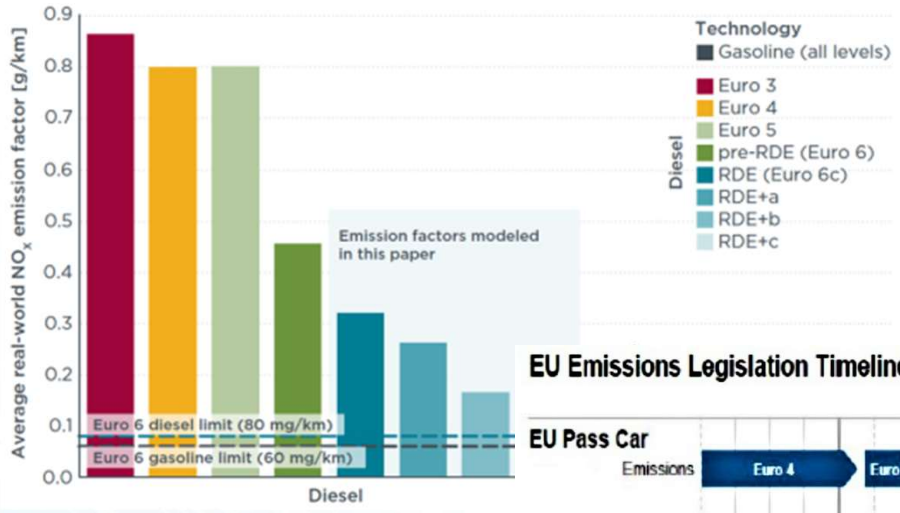
AVL United Kingdom Ltd. (ITS)

The Future of Powertrain and Vehicle Validation

Connected Workshop - 28th Nov. 2019

Nick Birger

WHY: NEED FOR A NEW TEST FIELD

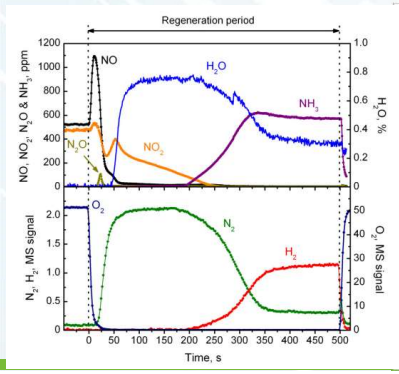


EURO 4 >> EURO 6 >> EURO 6d
NOx – 800 mg/km >>>>> 80 mg/km

Stricter

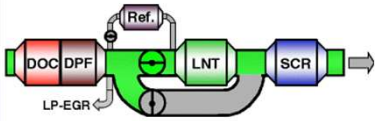
NEDC>>WLTC>>RDE
SteadyState >>>Highly Transient

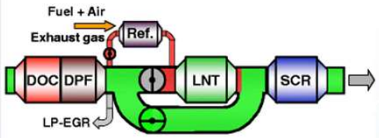
Transient

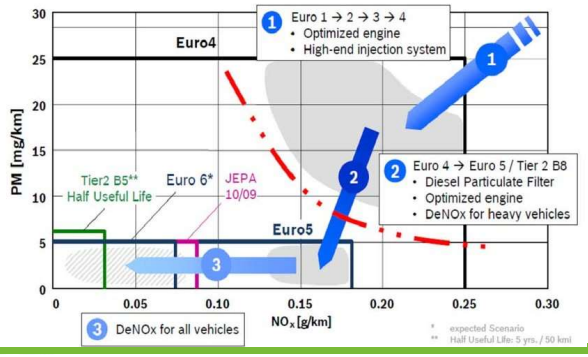


NO_x Adsorption Mode
→ Engine: λ > 1
→ LNT: λ > 1
NO_x-Adsorption
→ SCR: NO_x-Conversion
→ Reformer: inactive
→ Bypass: inactive

NO_x Regeneration Mode
→ Engine: λ > 1
→ LNT: λ < 1
NO_x-Reduction
NH_3-Formation
→ SCR: NH_3-Adsorption
NO_x-Conversion
→ Reformer: active
→ Bypass: active





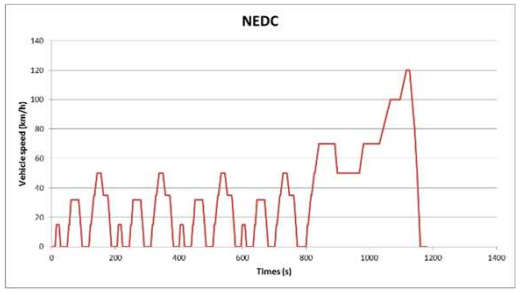


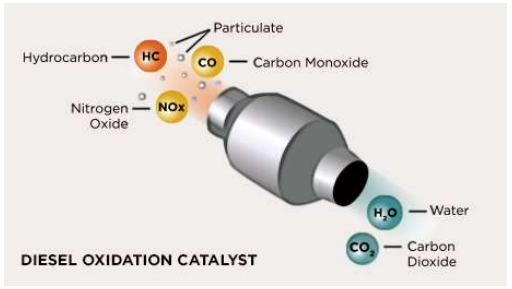
DOC>>>>>LNT+DPF+SCR
Complex Hardware + Software

Complex

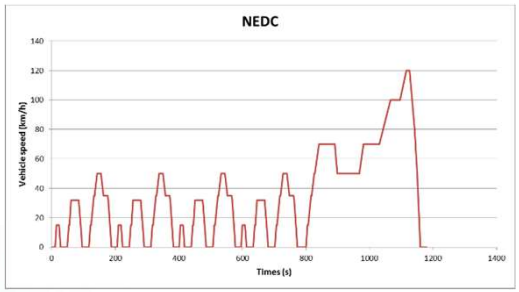
Credit: Mats Ivarson

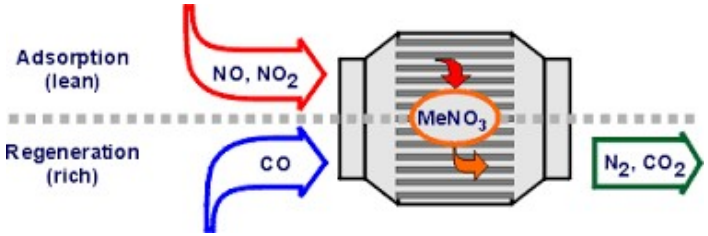
WHY: Diesel Passenger Car Development



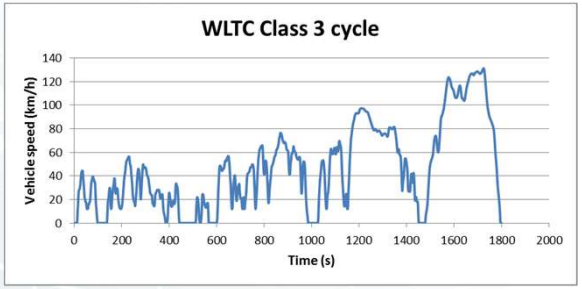


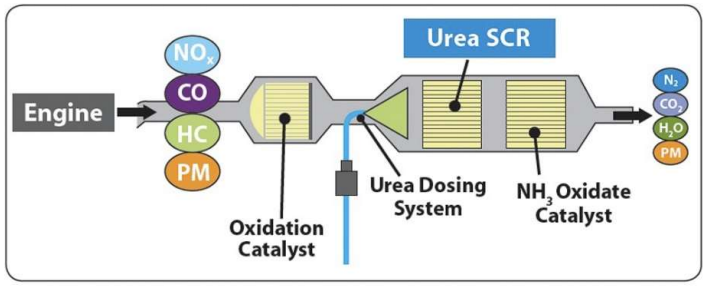
- NEDC
- ✓ DOC





- NEDC
- ✓ DOC
- ✓ LNT

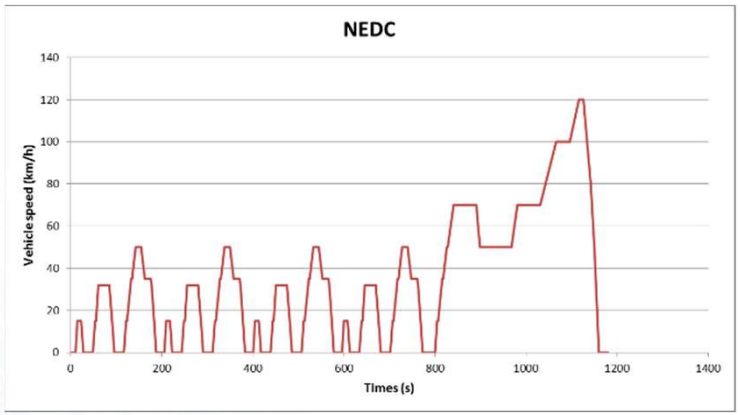


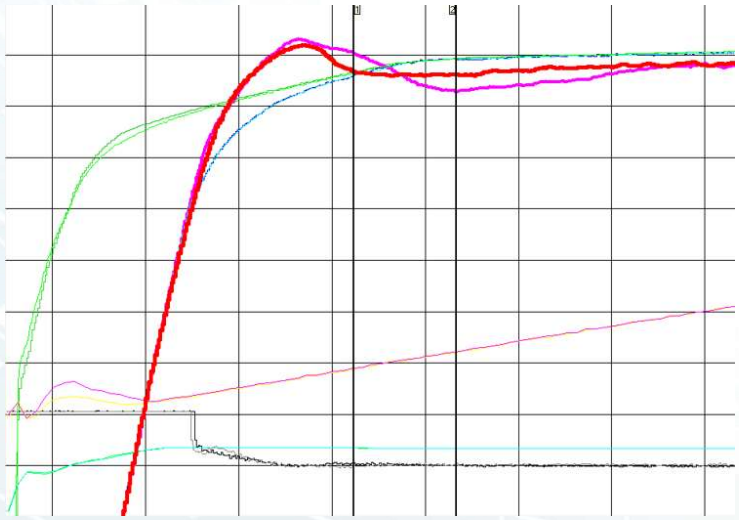


- NEDC
- WLTC
- RDE
- ✓ DOC
- ✓ LNT
- ✓ SCR

Credit: Mats Ivarson

WHY: Transient Activities in Test Bed: EURO-5





The emission cycle is close to stationary

-> No need to calibrate transient emission behavior to pass emission certification

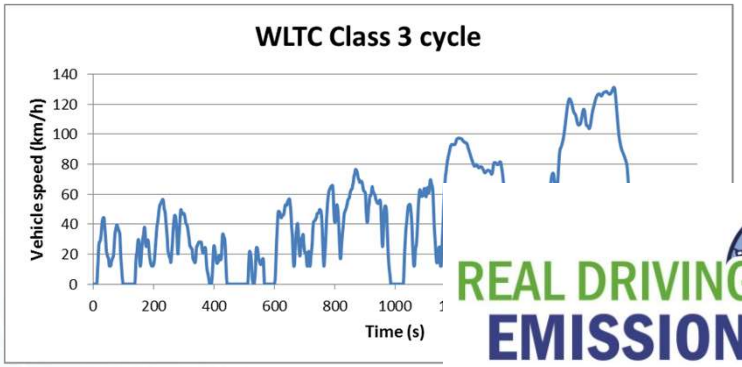
Transient activities mainly done in vehicles

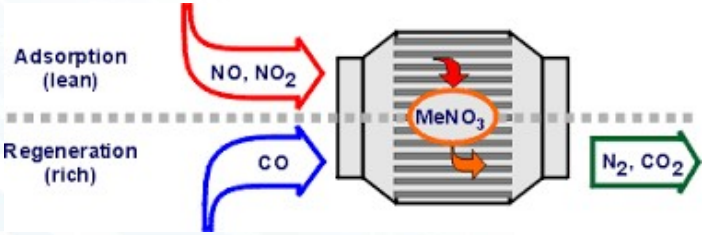
- Drivability
- Response
- Governor tuning – boost pressure, idle control

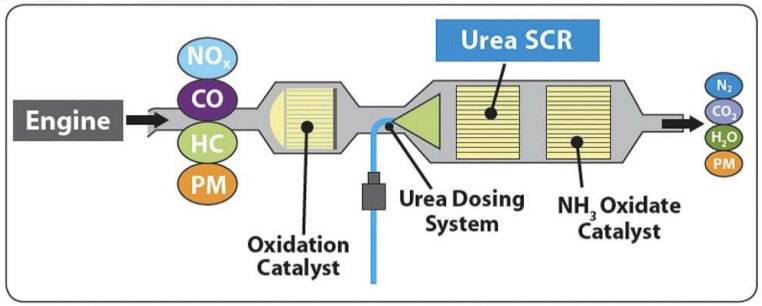
The transient tuning only required signals from the application system (e.g. INCA)

Credit: Mats Ivarson

WHY: Transient activities in testbed: EURO-6D







The emission cycle is transient

Real Driving Emissions (RDE) has to be considered.

