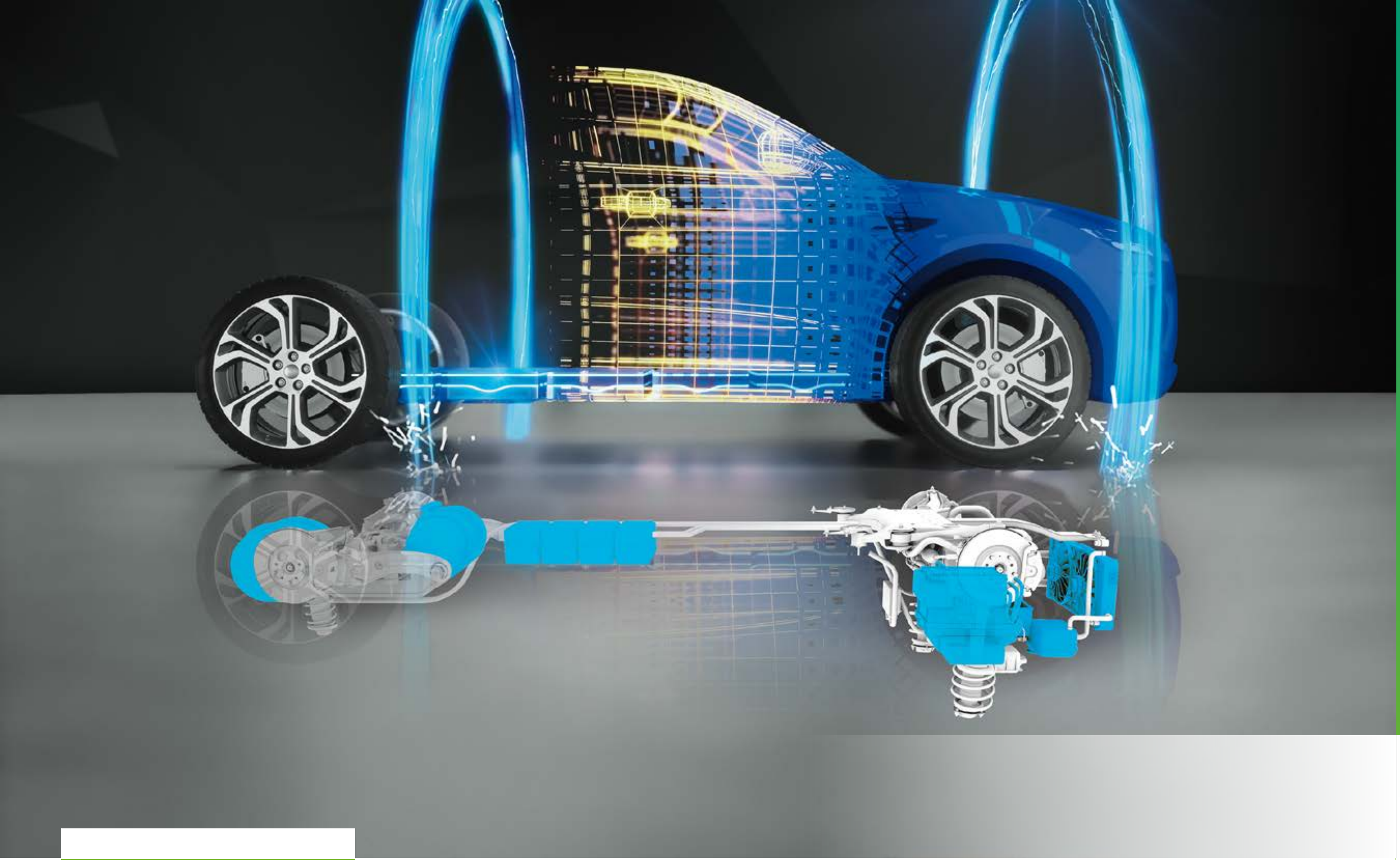


WHITE PAPER

Virtualization of Fuel Cell System Development

MOBEO – AVL's Virtualization Approach

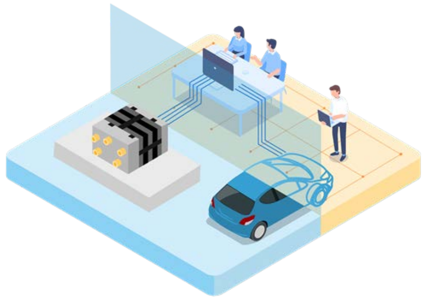
Virtualization of Fuel Cell System Development

MOBEO provides a virtual approach for the development of fuel cells, across all relevant testing environments

Office

It all starts with high-performance models in the office environment - to perform an initial optimization of the operating strategy. High-fidelity models in conjunction with optimization tools enable a high degree of automation here while ensuring a high level of optimization.

