

Learning Powertrain Intelligence: AI-driven REEV Control over Hardware Complexity

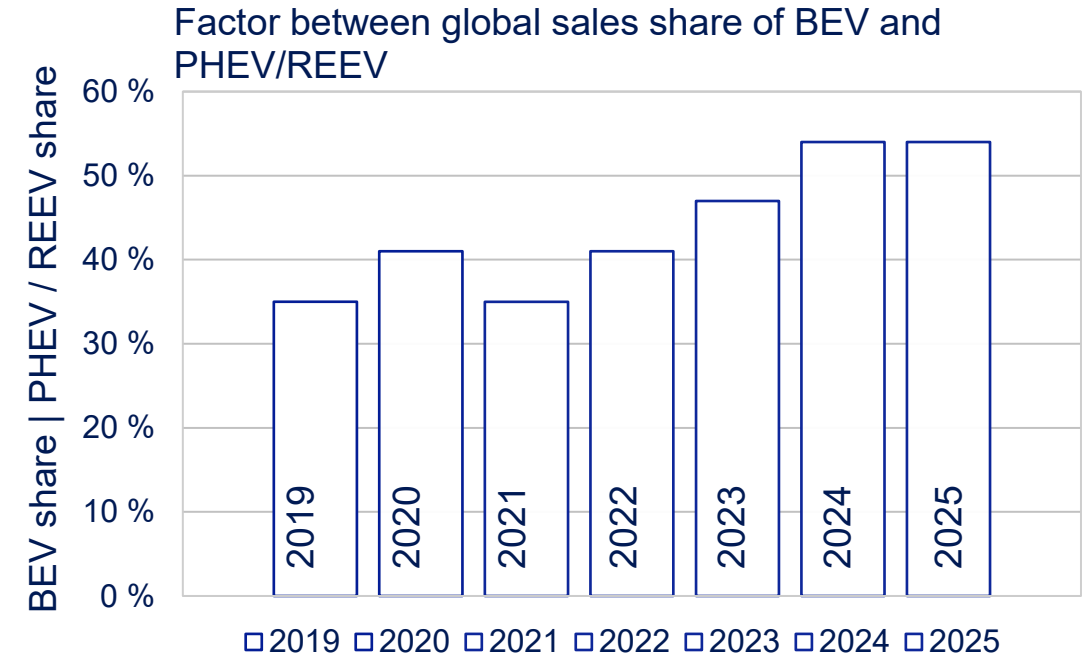
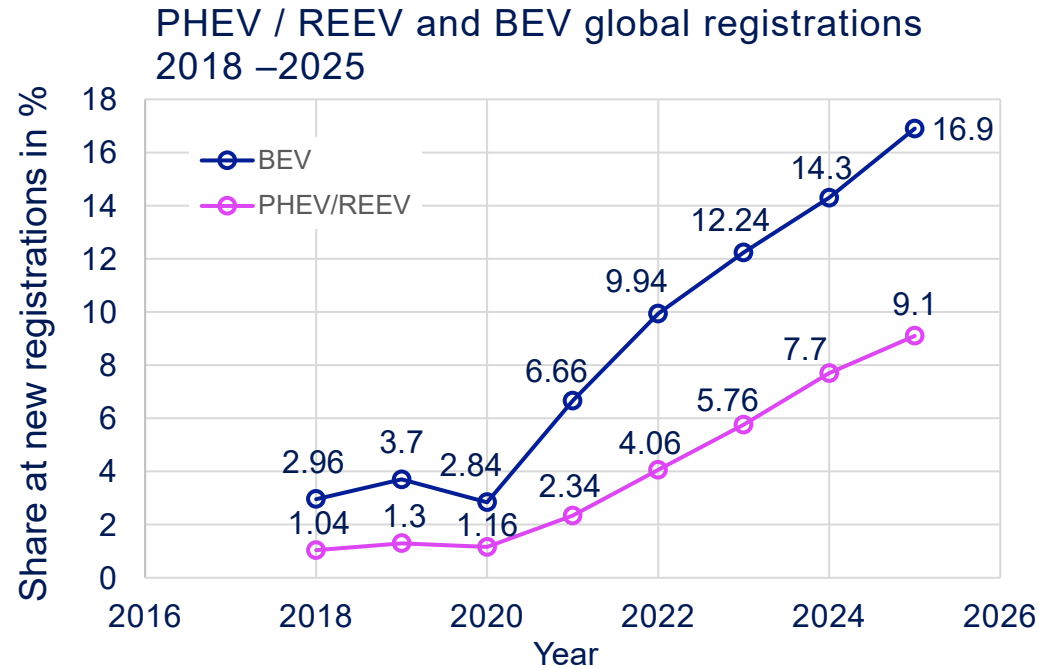
Aachen Automotive Colloquium 2026 | Aachen (Germany) | October 07th, 2026

Marc Sens, Dr. Alexander Fandakov, Joerg Mickeleit, Tiam Tahmasebi Dezfouli, Patrick Stracke



Why REEV/EREV

How Does the PHEV/REEV Share Evolve Compared to BEV



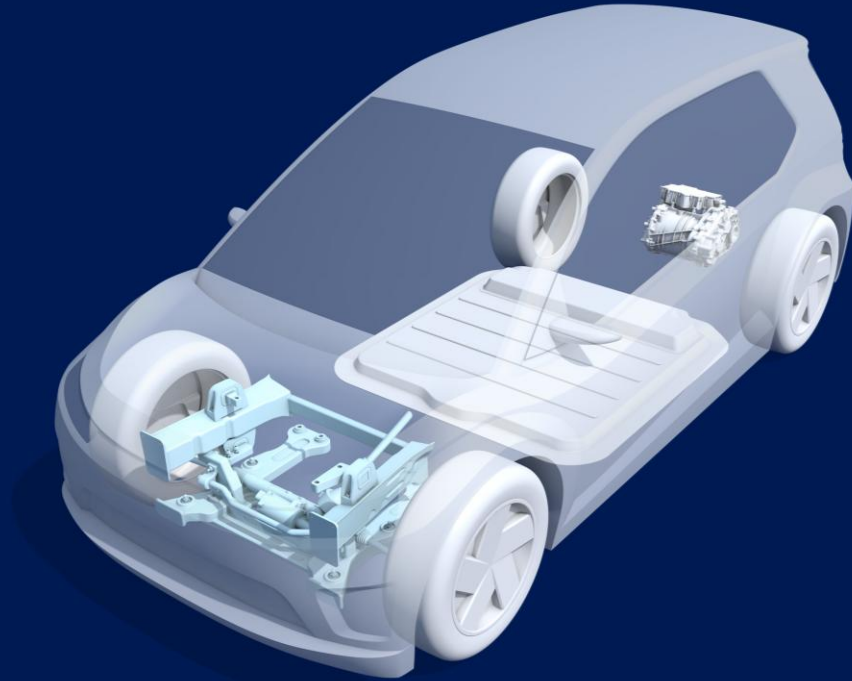
BEV sales are globally growing strongly year by year, started in 2020 → transition from ICE to dedicated BEV vehicle platforms is ongoing.

