Working Paper No. **HDH-13-03e**
(13th HDH meeting, 21/22 March 2013)

GRPE-HDH Research Project

13th meeting of the GRPE informal group on heavy duty hybrids (HDH)

Report of the Institutes on validation test program 1

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Content

- Summary of working tasks 1 at validation test program 1
- Summary of working tasks 2 at validation test program 1
- Drive cycle investigations
- Test methodology investigations
- Offer for validation test program 2

Validation test program 1 overview

Task 1) Adaptation of the Japanese HILS Simulator for serial hybrid

- Task 1) Adaptation of Japanese Serial Hybrid model is completed
  - Serial Hybrid model available at HDH download area (based on Japanese model structure)
  - Driver- and Thermal models implemented in vehicle model
  - SILS model test runs were performed with different generic vehicles (battery, motor power, mass, tires, drivetrain gear ratios,..)
  - New components have been identified at previous OEM meeting

			Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
	1	SILS for serial hybrid												
✓	1.1	Set up a serial HDH as SILS												
✓	1.2	Adapt driver model												
✓	1.3	Library for non electric components												
✓	1.4	Meetings with OEM's and stakeholders												
✓	1.5	Library for new power pack components												
✓	1.6	Thermal models												
✓	1.7	Simulation runs and validation												

Validation test program 1 overview

Task 1.4) Meetings with OEM's and stakeholders

- Meetings with Volvo, Scania, Daimler and MAN took place
  - drive cycle investigations with Daimler were intensified
  - approval of drive cycle approach with MAN and Daimler is scheduled (see upcoming slides)
- current hybrid models will not match with proposed OEM vehicles for validation test program 2
  - e.g. 2 separate electric drive motors coupled via transmission
  - hybrid models will have to be adapted to specific vehicle topology
- request by OEMs that WHTC remains as alternative type approval test
  - for low-volume and niche vehicles HILS type approval would be very high effort

Validation test program 1 overview

Task 1.5) Library for new power pack components

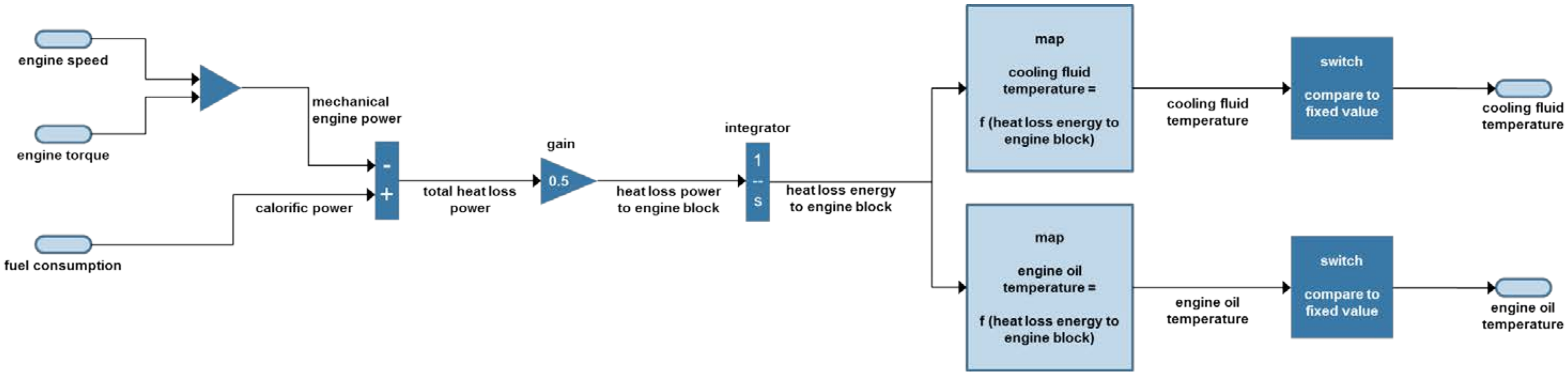
- Additionally required components were identified during last OEM meetings
  - DC/DC - Converter (to run el. components on different voltage levels)
  - Braking resistor (to dissipate energy and control energy flows)
  - Automatic transmission gearbox with torque converter

- 3 weeks of modelling and validating new components was planned
  - Remaining capacities will be used to start modeling DC/DC-converter and braking resistor
  - ATM can not be covered within this work program… (see upcoming slides)

Validation test program 1 overview

Task 1.6) Thermal models

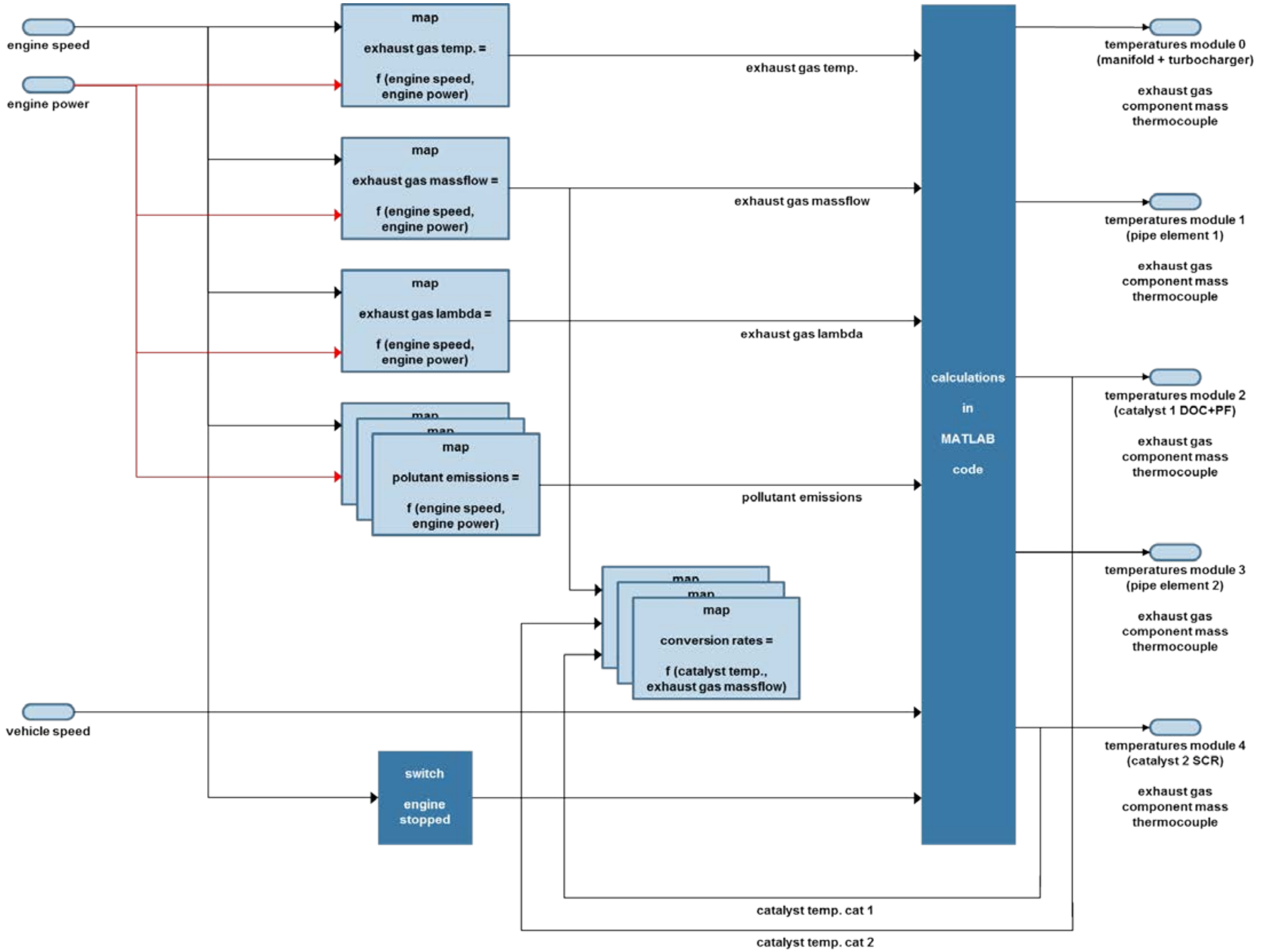
- model structure for engine cooling fluid and engine oil



