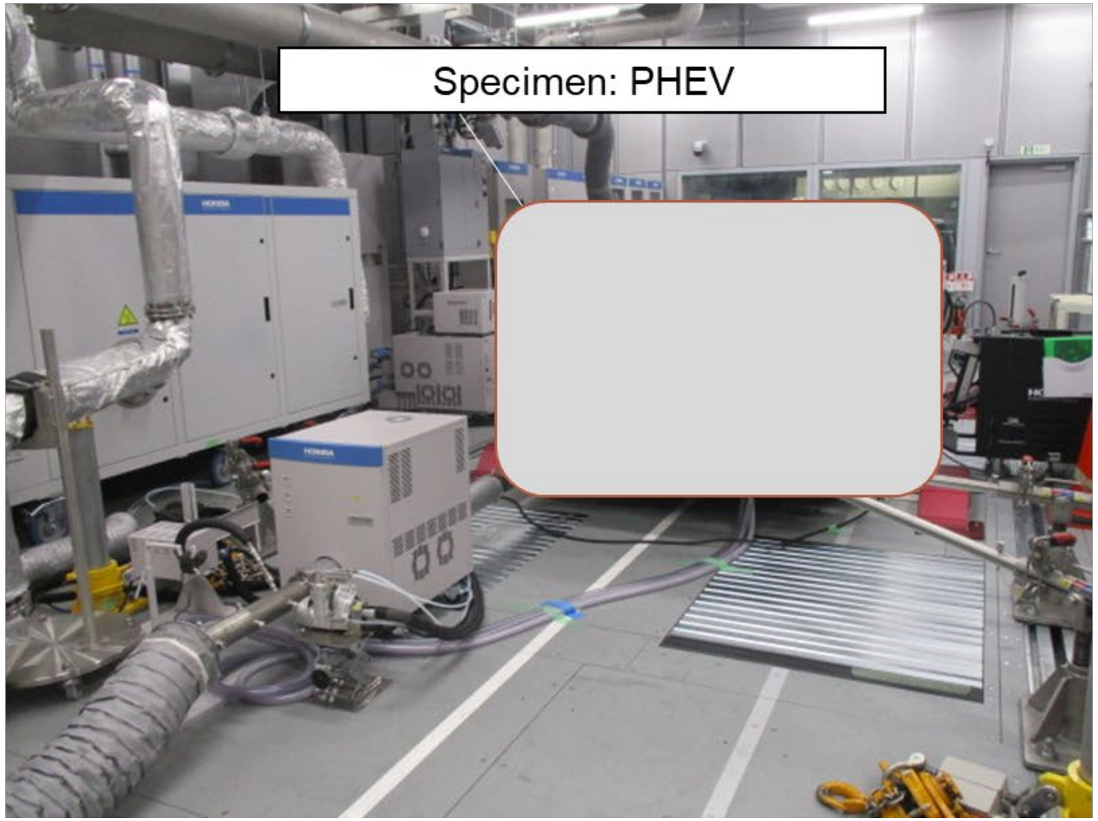
2. Robot Driver

3. Chassis Dyno

PHEV Test Setup in Lab and On-Road

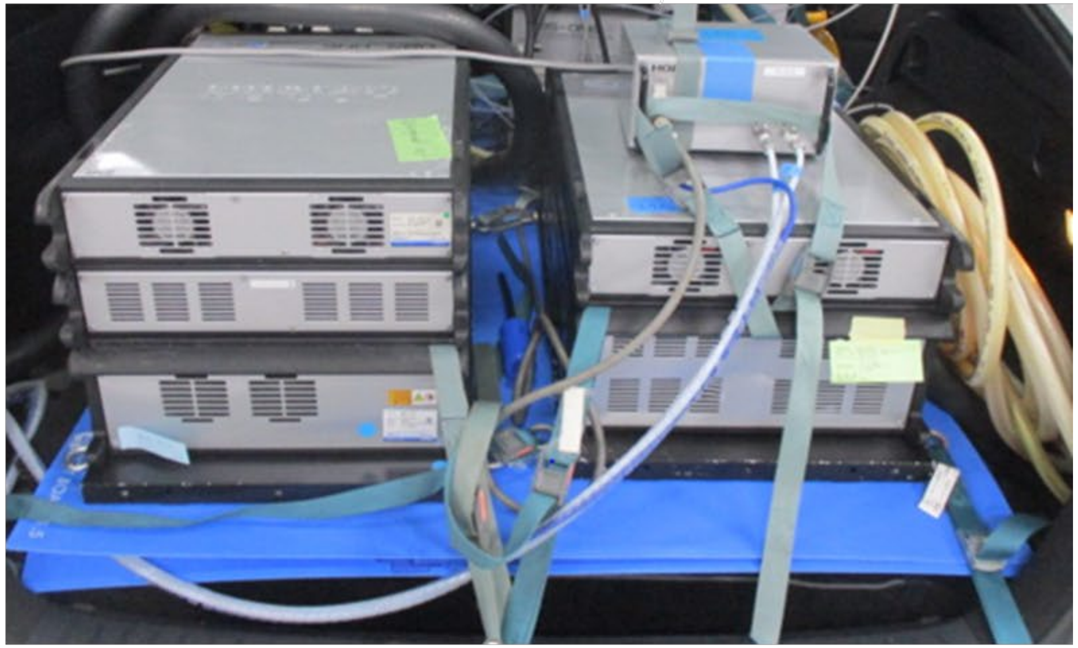
Independent Testing in Japan by applications group, independent from HTM developers

