Models everywhere: How a fully integrated model-based test environment can enable progress in the future

M. Ben Gaid
R. Lebas
M. Fremovici
G. Font
G. Le Solliec

A. Albrecht

Contributions

IFP Energies nouvelles is a public research, innovation and industrial training center, whose mission is to develop efficient technologies, economic, clean and sustainable in energy, transport and environment.

D2T Powertrain Engineering is a IFP Energies nouvelles subsidiary focused on the powertrain development from test bed equipment to engineering services.

Agenda

- A look on the simulation-based engineering
- The simulation environment as a key asset
- The example of a €6 powertrain target

Agenda

- A look on the simulation-based engineering
- The simulation environment as a key asset
- The example of a €6 powertrain target

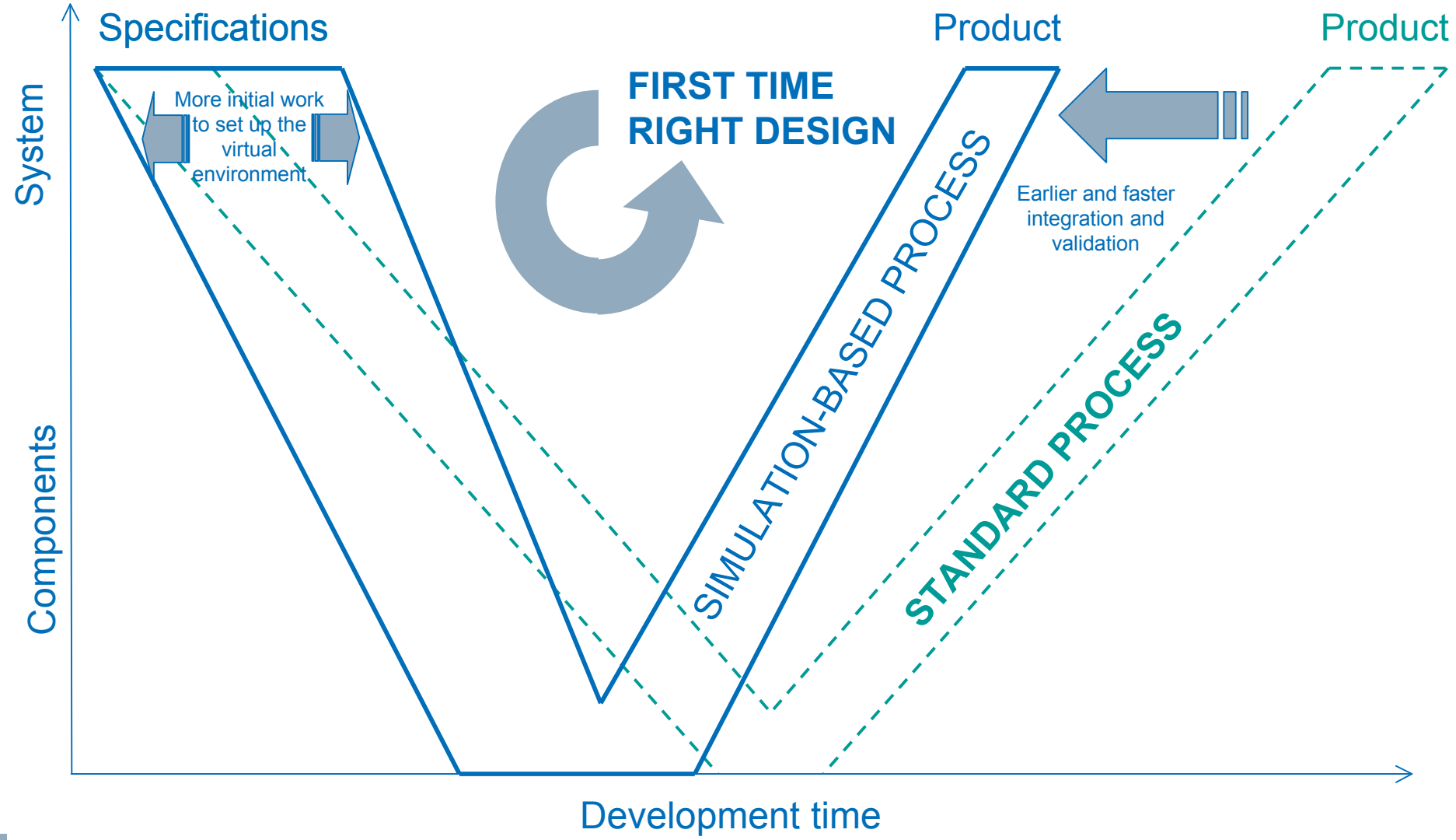
Simulation-based engineering

A strong potential ...

- to address the current powertrain technological challenges
  - ✓ wide range of technical domains (mechanics, electrics, fluids, chemistry, ...)
  - ✓ high versatility of powertrain solutions (hybrid, additional systems, ...)
  - ✓ all-in-one requirement of the design process (component sizing, powertrain architecture, energy management, ...)

- to support the cost & time reduction expectations
  - ✓ high flexibility to virtually investigate a lot of options at low cost
  - ✓ efficient complement to the test beds to focus experimentations on high added value tests
  - ✓ relevant way to postpone and reduce the hardware supports in the powertrain development process

Simulation-based engineering



Simulation-based engineering

... but still a lot of obstacles

- cultural issues
  - ✓ to be a profitable investment, simulation has to be involved in the whole development process, from the concept evaluation to the final validation
  - ✓ "collaborative platform", "model exchange", "co-simulation"... to set the simulation as a reference development support inevitably impact the engineer day-to-day practices

- technical issues
  - ✓ the models are not perfect and require specific knowledge to be used in a good way
  - ✓ the models are built in heterogeneous software according to the technical domains and goals
  - ✓ the simulation environments use modeling expert interface

Agenda

- A look on the simulation-based engineering
- **The simulation environment as a key asset**
- The example of a €6 powertrain target

Simulation environment

To face and overcome these limitations, the simulation environment can be a key asset if it allows:

- an efficient heterogeneous model integration
- high performances simulation execution
- a user friendly interface
- an easy combination with current supports and methodologies

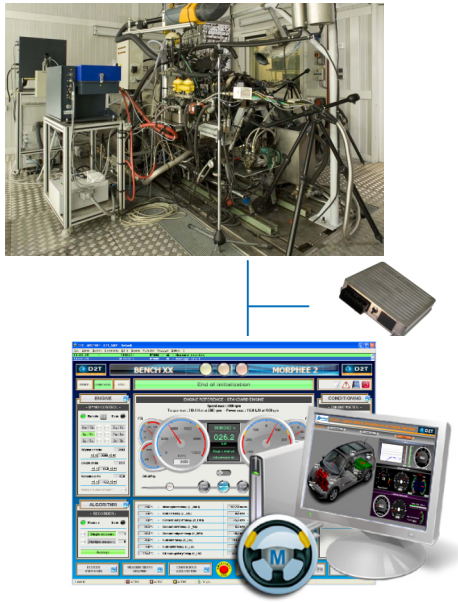
Simulation environment

The example of xMOD/MORPHEE 2 suite

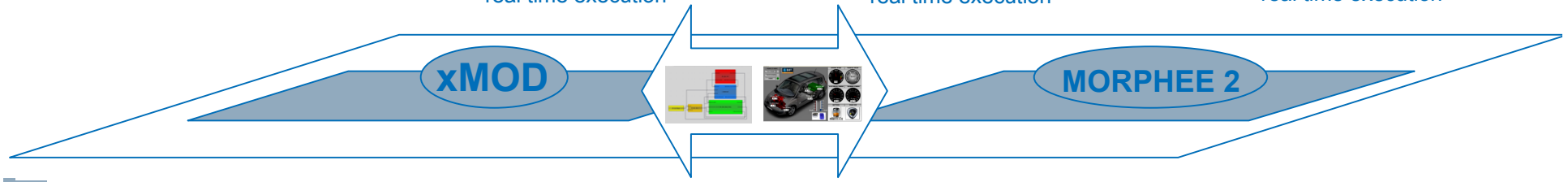
Software-in-the-Loop
100% virtual
not real time execution