Lab



To enable a more realistic operation of the fuel cell system, the integration of the vehicle simulation into the test execution is crucial. MOBEO offers simulation models that require only some parameterization, up to sophisticated vehicle models. Furthermore, the easy integration of real-time and non-real-time simulation models allows to further improve the test capabilities by co-simulation, e.g., to integrate a simulation of the entire thermal network and to consider it for the optimization of the operation strategy.

Virtual Lab

At a later stage, when real controls are already available, the use of a virtual calibration environment ensures a smooth transition to the final validation of the operating strategy on the real hardware. A major advantage of using a modeling approach in combination with real controllers is the possible state of the fuel cell - which can be freely set with respect to e.g., degradation state or temperature. This allows optimization and validation of the operating strategy at any defined state - without conditioning time.

Simulation Is Widely Used in the Design Phase

Why not also in testing and validation?

Fuel cell-based vehicles are one of the technology paths that the automotive industry has chosen as an alternative to conventional powertrains. Today, OEMs involved in fuel cell technology must focus on several development tasks, including control function calibration, material design, vehicle performance, integration, and durability. In fuel cell development processes, it is natural to rely on simulation results in the left part of the V-cycle to specify the design for the final hardware ,for instance.

So why not also apply simulation and virtualization on the right side to test and validate the hardware ?

AVL uses proven methods and tools in this area. With MOBEO, we bring simulation to testbeds or build a pure virtual environment to extend testing capabilities and drive development tasks from configuration to SOP.As an example, MOBEO makes it possible to study critical operating conditions by monitoring stress factors and manipulating them to avoid degradation. A few building blocks of this example are presented here.

The Challenge of Fuel Cell System Development

Developing, testing and validating at such conditions is very expensive

Performance

On one side it requires large numbers of prototypes, on the other side, costly test trips to different regions providing the testing conditions.

Function

Fuel cell is a rather complex system, considering the interaction of all the operating parameters such as power demand, system temperature but also external conditions including humidity and temperature.