The exhaust after treatment system is in many times consisting of both LNT and SCR.

The transient behavior of the emissions must be taken into account for the emission calibration, also in the testbed.

-> Requiring **new development methods** and a high performing data acquisition system.

Credit: Mats Ivarson

WHY: HISTORICAL – CHASSIS DYNAMOMETER

Field of application:

- Vehicle Certification / Homologation
- Emissions Testing
- EV Range Testing
- Development Work
- Largely Popular Means of Testing

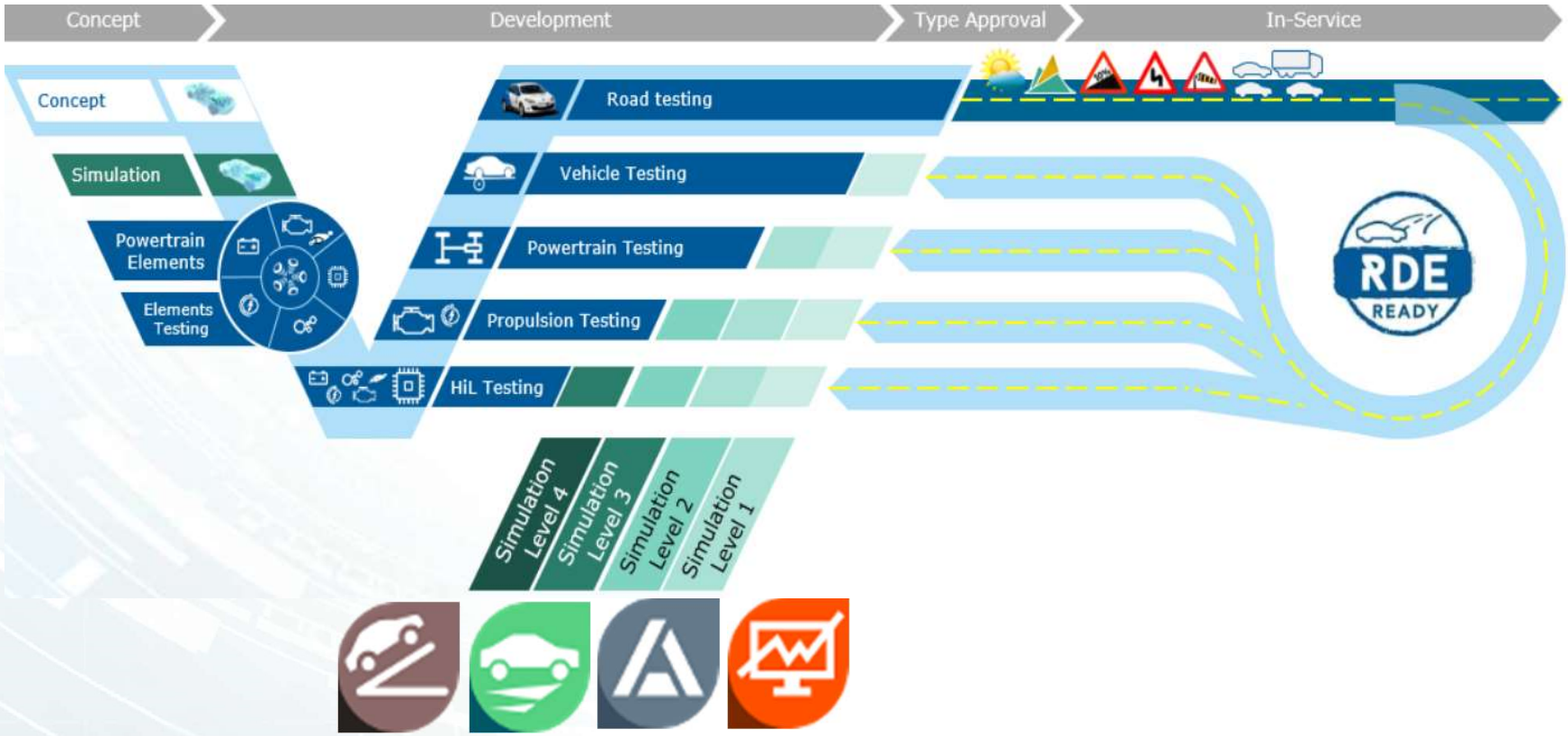
Disadvantages:

- Sizable test-to-test deviations relative to other test fields
- No independent wheel control
- With Euro 6d Legislation – Huge Increase in Certification Testing

Architecture of the test setup:

- Twin Roller Dynos – Tire to 'Road' Interface
- Human Driver
- Strapped or Fixed Vehicle Restraint

WHY: VIRTUAL DESIGN AND VERIFICATION METHODS



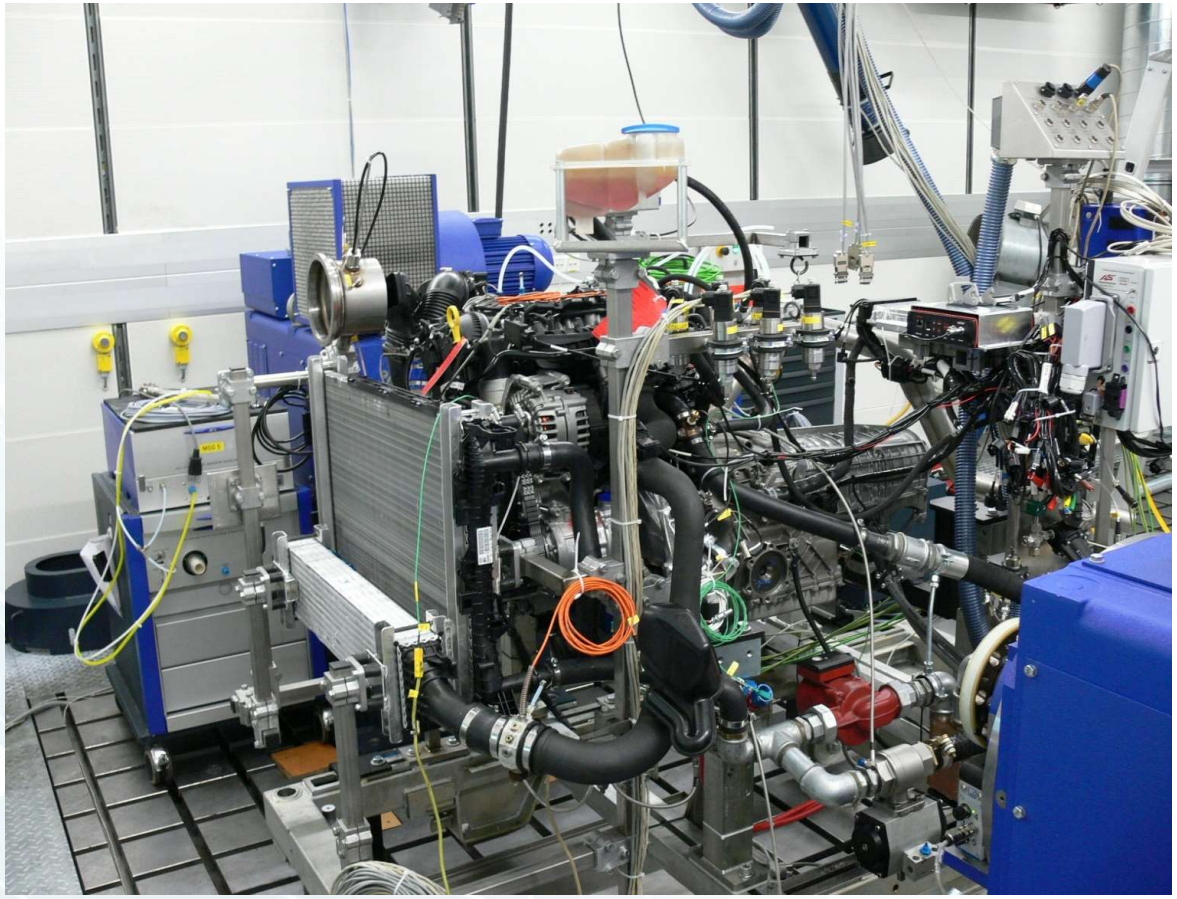
Background – What Test Fields Exist?