ECU Hardware-in-the-Loop
Virtual plant / Real ECU+actuators
real time execution

Component test bed
Virtual system environment / Real component
real time execution



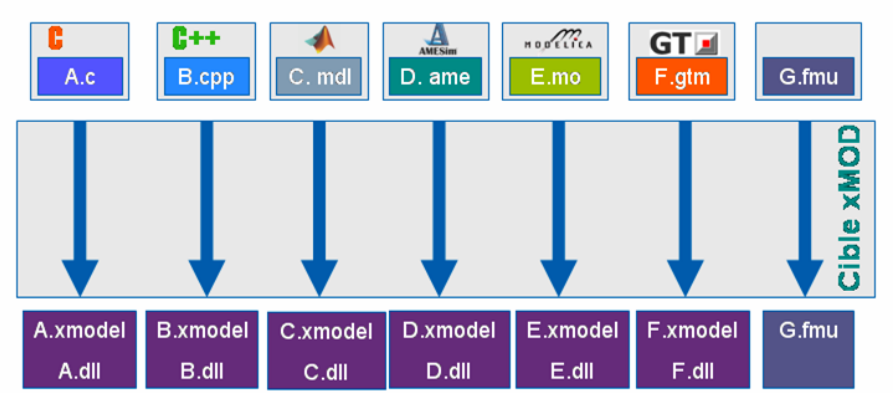
System test bed
Virtual system environment / Real subsystem
real time execution



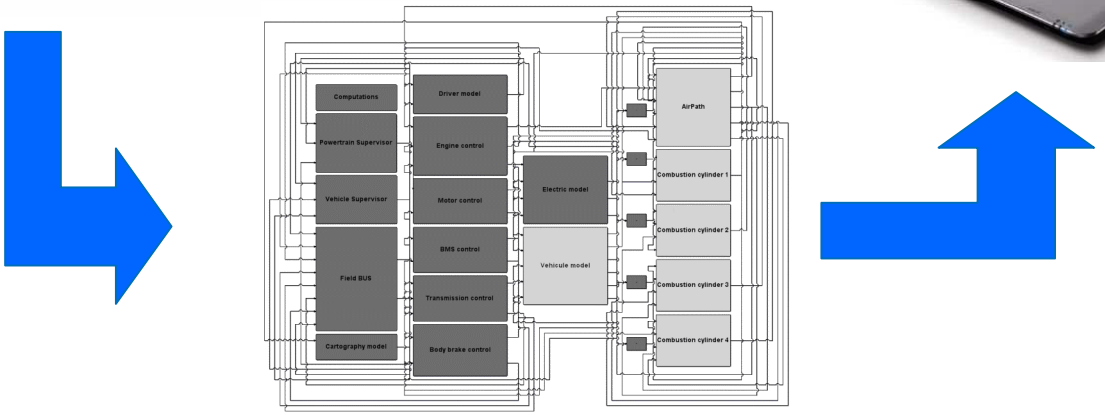
Simulation environment

The xMOD platform: overview

- multi-model integration environment
- stand alone optimized execution platform
- custom virtual testing interface