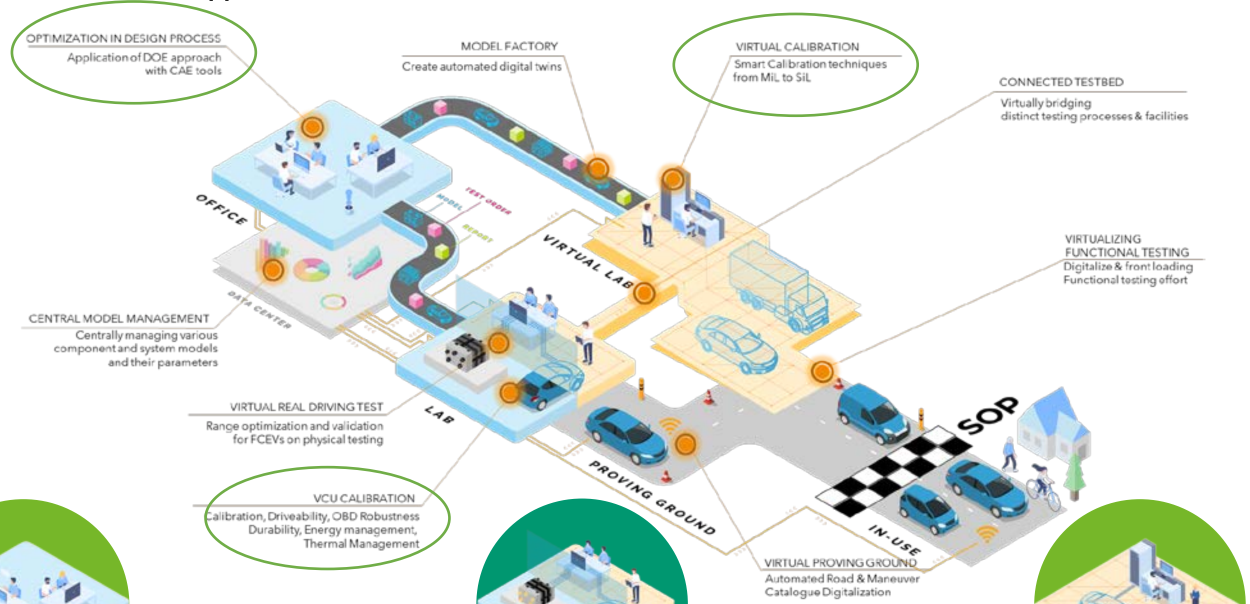
Durability

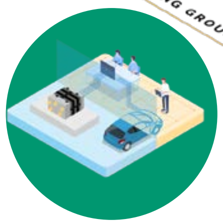
On the other side, we have a fuel cell stack which needs to be operated carefully within a giving operating range, to avoid degradation and optimize the durability. Maximizing the power output of the fuel cell allows to reduce the relative cost of the fuel cell – however possibly compromises the durability. In the end, the quality of the operating strategy is critical for a long lifetime of the fuel cell.

AVL

Virtualization of Fuel Cell System Development

MOBEO – AVL's Virtualization Approach





Office

It all starts with high-performance models in the office environment to enable initial optimization of the operating strategy. High-fidelity models in conjunction with optimization tools enable a high degree of automation here while ensuring a high level of optimization.

Lab

To enable a more realistic operation of the fuel cell system, the integration of vehicle simulation into the test execution is crucial. MOBEO offers basic simulation models up to sophisticated vehicle models. Furthermore, the integration of real-time and non-real-time simulation models allows to further increase the test capabilities by co-simulation.

Virtual Lab

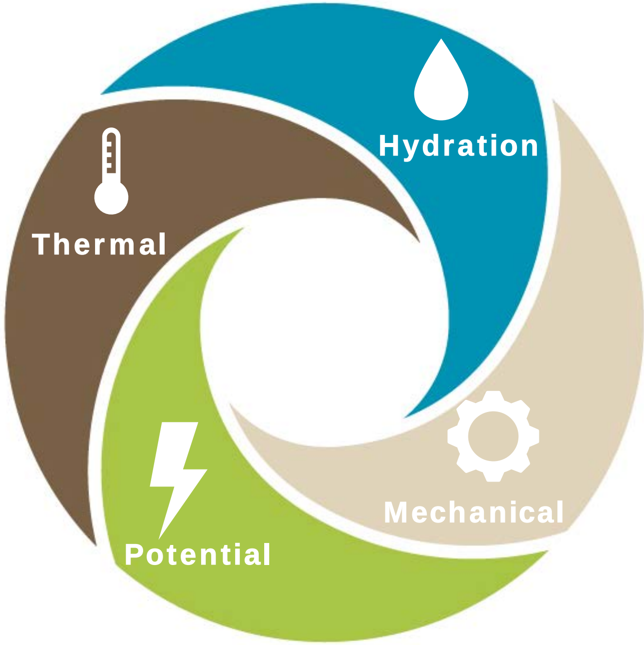
Using a virtual calibration environment to ensure a smooth transition to the final validation of the operating strategy on real hardware. An advantage of using a modeling approach is the possible state of the fuel cell - which can be freely set in terms of e.g., degradation or temperature. This allows optimization and validation at any defined state - without conditioning time.