Test cell (HOR E-LAB cell3)



PEMS

HOR OBS-ONE GS/PN



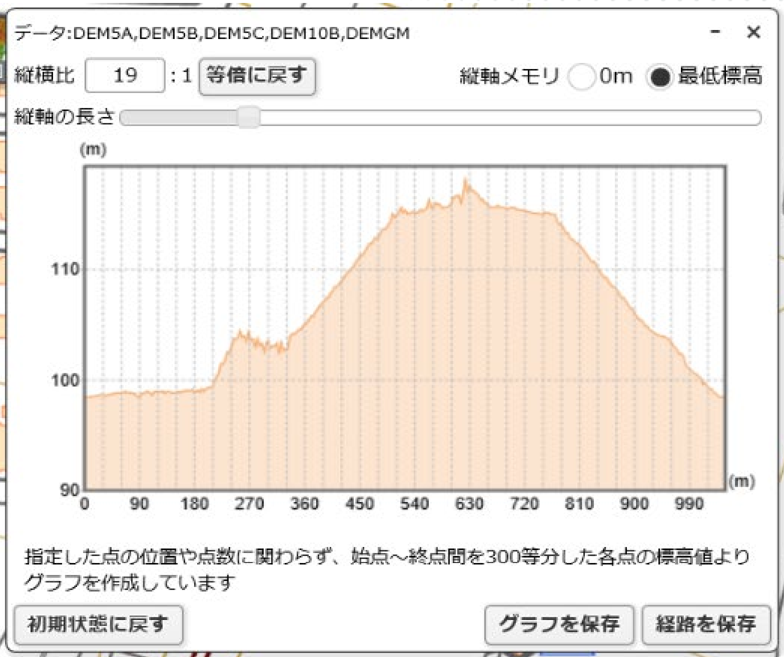
PHEV Real-World, On-Road Test

HORIBA BIWAKO E-HARBOR

HORIBA, Japan

- Distance: 1km
- Time: 3min
- Gradient: Max. 7%
- Altitude: 100-120m

X3 rounds



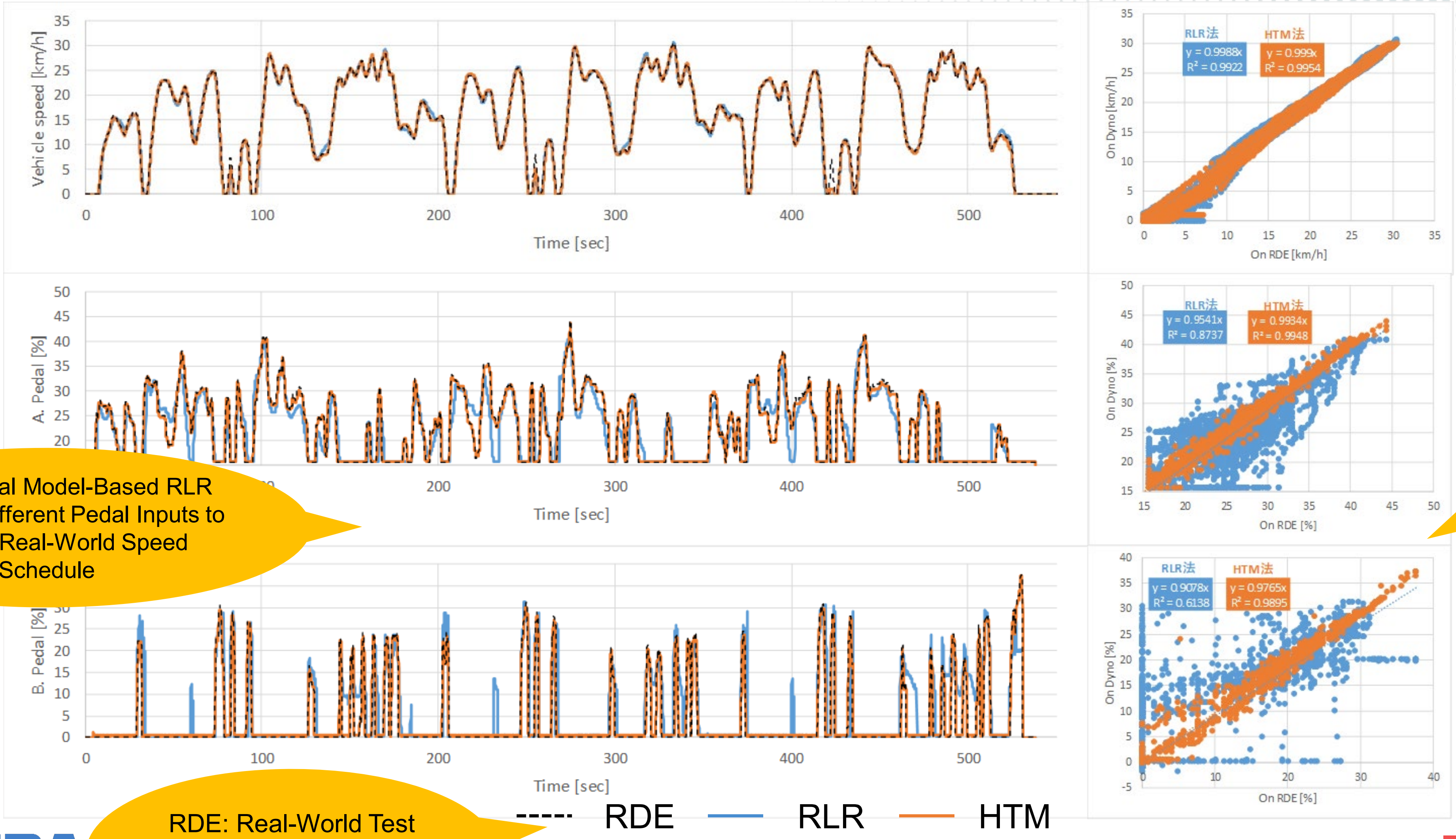

Uphill area


Factory area

HORIBA
Automotive

Confidential

Superior Replication of PHEV Control Parameters



Replication by Chassis Dyno