Since 2020, the share of PHEVs / REEVs has been closing the gap with pure BEVs year after year.

IAV REEV Solutions

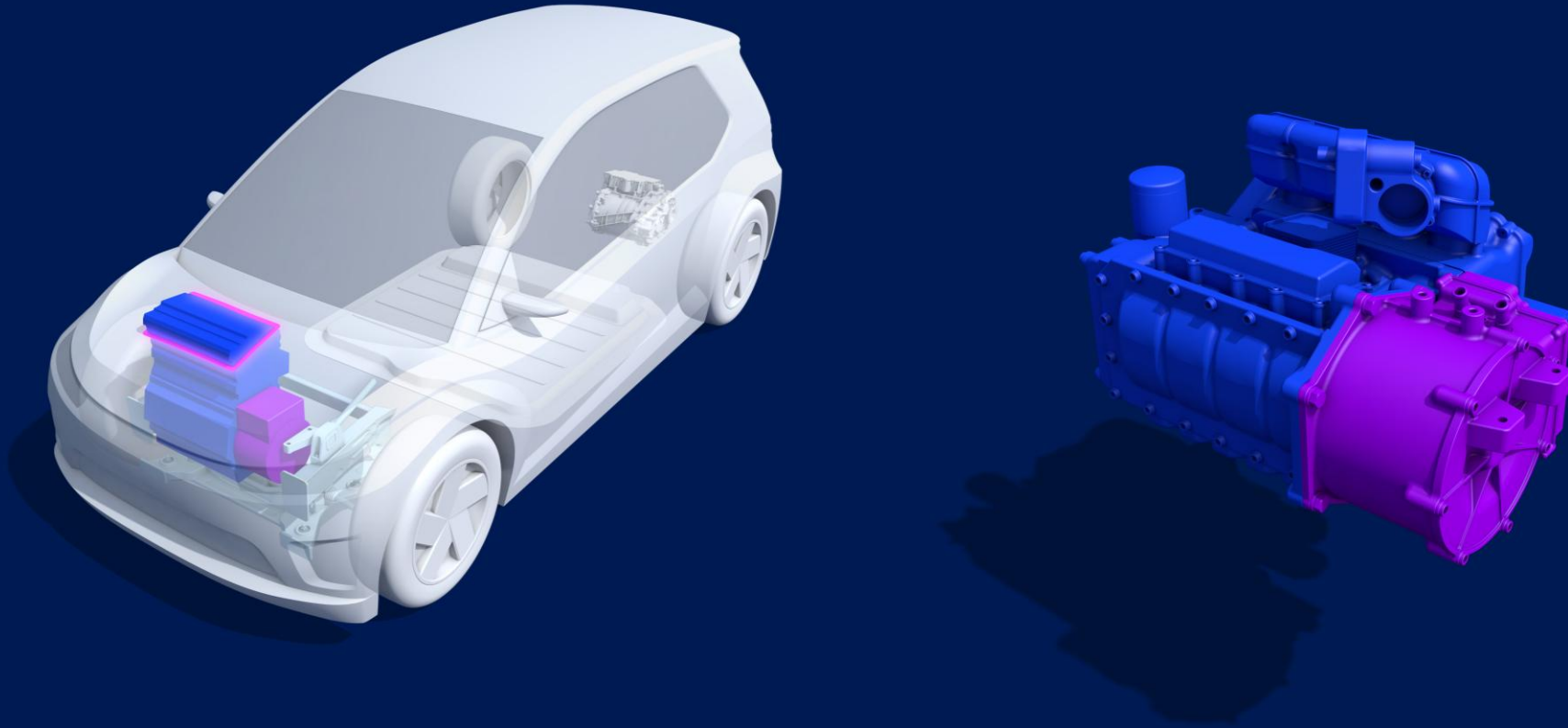
The Mechanical Part

The Package Challenge: How to Integrate an ICE into a BEV Platform



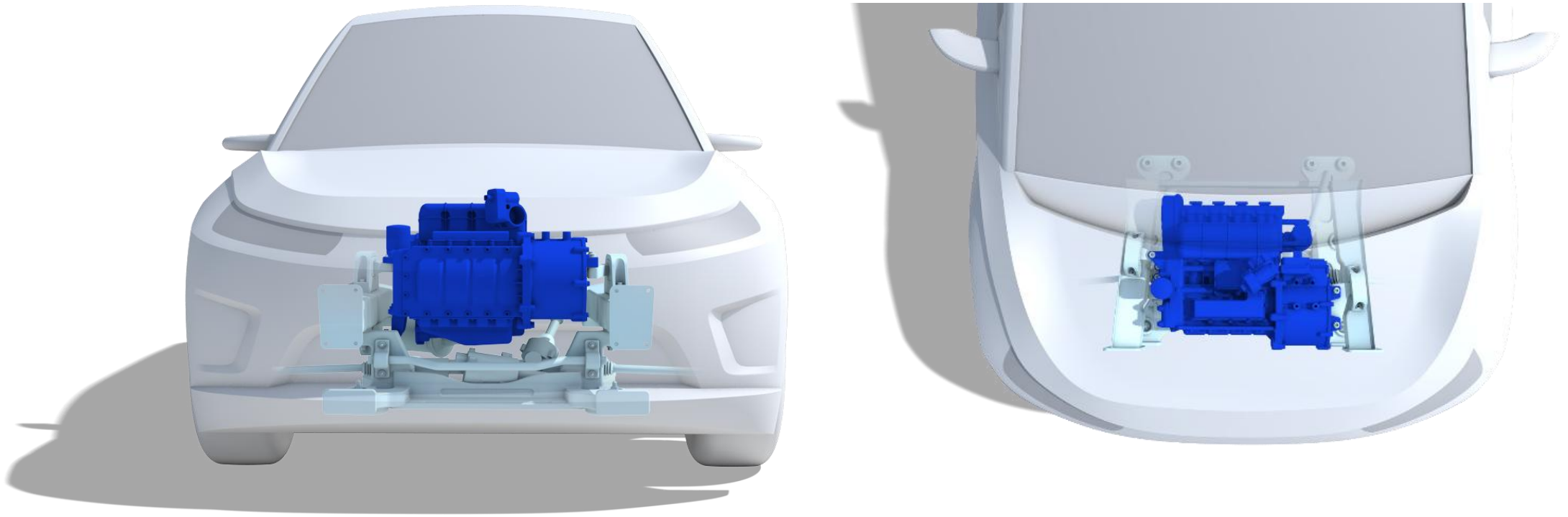
Short overhang and standard front axle design does not allow to integrate an ICE into the vehicle front compartment.