Validation test program 1 overview

Task 1.6) Thermal models

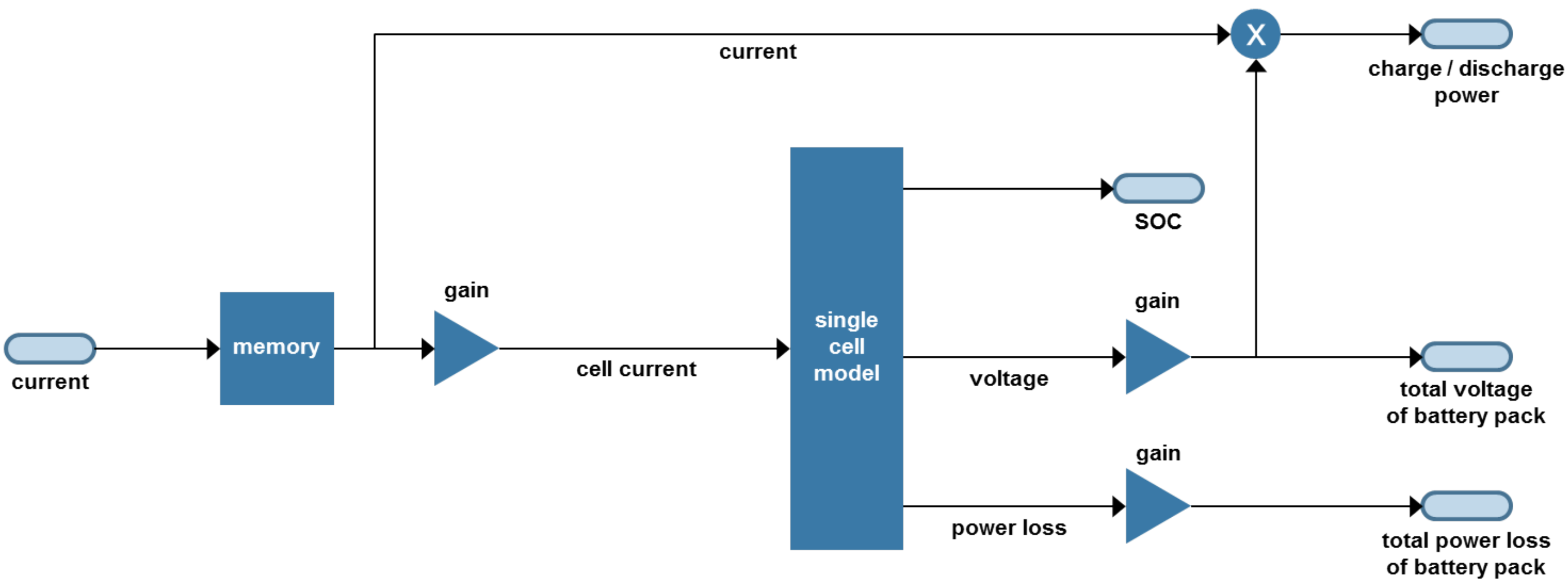
- model structure for exhaust system



Validation test program 1 overview

Task 1.6) Thermal models

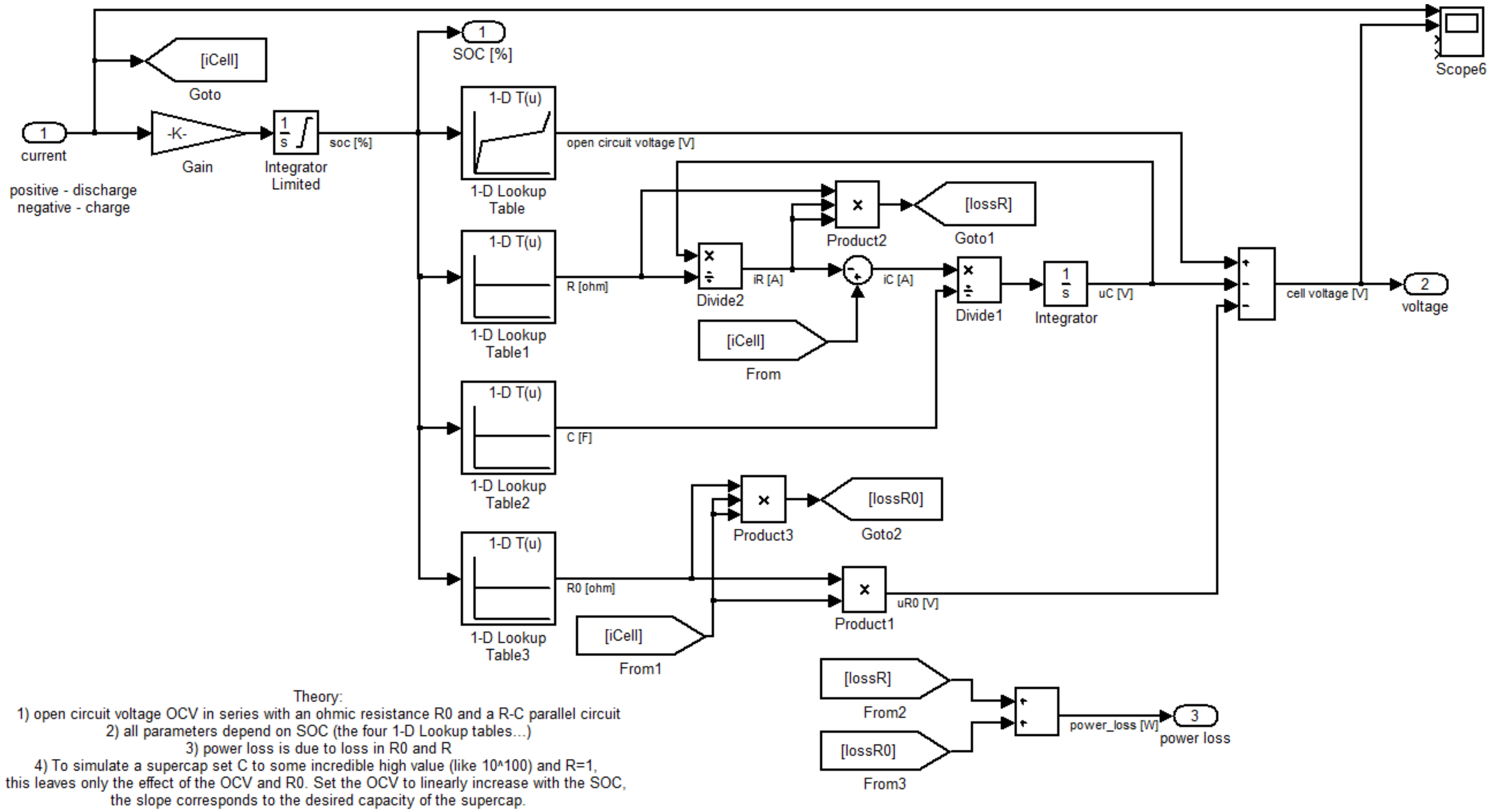
- model structure for RESS



Validation test program 1 overview

Task 1.6) Thermal models

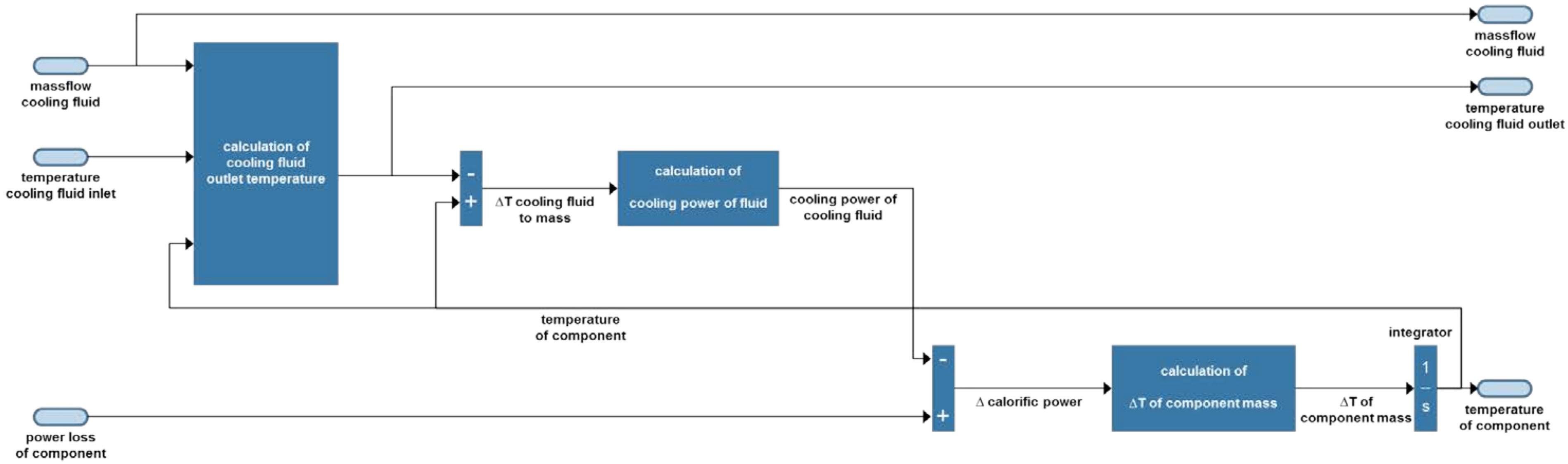
- model structure for RESS – single cell model



Validation test program 1 overview

Task 1.6) Thermal models

- model structure for component mass cooling (electric motor, RESS)



Validation test program 1 overview

Task 1.7) Simulation runs and validation

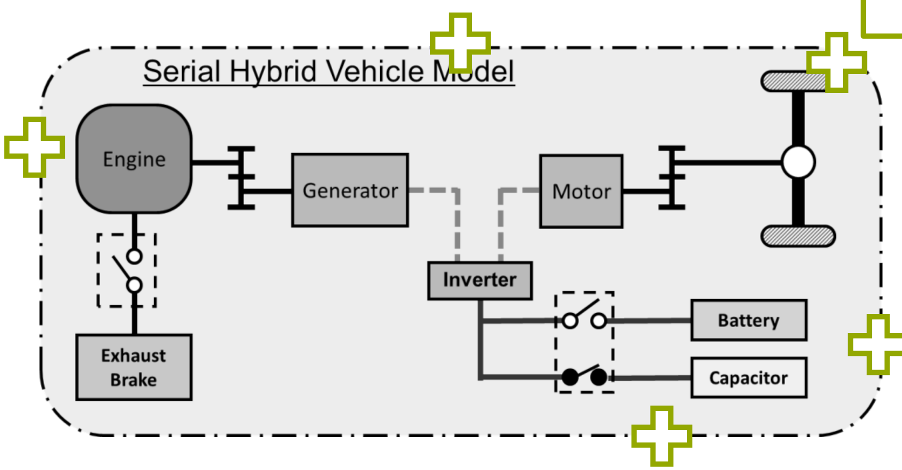
- Japanese Serial Hybrid Model was adapted