Development Methodology on Powertrain Test Beds
TB503 - Capable for Racing and High Performance Applications

- High-Dynamic, Low Inertia 4WD Dynos
- High speed headwind facility with Multi-Blower concept
- Brake dust extraction system and brake cooling system
- Real-time coupling with HexaPod Driving Simulator

Dyno	Power	Rotational Speed	Torque	Overload Torque
1 x Dyno Prime	370 kW	10.000 rpm	600 Nm	1.200 Nm
4 x Dyno Wheel	400 kW	3.700 rpm	2.000 Nm	3.500 Nm

Development Methodology on Powertrain Testbeds
TB502 – Powertrain-in-Loop and Component Testing



- Automated 24-Hour Testing
- Multi-Component Testing
- Emissions Testing
- Rapid Cooldown Capabilities
- CVS System

Dyno	Power	Rotational Speed	Torque	Overload Torque
1 x Dyno Prime	370 kW	10.000 rpm	650 Nm	820 Nm
2 x Dyno Train	220 kW	3.000 rpm	3.250 Nm	4.850 Nm

Development Methodology on Powertrain Testbeds
TB505 - Capable for Racing and High Performance Applications

- High-Dynamic, Low Inertia 4WD Dynos
- High speed headwind facility with Multi-Blower concept
- Brake dust extraction system and brake cooling system
- Real-time coupling with HexaPod Driving Simulator

Dyno	Power	Rotational Speed	Torque
4 x Dyno Wheel	260 kW	3.000 rpm	2.500 Nm

Development Methodology on HV-Integration TB506 – EV Powertrain Setup

Development Methodology on HV-Integration Testbed
TB506 – HV Testing equipment

HV-Battery Climatic Chamber:

- Temperature range: -30°C up to +70°C

eStorage Emulator/Tester Systems:

- 400kW, 1000V, 800A
- 250kW, 1000V, 800A
- 20kW, 60V, 350A

Mains Emulation:

- Freely Programmable AC Supply: eg. For US, JP etc
- 50kVA, 80A
- Single Phase-Shutdown

HV Measurement System:

- Measurement frequency up to 50kHz (800kHz on request)
- Range: up to 1000V and 700A (0,1%FC)
- Fully synchronized with PUMA Open automation system

Application/RBS System:

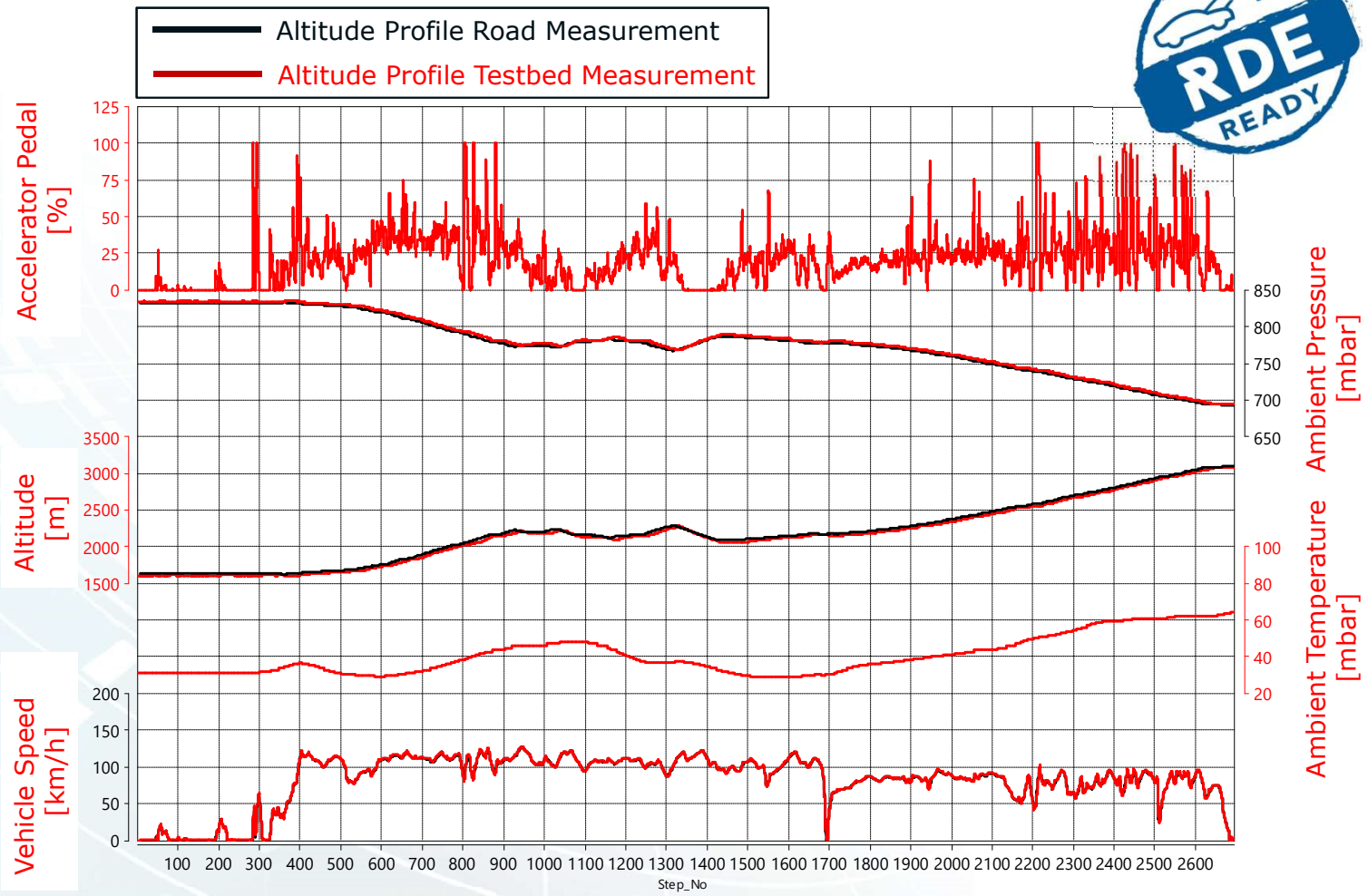
- VECTOR VN89xx, CANape/CANoe
- IXXAT
- ETAS ESxx, INCA

TB507 - AVL Climate Chamber Vehicle and Powertrain

- **Temperature range:** from - 40°C to + 60°C
  - **Temperature change rate:** 1K/min
- **Altitude range:** from sea level up to 5000m (1013mbar to 550mbar)
  - **Altitude Change Rate:** 165 m/min
- **Humidity control**
- **Emission measurement equipment:**
  - Unlimited and limited gaseous components (up to 4000m)
  - Particle mass and particle number measurement (up to 2000m)
- **Headwind simulation** up to 120.000m³/h (typically 200 km/h)
- **Low inertia wheel dynos** (1.26 kgm² rotor inertia) fully capable for Driveability calibration
- **24/7 unmanned operation** of legislative and RDE cycles

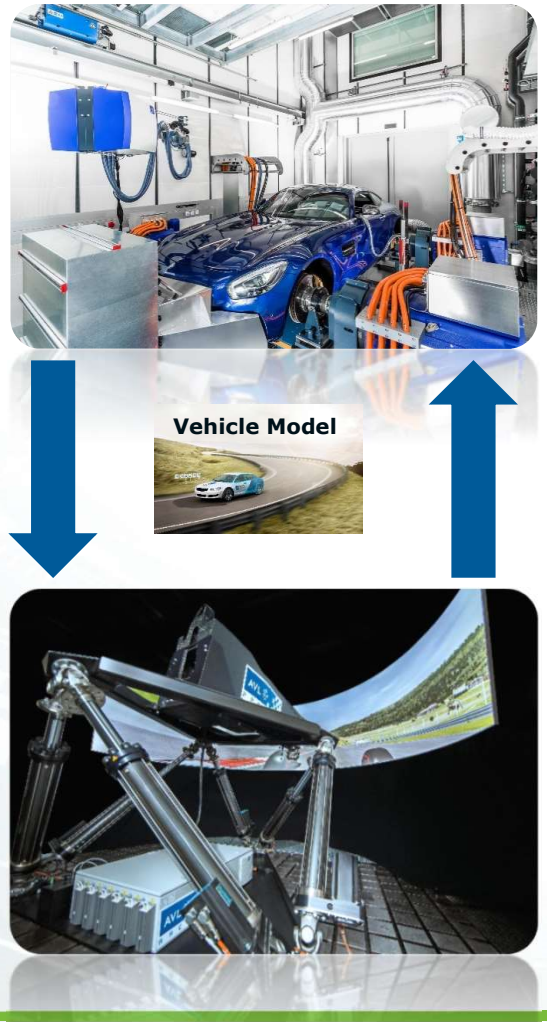
Dyno	Power	Rotational Speed	Torque
4 x Dyno Wheel	260 kW	3.000 rpm	2.500 Nm

TB507 - AVL Climate Chamber
Test Drive – Mount Evans, Summit Lake



- **Virtual Test drive to Mount Evans mountain road (Colorado, USA)** on TB507 at AVL Graz
- Ambient pressure demand trace from an AVL calibration expedition trip
- Precise control of
  - Ambient temperature
  - Ambient pressure

Development Methodology on Powertrain Testbeds



Field of application:

- 24/7 Automated Emissions & RDE Testing
- Drivability Assessments
- 4WD and Independent Wheel and Traction Control (ABS, Off-Road)
- Lap Time Optimization Around any Drive Cycle
- Many Other Confidential and Proprietary Applications
- Heavily Utilized by Motorsport, Top Global Light & Heavy Duty OEMs, Off-Road Industry

Advantages:

- Fully Automated (No Human Driver)
- Independent Wheel Speed/Torque Control
- Development on a Highly Reproducible Testing Environment
- High Level of Simulation Levels Possible
- Rapid Cooldown

Architecture of the test setup:

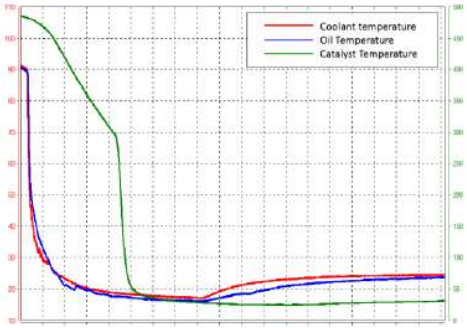
- Entire vehicle or Powertrain at 4WD Low Inertia Dynos
- Closed loop-coupling of Driving Simulator and a Powertrain Testbed
- AVL VSM simulation model operates Driving Simulator as well as the Powertrain Testbed

Development Methodology – Use Case Example

Dynamic Emission Powertrain Testbed

- Simulated vehicle variants

- Rapid cooldown system for coolant, engine oil and catalyst:



Benefits

- 24/7 testbed operation
- Up to 20 **cold** NEDC cycles per day
- High repeatability of test results, ideal e.g. for catalyst selection

Architecture of the test setup:

- Entire drivetrain and automated dataset exchange for ECU and TCU
- Rapid cooldown system capable to cool down a hot powertrain in 25 minutes to soaked conditions
- CVS system
- Cycle database (NEDC, FTP, JC08, RDE, …)
- Different simulated flywheel classes (SUV, Convertible, Sedan, Crossover)
- Test program controlled from the table of the emission calibration engineer (“ease of use”)

Development Methodology – Use Case Example

Methodology approach for OBD robustness testing:

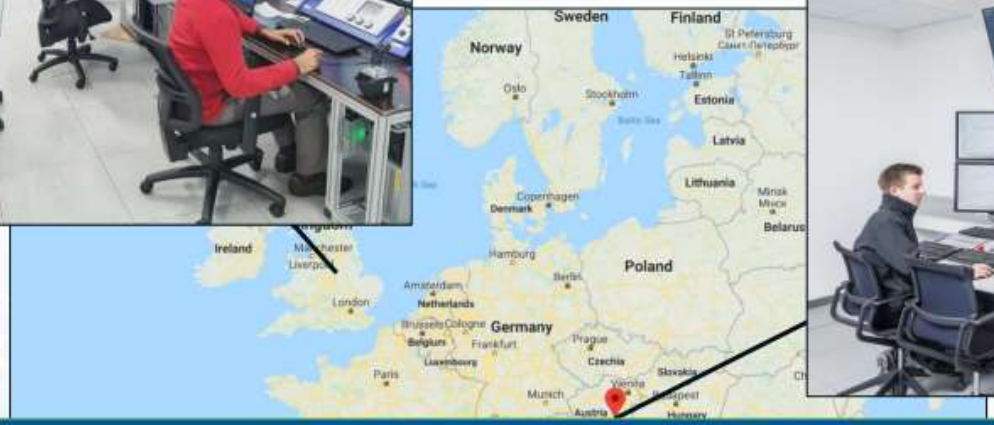
- Definition of **critical areas** and **conditions** for **diagnosis calibration**
  - Certain stationary operation (e.g. long fuel cutoff phases)
  - Borderline dynamic operation
  - Combination of critical events
  - Evaluation of the influence of different fuel types
  - Active misfire tests and effect on other diagnoses
- Definition of representative **reference driving cycles** in the AVL drive cycle library
- Testing on **powertrain testbed** with **automation** for 3 shift per day operation, 7 days a week with automated refueling
- Using **rapid cooldown systems** to allow up to 20 cold starts (20°C) per day
- Evaluation of diagnosis results with **OBD robustness evaluation tool**
- Test time for a wide range of diagnosis functionalities in typically 2 weeks of testbed operation

Development Methodology – Climatic/Altitude

Preliminary software prove-out/debugging and calibration for ambient corrections conducted on AVL CruiseM **Virtual Testbed**

Calibration engineers validate and refine dataset on test vehicle in real-time via **remote station**...