The Package Solution: Horizontal Installation of a Standard I4 Engine



Adapt an ICE designed for vertical installation to work for horizontal installation with as few modifications as possible.

The Package, NVH and Cost Solution: If Realized



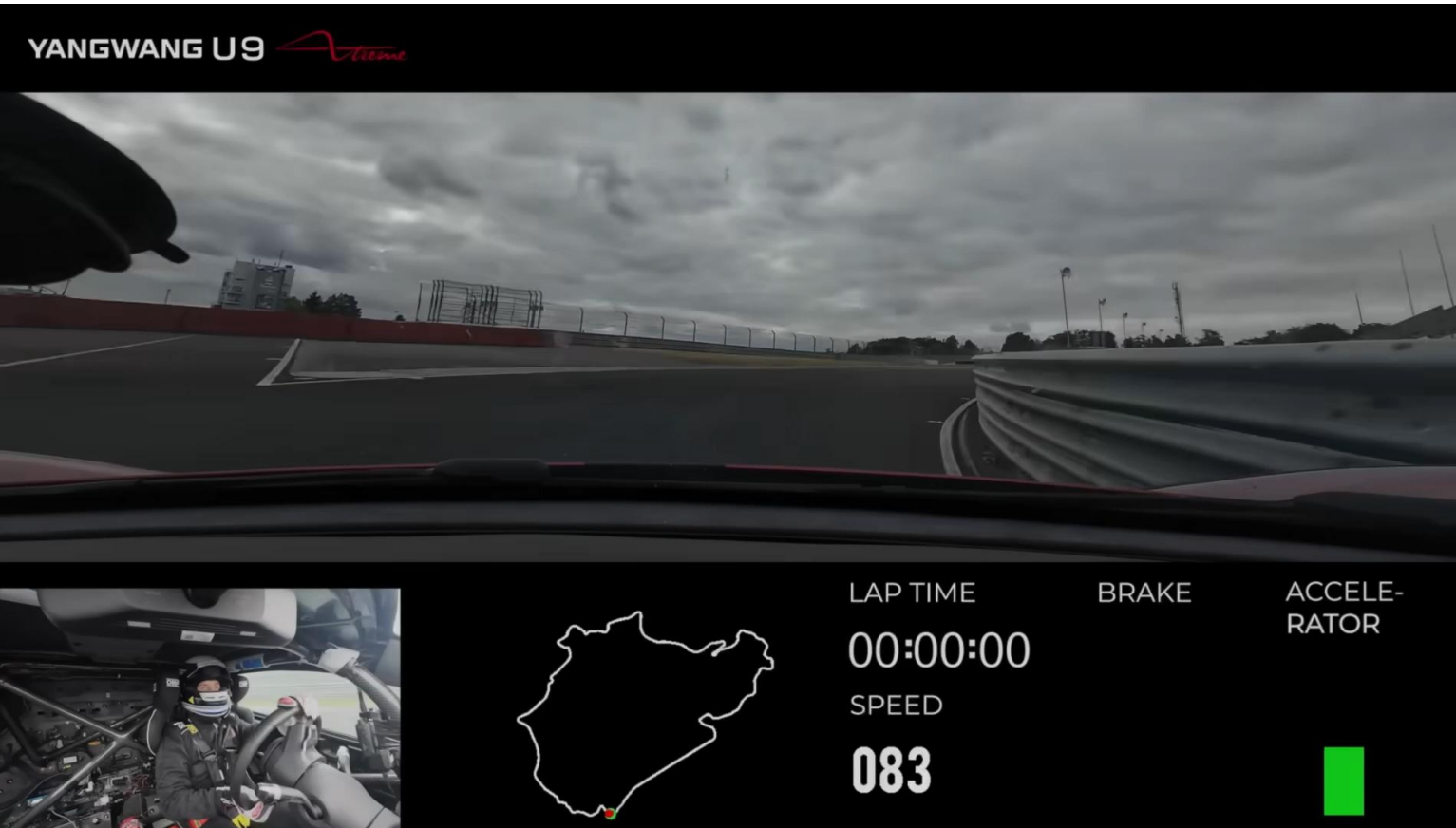
With a horizontal installation a standard inline 4-cylinder engine can be used for REEV concepts derived from BEV platforms with limited installation space.

Several very positive aspects are coming along with this, massive cost savings and a remarkable advantage in NVH.

The Emotion Challenge

Very Impressive, but Are you Missing Something here?

BYD YANGWANG U9 Xtreme at Nurburgring Nordschleife



- Very impressive driving and especially the acceleration looks absolutely outstanding
- But without “musical” accompaniment, the emotion doesn't really come across —at least not for almost everyone...
- Or – am I wrong?

The Emotion Challenge: ... and is that Different here?



- Very impressive driving and acceleration from this hybrid powertrain, featuring an ICE, too ...
- And thanks to the soundscape created by the highly dynamic, high-revving engine, emotions are stirred — at least in most people, especially supercar enthusiasts