Replication by Robot (can be "by-wire")

Conventional Model-Based RLR Results in Different Pedal Inputs to Maintain Real-World Speed Schedule

RDE: Real-World Test
RLR: Road Load Control
HTM: HORIBA TM

HORIBA Automotive

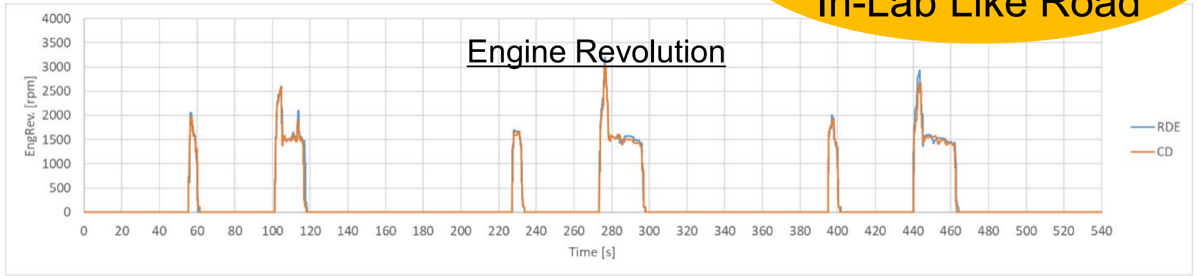
Reproduction of ICE Resulting Operational Parameters

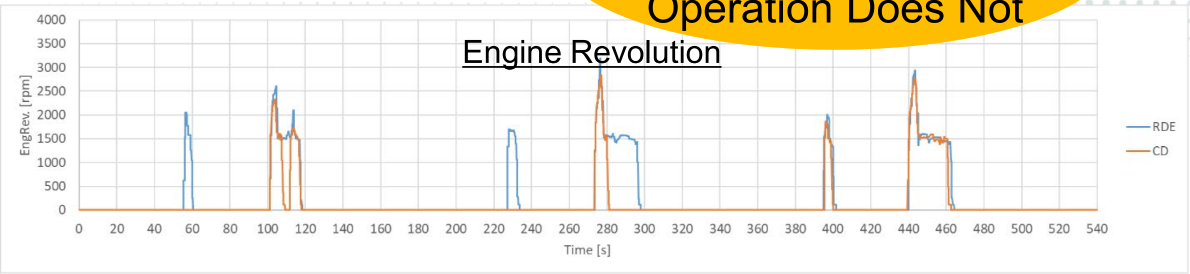
HTM (HEV)

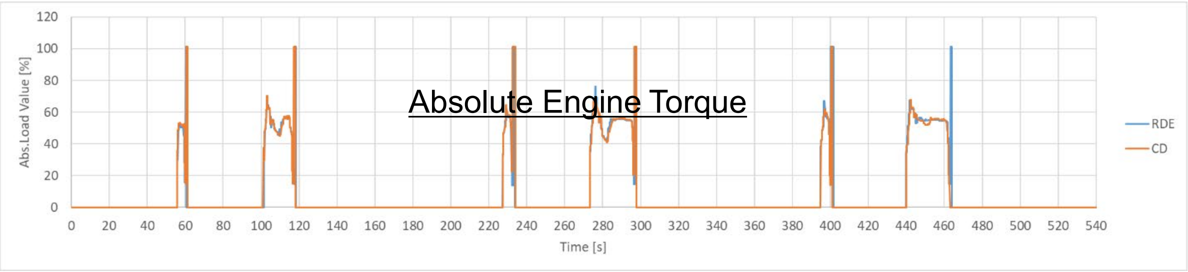
HTM Results in Engine Operating In-Lab Like Road