Thermal model for electric motor/generator

Driver models for vehicle speed and propulsion power demand

Thermal model for ICE oil and water

Thermal model for ICE exhaust system



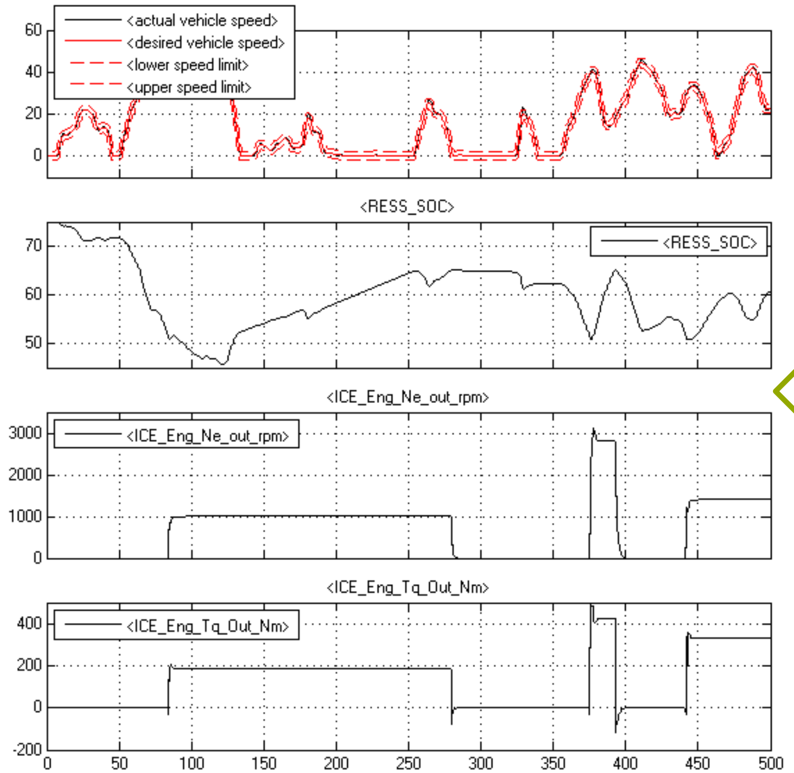
Thermal model for energy storage

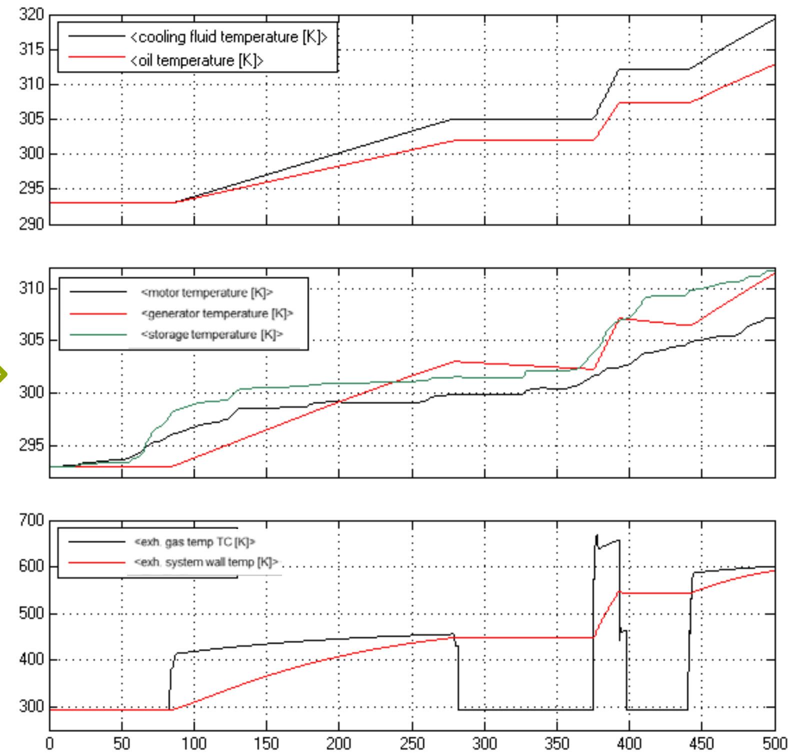
Energy storage model

Validation test program 1 overview

Task 1.7) Simulation runs and validation

- Outline of simulation test runs
  - ICE torque/speed pattern as final result for emission test





Validation test program 1 overview

Task 2) Adaptation of the Japanese HILS Simulator for parallel hybrid

- 2.1 Meetings with OEM's and stakeholders
- 2.2 Set up a data bus system in the model to allow various combinations of engines, gear boxes and storage systems
- 2.3 Adapt the Software to simulate a parallel HDH
- 2.4 Simulation runs and validation of basic functions, including the functions from task 1

			Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
	2	Adaptation of SILS for parallel HDH												
O	2.1	Meetings with OEMs and stakeholders												
O	2.2	Set up a data bus system in the model												
✓	2.3	Adapt the Software to parallel HDH												
O	2.4	Simulation runs and validation												
	3	Procedure and Manual writing/reporting												
	3.1	Report on test procedure, user manual												
	3.2	Provide the interface system for real ECUs												
	3.3	Adaptations and improvements of methods												

Task 2.1)

- Deliverables

- **Meetings with OEM's and stakeholders**
  - See Task 1.4

Task 2.2)

- Deliverables

- **Set up a data bus system in the model to allow various combinations of engines, gear boxes and storage systems**

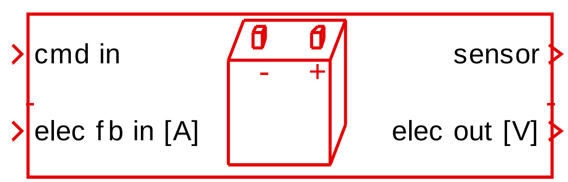
  - Difficult in the current model to setup a data bus system
    - Components are represented in different ways in the two vehicle models
    - Components are lumped in different ways
  - There is a need to restructure the models

Task 2.2)* Restructuring of Models

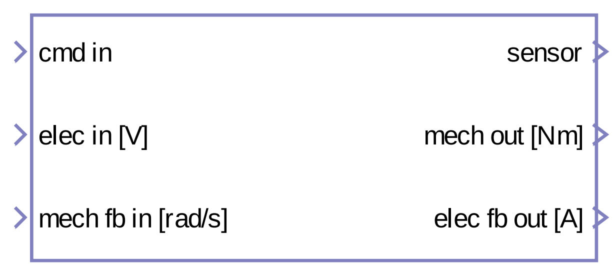
- Two types of interfaces are needed:
  - The *physical interface* is related to how different components are connected together physically

	Electrical	Mechanical (rotational, translational)	Chemical	Fluid
Flow Effort	Voltage [V] Current [A]	Torque [Nm], Force [N] Speed [rad/s], Velocity [m/s]	Spec. energy [J/kg] Mass flow [kg/s]	Pressure [Pa] Flow [m^3/s]

  - The *signal interface* is related to control/sensor signals (needed for ECU)