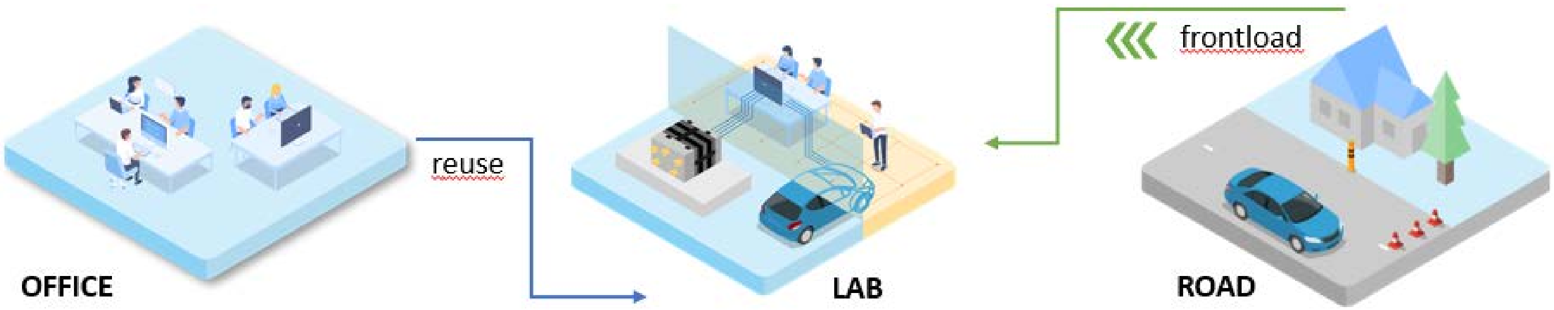
The Power of Simulation at the Testbed

Enhancing fuel cell system testing with simulation

Simulation of fuel cell system lifetime and degradation is considered as one of the focus areas of fuel cell development programs.
Fuel cell degradation mechanisms are associated with multi-physical phenomena such as thermal, electrical, hydrogenation or mechanical stress factors. The identification and understanding of such a mechanism requires a specific methodology and test automation, fully supported by virtualization at different stages.

At AVL, we have developed a software toolchain that supports you in exactly such activities.





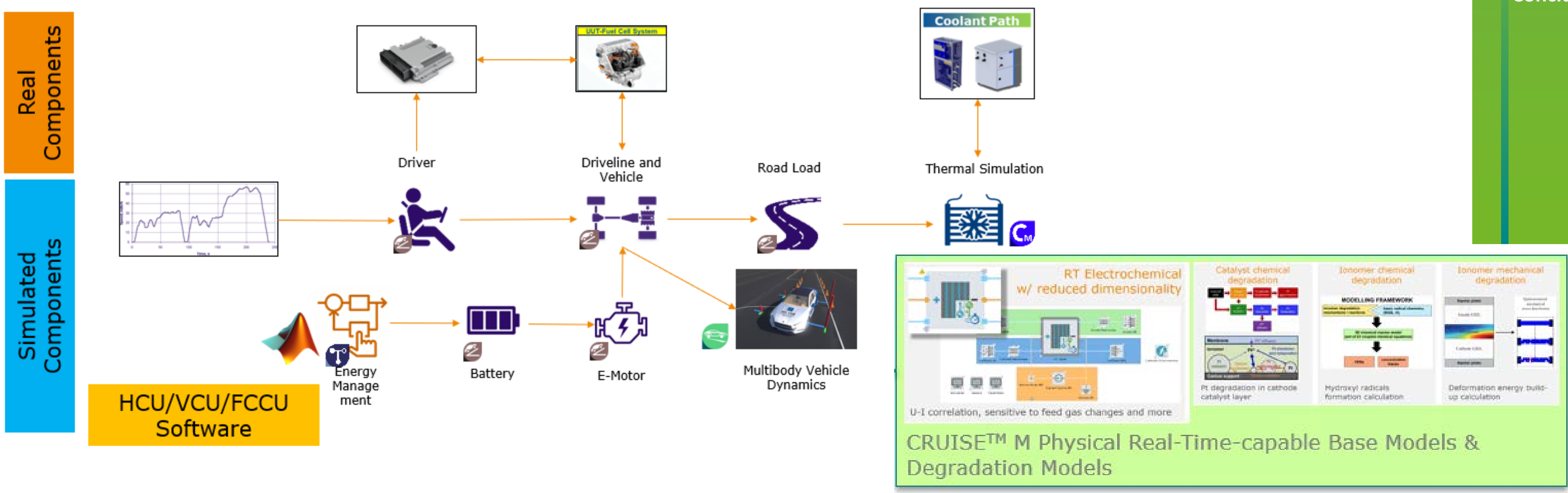
FEATURES

Durability – Thermal Management

Enhancing fuel cell system testing with simulation

Our multidisciplinary simulation and virtual test technologies support your durability-related verification and calibration activities. You can use these loading factors to automatically define your verification program, including accelerated loading conditions on the component or fuel cell system test bench.
You can test your fuel cell systems under all kinds of conditions to see what triggers such phenomena. And you can automate these activities to ensure quality and save time. Any available hardware can be tested by combining real testbed activities with a virtual Balance of Plant (BOP) simulation, such as a cooling cycle emulation. You can then perform life prediction studies, diagnostic function development, and calibration, even if only some hardware components are available for testing.