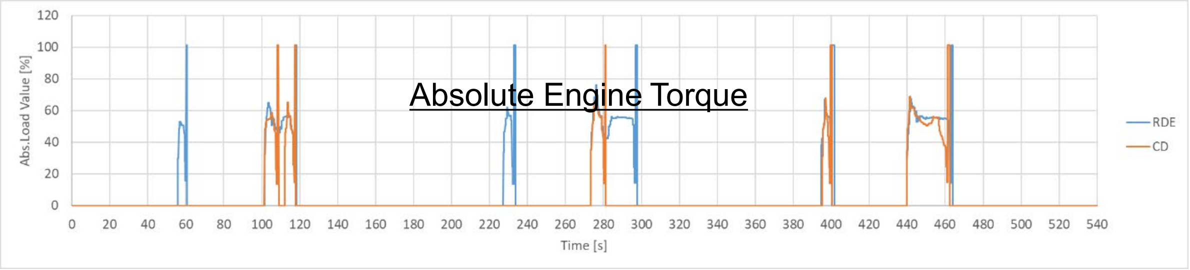
RLR (HEV)

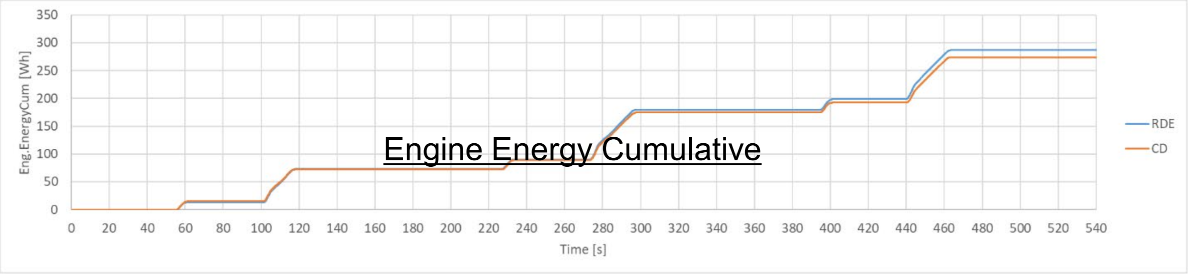
Conventional Road Load Dyno Operation Does Not

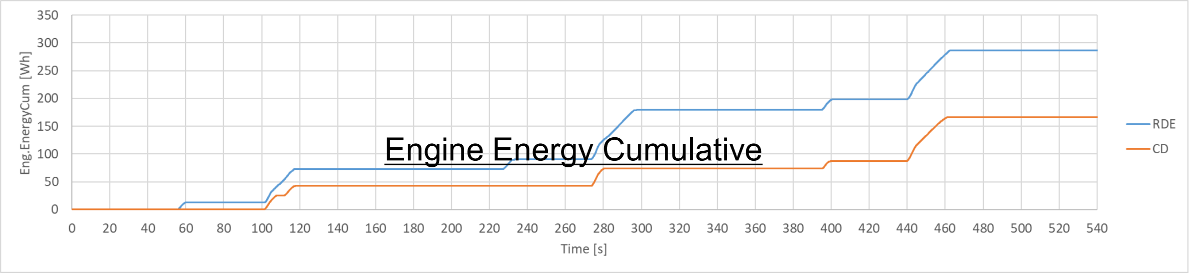












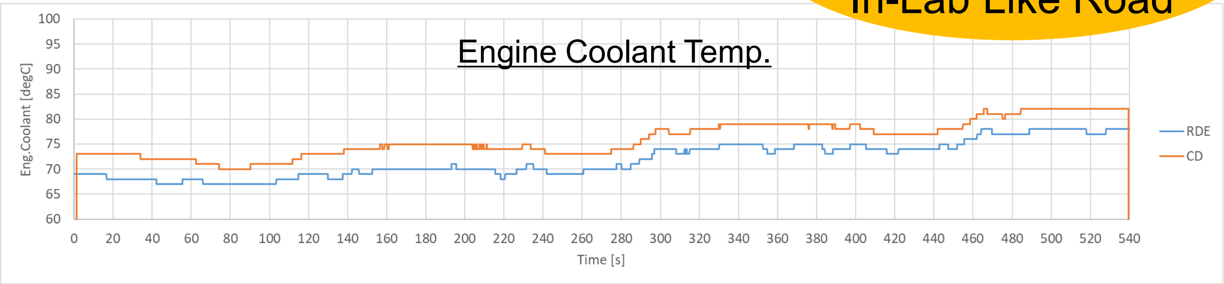
Reproduction of ICE Resulting Operational Parameters