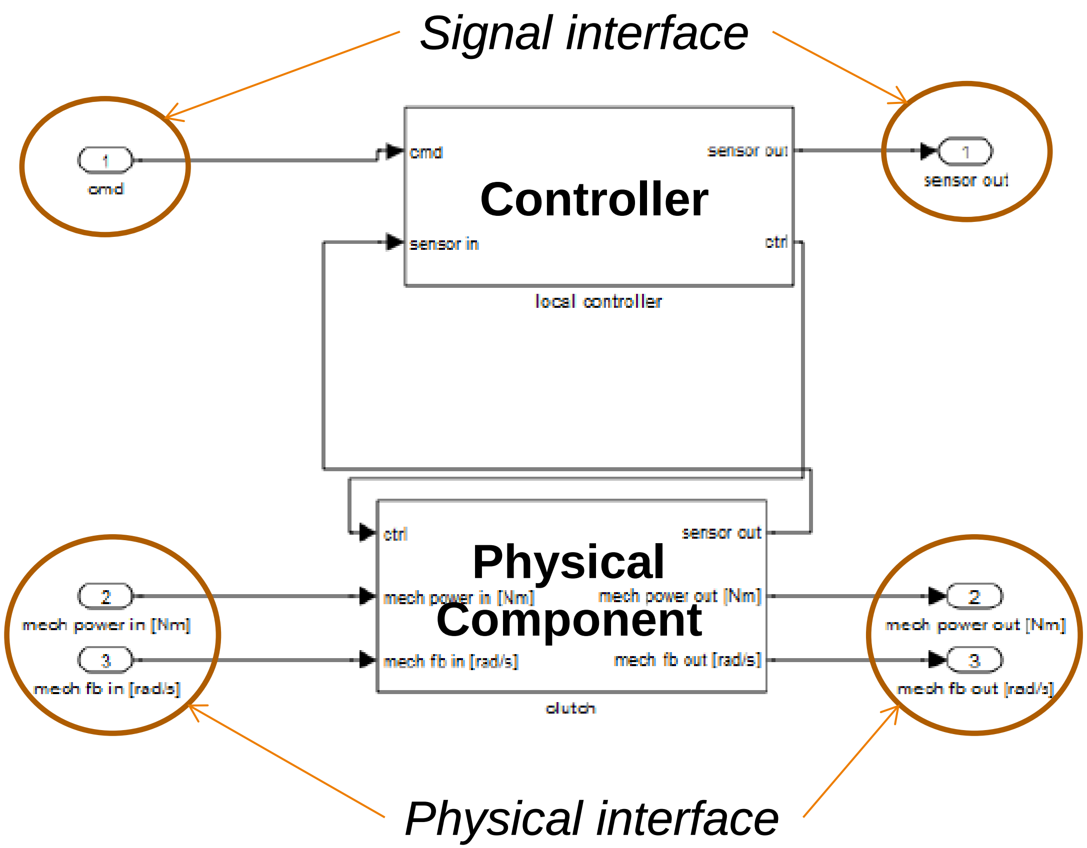


RESS



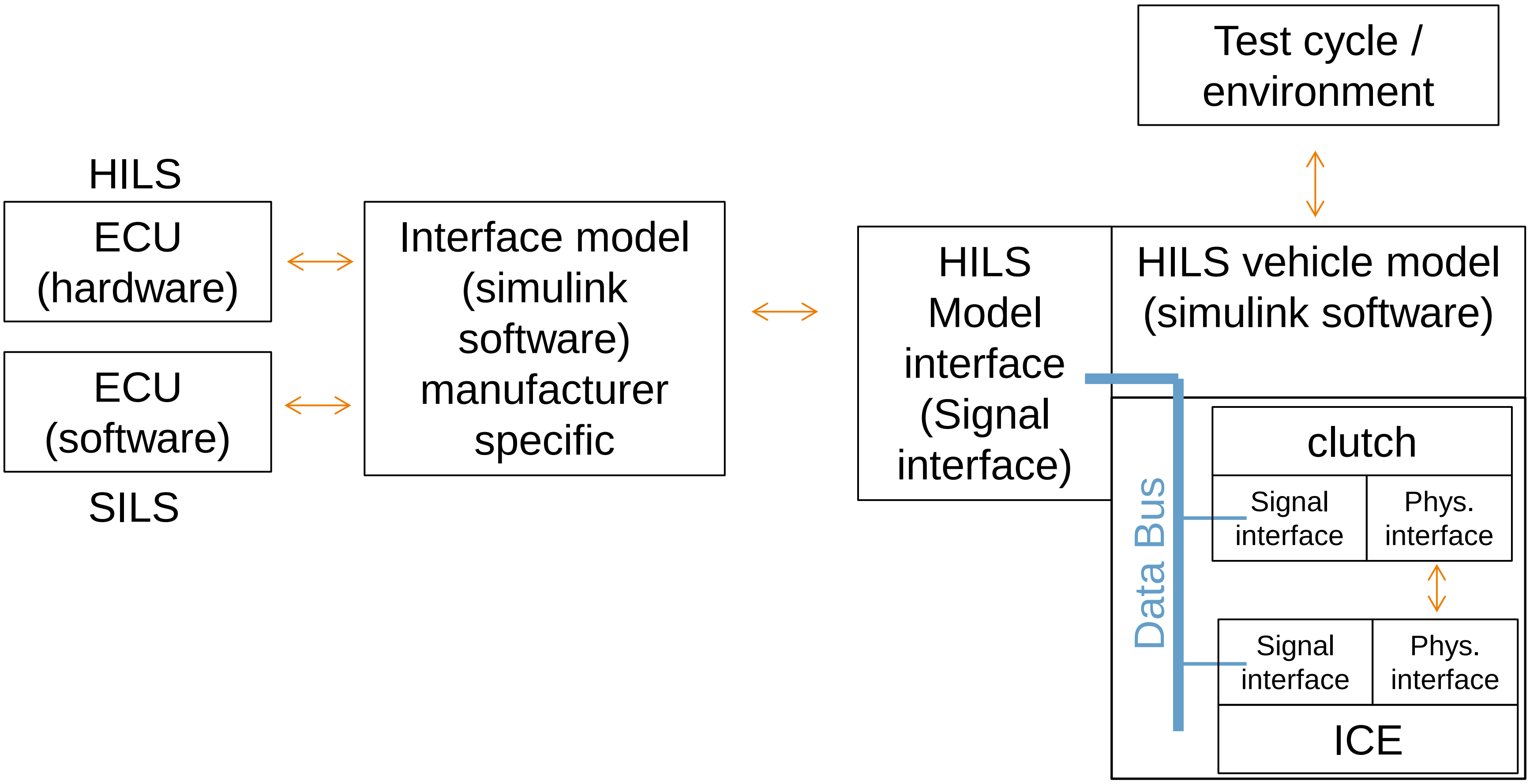
electricmotor

Task 2.2)* Restructuring of Models

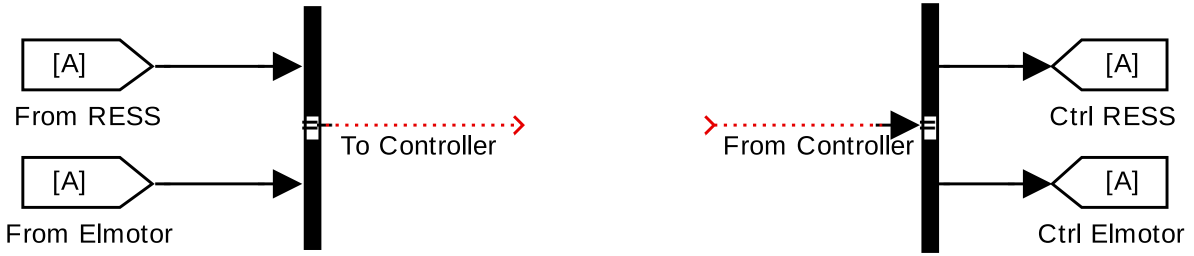


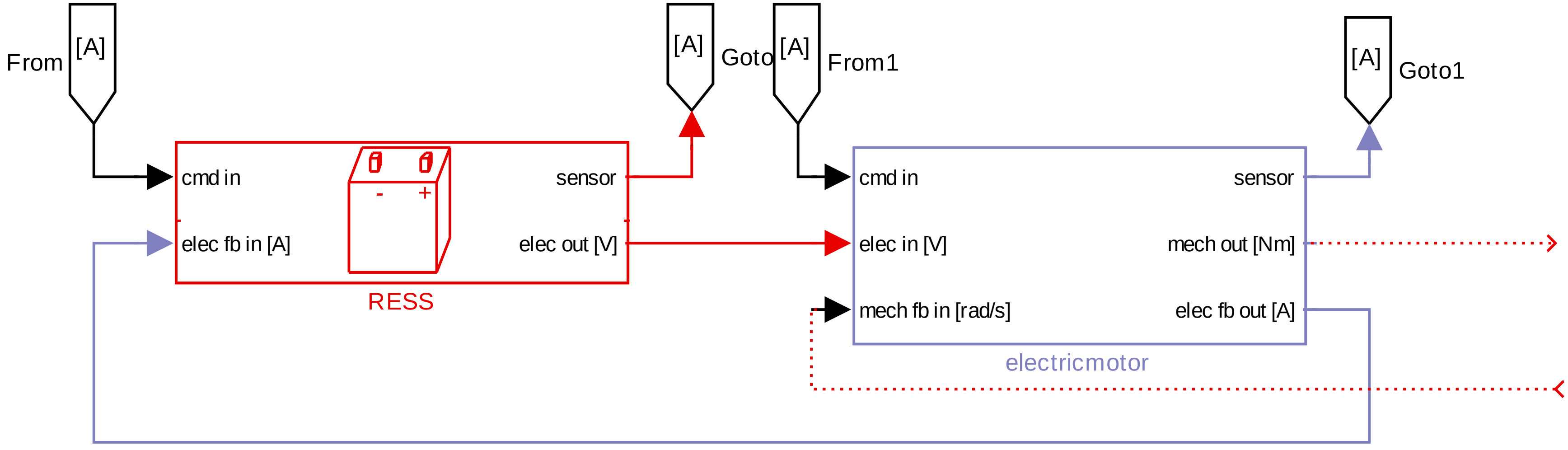
A port based approach: This structure is similar as the simulation models in for example Autonomi, Dymola (Powertrain library), CAPSim, VSIM, TruckSim

Task 2.2)* Restructuring of Models



Task 2.2)* Restructuring of Models



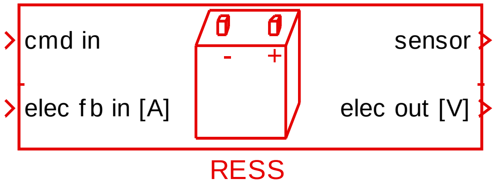


Task 2.2)* Restructuring of Models

- Parameter and signal naming must be defined
  - Proposal:
    - Parameters
      - dat.parameter.comment
      - dat.parameter.unit
      - dat.parameter.value
    - Signals
      - description [unit]

- Signals can be lumped together in a MATLAB/Simulink databus
  - Flexible structure
  - Easy to new add signals

Model and associated data file




```
dat.comment = 'Open source model battery data';
dat.filename = 'para_battery_open.m';
dat.version = '1';
dat.lastModified = '14.03.2013';
dat.modifiedBy = 'Jonas Fredriksson';

dat.capacity.comment = 'cell capacity';
dat.capacity.unit = 'Ah';
dat.capacity.value = 6;

dat.initialSOC.comment = 'initial state of charge';
dat.initialSOC.unit = '%';
dat.initialSOC.value = 60;
```

Task 2.2)* Restructuring of Models

- In the GTR:
  - the physical interface can be specified (fixed)
  - a minimum set of control/sensor signal can be specified*

*) If other signals are needed or more complex models are needed (no change of physical interface) it is possible for OEMs to include those without effecting the model structure

Task 2.3)

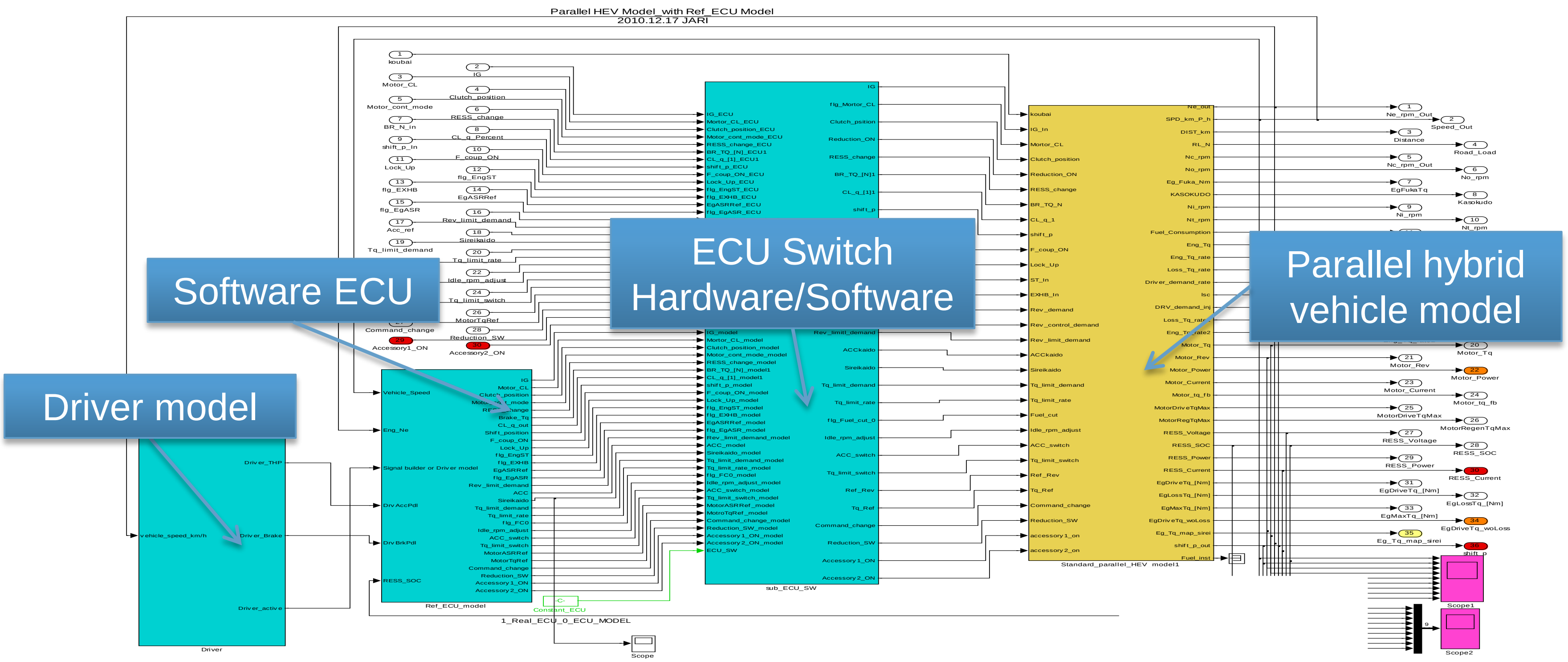
- Deliverables

- **Adapt the Software to simulate a parallel HDH**
  - Basic parallel hybrid model was provided by JARI
  - ECU control strategy was added
  - Driver model running the model, from **Task 1.1 and 1.2**

Task 2.3)

Set up a serial HDH in the simulator with the ECU as software in the loop

- Basic parallel hybrid model was provided by JARI
- ECU functions were added



Task 2.4)

- Deliverables

- **Simulation runs and validation of basic functions, including the functions from task 1**
  - The same simulation runs from task 1.7 can be performed for task 2.4

  - Additional slides will be added (simulation results)