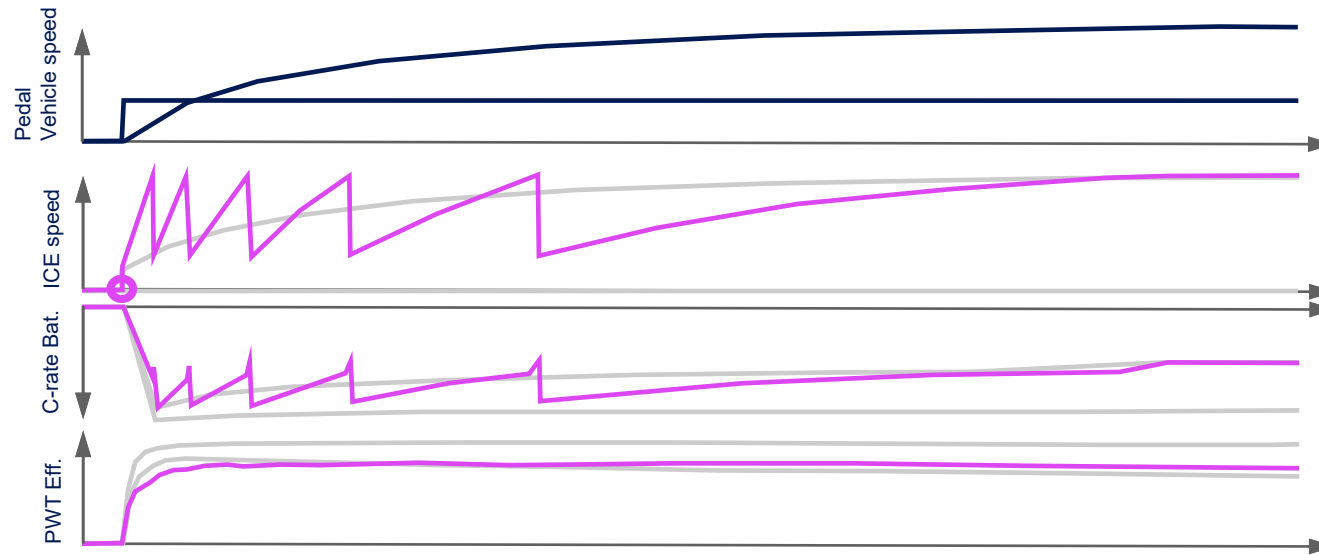
The Emotion Solution: IAV's Hyper REEV Concept (Patent Pending)

General Introduction



- The **Hyper-REEV powertrain is a typical serial hybrid** – the ICE has no mechanical connection to the wheels
- The **battery has a lower energy density** than that of a standard BEV, but is large enough to drive purely on electric power over longer distances – up to 150-200 km
- Under standard conditions, the **vehicle operates purely on electric power from the battery**, and the range extender internal combustion engine (REx) kicks in as soon as the charge level falls below a critical threshold
- If Hyper-REEV mode is selected by the driver via a menu in the vehicle's HMI, the **REx starts immediately and runs as long being in Hyper-REEV** mode, regardless of the battery's charge level
- The **REx varies its power output depending on the c-rate** required from the battery, which in turn is directly related to the driver's desired torque – achievable PWT performance/power level depends only on the power level of the ICE chosen...i.e. a **V8 engine with i.e. 800 hp**
- As a result, when the ICE is in operation, **it gives the driver the impression that it is propelling the vehicle in a highly dynamic manner** (the generator driven by the ICE produces electricity that reduces the c-rate from the battery).
- For **improving efficiency, the engine varies its speed**, similar to the vehicle's drivetrain
- **Driver can in Hyper-REEV mode choose between a virtual number of gears** helping to increase powertrain efficiency and he can choose between ICE torque response feeling of the powertrain (BEV vs. TC-ICE vs. N/A-ICE)

The Emotion Solution: REEV with Emotionalizing ICE Sound Feedback



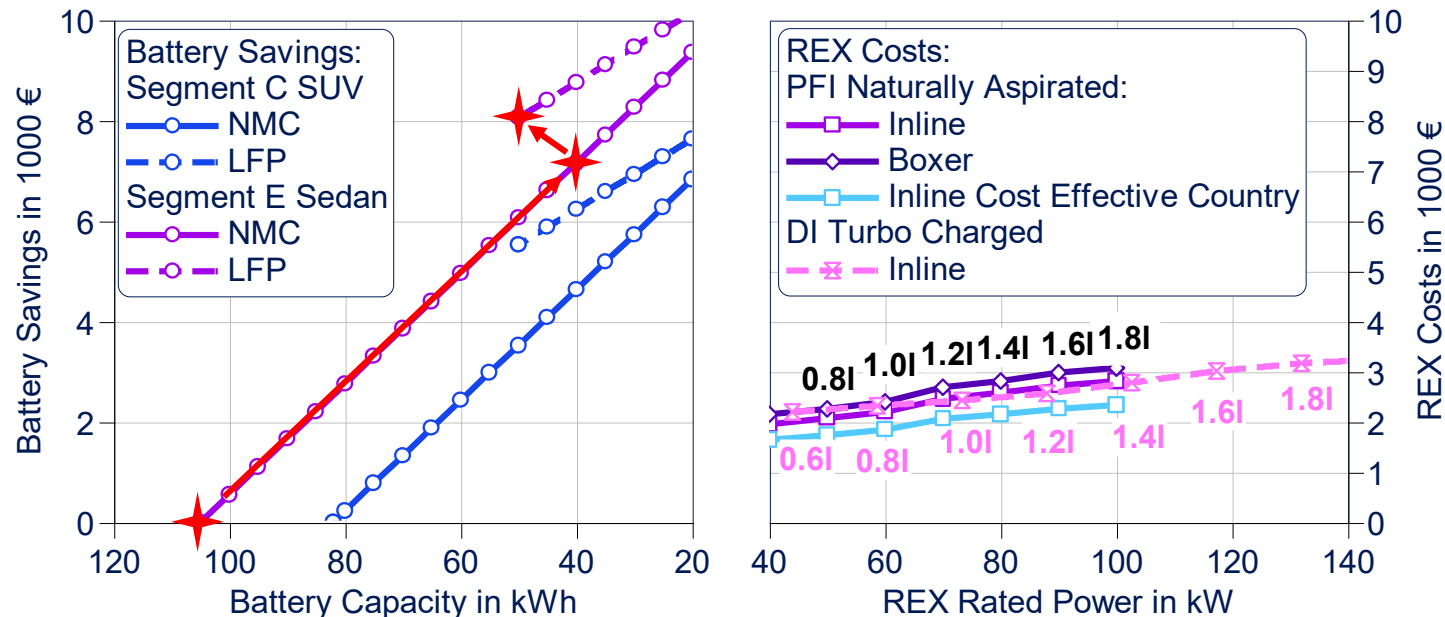
Introducing the so called REEV efficiency swing helps to increase the PWT efficiency

Resulting operation of the ICE during dynamic driving with sound thus produces a real ICE powertrain driving feeling

IAV REEV Solutions

A Cost Assessment

Costs: Active Material vs. Additional Components



NMC battery capacity reduction from 105 kWh to 40 kWh reduces cost by ~7,000 €

With another chemistry, even when going back up to 50 kWh, gives another ~1,000 €

REx incl. periphery cost around 2,750 € → REX can be offered at competitive cost.

Further cost reduction potential possible when deconting powertrain hardware based on operating strategy neutral cost?