The toolchain's modularity and openness to third-party tool vendors provide unprecedented holistic solutions for fuel cell applications. For example, you can adjust stress factors such as thermal loads or humidity cycling to account for other subsystem models, including the E-axis and battery.
Tool consistency, reusable methodologies, and process efficiencies further support your efforts. As a result, you can avoid over-engineered countermeasures, save time, and reduce costs through realistic investigations. Tool consistency, reusable methodologies, and process efficiencies further support your efforts, enabling you to avoid over-engineered countermeasures, save time and reduce costs, by conducting realistic investigations.



FEATURES

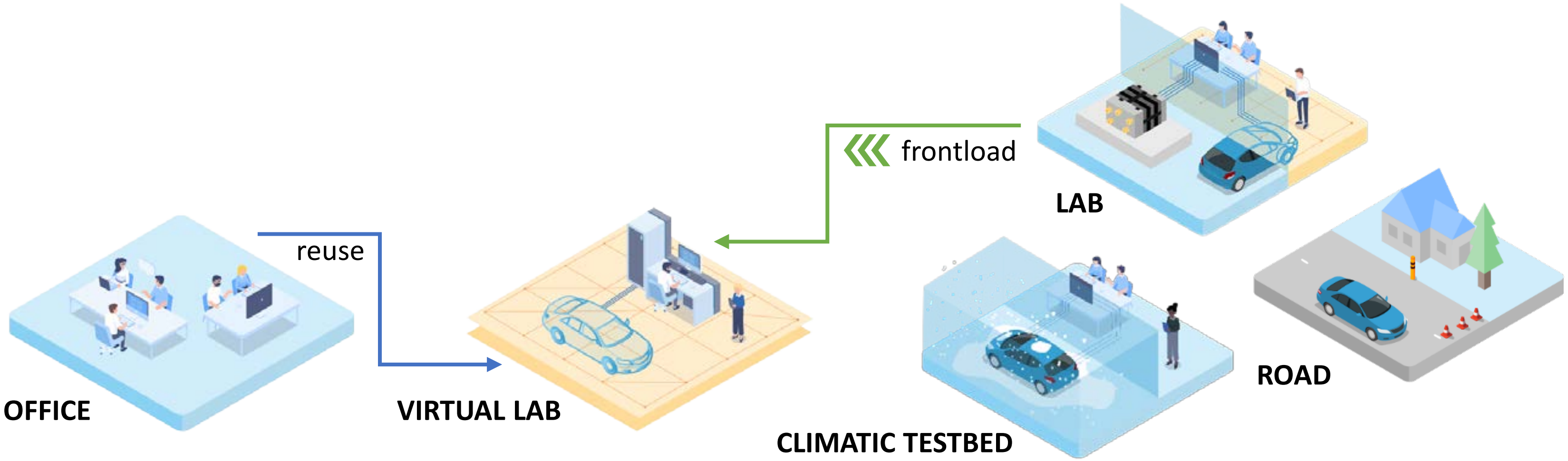
Virtual Calibration of Fuel Cell Systems

Leveraging the virtual lab

When developing and parameterizing controls for fuel cell systems, a high number of work packages can be preloaded into the virtual test bench. Modern plant models of fuel cell systems allow a large number of use cases of virtual calibration. Effects such as degradation can also be simulated.

For fuel cell system operation, it is important to ensure safe and efficient operation under both standard and non-standard environmental conditions. This includes, for example, common situations such as cold start operation. However, less common factors must also be considered, and control adjustments must account for environmental conditions such as extreme temperatures, humidity, or high altitudes.

Testing and validation is already an expensive and complex activity but taking such factors into account increases this effort. This requires a large number of prototypes as well as costly test trips to study the performance of the systems in different climates. Using the virtual testbed helps overcome these challenges and get to a final product faster, at lower cost and higher quality.