System level verification

- Criteria $$r^2 = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sum_{i=1}^{n}(X_i - \bar{X})^2 \sum_{i=1}^{n}(Y_i - \bar{Y})^2}$$
- First 120 s of a driving cycle:

	Vehicle speed	Electric motor torque	Electric motor power	Engine torque	Engine power	Battery power
Tolerance	≥ 0.97	≥ 0.88	≥ 0.88	≥ 0.88	≥ 0.88	≥ 0.88

- Complete driving cycle:

	Vehicle speed r^2	Engine torque r^2	Engine positive work $W_{engHILS}/W_{eng}$	Fuel economy FC_{HILS}/FC_{veh}
Tolerance	≥ 0.97	≥ 0.88	≥ 0.97	≤ 1.03

System level verification

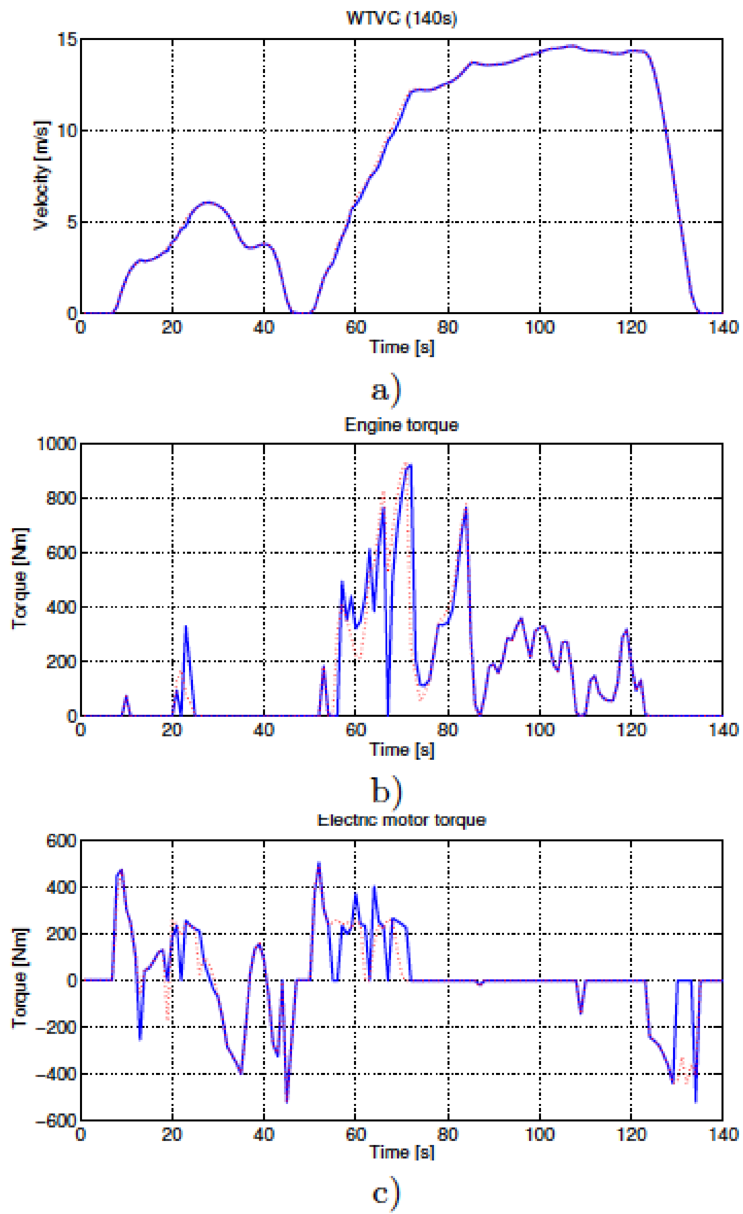
- **Example:** Gearshift timing "error"

- First 140 s of WTVC:

	Vehicle speed	*Electric motor torque*	*Electric motor power*	*Engine torque*	*Engine power*	*Battery power*
Tolerance	≥ 0.97	≥ 0.88	≥ 0.88	≥ 0.88	≥ 0.88	≥ 0.88
Simulation results	0.99	0.72	0.54	0.82	0.83	0.41

- Complete WTVC:

	Vehicle speed r^2	*Engine torque* r^2	*Engine positive work* $W_{engHILS}/W_{eng}$	*Fuel economy* FC_{HILS}/FC_{veh}
Tolerance	≥ 0.97	≥ 0.88	≥ 0.97	≤ 1.03
Simulation results	0.99	0.94	0.99	-

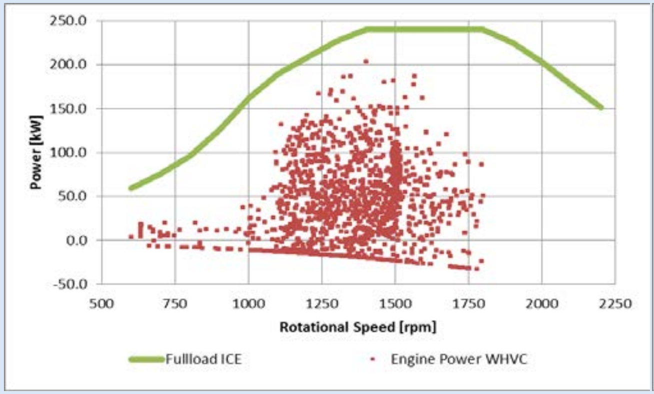


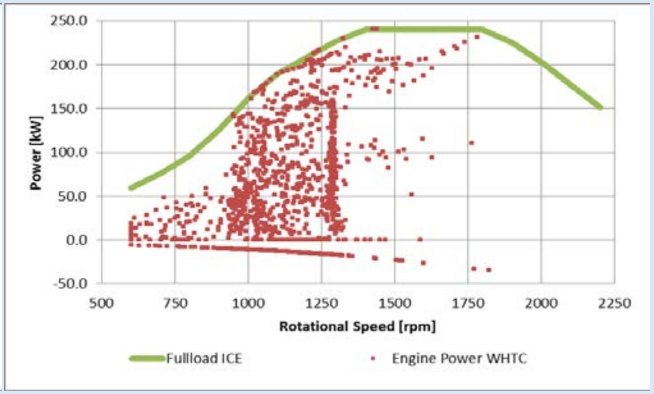
Drive cycle investigations

Motivation

- Test methodology for conv. engines (WHTC) and hybrids (HILS) should lead to comparable emission results
- HILS uses WHVC → add road gradients to match WHTC power curve
  - Huge changes of road gradient every second due to highly fluctuation WHTC power curve
  - *Statement after investigations*: currently no prospect for a practical solution

Comparison of engine load points for a conventional HD vehicle (14 ton / 240 kW)

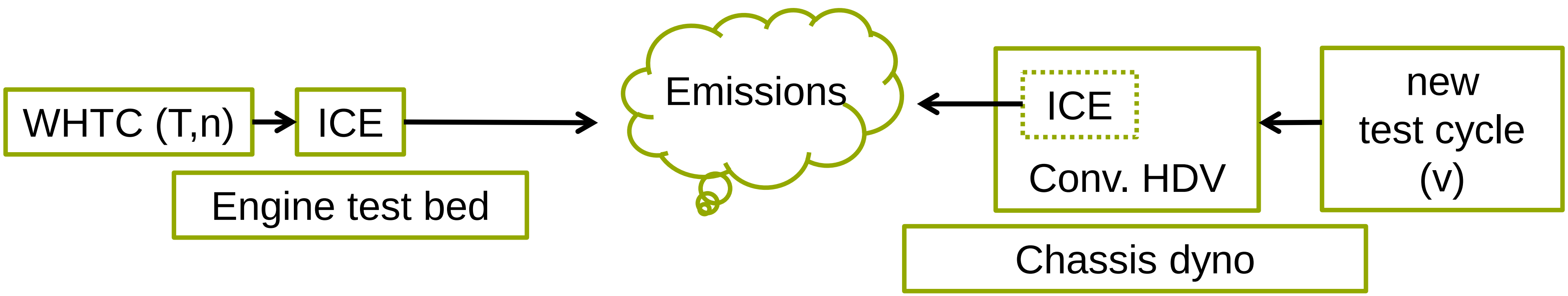




Drive cycle investigations

Promising HDH drive cycle approach

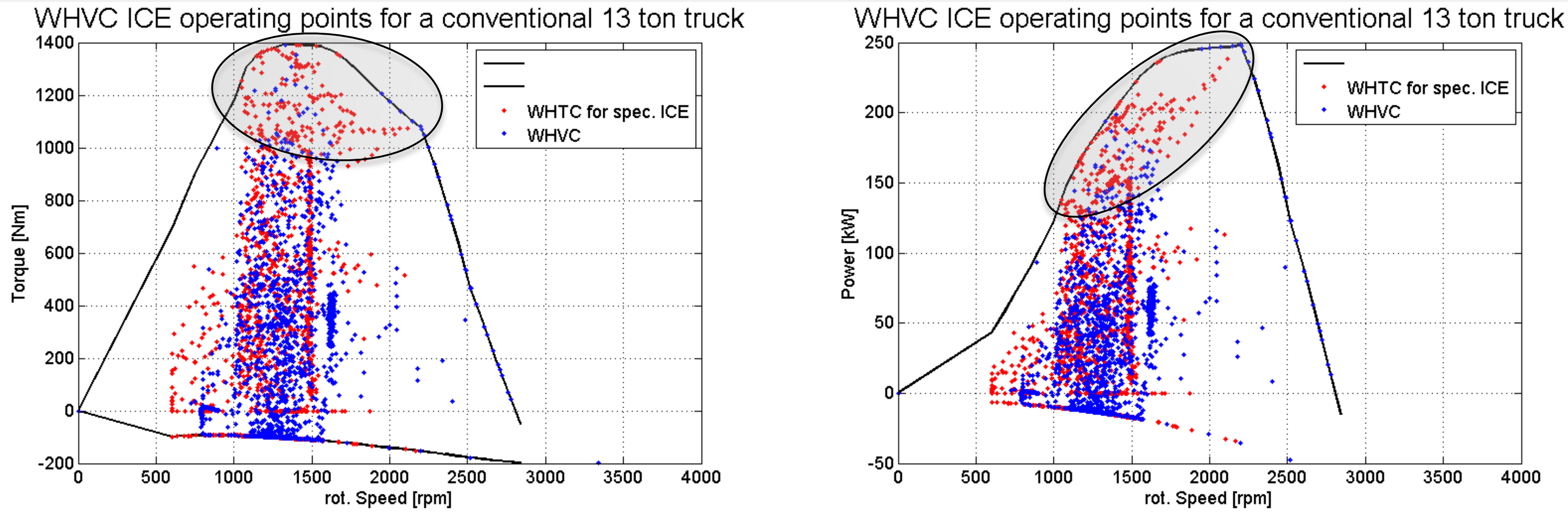
- Identified boundary conditions
  - Developed drive cycle should
    - be drivable on chassis dyno
    - have WHTC cycle work and similar load/speed pattern (cover full load operation)
    - produce similar emission results than WHTC for a conventional vehicle