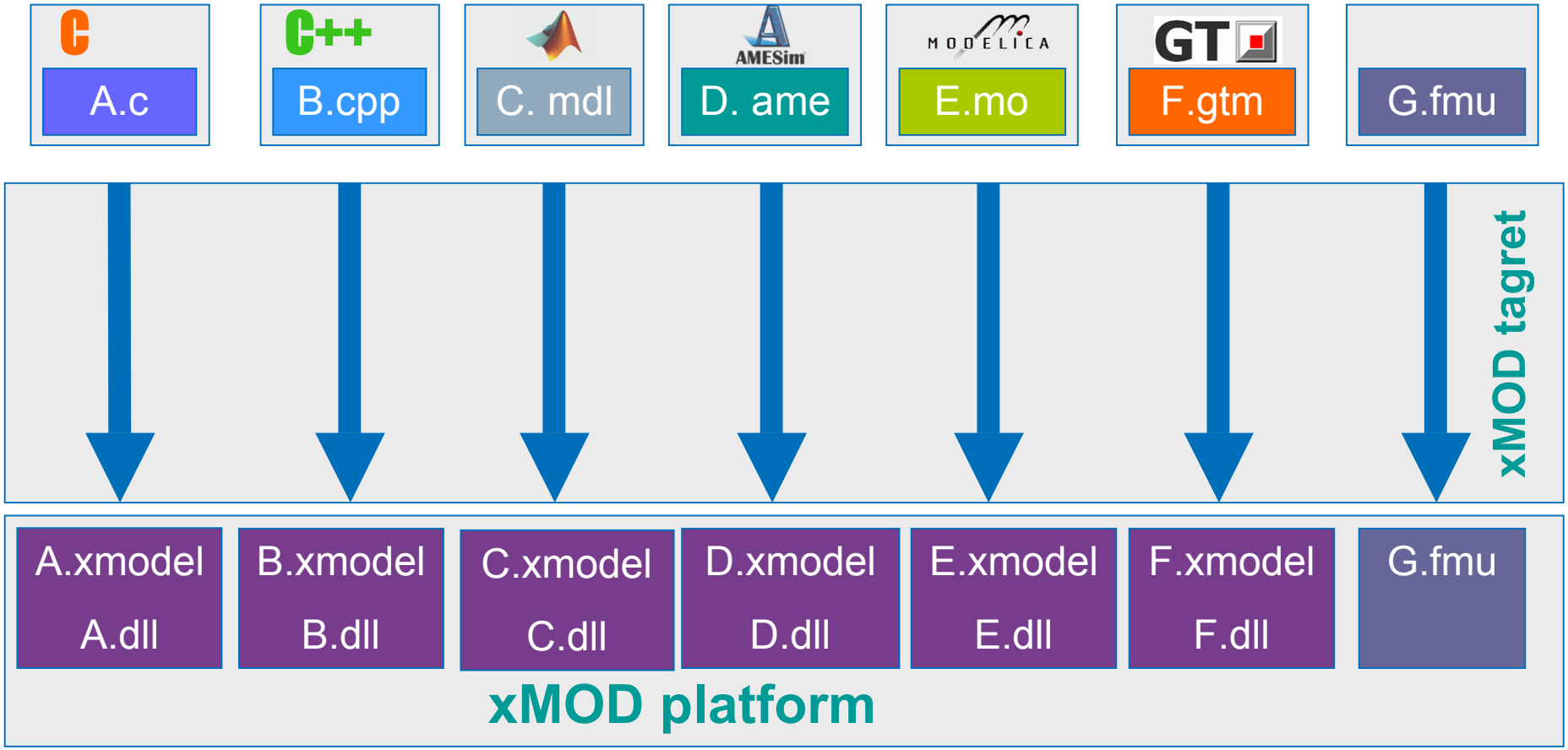


multi-core
multi-solver
multi-time step



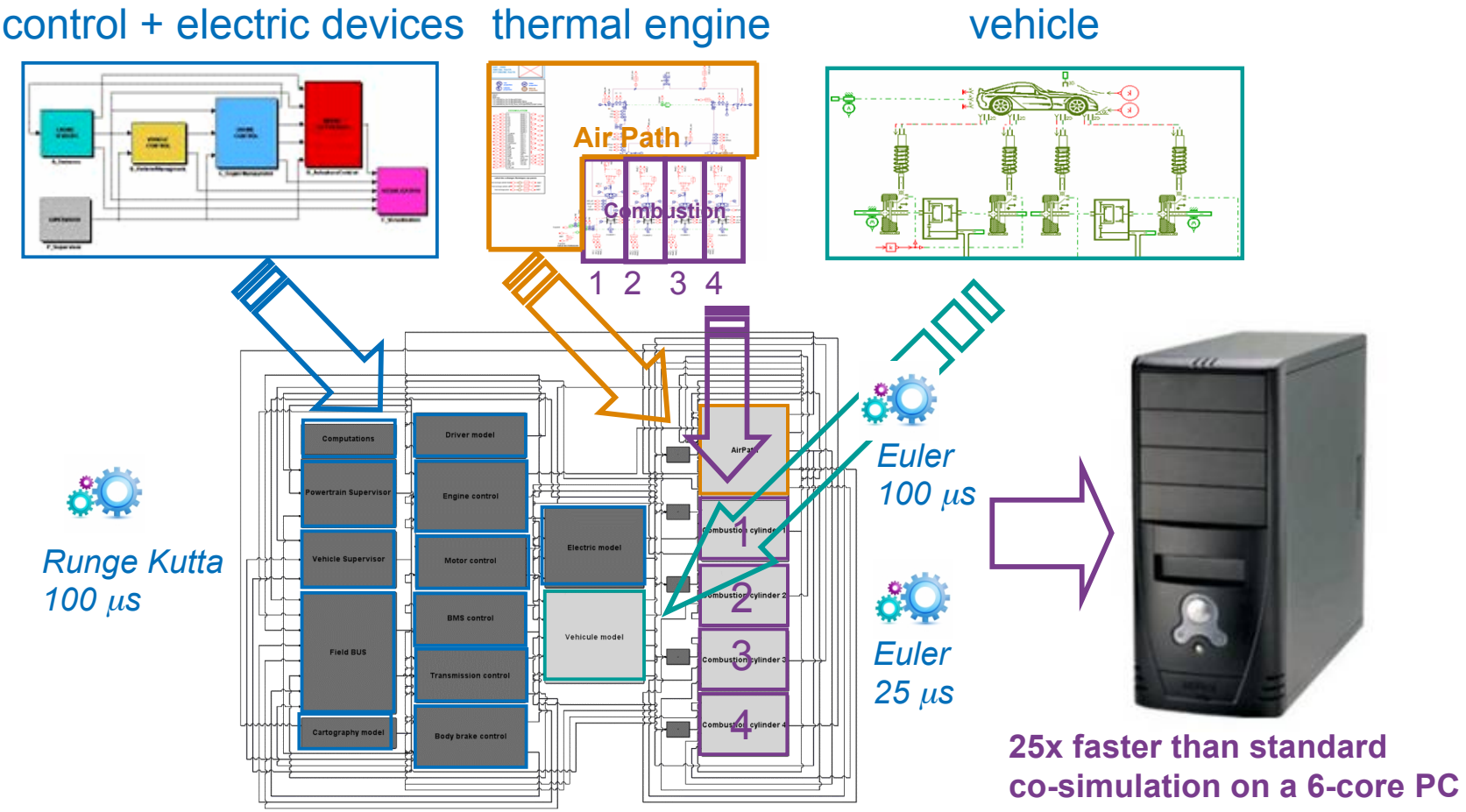
Simulation environment

The xMOD platform: multi-model integration



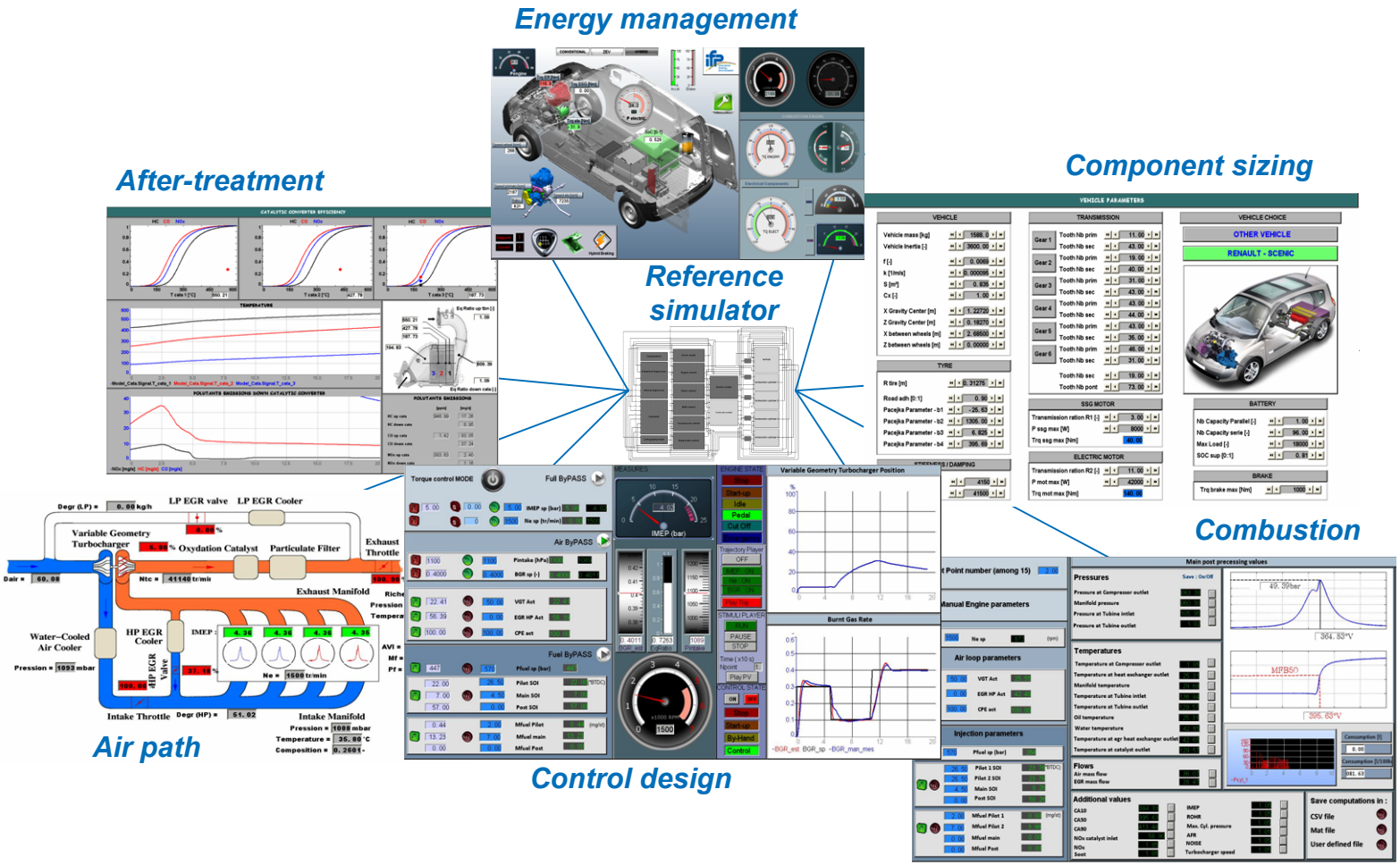
Simulation environment

The xMOD platform: stand alone optimized execution



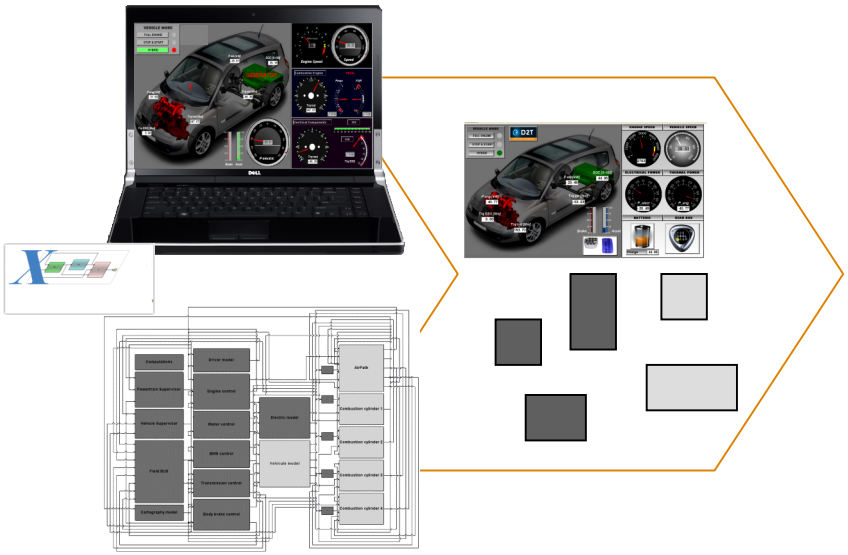
Simulation environment

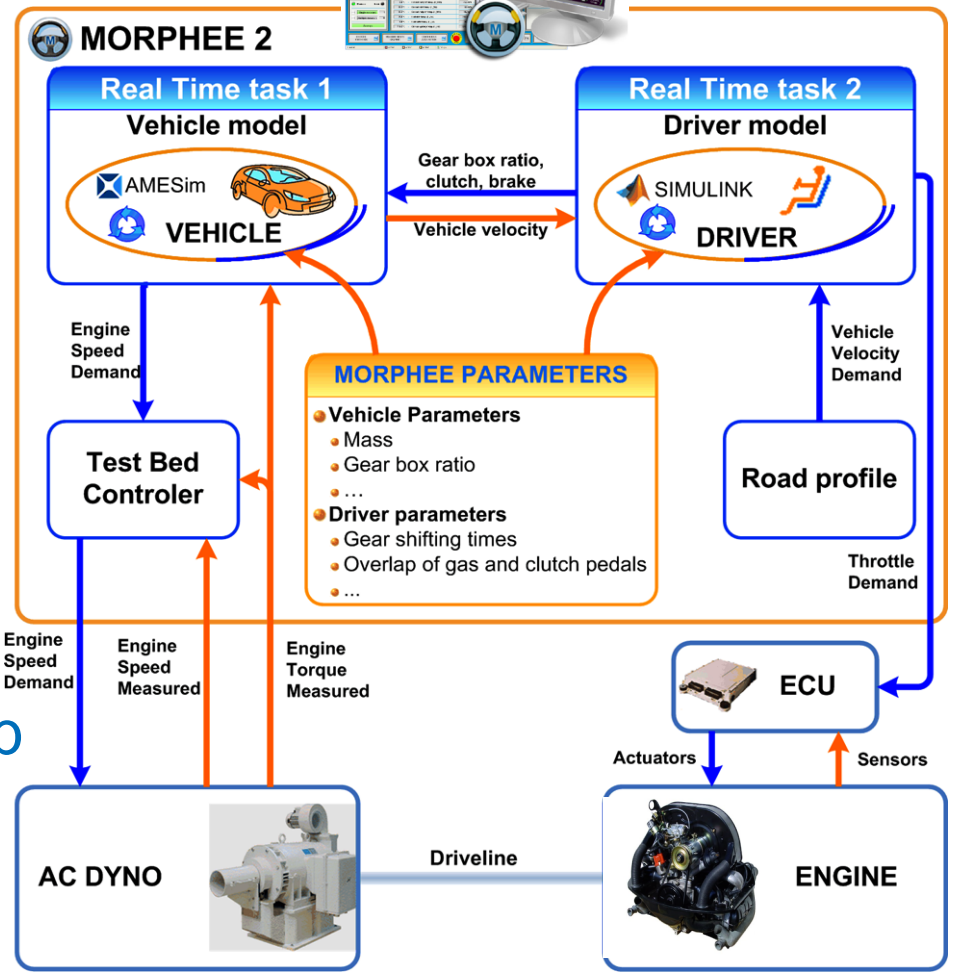
The xMOD platform: custom virtual testing interface



Simulation environment

xMOD to MORPHEE 2





Hybrid Hardware-in-the-Loop dynamic test bench

Simulation environment

- Combining the relevant characteristics, the simulation environment becomes a powerful support to be mixed with experimental facilities to develop powertrain

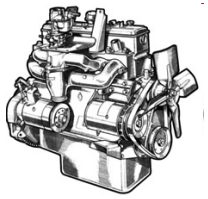
- The xMOD/MORPHEE 2 suite is an example of such a kind of model-oriented solutions

Agenda

- A look on the simulation-based engineering
- The simulation environment as a key asset
- **The example of a €6 powertrain target**

€uro 6 powertrain target

Multiple ways to reach €uro 6



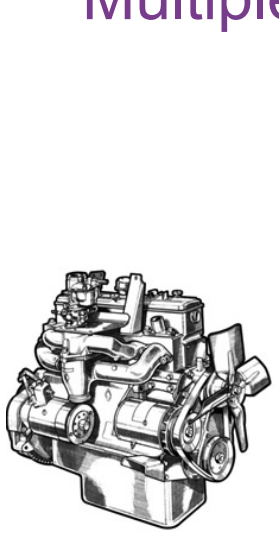
€uro 5
thermal engine

?