Battery system savings

- Lowering battery capacity enabling leveraging REX costs
- Chemistry switch providing additional cost reduction boost

REx (+periphery) cost

- REX cost efficiency through existing technologies and production lines
- NA PFI ICE requires larger displacement, offsetting space-saving and cost advantages
- Boxer more expensive, REX for pure BEV manufacturers as a purchased low-cost component

IAV REEV Solutions

The Operating Strategy

Learning Powertrain Intelligence – REEV Operating Strategy

Evolution of REEV Operating Strategies

REEV Operating Strategies Evolution						
Charge Sustaining Strategy	Predictive Energy Mgmt.	Constant Eff. Strategy	Demand following Strategy	Power Assist Strategy	Load Leveling Strategy	Multi Objective Optimization
How does it work						
Electric Driving first down to min. SoC, then SoC maintained at min. SoC	Anticipatory control using navigation, topography, traffic data	Engine operates only at selected pre defined high efficiency points	Generator output follows actual power demand	During accel. or hill climbing both sources contribute simultaneously	Range extender reduces battery peak loads	AI based optimization of multiple vehicle objective
Main Advantage						
Max. electrical driving share,	Higher overall efficiency, Reduced battery cycling,	Max. ICE efficiency, Simpler ICE calibration,	Reduced battery throughput Battery can be smaller	High-performance reserve.	Smaller batteries possible. Reduced C-Rates (battery life).	Highest potential for reducing energy consumption,

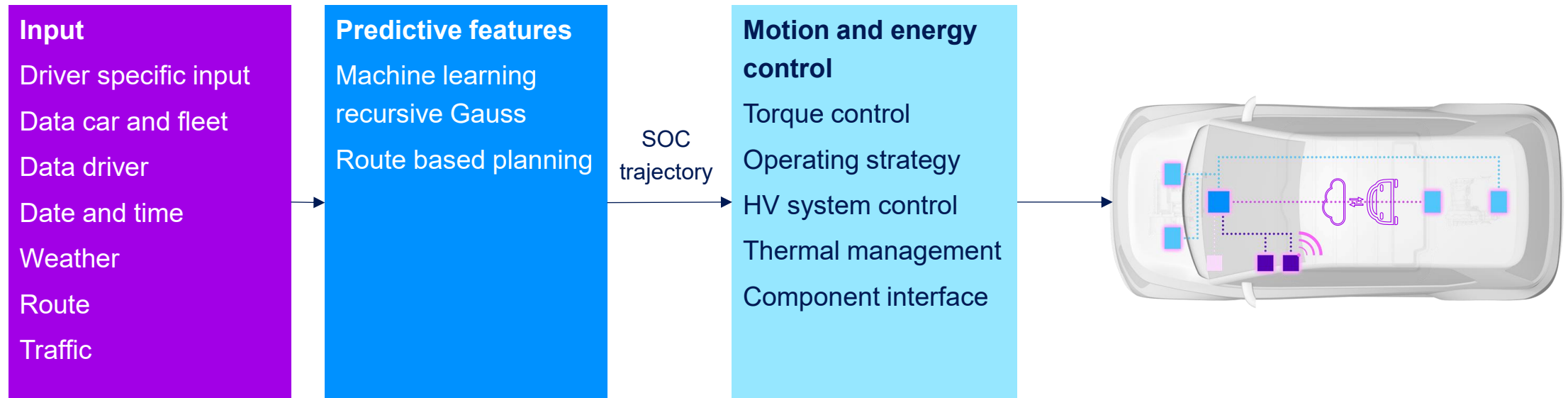
From simple strategies to intelligent, learning based energy management

Learning Powertrain Intelligence – REEV Operating Strategy

Basis for an Extended REEV Operating Strategy

Operating strategy

- Holistic system optimization drives performance, efficiency, emissions and NVH while serial architecture enables flexible Rex operation
- Modes: Pure EV | serial battery assist | REx-dominant traction | battery charging by Rex

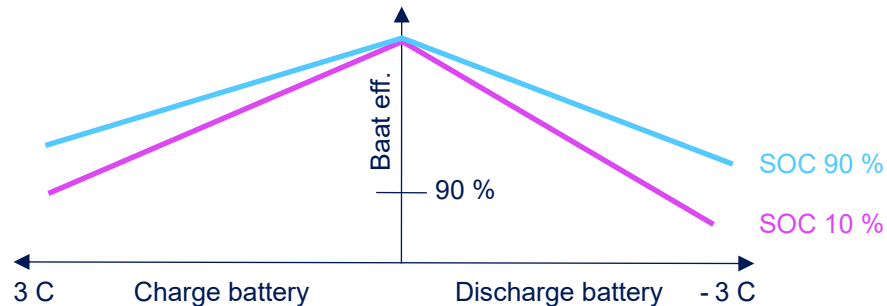
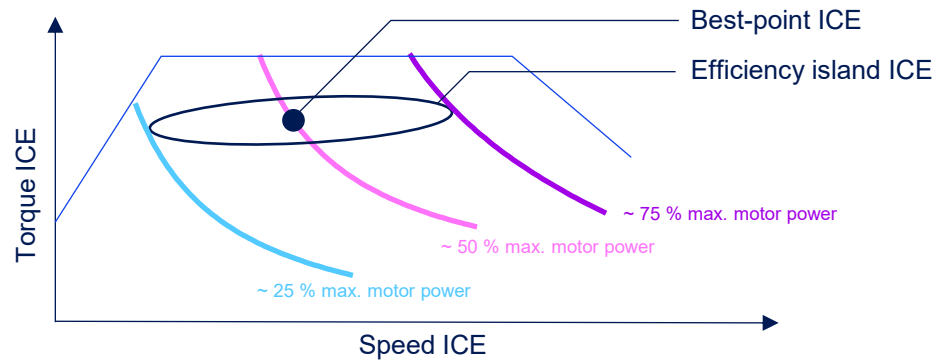


For leveraging the full potential of advanced operating strategy a SDV vehicle architecture is mandatory

As more data from the vehicle, cloud, other vehicles or general information are available as higher the expected potential

Learning Powertrain Intelligence – REEV Operating Strategy

Key Levers & Considerable Boundaries for a REEV Operating Strategy



Higher overall system efficiency by fewer battery cycling and more robust real-world drivability.