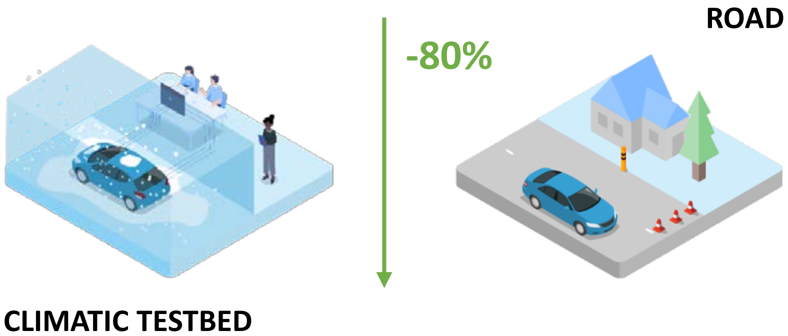


FEATURES

Virtual Calibration of Fuel Cell Systems

Validation of controls at non-standard conditions

Using our Virtual Testbed™ can reduce the use of climatic test stands by up to 80%. You can pre-calibrate a variety of tasks, such as pre-calibration and calibration of control and diagnostic functions, protection functions, and temperature-dependent purge or drain calibrations. These can all be examined immediately under different ambient conditions, component temperatures and component states - and in high quality.



TEST CONDITIONS

Ambient conditions
Initial component temperatures
Vehicle load state
HV-Battery SOC at cycle start
Altitude / inclination Profile

METHODOLOGY

Initial high-altitude calibration
Test Automation with AVL PUMA 2 fuel cell and calibration via CAMEO™
Refinement by **global DOE**
Considering varying ambient conditions
Validation under standard and non-standard conditions

RESULTS

Pre-validated calibration at HIGH/LOW Temperatures and HIGH/LOW altitude

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The AVL Solution
Solution 1
Solution 2
Solution 3
Conclusion

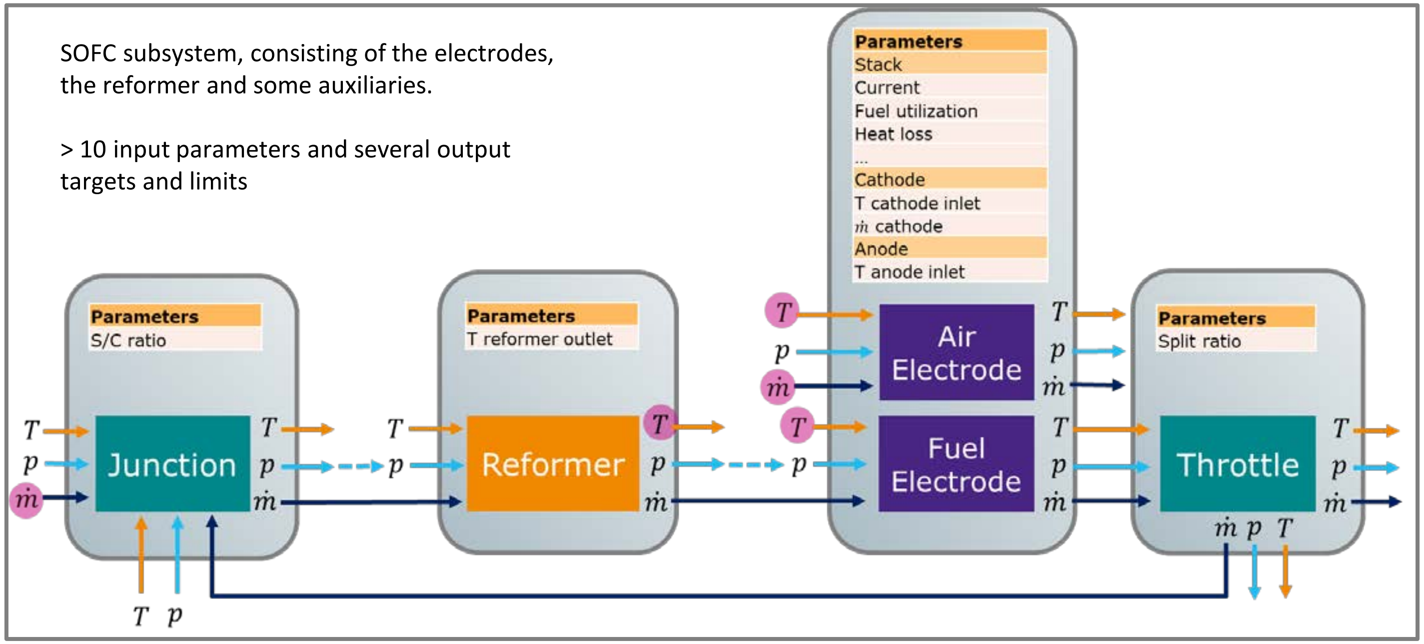
Optimization of fuel cell system hardware and operating strategy