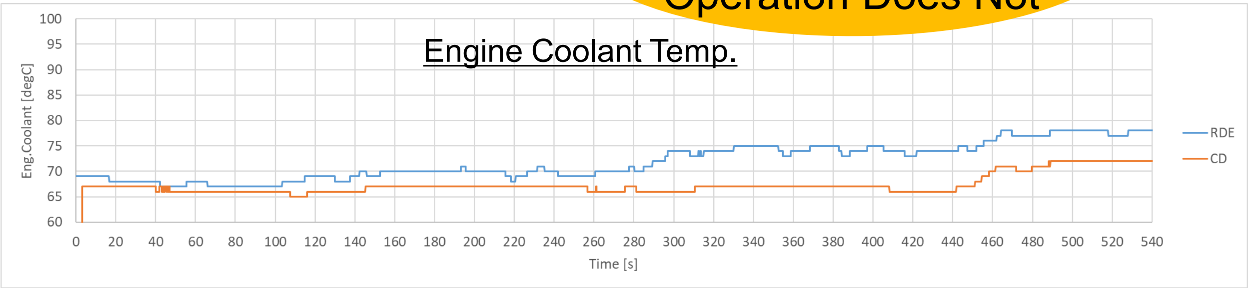
HTM (HEV)

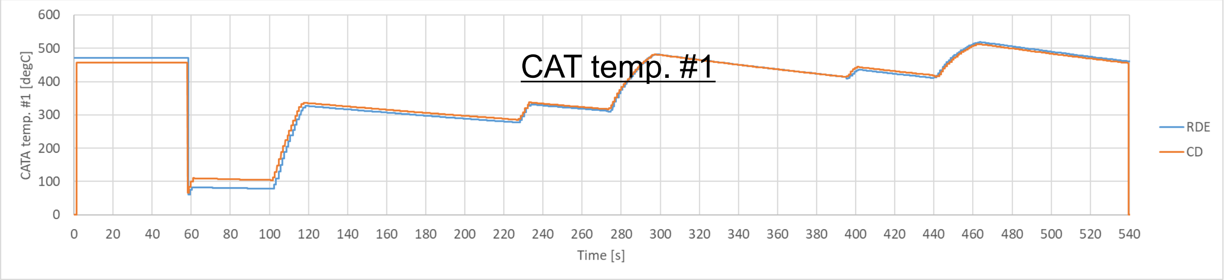
HTM Results in Engine Operating In-Lab Like Road

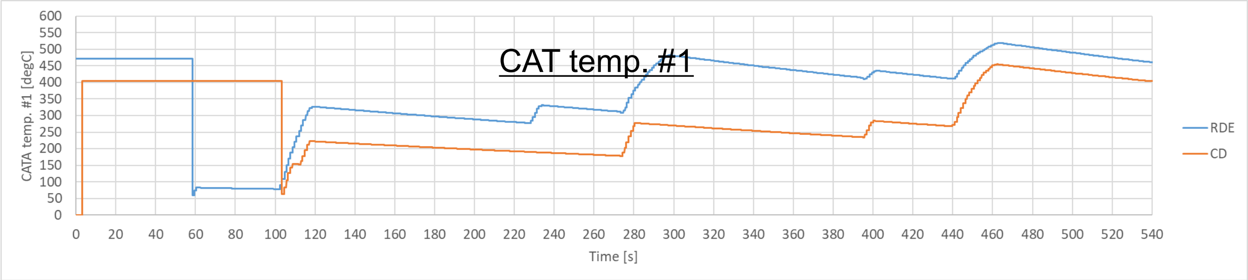
RLR (HEV)

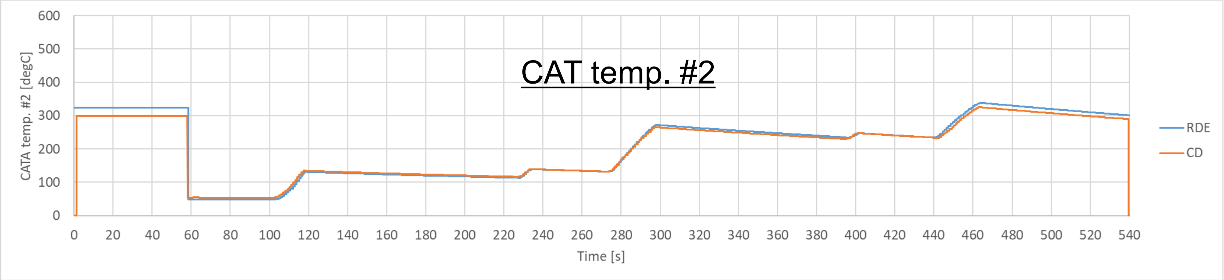
Conventional Road Load Dyno Operation Does Not