...with live communications and software link to vehicle and operations team at Graz **altitude ViL PTTB**

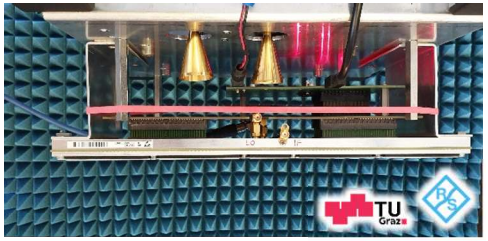


Customer benefits:

- *VTB allows **pre-calibration** of dataset and ambient corrections in **low-cost, maintenance-free** environment*
- *Ability to fully **replicate test procedures** from TCC, but with full range of **ambient temperature/pressure** conditions on Graz TB507*
- *More **repeatable, flexible and capable** than traditional test trips, with **24/7** running capability with **rapid-cooldown***
- *Vastly **reduced number of prototype vehicles**, plus associated transportation/maintenance costs*
- ***Travel costs** for engineering staff **eliminated***

The Future!
ADAS … as addon to AVL test beds

Radar Stimulus

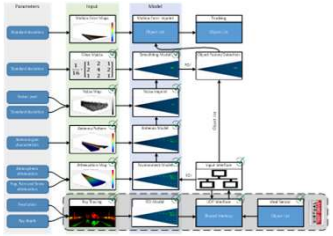


Camera Stimulus

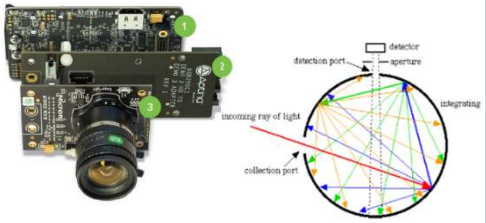
Ultrasonic Stimulus

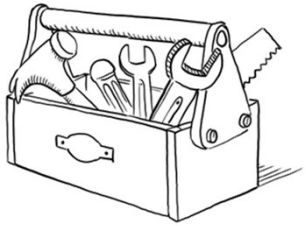
GNSS Stimulus

Radar Simulation

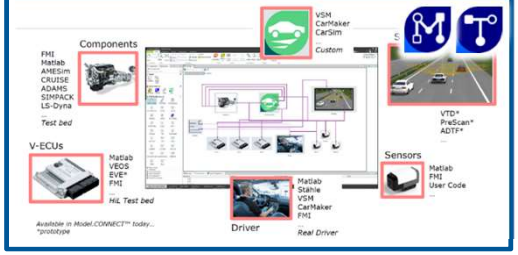


Camera Simulation

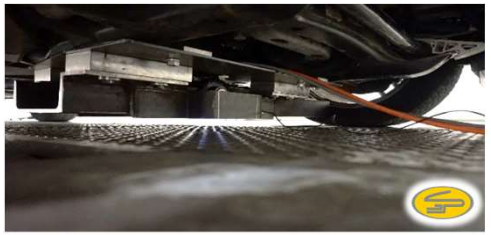




Integration Platform



Dyn. Steer. Force Mod.



Test Bed

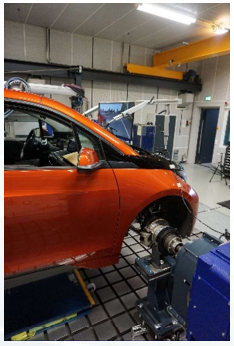
Environm. Simulation

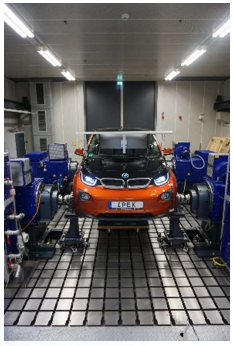
Etc.

⊕

Additional components will follow

Example AVL DRIVINGCUBE™ Camera-based ADASystem





Customer Reference
JLR BEV validation on Powertrain testbed

Benchmark of BEV driveability on Powertrain Testbed

AVL tool-chain

AVL Tool Contribution:

- **AVL VSM** Realistic vehicle dynamics simulation
- **AVL-DRIVE™** Objective driveability assessment

Scope of the project

- **Battery electric vehicle driveability benchmark using Driveability Methodology and Toolchain in powertrain testbed environment**
  - Installation of the toolchain
  - Driveability manouvers to allow benchmark against AVL-DRIVE BEV scatterband and detailed comparison with Tesla Model X
- **Driveability maneuver testruns considering SOC**
  - **Tip-In / Tip-Out** at different speeds, pedal positions
  - **Part load and full load acceleration; driveaway**
  - **Hill climb with different friction/slopes** – on dedicated test track and comparison with PTTB
- **Verification regarding:**
  - AVL-DRIVE™ rating
  - Physical signal level (chassis acceleration, engine speed, engine torque, etc.)

Project results

Jaguar Land Rover

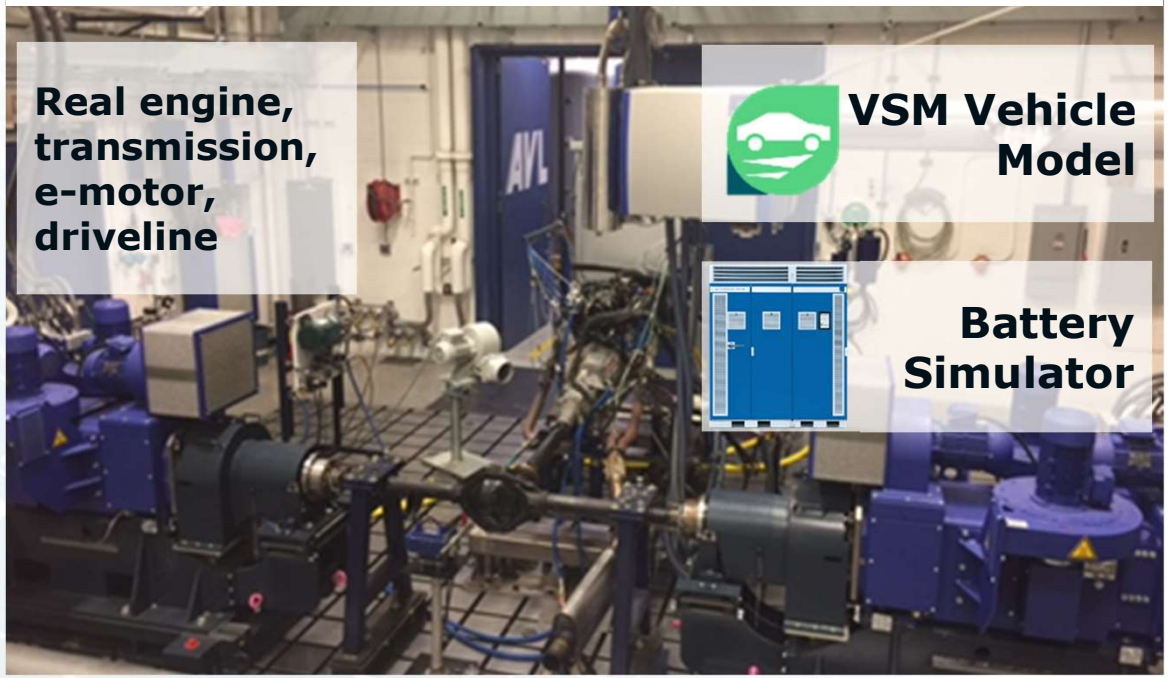
JLR BEV SUV on powertrain test bed, low inertia dynos

Results of benchmark:

Customer Reference
Ford US Hybrid calibration on Powertrain testbed

Calibration of hybrid functions before the first vehicle including regen braking, starts and drive-away

ROAD → POWERTRAIN TESTBED



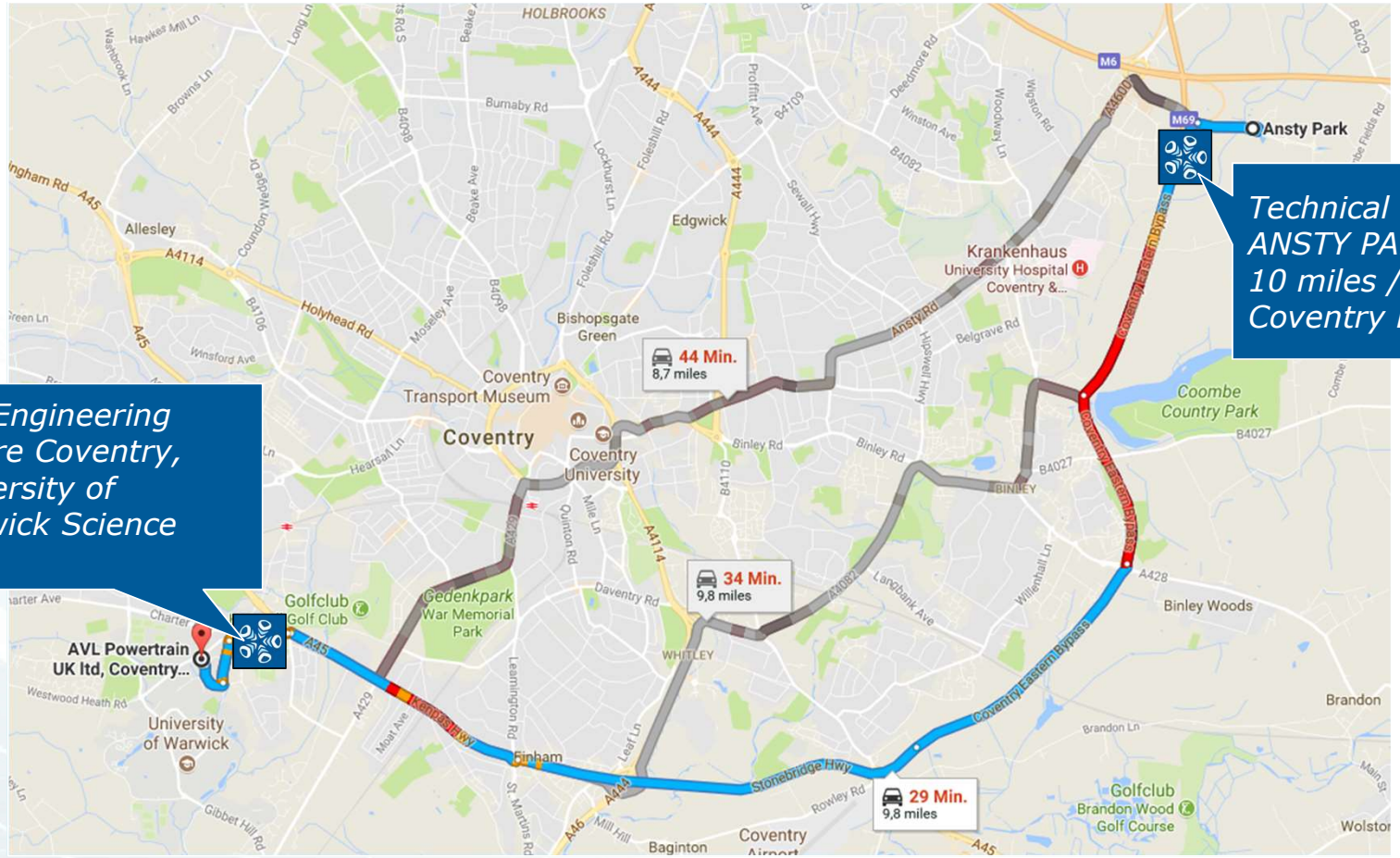
Proven Benefits

Reduction of development and testing time	▪ Calibration started **6 months** before first vehicle was available ▪ High degree of automation in comparison to road
Reduction of cost	▪ **Reduced use of expensive vehicle prototypes** ▪ **Calibration procedures** designed to specifically to PTTB.
Increased product quality	▪ **Higher testing coverage** leading to higher product quality ▪ **More development iterations** possible before SOP