Application of online modelling to CAE optimization

Fuel cells are complex systems, and to operate them safely, it is important to consider the interaction of many operating parameters and external conditions, such as power demand, system temperature, humidity and temperature. Optimizing the operating strategy of a fuel cell stack is critical to avoid degradation and maximize useful life. For best performance, total system efficiency is also an important consideration, to help minimize fuel use, and maximize current output. To achieve this, the optimal combination of hardware and fuel cell operating conditions must be found.

AVL has 20 years of model-based powertrain development experience, and the same benefits developed for physical testing, have also been applied successfully to CAE based development. If the components of the system can be modelled effectively, as can be achieved with fuel cells, then in most cases it makes sense to front-load work that will determine the hardware configuration, into simulation. This is because physical testing on prototypes is very time and cost intensive.

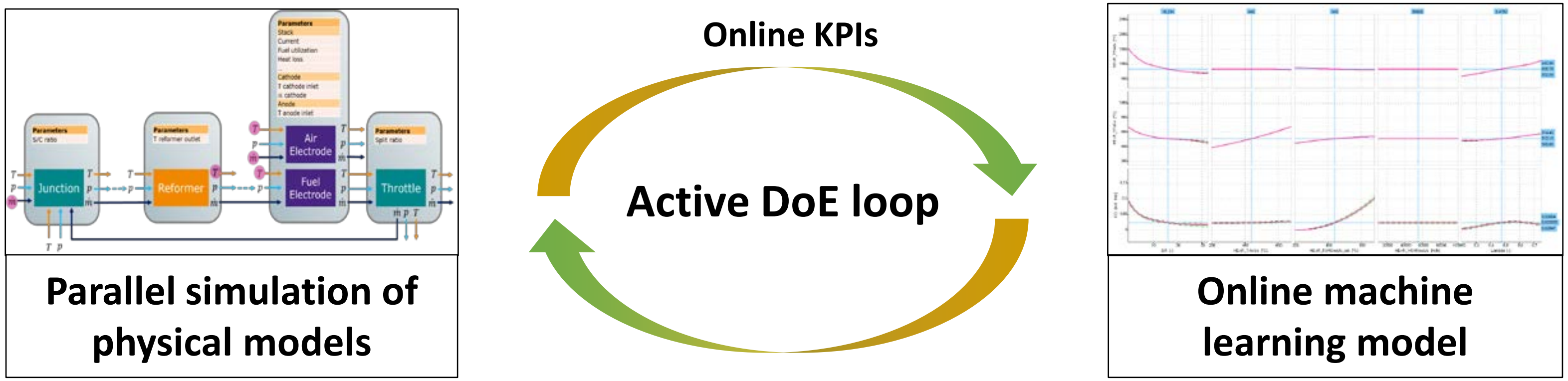
Therefore, the optimal operating strategy, in combination with the hardware, and multiple target and limit criteria, must all be considered together in order to ensure total system optimization. With so many input variations, and limited resource, is it possible to consistently find the optimum combination of input parameters, in the shortest possible time? In this case, a virtual approach is required - and that is exactly what we have created with MOBEO.



Optimization of fuel cell system hardware and operating strategy

Application of online modelling to CAE optimization

This example is a SOFC subsystem consisting of the electrodes, reformer and some auxiliaries. As is often the case, the goals and system limits are known in advance (minimizing H2, maximizing output current, limiting maximum temperature, maintaining humidity in range, etc.). However, which input combinations achieve the goals is not known. This means that with the traditional method, space filling must be done in over 10 dimensions, resulting in a large number of simulation runs that are far from optimal. By making the model online after each simulation run, Active DoE can identify significant variables and trends and change which input combinations to run next. This also means that there is less need to reduce the number of input variables or tighten the input ranges in advance. The algorithm efficiently explores the promising input combinations and also stops automatically when the required model quality and coverage is reached. Of course, there are simulation-specific extensions, such as parallelization and headless running for integration into custom toolchains, both locally and in the cloud. The resulting surrogate models can be exported to a variety of formats for further virtual optimization and calibration tasks, many of which support real-time co-simulation.