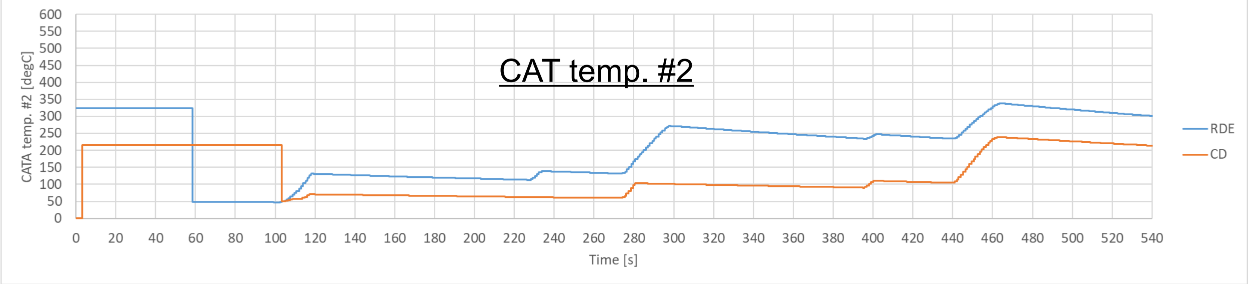




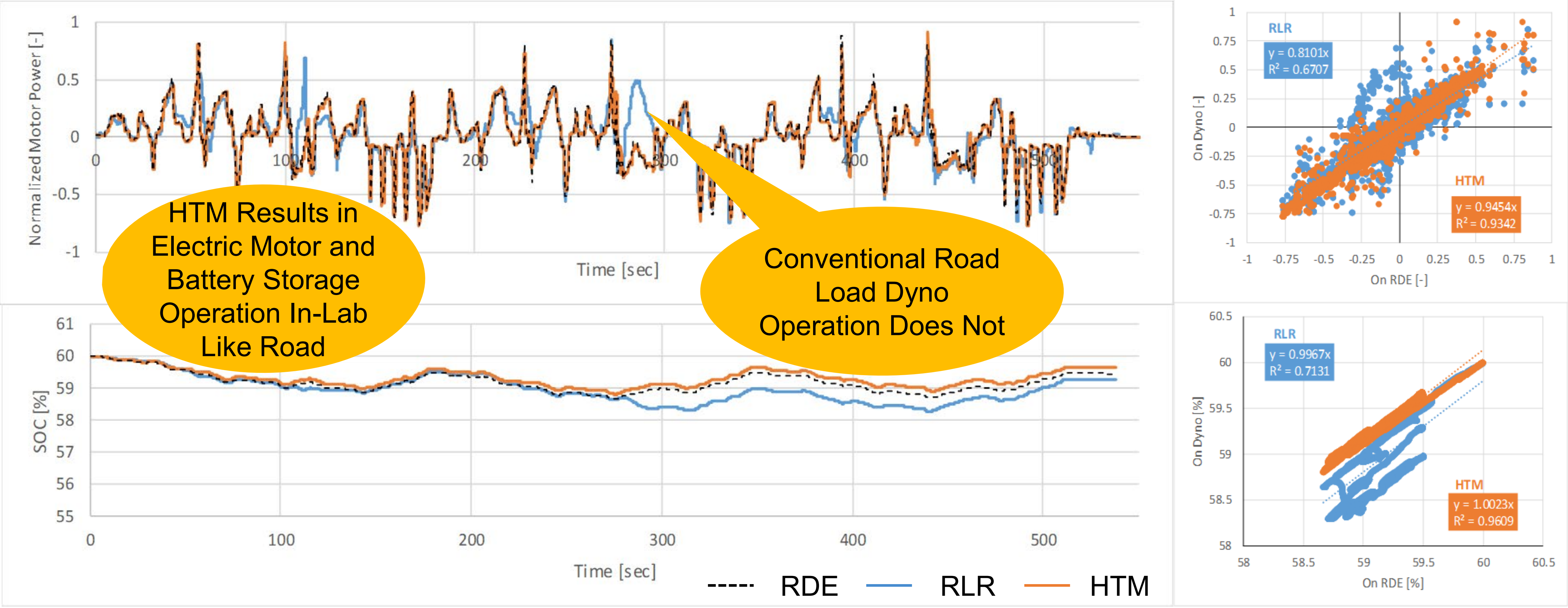








Reproduction of EV Resulting Operational Parameters



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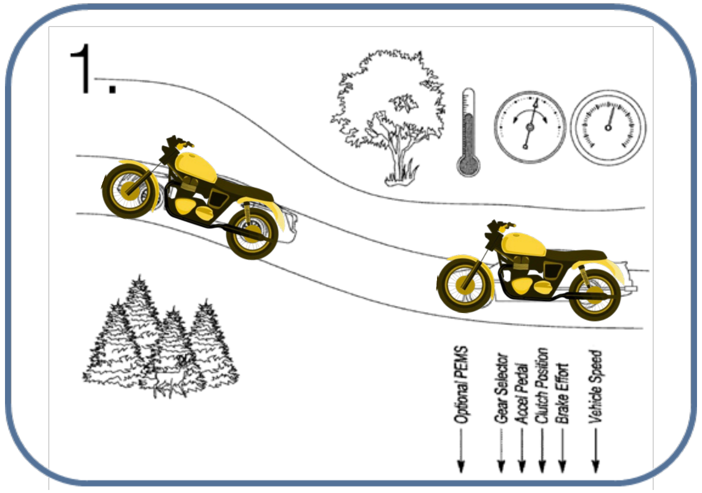
HORIBA Torque Matching (HTM) Method - Motorcycles