Drive cycle investigations

Promising HDH drive cycle approach

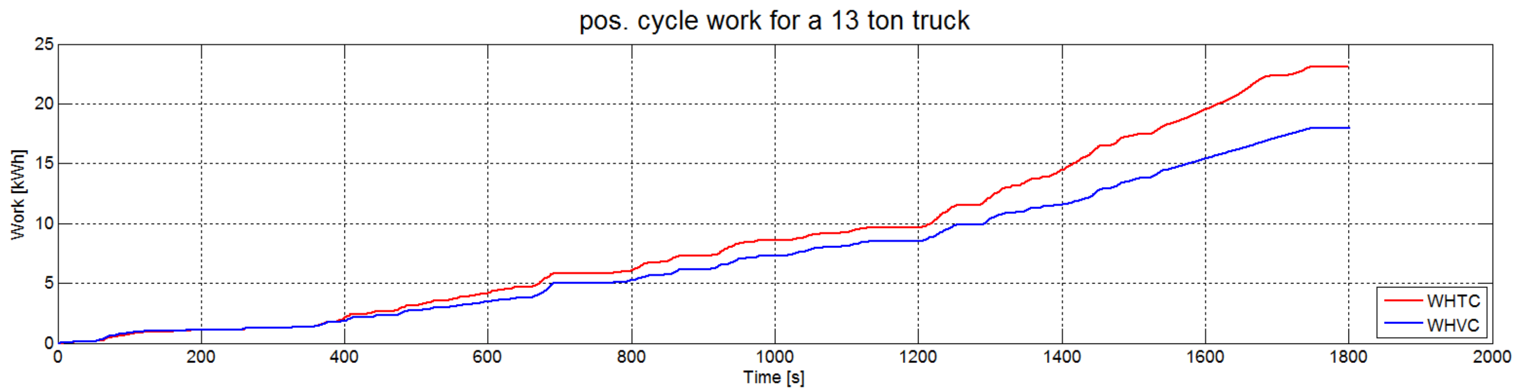
- Approach was simulated with a conventional HDV
  - 13 ton delivery truck, 248HP EU5, 12 speed transmission
  - At least 4 sec. remaining in one gear, pref. shifting speed, allow to skip one gear if low torque demand
- 1. Step: simulate vehicle at WHVC (plane road)



Drive cycle investigations

Promising HDH drive cycle approach

- 2. Step: calculate positive WHTC cycle work for specific ICE and compare it to WHVC cycle work for tested vehicle

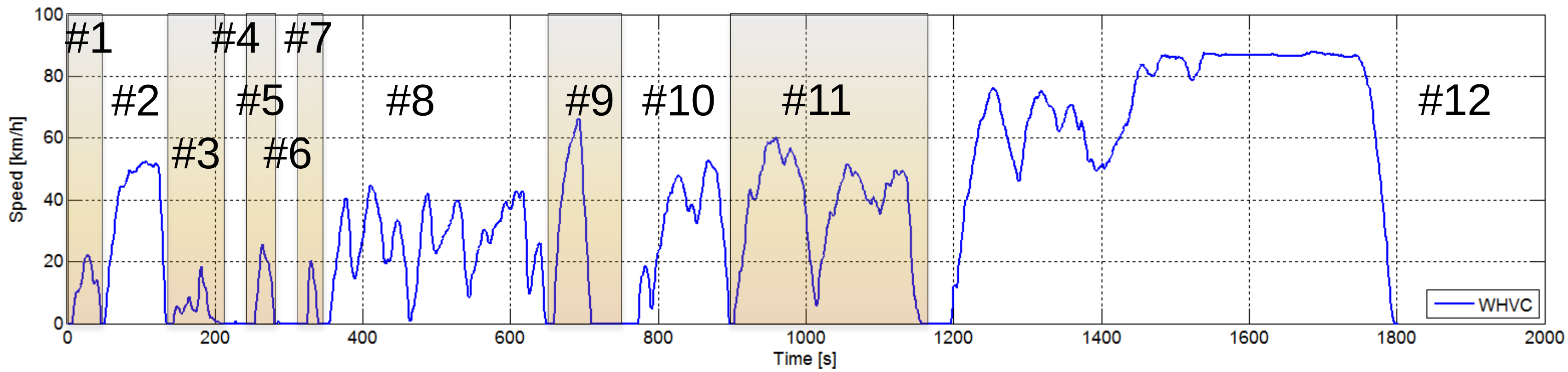


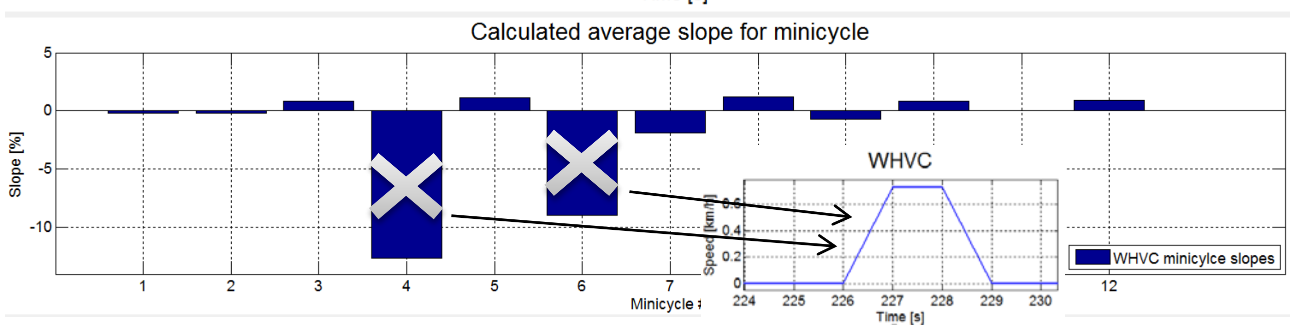
- Different work load for same IC engine due to different test methods (WHVC / WHTC)

Drive cycle investigations

Promising HDH drive cycle approach

- 3. Step: divide WHVC in “mini-cycle” parts (from zero to zero speed)
- Calculate WHTC/WHVC work difference for each mini-cycle and transform it into average mini-cycle slopes

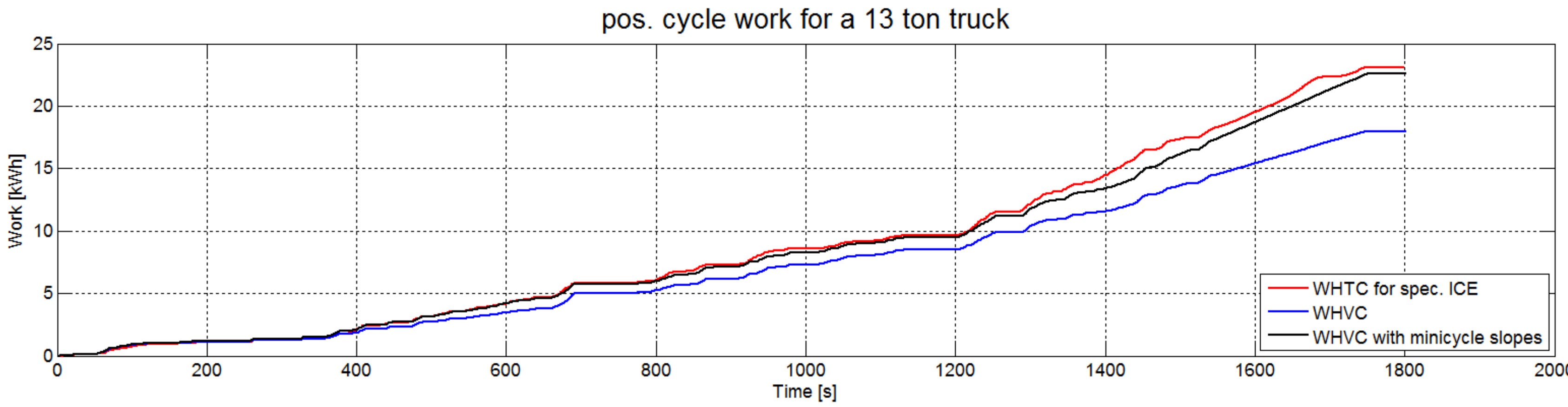




Drive cycle investigations

Promising HDH drive cycle approach

- 4. Step: simulate vehicle at WHVC with calculated slopes and again calculate cycle work

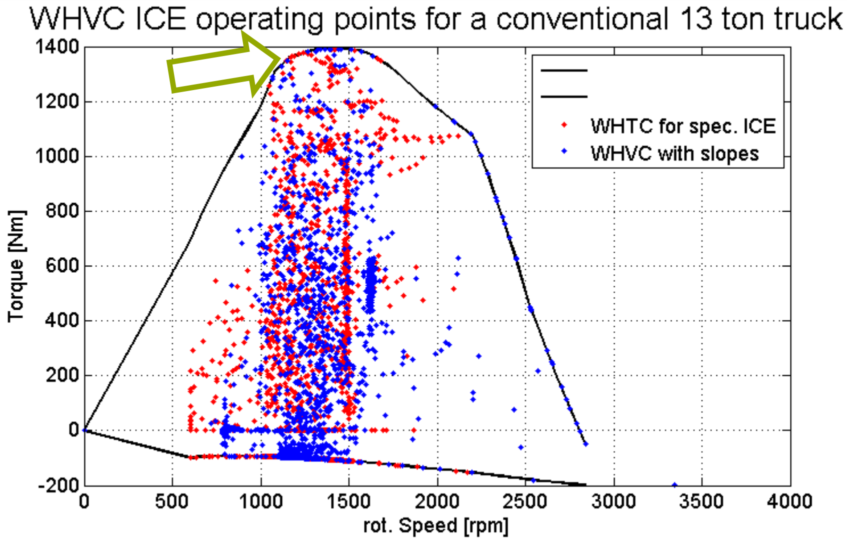


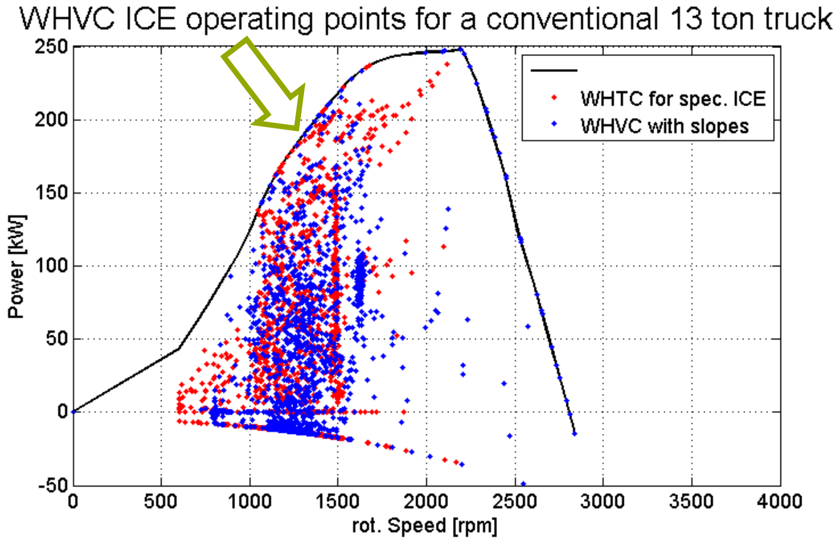
- After one iteration loop, cycle work matches within ~2%
- Adapt calculated slopes for better matching (e.g. at mini-cycle #12)