Accurate but slow running
Difficult to understand which parameters are influencing the output
Difficult to decide which inputs and input ranges to simulate

Very fast evaluation
Significant parameter analysis and optimization
Multi-format export e.g. FMU, Matlab, Excel etc.
Can be used during the test to find the optima
Can be exported for real-time co-simulation

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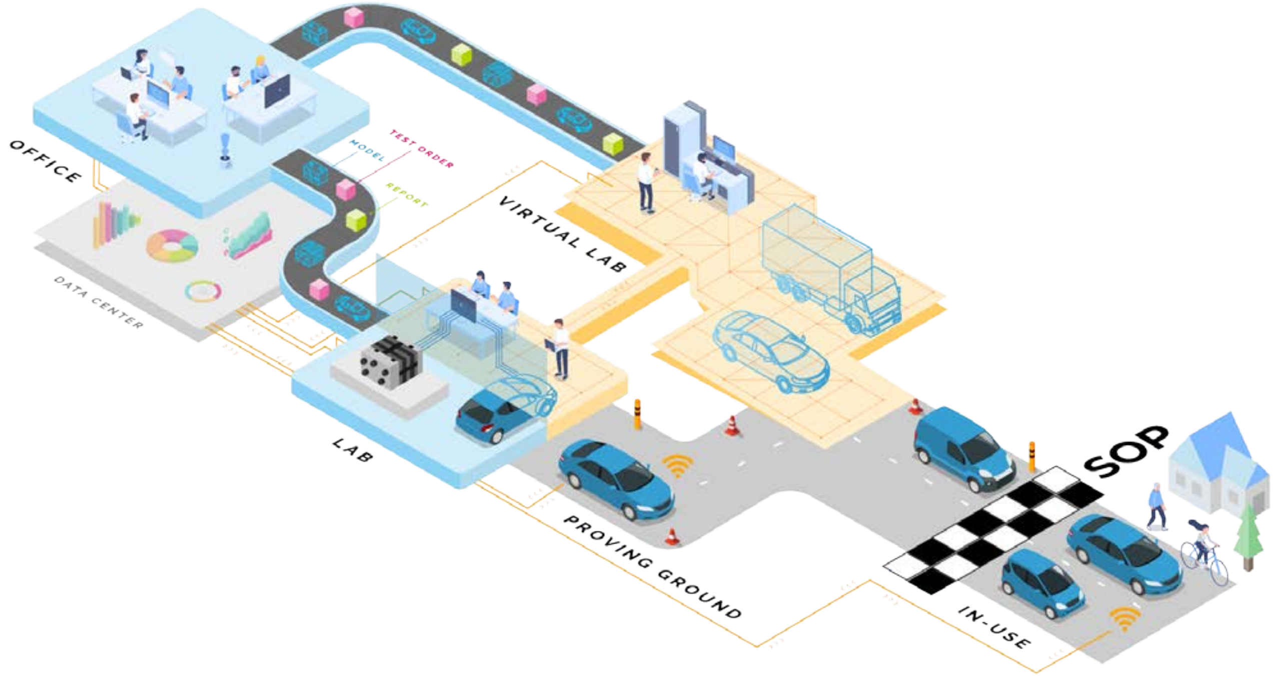
Virtualization of Fuel Cell System Development

MOBEO provides a virtual approach for the development of fuel cells, across all relevant testing environments

MOBEO, AVL's virtualization approach, has recently been extended to the fuel cell domain with seamless tool and application knowledge. Integrated solutions from office simulation and test automation, modularity with the toolchain, and openness to third-party vendors provide unprecedented holistic solutions for fuel cell applications in the automotive industry. Decades of experience in developing unique and proven methodologies, supported by virtual testing, are now implemented and ready for our customers' fuel cell development and verification programs.



FEATURES

AVL is the world‘s largest independent technology partner for the development, simulation and testing of powertrain systems as well as innovative automotive solution concepts.

FIND OUT MORE

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