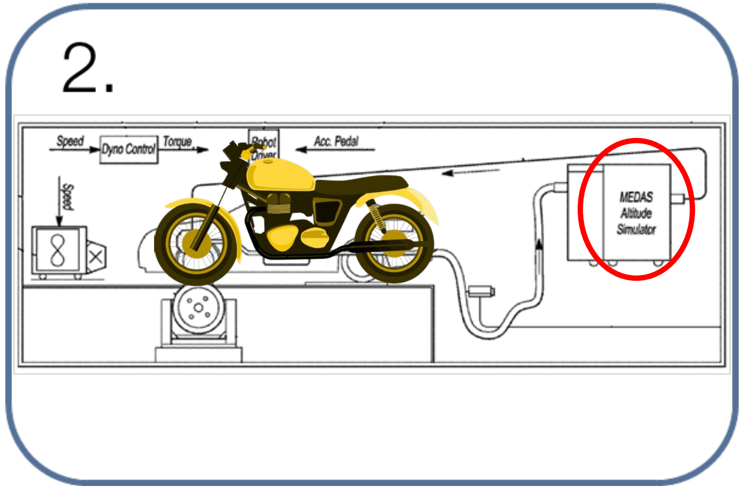
3 Steps to Precision Real-World Testing in the Laboratory Under Any Real-World Conditions

Road Test



- Record speed, pedals, ambient conditions (engine speed or gear shifts)
- Any grade, surface, weather, altitude, and cornering
- Optionally measure emissions for validation (concentrations only with small 5 gas analyzer)

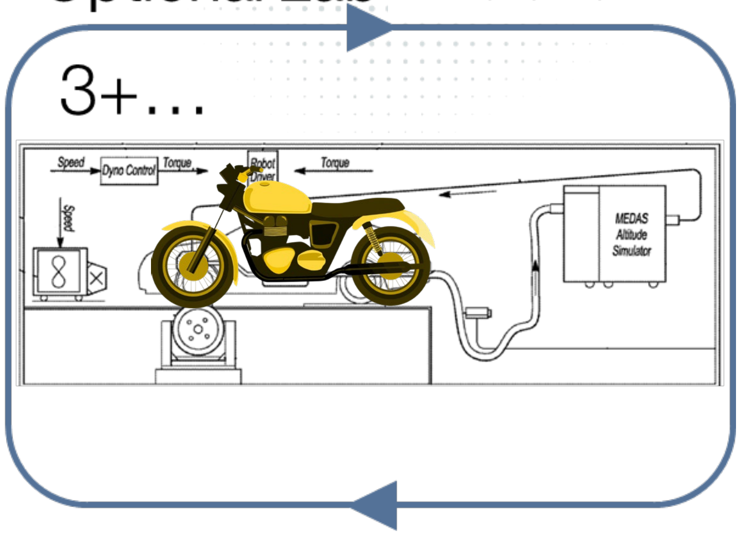
Lab Replication/Validation



- MEDAS replicates ambient
- Dyno replicates speed
- Robot driver replicates pedal or throttle
- Dyno torque *recorded*
- Emissions and load match road test

(Motorcycle robot for throttle, brakes, and gear shifts)