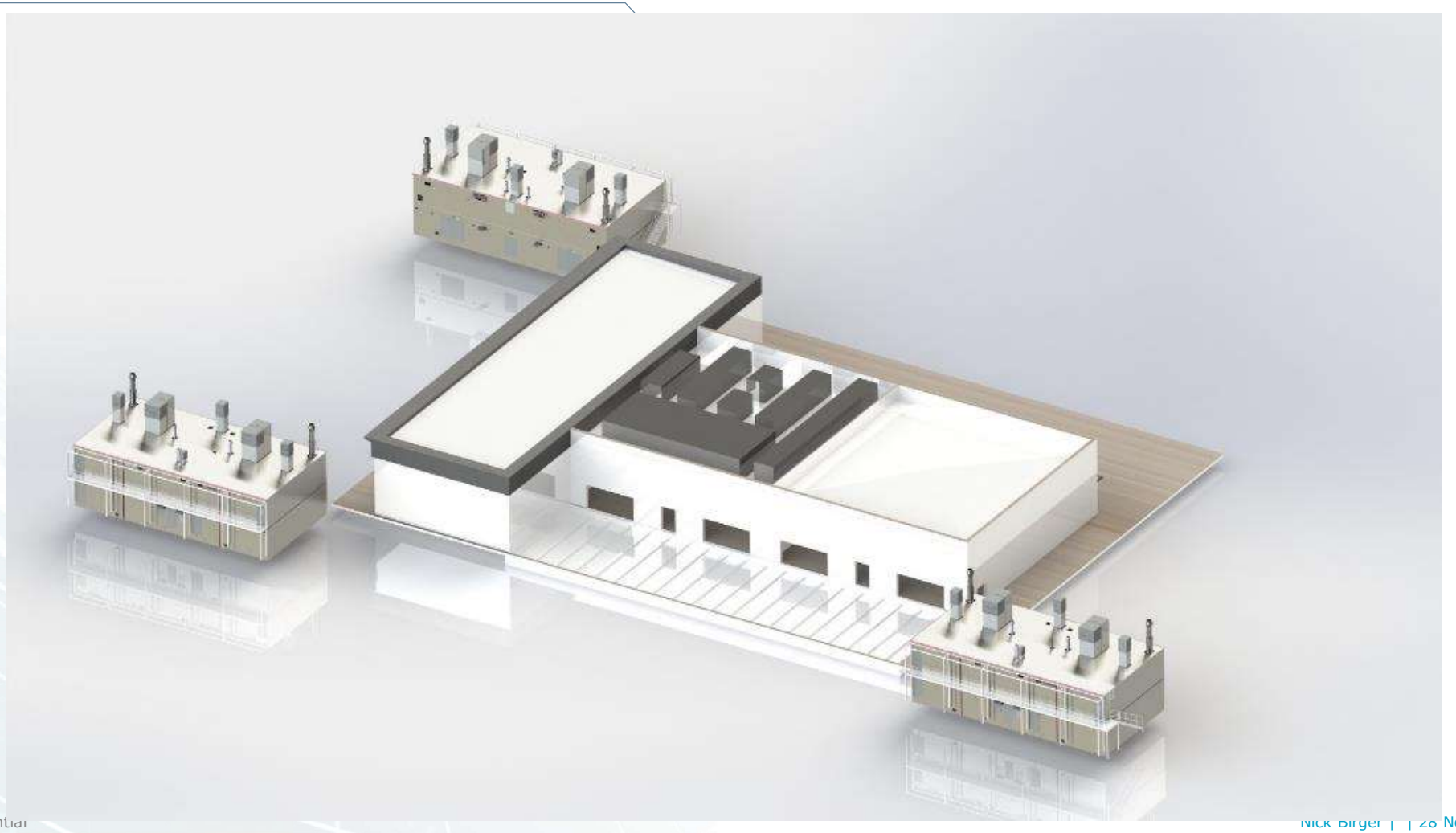
So… What Happens When A Customer Wants This Technology?

TESTING TECH CENTRE COVENTRY (TCC)
AVL PTE UK

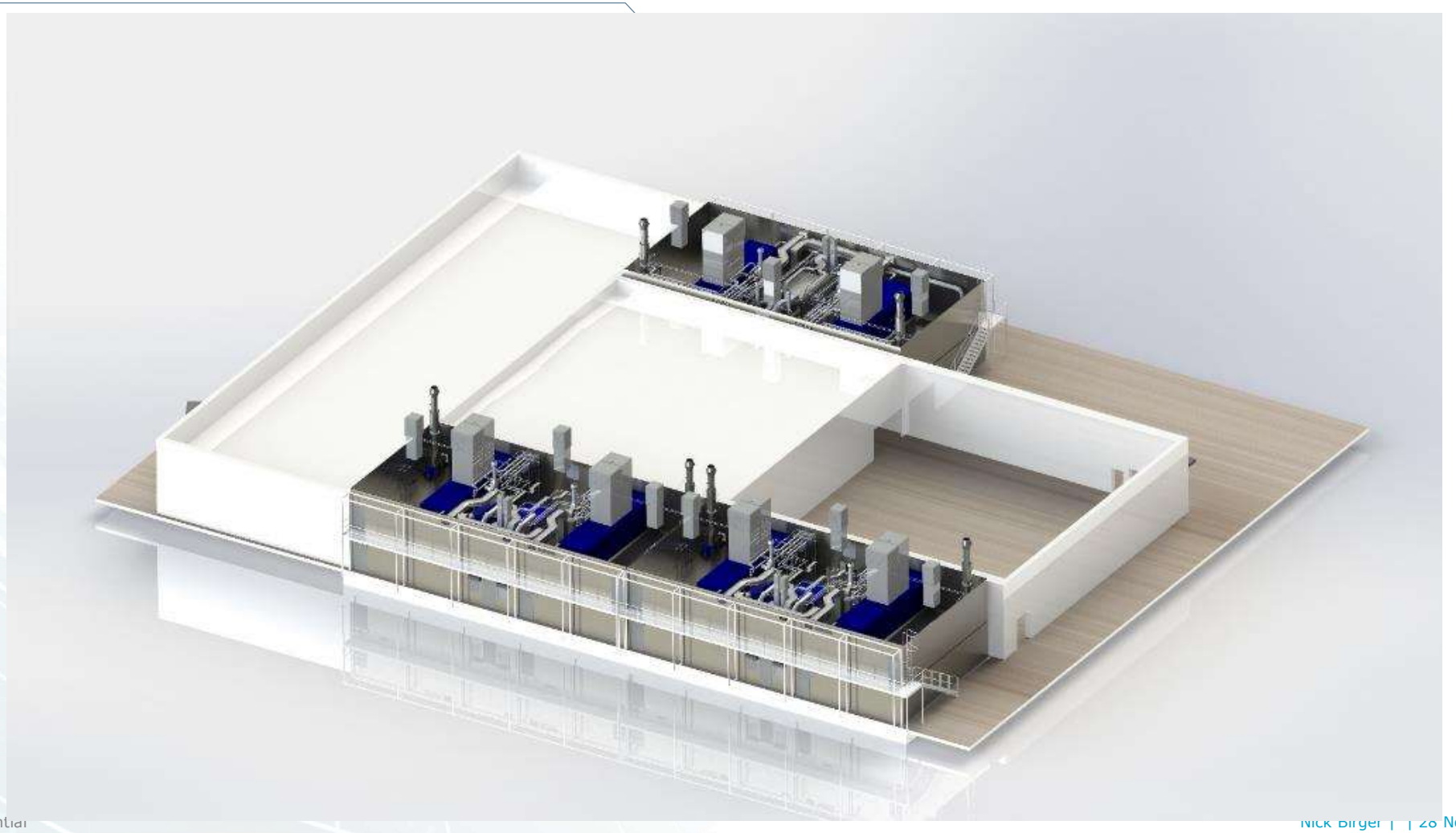
TESTING TECH CENTRE COVENTRY (TCC) LOCATION