REx operation in best-point

- Fixed optimal REx operating point ensures high efficiency but offers limited flexibility under dynamic load conditions

REx operation in efficiency island

- Use of an efficiency island enables flexible power adjustment, improved load coverage and reduced battery cycling incl. charge/discharge losses

SOC / SOH impact

- Beyond minimizing battery cycling for keeping the SOH longer at a higher level, battery operation in healthier upper SOC regions improves battery efficiency

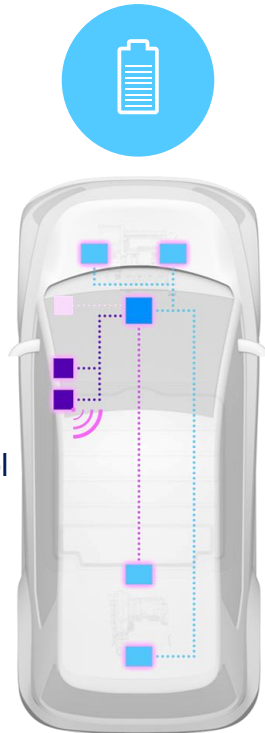
Learning Powertrain Intelligence – REEV Operating Strategy

Potential of Two Advanced Operating Strategies vs. Charge Sustain. OS

Charge Sustaining Strategy

SOC trajectory planning

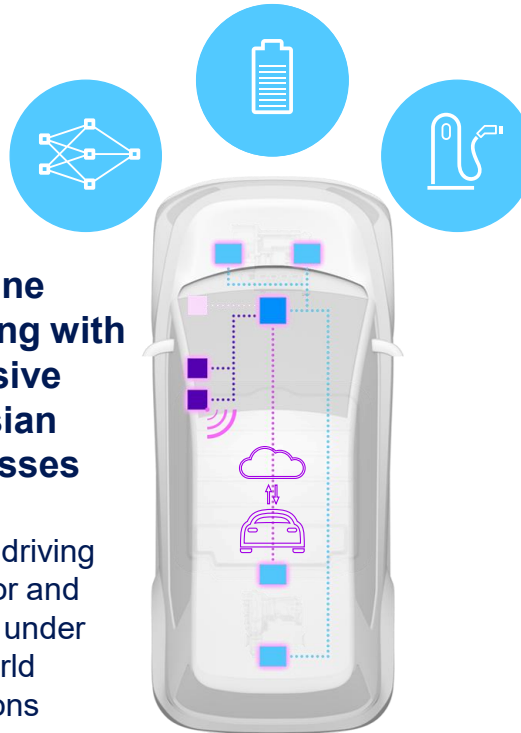
As central control objective for optimal REx and battery operation



Machine Learning based on Driver specific Data from Past

Machine learning with recursive gaussian processes

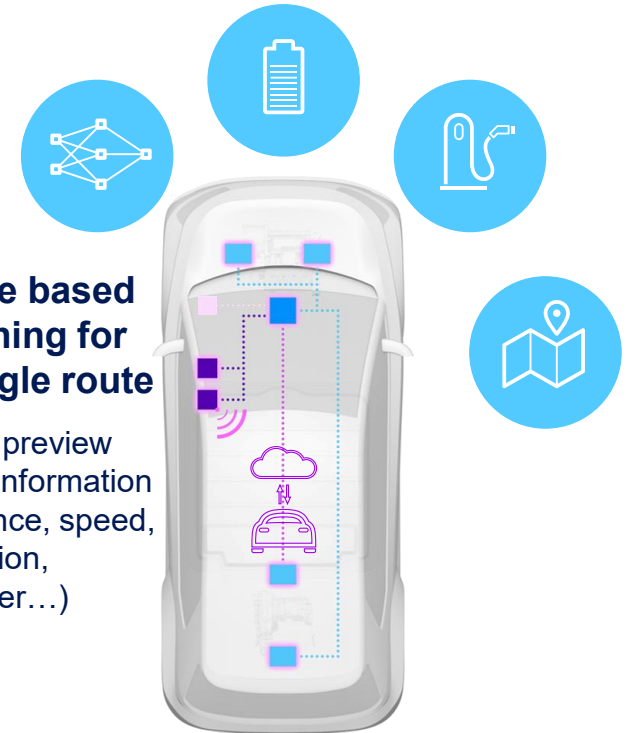
Learns driving behavior and pattern under real-world conditions



Machine Learning from Past & Predictive Single Route Optimization

Route based planning for a single route

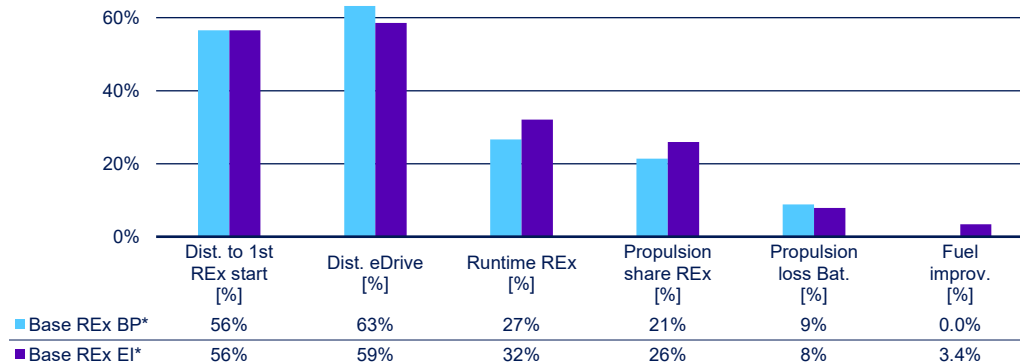
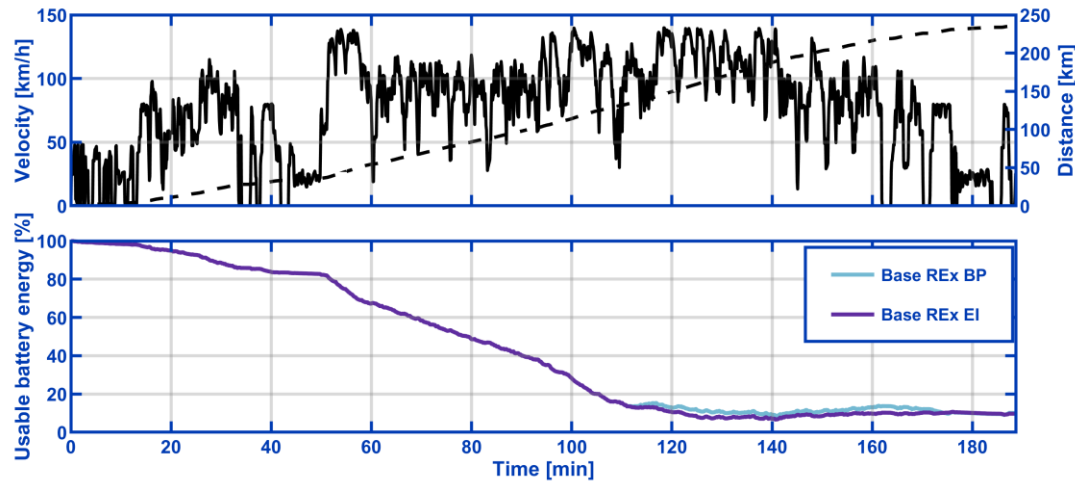
Using preview route information (distance, speed, elevation, weather...)