€uro 6
powertrain

€uro 6 powertrain target

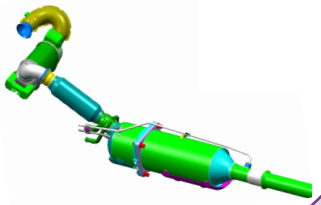
Multiple ways to reach €uro 6



€uro 5
thermal engine

€uro 6
thermal
engine

raw emission
reduction



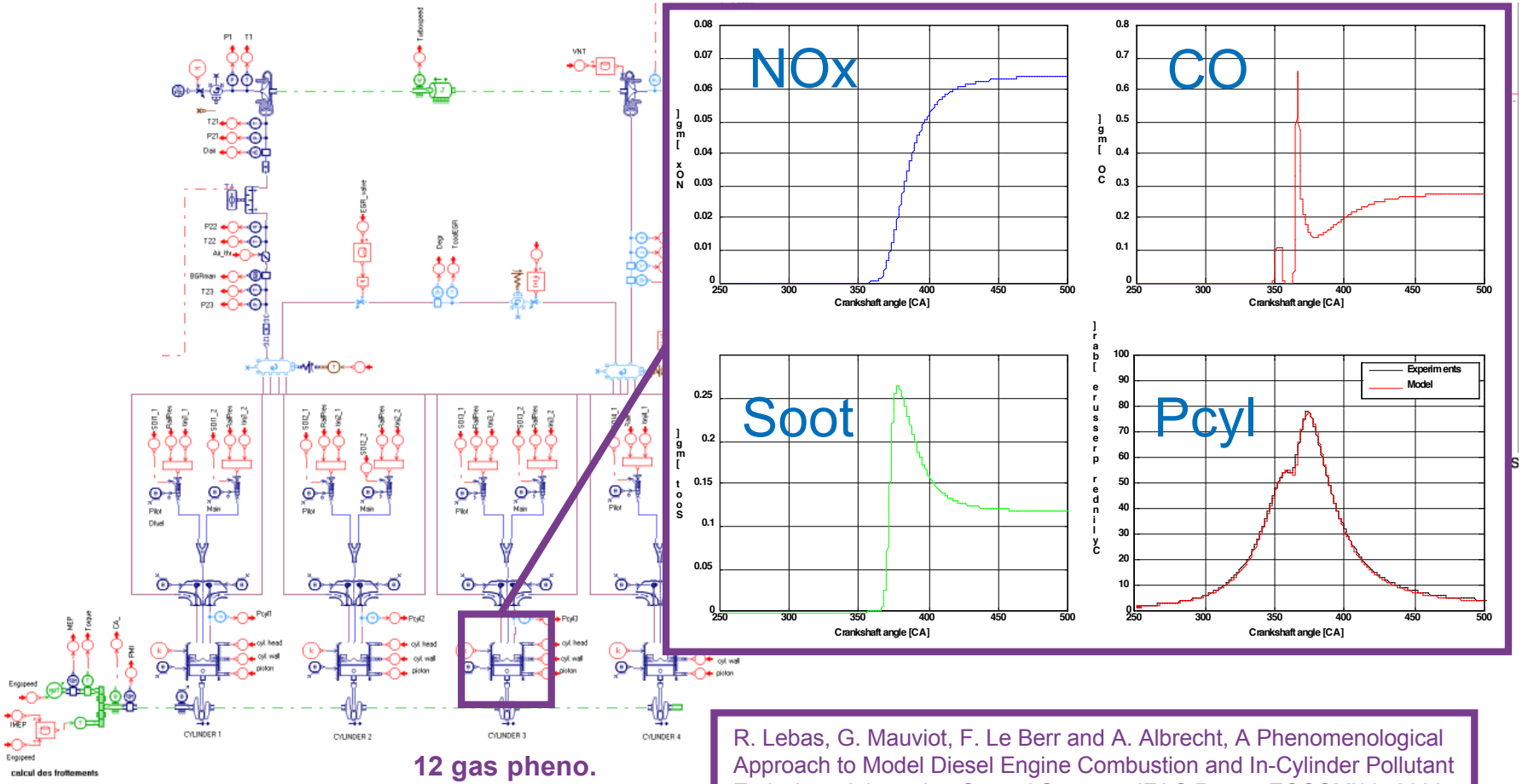
after-treatment

hybridisation

€uro 6
powertrain

€uro 6 powertrain target

Based on advanced modeling approaches



12 gas pheno. combustion model

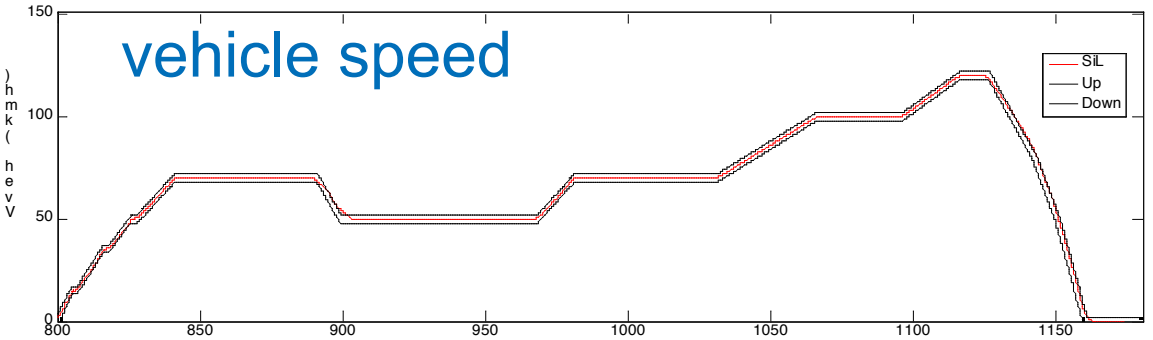
R. Lebas, G. Mauviot, F. Le Berr and A. Albrecht, A Phenomenological Approach to Model Diesel Engine Combustion and In-Cylinder Pollutant Emissions Adapted to Control Strategy, IFAC Paper, ECOSM'09, 2009

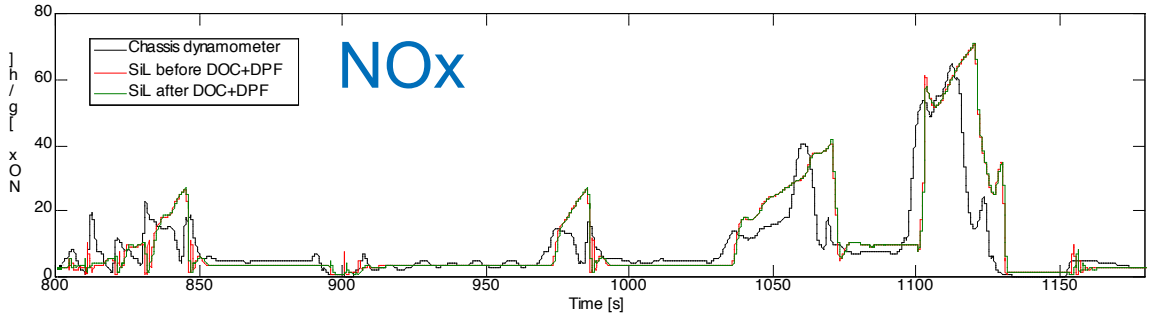
€uro 6 powertrain target

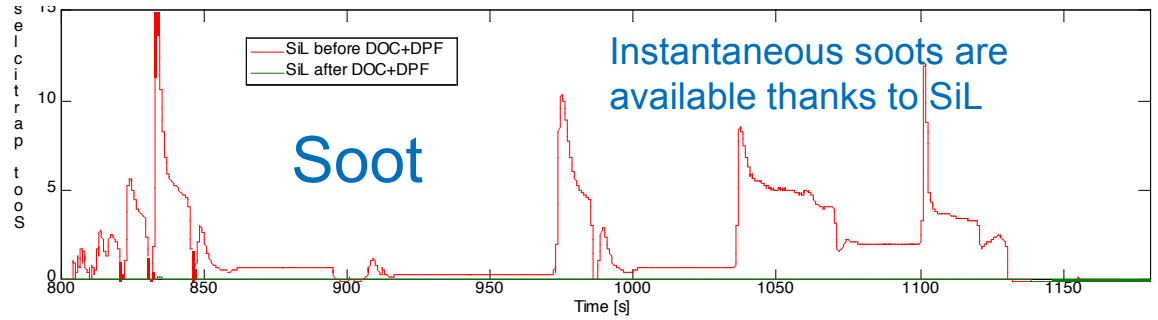
From €uro 5 thermal engine (with DOC/DPF)