Tech Center Coventry

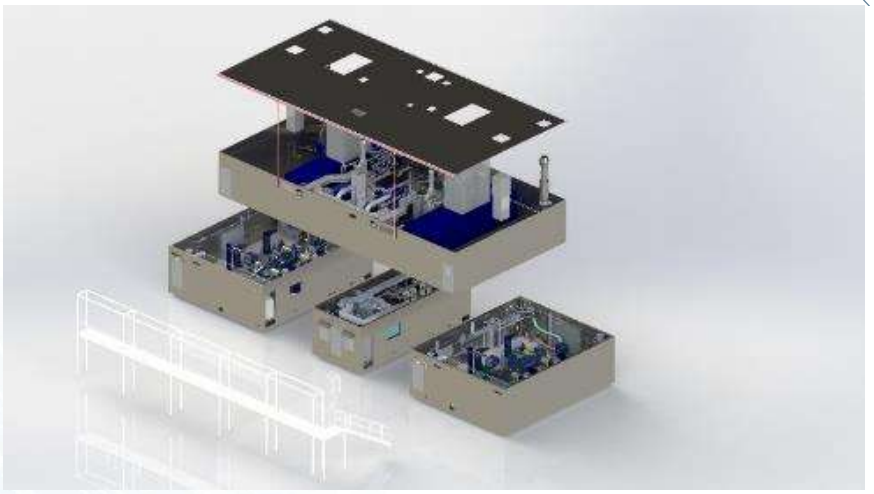


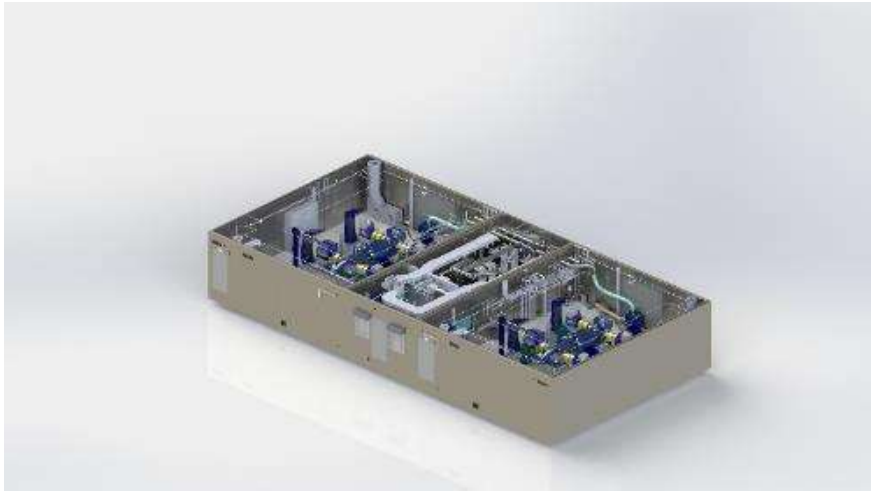
Tech Center Coventry

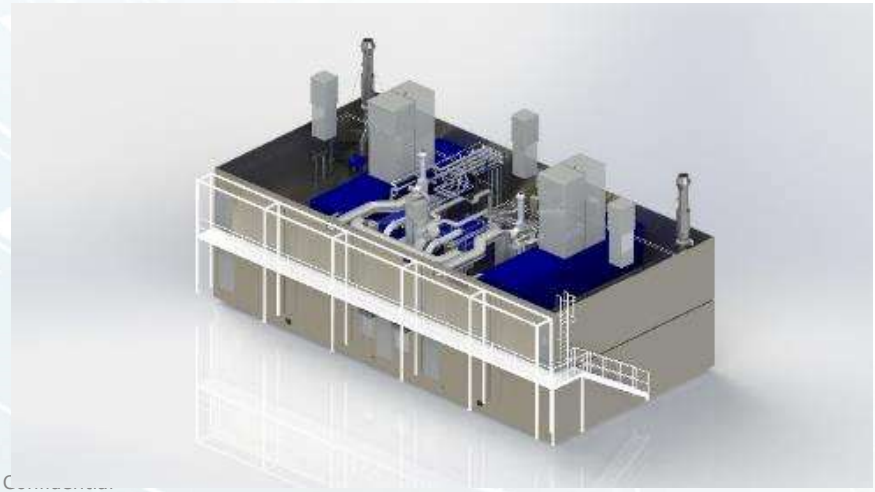


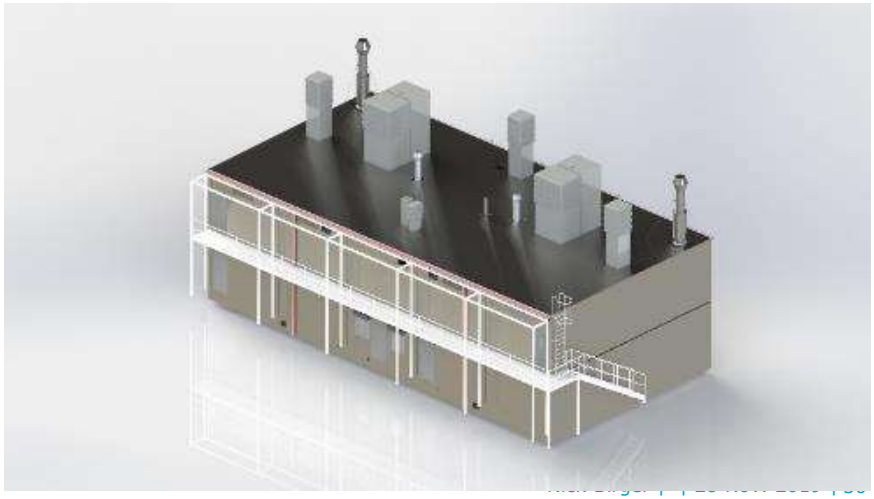
Tech Center Coventry

Tech Center Coventry









Tech Center Coventry

Tech Center Coventry

Tech Center Coventry

Tech Center Coventry

Tech Center Coventry Completion On Time

TESTING TECH CENTRE COVENTRY (TCC) RAMP-UP PHASE

FACILITY:

- Container Manufacture & pre assembly
- Building construction
- Utility installation

PEOPLE: CUSTOMER

- Recruitment
- Training by AVL @ Graz

PEOPLE: AVL

- Recruitment
- Training by AVL @ Graz and Stuttgart

Final total Hand Over

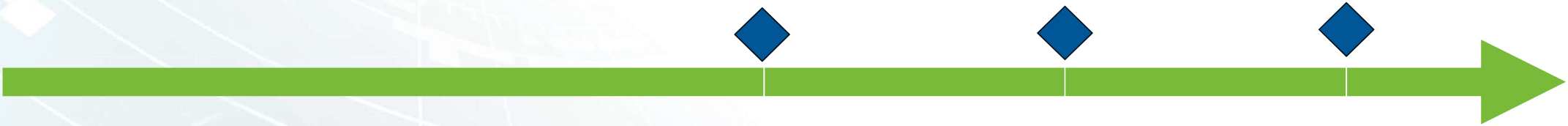
October 2016 | **March 2017** | **October 2017** | **26 Feb 2018**

TESTING TECH CENTRE COVENTRY (TCC) OPERATIONAL START MODULE 1, 2 & 3

Powertrain test beds 1&2

Powertrain test beds 3&4

Powertrain test beds 5&6

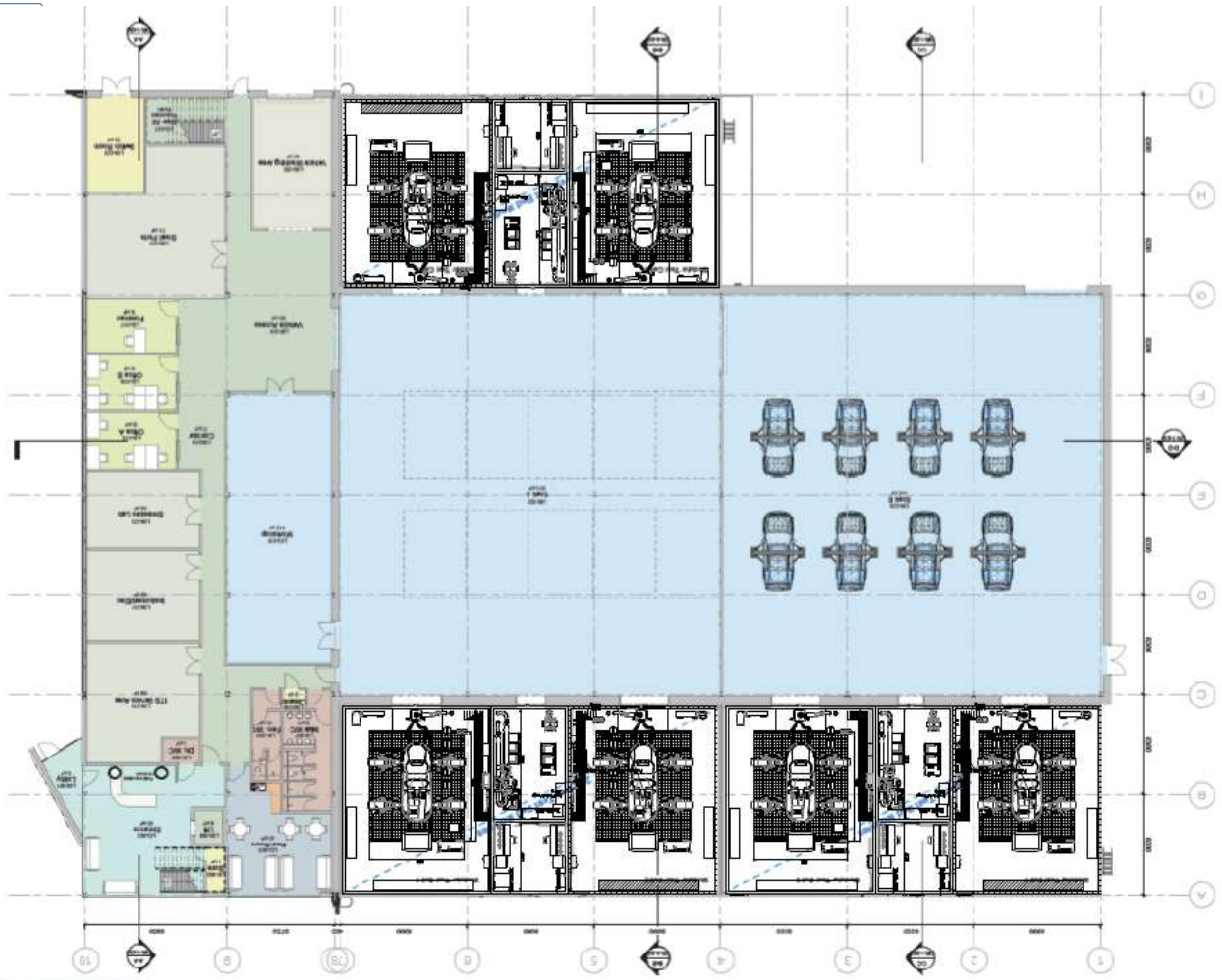


October 2017 **December 2017** **February 2018**

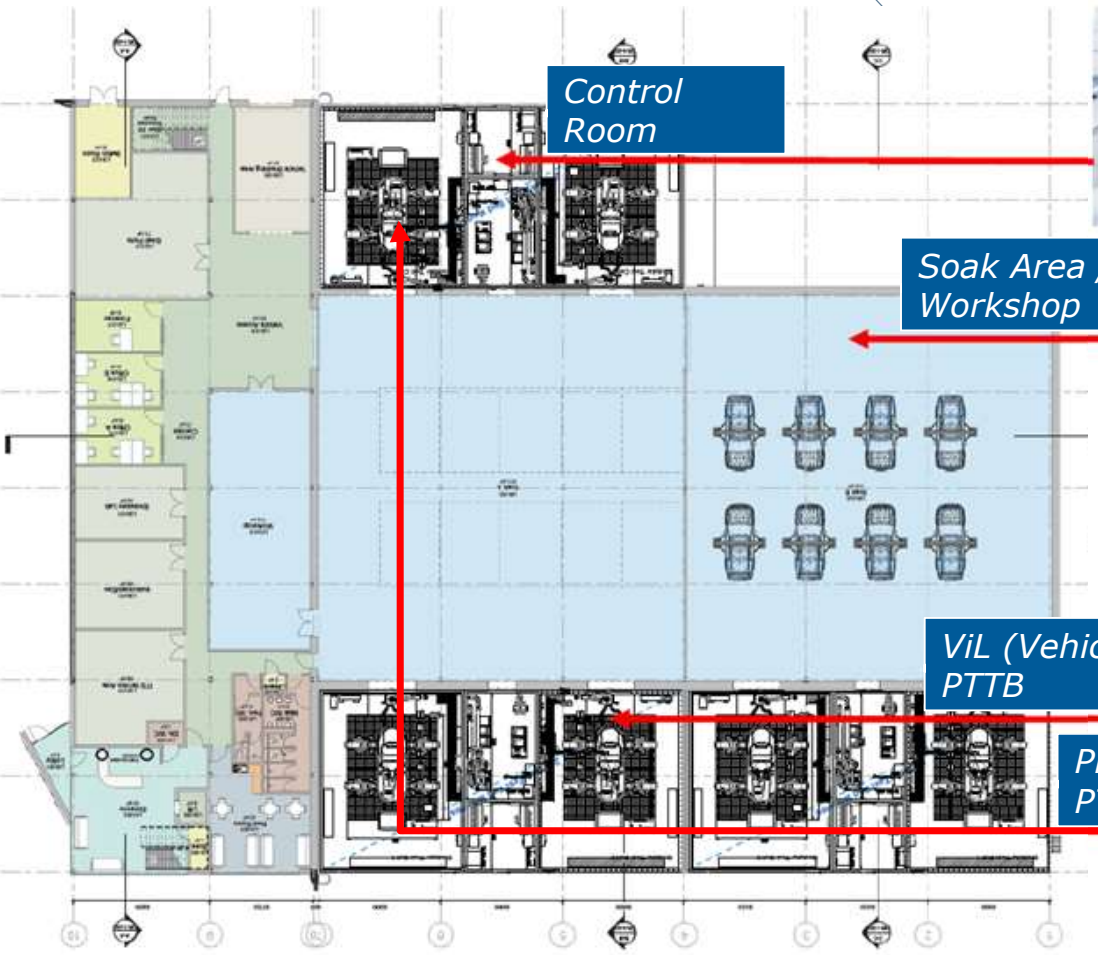
TESTING TECH CENTRE COVENTRY (TCC) BUILDING - LAYOUT