Strategies assessed based on realistic customer driving cycle data of around 190min duration – no artificial cycle

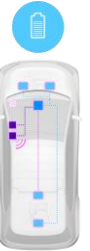
Learning Powertrain Intelligence – REEV Operating Strategy

Charge Sustaining Strategy with two Different REx Operating Scenario's



Efficiency island operation

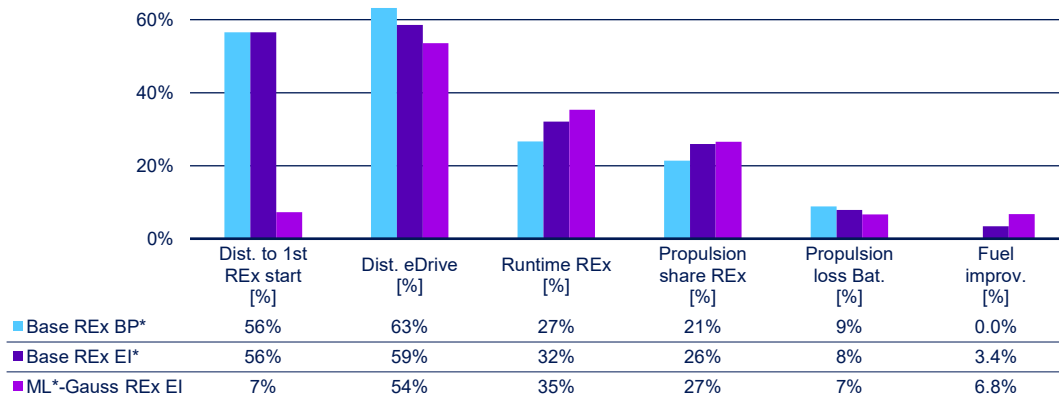
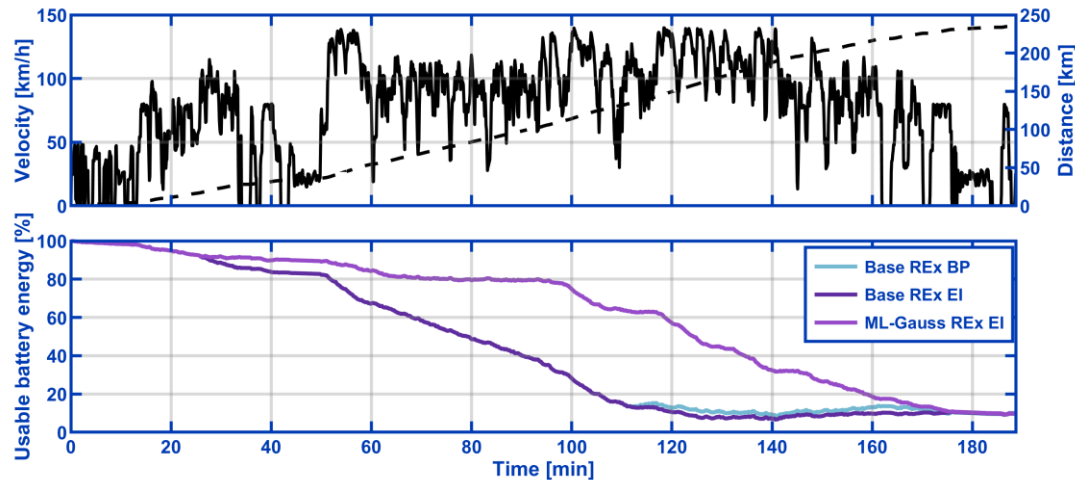
- 3.4 % fuel savings by minimizing battery cycling through increased REx propulsion support in the low-SOC range, at the cost of - 4 % pure electric drive



*BP = Best point | *EI = Efficiency island

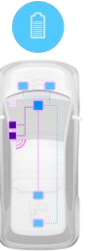
Learning Powertrain Intelligence – REEV Operating Strategy

Learning from past Driver behavior by Machine Learning



Efficiency island operation

- 3.4 % fuel savings by minimizing battery cycling through increased REx propulsion support in the low-SOC range, at the cost of - 4 % pure electric drive



Machine learning with recursive Gaussian processes

- Further + 3.4 % fuel savings by increased REx propulsion support and mainly higher SOC operation, at the cost of further - 5 % pure electric drive and earlier REx start

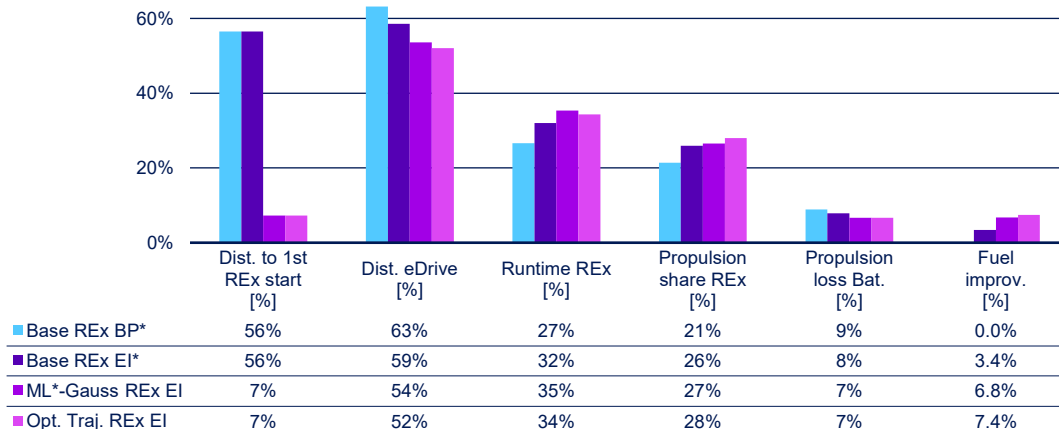
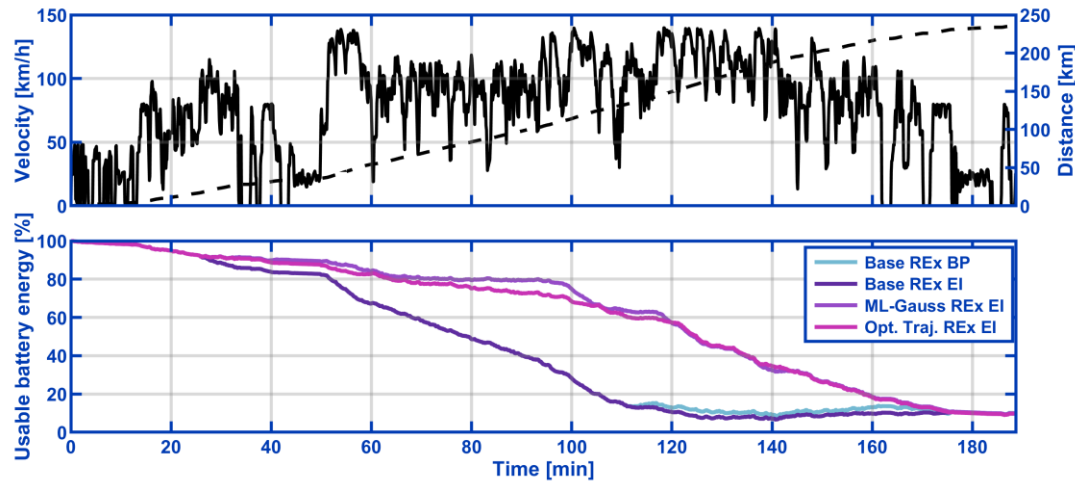