Software-in-the-Loop

Chassis dynamometer







€uro 6 powertrain target

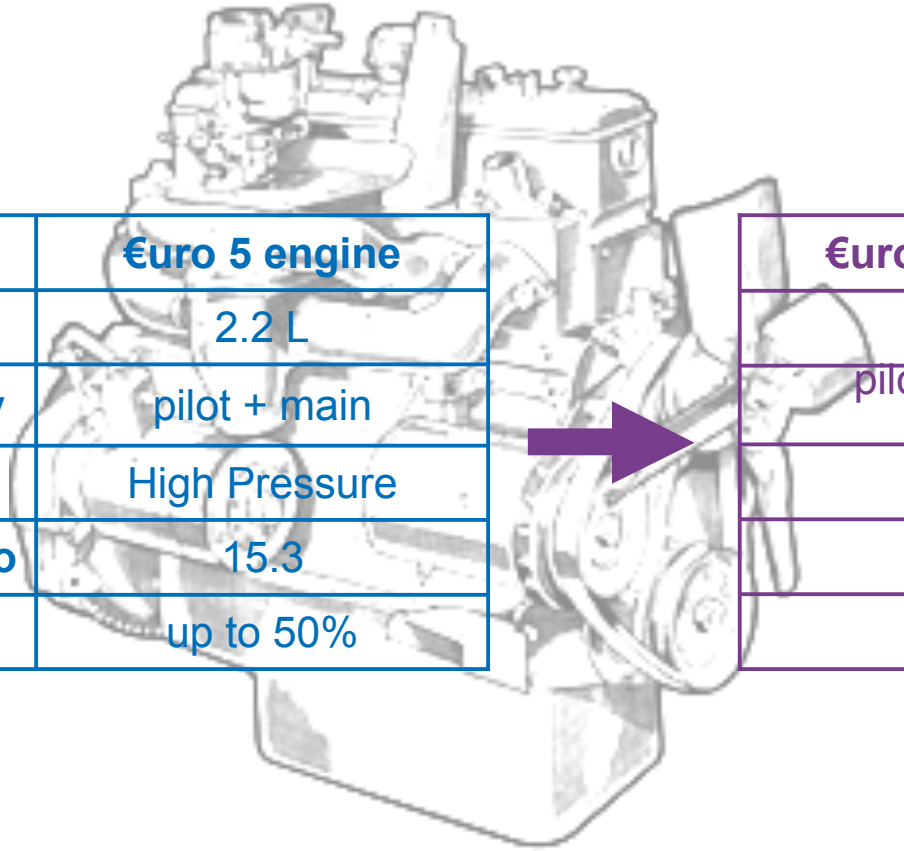
From €uro 5 thermal engine (with DOC/DPF)

Configuration	Platform	NOx [mg/km]	Soot before DPF [mg/km]	Soot after DPF [mg/km]
SiL	xMOD	173.9	28.8	-
Chassis dyno.	Morphée 2	175.9	27.2	-

- The SiL is representative of vehicle pollutant emissions on NEDC cycle
- Combining experiments & simulations allows to achieve 1 test at the chassis dyno. in the morning and more than 10 NEDC with SiL in the afternoon

€uro 6 powertrain target

Upgrading €5 engine to €6 configuration



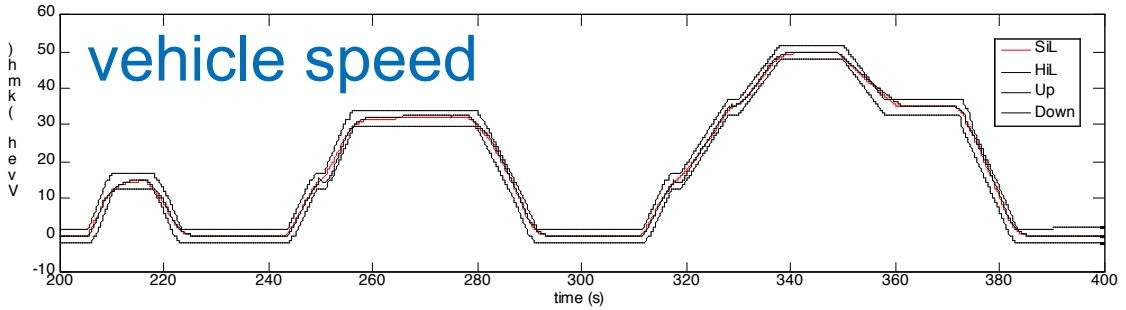
	€uro 5 engine	€uro 6 configuration
Engine capacity	2.2 L	1.6 L
Injection strategy	pilot + main	pilot + main or split injections
EGR Loop	High Pressure	Low Pressure
Compression ratio	15.3	15.9
EGR levels	up to 50%	up to 65%

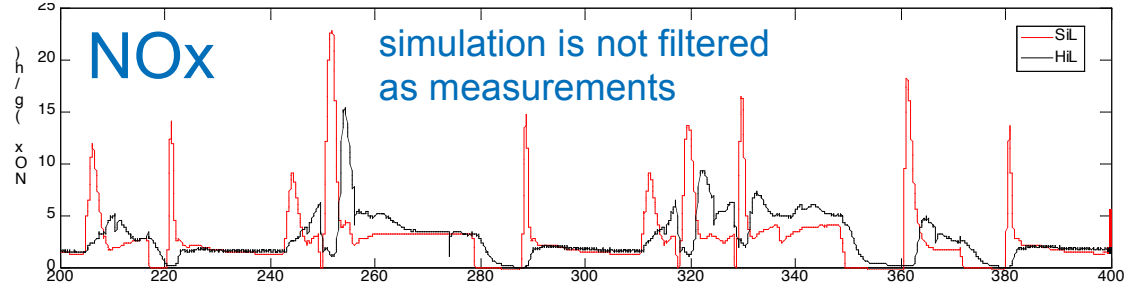
€uro 6 powertrain target

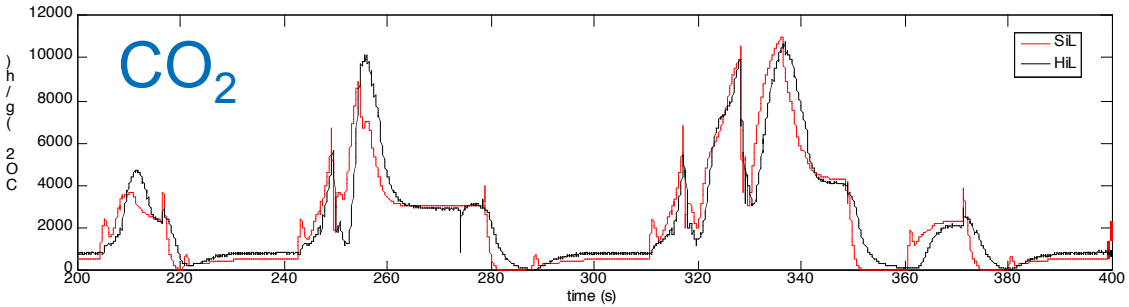
Evaluating the €uro 6 thermal engine (w/o DeNOx catalyst)