Drive cycle investigations

Promising HDH drive cycle approach

- 5. Step: check if ICE load/speed distribution is similar to WHTC



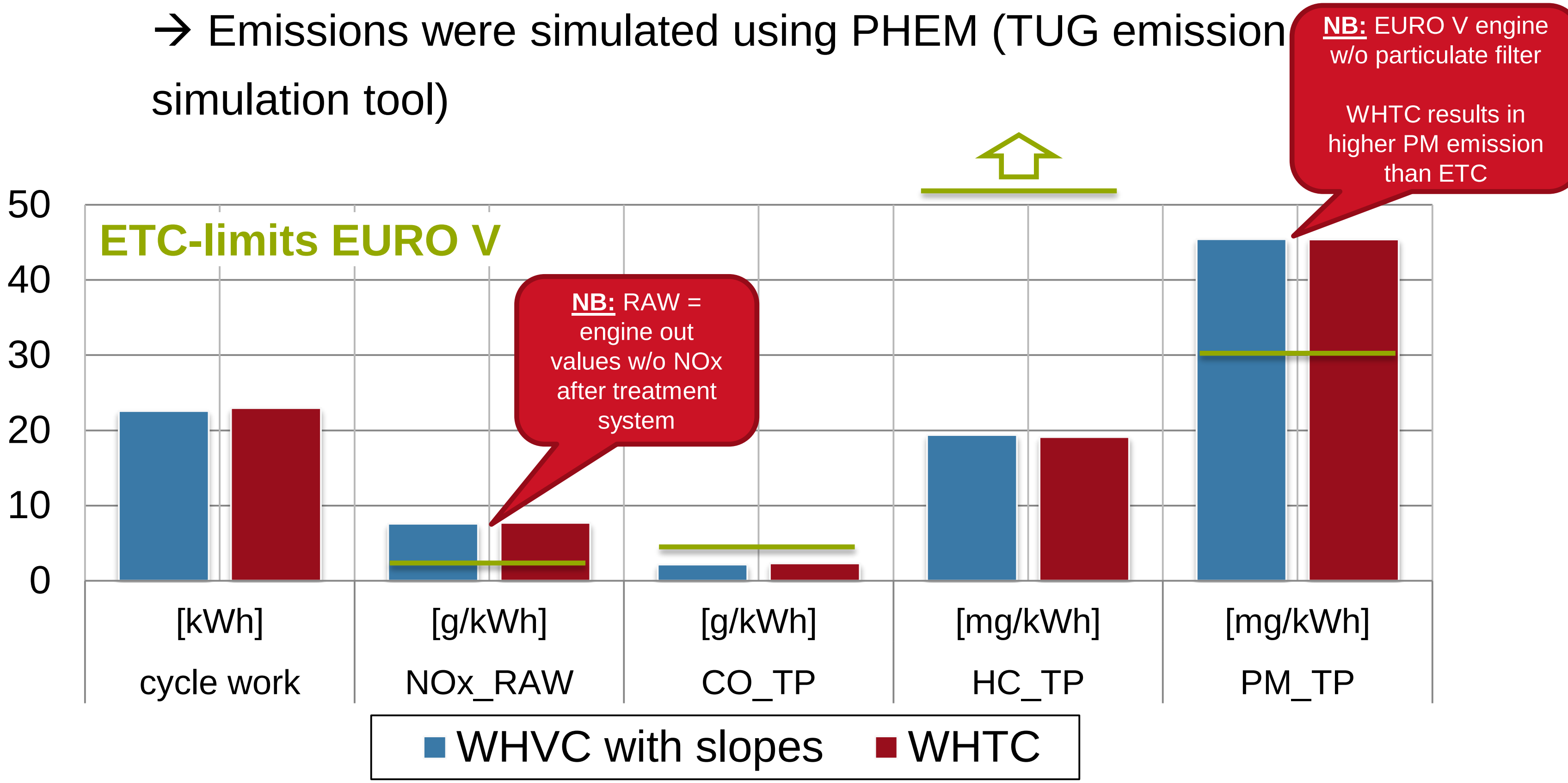


- Enriched operational points at full load
- Similar operation pattern like WHTC

Drive cycle investigations

Promising HDH drive cycle approach

- 6. Step: compare emissions / WHVC with slopes vs. WHTC
  - For this early investigations no measurement data was available → Emissions were simulated using PHEM (TUG emission simulation tool)



Drive cycle investigations

Promising HDH drive cycle approach

- Conclusion
  - Approach seems to deliver comparable results between engine and vehicle test cycle and is therefore feasible for HDH
  - Calculation of mini-cycle slopes can be automated in HILS tool
- Robustness of method has to be proofed
  - Simulation of several different con. vehicles, investigate influencing factors (gearshift strategy, extreme power/mass ratios,…)
  - Validate with measurements of specific vehicles and engines (drivability on chassis dyno, compare emissions,…)
- Also test HILS and drive cycle approach with conv. EURO 6 vehicle
- Solve remaining questions (set slopes to zero for HDH deceleration,..)
- ***Further investigations in validation test program 2 proposed***

Drive cycle investigations

Possible test sequence

- Test object: 12 ton HDH delivery truck

Define rated power of hybrid power pack
- just rated power - not shape of full load curve

Denormalize WHTC with rated power and calculate reference work for WHVC test run

Run WHVC and calculate slopes
- WHVC can be run with specific vehicle data
- or with generic vehicle data (avg. vehicle mass of class or depending of rated power,….)
  - Only affects available recuperation energy

Re-run WHVC with slopes

Get ICE operation pattern from HILS model for emission test

Drive cycle investigations

Summary

- HILS model can be run with vehicle speed referenced test cycle (compatible to Japanese test procedure)
  - Due to added slopes – emission results should be comparable to conventional vehicles
- New approach replaces power cycle (pre-, post-transmission) approaches
- Ability of running power cycles (e.g. WHDHC) in HILS remains for a later possible CO2 interface

Test methodology investigations

Japanese test procedure

build HDH vehicle simulation model according to vehicle topology

↓

determine input parameters and component maps for the HDH vehicle to be tested

(according to standard values from regulation, specific vehicle data and component tests)

↓

actual vehicle test by means of system bench or chassis dynamometer

↓

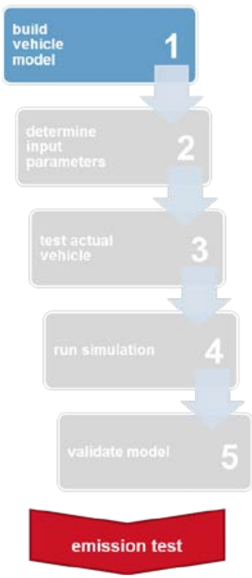
run simulation with vehicle model using identical test cycle from system bench or chassis dynamometer

↓

compare measured values to simulated output values to check if vehicle model represents real vehicle operation

↓

ICE emission test



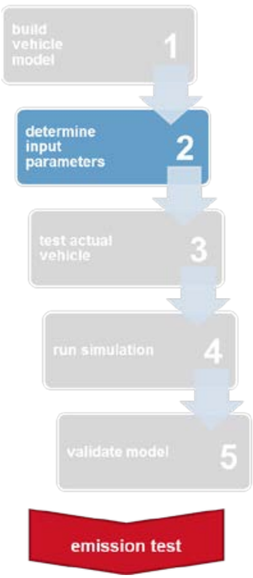
Test methodology investigations

Modelling depth and handling

Points to discuss for GTR / Open questions

- „Simple" standard vehicle models should be preferred
  - Driver model and gear shifting affects ICE operation and emissions → one standardized driver model with tunable parameters + defined gear shifting for MT is proposed (VECTO gear shift model)
  - Also simple model must be able to depict shift events → currently no interruption of traction force during gear shift event at parallel hybrid → influence on ICE operation and emissions
  - For hybrid power pack certification, gearbox model of VECTO could be used

- OEM specific models should also be allowed by using GTR model structure



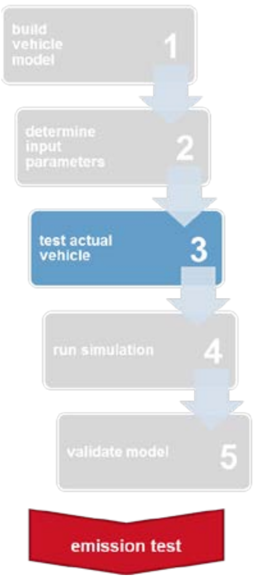
Test methodology investigations

Component tests

Points to discuss for GTR / Open questions

- pre-conditioning / aging status of components for testing
  - Mainly important for energy storage
  - Boundary conditions for components to be tested have to be defined
  - Pre-conditioning cycles have to be defined

- Component tests acc. to regulation vs. OEM component data
  - Do component tests acc. to the regulation have to be proofed to the type approval authority?
  - Use OEMs specific data >>> just pass verification criteria?