Engineering Areas:

- 6x Powertrain Test Beds
- 1x Inverter Test Bed
- 3x Virtual Test Beds
- Soak Area
- ITS Service, Maintenance and Calibration Centre
- Workshop & assembly area
- VTB and engineering offices on 1st floor



TESTING TECH CENTRE COVENTRY (TCC) BUILDING - LAYOUT



6 Powertrain Test Beds, each with

4x LS-PMM260:

P= 260 kW x4 dynos

T = 2,500 Nm

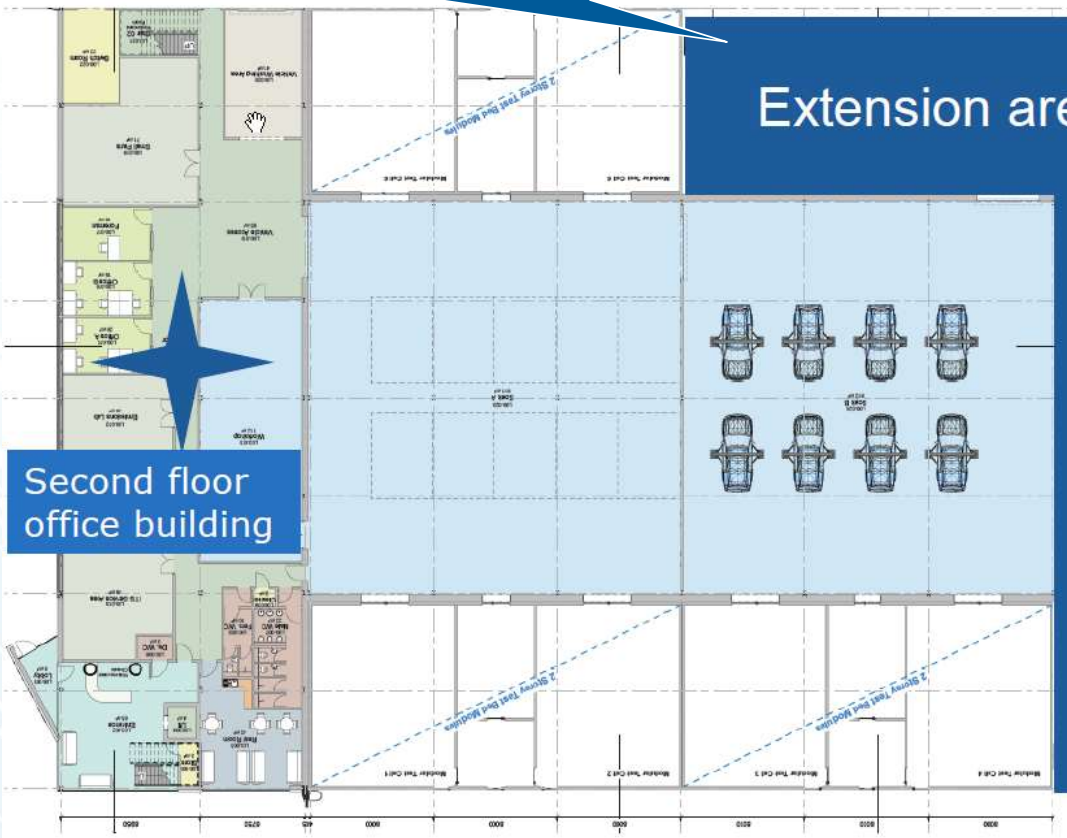
n_max = 3,000 rpm

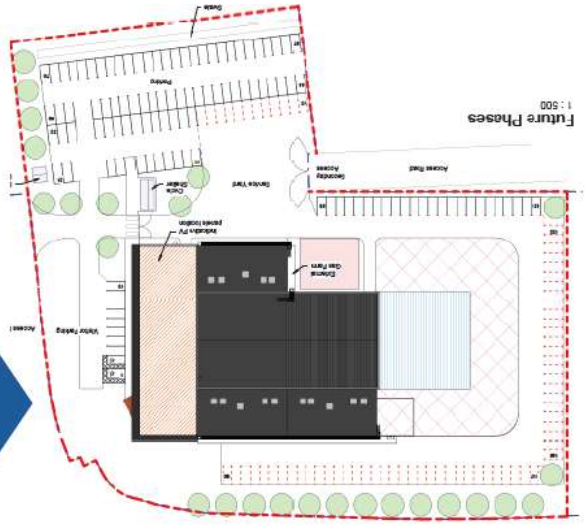
TESTING TECH CENTRE COVENTRY (TCC) BUILDING - LAYOUT