Software-in-the-Loop

Conventional HiL dynamic engine bench







€uro 6 powertrain target

Evaluating the €uro 6 thermal engine (w/o DeNOx catalyst)

Configuration	Platform	NOx [mg/km]	CO2 [g/km]	Fuel cons. [L/100km]
SiL	xMOD	**108**	118.0	4.42
Conventional HiL dynamic engine bench	Morphée 2	**109**	116.4	4.35

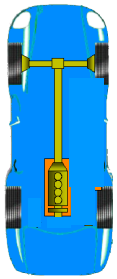
Rk: the results in the paper are different because the engine map is not the same

- With €6 combustion, the SiL continues to be representative of the experimental results
- Without DeNOx catalyst, the powertrain hybridization is required to reach the 80mg/km NOx standard

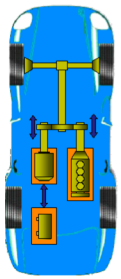
€uro 6 powertrain target

Powertrain hybridization with simulation

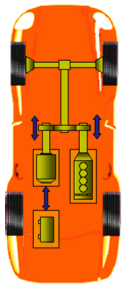
Software-in-the-Loop



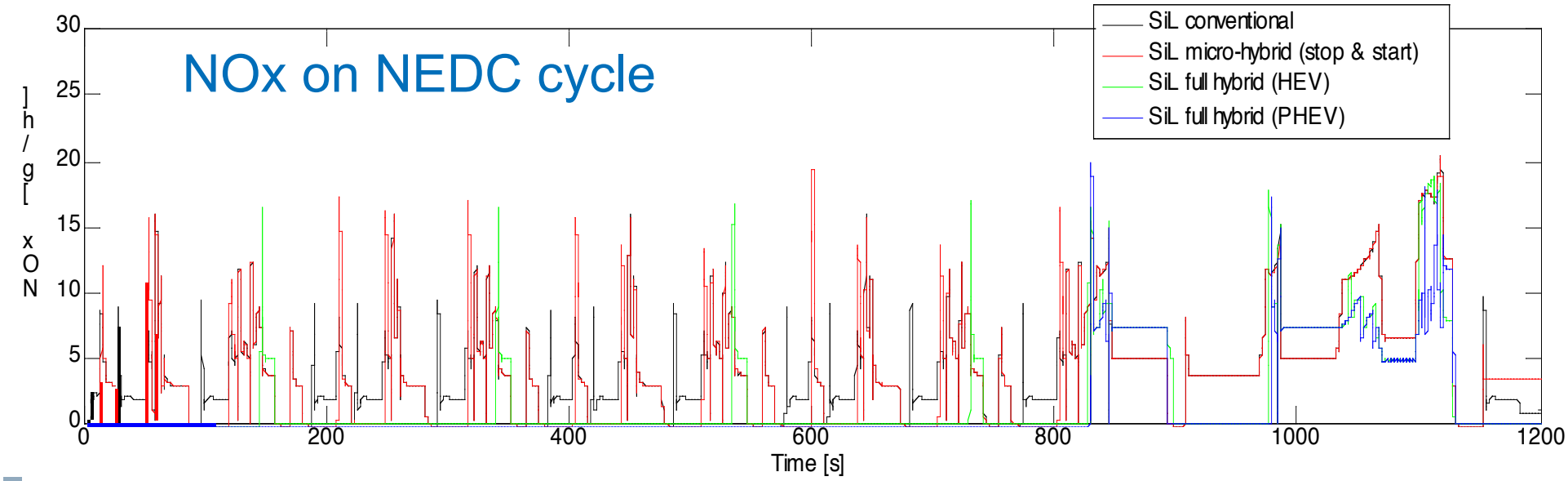
conventional



micro-hybrid
stop&start



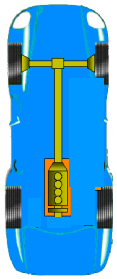
HEV / PHEV
plug-in



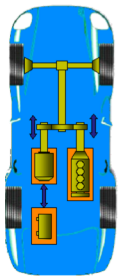
€uro 6 powertrain target

Powertrain hybridization with simulation

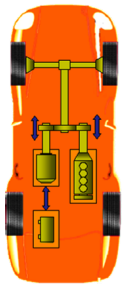
Software-in-the-Loop



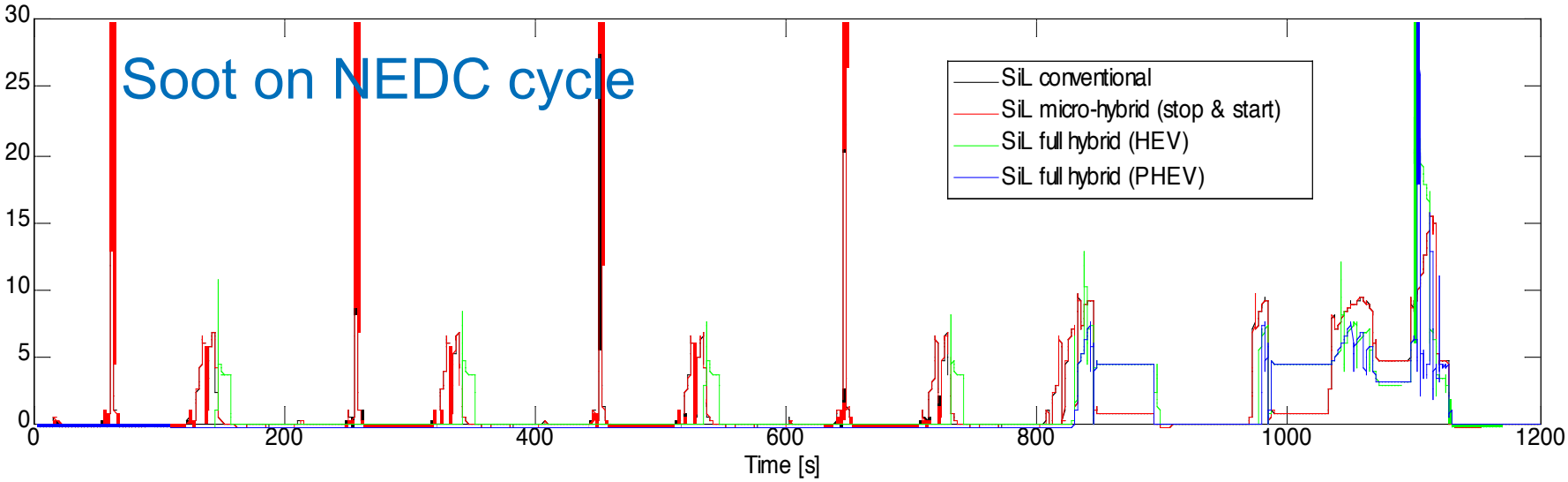
conventional



micro-hybrid
stop&start



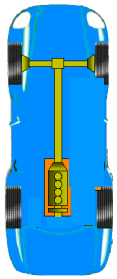
HEV / PHEV
plug-in



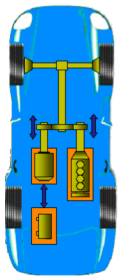
€uro 6 powertrain target

Powertrain hybridization with simulation

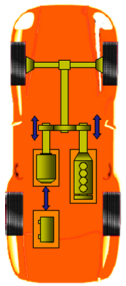
Software-in-the-Loop



conventional



micro-hybrid
stop&start



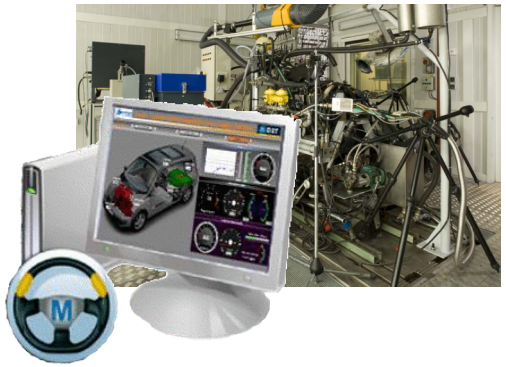
HEV / PHEV
plug-in