Test methodology investigations

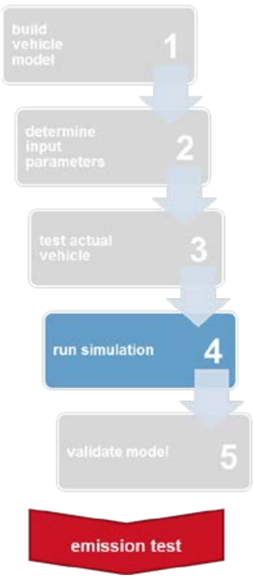
Vehicle measurements for model verification

Points to discuss for GTR / Open questions

- Vehicle test (measurements) on chassis dyno/testbed required for model verification acc. to Japanese regulation
  - complex, expensive infrastructure
  - On-road tests could be an attractive alternative

- Verification of model with on-road data can be challenging
  - manageable acc. to meetings with OEMs
- Vehicle model will be verified with data from one specific test (e.g. on-road test cycle)
  - model still valid for different certification cycle (i.e. modified WHVC)?

- ***Further investigations in validation test program 2 proposed***



Test methodology investigations

OEM specific interface model

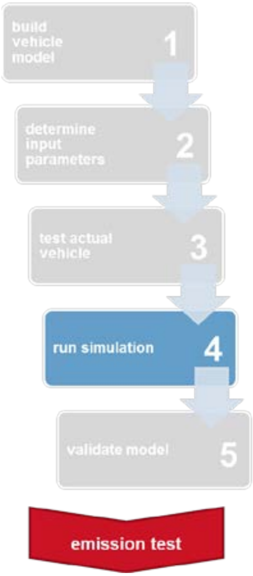
Points to discuss for GTR / Open questions

- Interface model will be designed for vehicle at HILS verification test
- For testing other vehicles with validated HILS model

  → changes in the interface model may become necessary
  - e.g. tested vehicle without traction control → new derivative with TC → additional control bits are needed in interface model

    → **new HILS verification necessary?**
- Which / how much changes are allowed before new model validation is needed

- Description of interface model indispensable in GTR



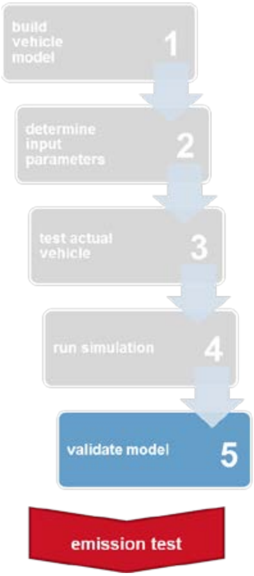
Test methodology investigations

Multiple ECUs

Points to discuss for GTR / Open questions

- High manpower and cost effort for multiple ECUs at HILS test rig
- Several ECU logics are supposed to be represented in OEM specific interface model

- Functions and modifications in interface model have to be defined
- Further investigations necessary
- Japanese regulation not sufficient at this point

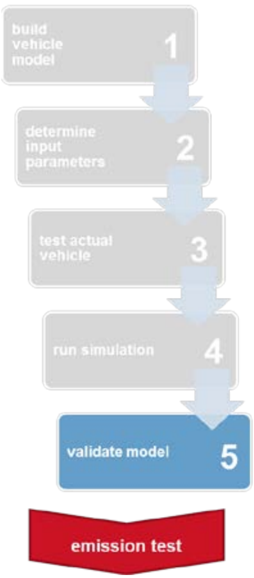


Test methodology investigations

Re-Verification of simulation model / Re-Certification of ICE emissions

Points to discuss for GTR / Open questions

- What can be changed in the HILS system (i.e. parameters, maps, signal interface definition, OEM specific interface, hardware ECU) without having to verify the model again?
  - avoid frequent real-vehicle measurements for verification
  - prevent model inaccuracy and deviation from real-vehicle operation
- What can be changed in the HILS system without having to certify the ICE for emissions again?
  - dependent on resulting engine operation points
  - definition of limits possible? (What is new worst case scenario?)



Test methodology investigations

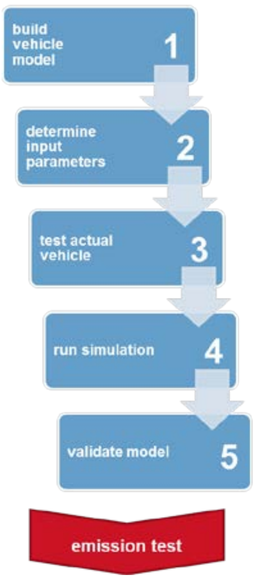
Disclosure of models and parameters

Points to discuss for GTR / Open questions

- Which items have to be disclosed to the type approval authority?
  - Models (e.g. OEM specific component models)?
  - Parameters / Maps for components?
  - OEM specific interface model?
  - CAN communication?

- Is data stored at the type approval authority?
- Data protection by type approval authority?
- NDAs with suppliers
  - component parameters / software logics in interface model

- Influences on modeling depth / accuracy

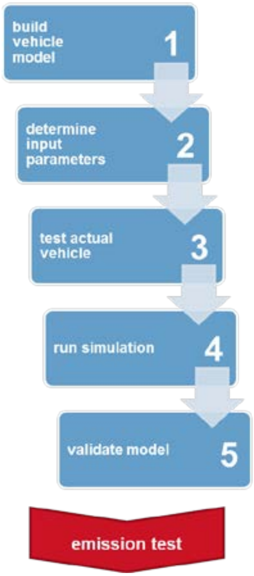


Test methodology investigations

Vehicle-independent emission certification

Points to discuss for GTR / Open questions

- vehicle-independent emission certification of a hybrid-powerpack would be a desireable approach to reduce complexity and effort
  - standardized vehicle parameters (e.g. depending on rated power or vehicle class)
  - just **one engine emission test** per powerpack needed
  - powerpack could be used in all ***„similar“*** vehicles („family concept“)
- elaboration of alternative new test procedure necessary
  - standardized vehicle parameters for HILS test need to be defined
  - limits of vehicle specifications usage of powerpack need to be defined
    - What is a „similar“ vehicle?(„family concept“)
  - limits of vehicle specifications for model verification need to be defined
- ***Further investigations in validation test program 2 proposed***



Test methodology investigations

Emission test options / requests by OEMs

Points to discuss for GTR / Open questions

- request by OEMs that WHTC remains as alternative type approval test
  - for low-volume and niche vehicles HILS type approval procedure would be very high effort
  - Viable solution?

- Output of test cycle for combustion engine from HILS model
  - engine test cycle typically in 1Hz
  - model simulation timesteps in 2000Hz
  - conversion method of engine speed and torque from 2000Hz to 1Hz has to be defined (esp. loads changes at gearshifts should not be filtered)

Offer for Validation Test Program 2

Identified work packages - outline

(1) Software

- 1.1) Finalization of new model structure for GTR
- 1.2) Implementation of new structure in HILS models

(2) OEM Support and adaptation of HILS model

- 2.1) Adapt HILS model to OEM specific needs
- 2.2) Supervise/support validation test of OEMs – close cooperation
- 2.3) Support Matlab models and test methodology
- 2.4) Elaborate options for HILS model verification, discuss with OEMs (interaction with WP 3)

Offer for Validation Test Program 2

Identified work packages - outline

(3) Provide methodology to verify the HILS model in the GTR

- 3.1) Verification of HILS simulation model according to
  - a) Japanese method
  - b) test alternative methods (e.g. frequency distribution in engine map,…)

(measurements from OEMs or JRC and from 3.2) and 3.3) to be analysed from 3 HDH, Basis is WHVC, test also one or two alternative cycles on the chassis dyno)

- Analyse the measurands to be recorded at the vehicle test
- Analyse relevant accuracy between HILS model and measurement for each measurand
- Elaborate tolerable margins for the relevant measurands
- Compare instantaneous versus integrated data demands

- Different options for measuring the vehicle are analysed in 3.2) to 3.4)

Offer for Validation Test Program 2

Identified work packages - outline

(3) Provide methodology to verify the HILS model in the GTR

- 3.2) On-road measurements on one HDH (On-road tests could be an attractive alternative to Japanese method)
  - It is suggested to test the first validation HDH within the consortium to allow quick and flexible adaptation of test program
  - Measurands to be recorded as identified in 3.1
  - Test track short cycle (SORT like cycles)
  - On-road PEMS driving procedure
  - Use measured wheel hub torque as input to the HILS model and compare simulation results with measured values. Methods like in 3.1

Offer for Validation Test Program 2

Identified work packages - outline

(3) Provide methodology to verify the HILS model in the GTR

- 3.3) Chassis dyno measurements by TUG on one HDH
  - Test cycles are WHVC and a test cycle from 3.2. (on road test)
- 3.4) Analysis of transferability of on-road test to chassis dyno
  - Compare results to analyse if chassis dyno provides representative results for HDH (e.g. only one axle braked on chassis dyno with effects on brake energy recuperation)
- 3.5) Elaborate new draft verification procedure for GTR
  - on-road / dyno / both
  - simulation rules for gear box and gear shift needed
  - **description of interface model and hybrid ECU needed**

Offer for Validation Test Program 2

Identified work packages - outline

(4) Elaborate definitions for the validity of a verified simulation model

"Family Concept"

- 4.1) vary power-pack & vehicle parameters to test limits of change without affecting the accuracy of the simulation model
- 4.2) Evaluation and analysis of measurements with different vehicle & power-pack set ups
- 4.3) Which vehicle set-up (combination of parameters) has to be used for HILS-model verification?
  - Evaluation and analysis of effects of: Battery, vehicle mass, final drive ratios, ….
- 4.4) Sensitivity analysis of verification method for the HILS model

- HILS test stand assumed to be installed at OEM and results provided to consortium for results (engine test cycle) for variations in vehicle set up

Offer for Validation Test Program 2

Identified work packages - outline

(5) Test and certification cycles

- 5.1) Improvement of WHVC modification method *(as presented on 21.03.2013)*
  - Simulation of several different vehicles, investigate influencing factors (gearshift strategy, extreme power/mass ratios, …)
- 5.2) Drivability investigations on chassis dyno (“road slopes”)
- 5.3) Compare resulting engine torque and speed with WHTC
- 5.4) Compare resulting emissions
  - Option a -> by simulation
  - Option b -> by measurements (would need engine tests also)

Investigations for 5.1 to 5.4 can be done with a conventional HDV

A comparison of resulting engine test cycles can be done with any HDE, e.g. the results from HILS for HDH can be compared with WHTC for a conventional EU VI engine

(6) Adapt HILS test description for GTR

- component test procedures, HILS test procedure, verification procedure

THANK YOU FOR YOUR ATTENTION!

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