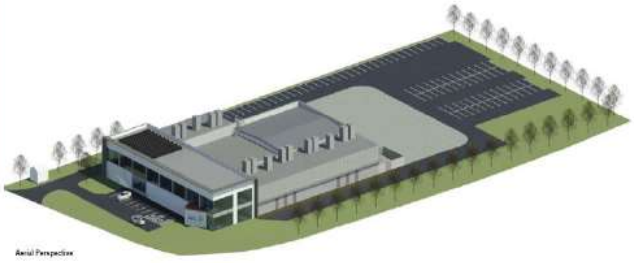
Further expansion possible

Extension areas

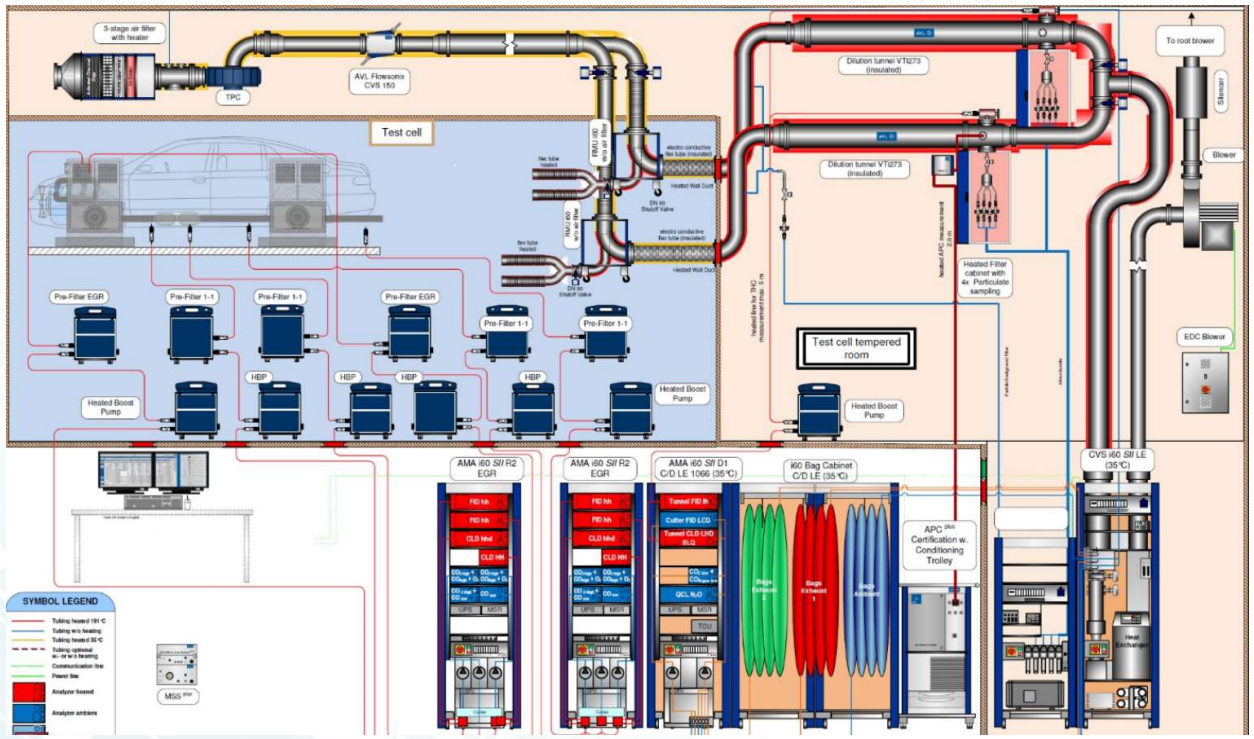
Second floor office building





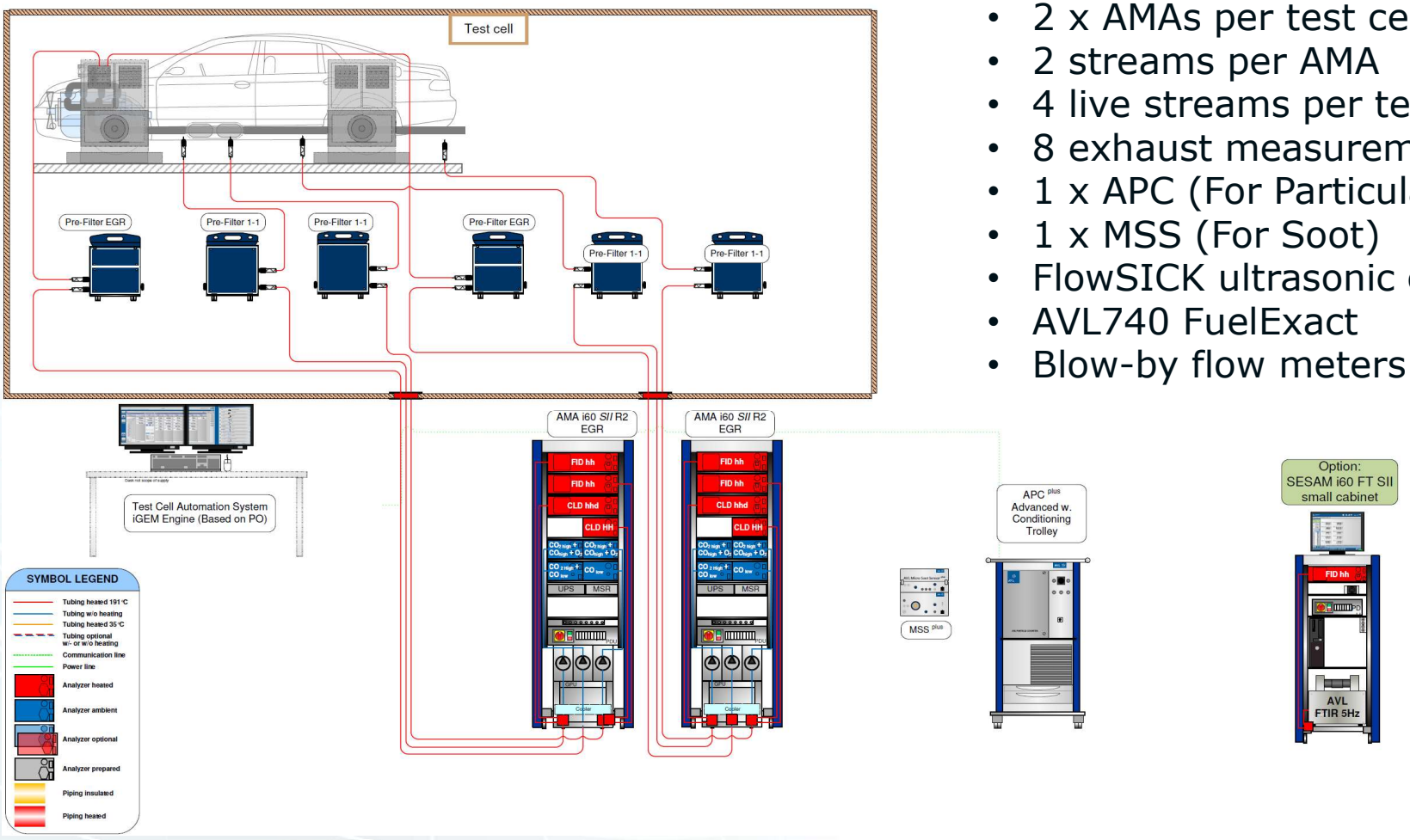


EMISSION MEASUREMENT CAPABILITY
2 X VIL (TB 1 & TB 2)



- Full CVS bagged emissions
- Continuous dilute emissions
- 2 x AMAs per test cell
- 2 streams per AMA
- 4 live streams per test cell
- 8 exhaust measurement locations
- 1 x APC (For Particulates)
- 1 x MSS (For Soot)
- FlowSICK ultrasonic exhaust flow
- Blow-by flow meters

EMISSION MEASUREMENT CAPABILITY
2 X VIL (3 & 4), 2 x PIL (5 & 6)



- 2 x AMAs per test cell
- 2 streams per AMA
- 4 live streams per test cell
- 8 exhaust measurement locations
- 1 x APC (For Particulates)
- 1 x MSS (For Soot)
- FlowSICK ultrasonic exhaust flow
- AVL740 FuelExact
- Blow-by flow meters

TESTING TECH CENTRE COVENTRY (TCC)
ViL CAPABILITY

4 x AVL Dyno Wheel	Power 260 kW	Max Wheel Speed 3000 rpm	Torque 2500 Nm

Virtual Integration

- Highly Dynamic Manoeuvre Execution (~30Hz)
- Wheel Slip Simulation
- Road Load Simulation
- Driver Style Simulation
- Road Grade & Curvature Simulation
- Inertia Simulation

Target Use Cases	• Automated Emissions Testing • Vehicle/Transmissions/Engine Calibration • Vehicle Advanced Driveability Optimisation • Component Durability, OBD Robustness
Emissions Capability	• Shared CVS Emissions Capability • 4 x Raw Emissions Measurement/Test Cell • Particulate Number and Soot Measurement • Ultrasonic Exhaust Flow Measurements • **Airflow:** Compliant with Euro 6c, CFR1066, and all LD global emissions regulations. Max wind speed 160kph
Cell Conditioning	• Rapid chill down system ~ 13 cold WLTC's in 24hrs • 23°C ±3°C with humidity maintained between 5.5 ≤~≤ 12.2 (g/H20/kg dry air). 14°C ±3°C with humidity maintained between 3.0 ≤~≤ 8.1 (g/H20/kg dry air)
EV Capability	• Shared Battery Emulator between 2 cells • AVL E-Storage BE with 250kW / 600A / 1200V (HV Hybrid Applications) • AVL E-Storage DC Power Unit with 32KW / 60V / 600A (LV Mild Hybrid Applications)
Test Automation	• Automated test cycle execution • Automated calibration dataset changes • Automated refuelling b/w tests • Real-time vehicle modelling capabilities • Integrated test bed toolchain capability

TESTING TECH CENTRE COVENTRY (TCC)
PiL CAPABILITY

4 x AVL Dyno Wheel	Power 260 kW	Max Wheel Speed 3000 rpm	Torque 2500 Nm

Virtual Integration

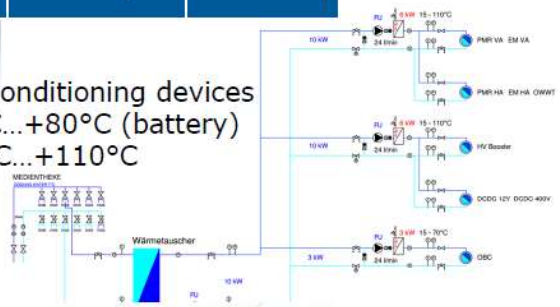
- Highly Dynamic Manoeuvre Simulation (~30Hz)
- Wheel Slip Simulation
- Road Load Simulation
- Driver Style Simulation
- Road Grade & Curvature Simulation
- Inertia Simulation

Target Use Cases	• Early Stage Development Programmes • E-Integration, Component Validation • Powertrain Durability Testing • Aftertreatment Development, Component Calibration
Emissions Capability	• 4 x Raw Emissions Measurement/Test Cell • Particulate Number and Soot Measurement • Ultrasonic Exhaust Flow Measurements
Air Conditioning	• **Combustion Air Control: Max Flow Rate:** 2500 m3/h, **Intake air temp:** Between -10 to + 40 C. Accuracy ±0.4 C, **Humidity:** Between 10% and 90% relative humidity. Accuracy ±5 %, **Pressure:** Between BARO+50 & BARO-100 mbar. Accuracy ±1 mbar • Altitude simulation and back pressure control
EV Capability	• 1 Battery Emulator per test cell • AVL E-STORAGE BE with 250kW / 600A / 1200V (HV Hybrid Applications) • AVL E-STORAGE DC POWER UNIT 32KW / 60V / 600A (LV Mild Hybrid Applications)
Fluid Conditioning	• **Fluid Control:** Coolant control in steady state, dynamic steps & UUT not running. Coolant (-10 to 110C), Oil (-10 to 120C), Intercooler (0 to 90C). Accuracy ± 0.4C

TESTING TECH CENTRE COVENTRY (TCC) ELECTRIFICATION CAPABILITY

Dyno	Power	Rotational Speed	Torque
4 x Dyno Wheel	260 kW	3.000 rpm	2.500 Nm

Multiple conditioning devices
- -40°C...+80°C (battery)
- +15°C...+110°C



HV battery in vehicle and/or climatic chamber

Application Areas:
Classic ICE, PHEV, HEV, BEV

E-Mobility UseCases:
- HV System Testing
  - HV safety tests
  - Cycle simulation
  - Concept testing and evaluation
  - DC/AC charging test
  - Thermal management validation
- HV Component Testing
  - Power electronics, EM
  - Battery
  - DC/DC converter
  - etc

Advantages:
- Development close to reality in early phases, where only single HV components are available
- HV safety tests in a virtual environment
- Development on a highly reproducible testing environment

TESTING TECH CENTRE COVENTRY (TCC)
PTTB TOOLCHAIN CAPABILITY

AVL PUMA OPEN

AVL ISAC

AVL ARTE

AVL CONCERTO

AVL CAMEO

AVL INDICOM

AVL VSM

AVL DRIVE

AVL EMCON

ETAS INCA

CANape

CANalyzer

CANoe

Flexray

Scalexio

BRAKING STRATEGIES OVERVIEW

There are several possibilites for braking a vehicle on a powertrain testbed.

1) Deceleration from dyno simulation

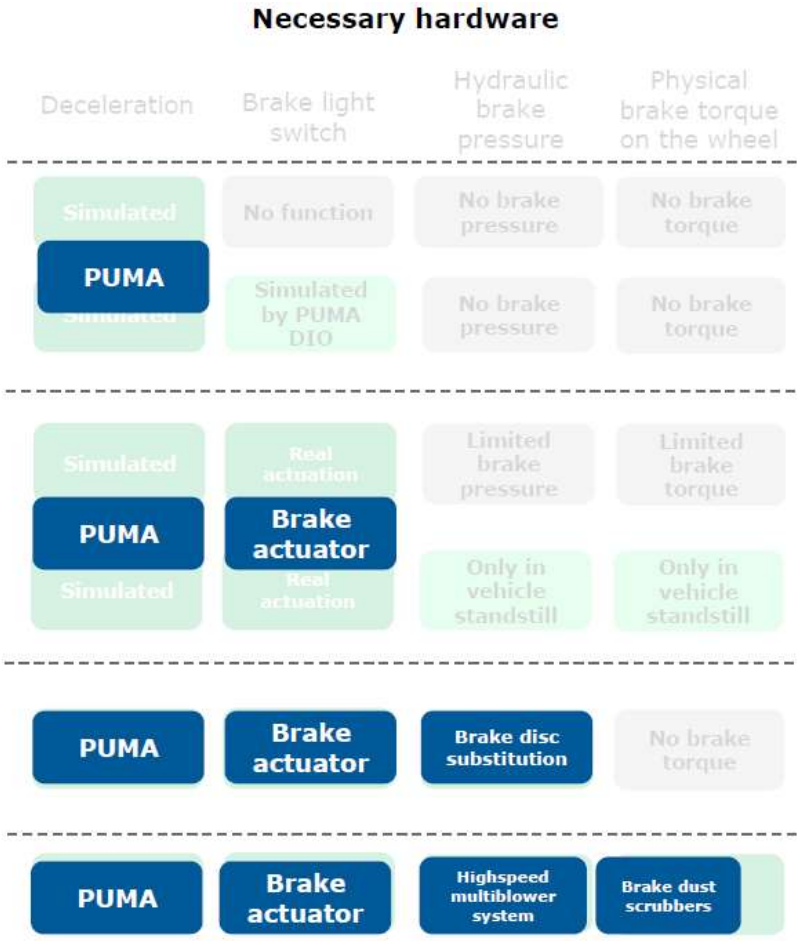
2) Deceleration from dyno simulation
Close the brake light switch with PUMA DIO (digital input/output) electrically without physical brake pressure

3) Deceleration from dyno simulation
Close the brake light switch with a brake actuator

4) Deceleration from dyno simulation
Close the brake light switch with a brake actuator
Physical brake pressure in vehicle standstill

5) Deceleration from dyno simulation
Physical brake pressure in all driving conditions,
Brake caliper dismounted from brake disc and brake disc in caliper physically substituted.

6) Deceleration from physical braking
Physical brake pressure in all driving conditions



TESTING TECH CENTRE COVENTRY TCC

Thank You

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