Optional Lab Emulation



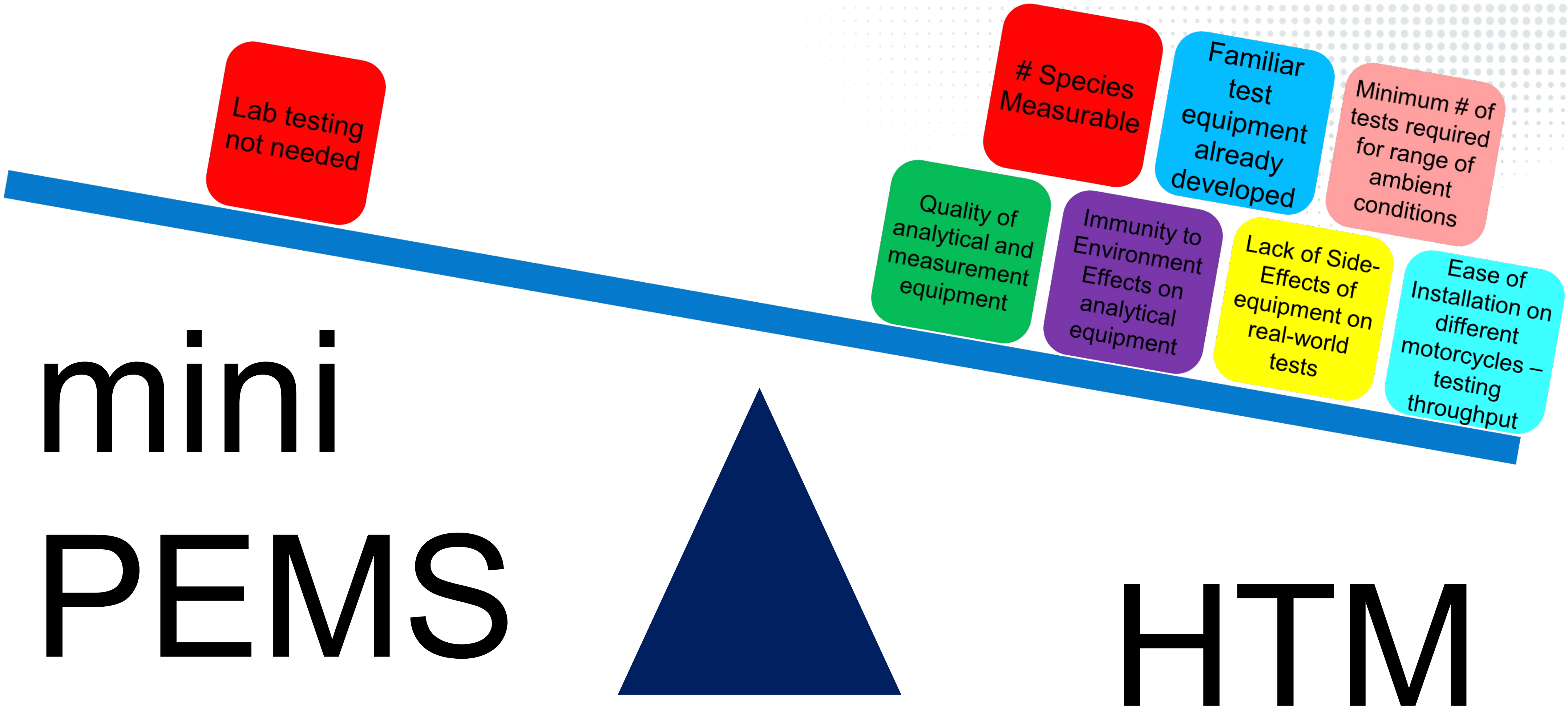
- MEDAS emulates ambient
- Dyno replicates speed
- Robot driver replicates <u>*dyno torque*</u>
- Change engine calibration or emission controls as desired and repeat test for comparison
- Emissions and load would match road test if run

HORIBA Automotive

HTM vs. Mini-PEMS for Motorcycles (+/-): Net +

- Any pollutant or parameter that can be measured in the lab can be measured from a motorcycle while replicating or emulating a real-world drive – high precision, accuracy, and breadth of measurements
- Exhaust flow measurement does not need to be roadworthy
- Avoids effects of wind and ambient effects on gas analyzers
- Real-world emissions events of interest can be reproduced for diagnostic purposes in the lab
- Some emissions events can be eliminated using the precision of the lab once they've been diagnosed
- A single road drive can be used as the base test for multiple HTM tests conducted under different weather conditions or with different powertrain calibrations or replaced faulty components
- An alternative and suitable mini-PEMS still needs to be developed and may not get to market in a usable form factor or with desired accuracies and breadth of measurements – HTM uses existing gas analyzers and flow measurement
- Program measurement errors using Mini-PEMS will be comprised of: concentration errors (analyzer quality and environmental factors), flow errors, instrumentation aerodynamic effects, unavailability of instruments for some pollutants?
- Program measurement errors using HTM results in smaller concentration errors, smaller flow errors, HTM replication discrepencies

HTM for Higher Quality Overall M/C Testing Program



Agenda

1. Introduction to the HORIBA Torque Matching (HTM) Method
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HTM Replication Extends Lab Measurements to Real-World

- Screening road tests can be replicated in the laboratory for diagnostic purposes
- What are the real-world emissions of trace pollutants for which no portable instruments exist?
- Low NOx real-world vehicle/engine testing using laboratory measurements enabled by HTM replication
- Motorcycles can be tested without custom installations or fabrications of flow meters
- High quality data for regulation development, e.g. motorcycles
- HD/LD In-Use Test Programs, e.g. finding real-world problems (HTM Step 1), diagnosing them in the lab (HTM Step 2), then proving fixes by component substitutions or calibration changes (HTM Step 3)

HORIBA
Automotive

HTM Emulation (Step 3) Answers What-if’s

A vehicle met the required emissions standards at sea level in warm weather, what if:

- The temperature was colder?
- It was operating at a higher altitude?

An in-use vehicle failed to meet the required emissions standards either on the road with PEMS, or during an HTM replication test, what if:

- A suspect EGR valve was replaced?
- A suspect catalytic converter was replaced?
- A suspect leaky fuel injector was replaced?

How would a baseline emissions inventory or emissions map of a geographic area or commuter corridor improve if experimental emissions controls were demonstrated on high volume vehicles, or how much would emissions geofencing degrade emissions in a geographic area – differences in traffic and weather are avoided, i.e. test results reflect only the intentional change.

Thank you

Omoshiro-okashiku
Joy and Fun

감사합니다

Cảm ơn

ありがとうございました

Dziękuję

धन्यवाद

Grazie

Merci

Ýęč z ßẽ

z ðđf

谢谢

நன்றி

Obrigado

Σας ευχαριστούμε

شُكْرًا

Tack ska ni ha

Большое спасибо

Danke

Gracias