Architecture	Platform	NOx [mg/km]	Soot [mg/km]	Fuel consumption [L/100km]
Conventional	xMOD	108	14.5	4.4
Micro-hybrid	xMOD	100	12.7	4.2
Hybrid (HEV)	xMOD	45.9	11.3	3.6
Hybrid (PHEV)	xMOD	35.8	8.1	2.3

Rk: the ΔSOC is not zero on these simulations

€uro 6 powertrain target

Powertrain hybridization with hybrid dynamic engine bench



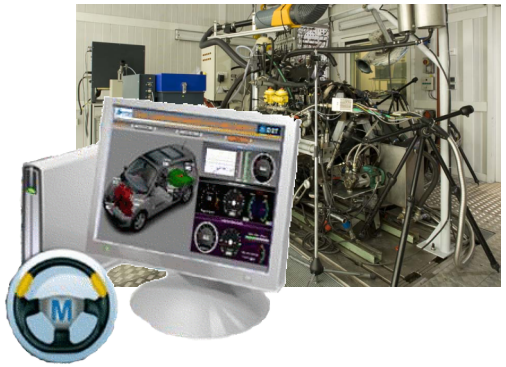
Two energy management strategies are investigated:
- CO_2-oriented strategy **(Hybrid 1)**
- NOx-oriented strategy **(Hybrid 2)**

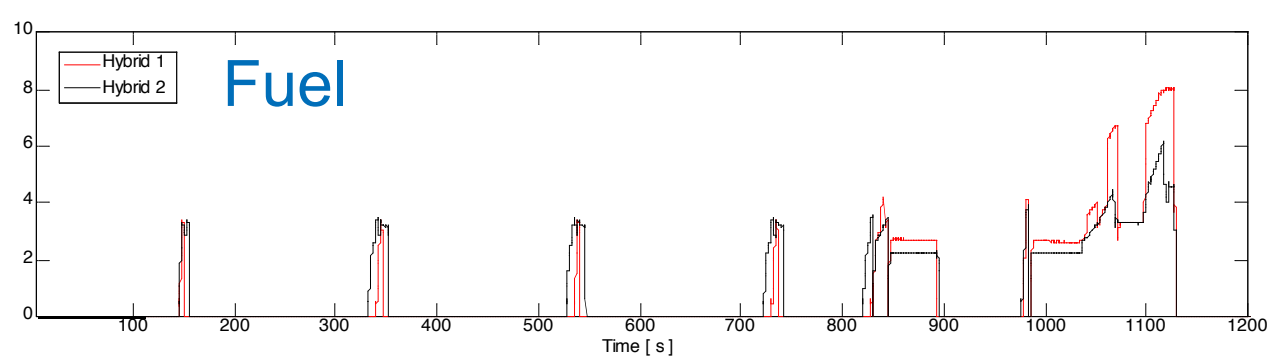
The control optimization is based on a SiL campaign with more than 100 NEDC simulations ($\Delta SOC = 0$)

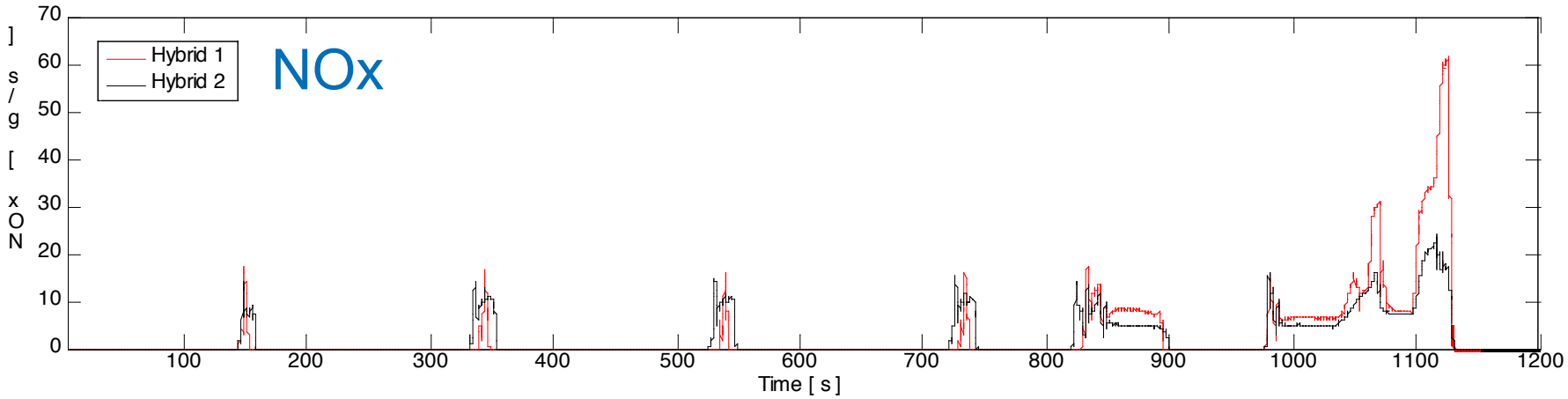
Architecture	Platform	NOx [mg/km]	HC [mg/km]	Fuel cons. [L/100km]
Conventional	Morphée 2	**108**	120	4.4
Micro-hybrid	Morphée 2	**100**	111	4.2
Hybrid 1 (HEV)	Morphée 2	**82**	20	3.4
Hybrid 2 (HEV)	Morphée 2	**67**	27	3.5

€uro 6 powertrain target

Powertrain hybridization with hybrid dynamic engine bench







Conclusion

- Simulation-based approach has a strong potential to be fully integrated in the powertrain development process but some obstacles are still subsisting

- To support this approach with adapted and efficient model-based environments is a key asset to overcome these brakes

- The xMOD/Morphée 2 suite is an example of such a kind of platforms which allow to easily mix virtual and real test facilities to develop modern powertrains

See us on booth 1820 : Testing Expo

For any further information: philippe.lacassagne@d2t.fr

Thanks for you attention