*BP = Best point | *EI = Efficiency island

*ML-Gauss = Machine learning with recursive Gauss regression | *Opt. Traj. = Optimal route-based trajectory

Learning Powertrain Intelligence – REEV Operating Strategy

Knowing the Routing will help to gain a further Potential



Efficiency island operation

- 3.4 % fuel savings by minimizing battery cycling through increased REx propulsion support in the low-SOC range, at the cost of - 4 % pure electric drive



Machine learning with recursive Gaussian processes

- Further + 3.4 % fuel savings by increased REx propulsion support and mainly higher SOC operation, at the cost of further - 5 % pure electric drive and earlier REx start



Route based planning

- Incorporating route preview information results in additional + 0.6 % fuel savings, at the cost of further - 2 % pure electric drive

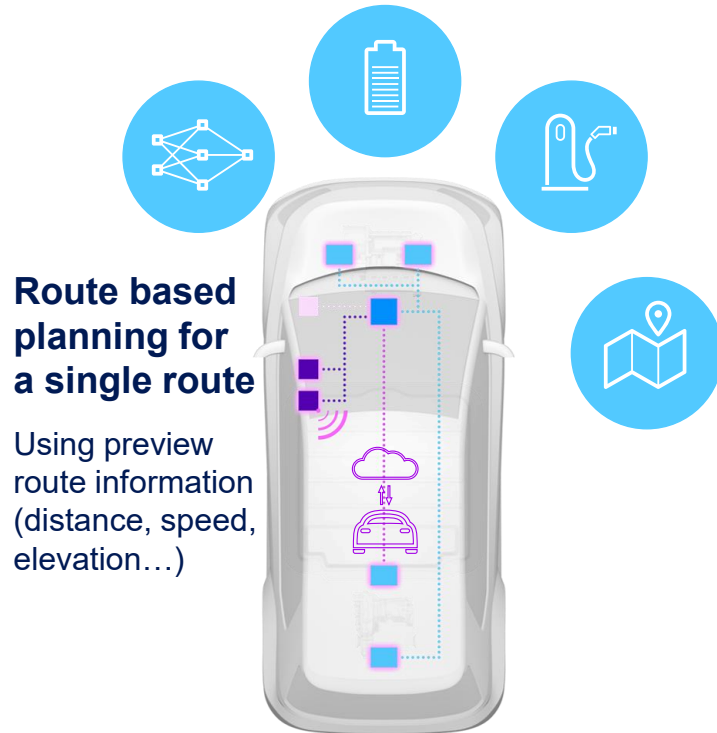


Optimized strategy enable + 7.4 % fuel savings with costs of - 11 % pure electric drive

Learning Powertrain Intelligence – REEV Operating Strategy

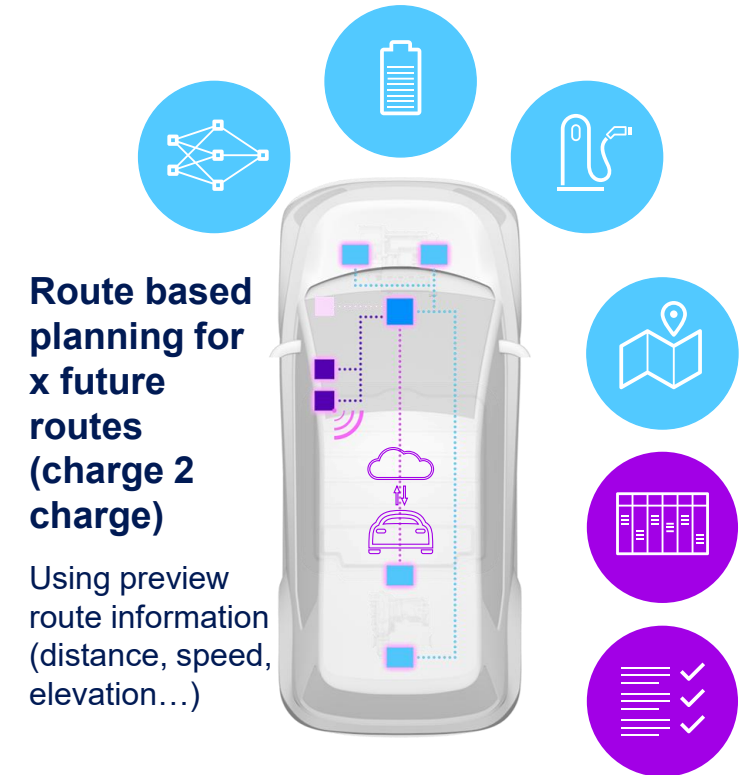
Potential of Two Advanced Operating Strategies vs. Charge Sust. Strat.

Machine Learning from Past & Predictive Single Route Optimization



What further potential?

Machine Learning from Past & Predictive Routing Optimization



Machine learning operating strategy with data from the past enriched with data from the future – further potential?

Learning Powertrain Intelligence – REEV Operating Strategy

Extension of ML Strategy from Single Route to Multi Route Optimization

Single Route Optimization

- Single route will be optimized based data such as:
 - Driving style of driver
 - Weather conditions
 - How many passengers are in the vehicle
 - Typical charging scenario
- Routing of single driving event is known before start of the route (either navigational system or learned based on car usage profile)

Multi Route Optimzation

- Multi routing will be optimized based on data such as:
 - Driving style of driver
 - Weather conditions
 - How many passengers are in the vehicle
 - Typical charging scenario
- All routes between two charging events are known to the system (either due to context menu or learned based on car usage profile)

For both optimizations the models are trained with a high number of different driving cycles from real customer use cases, assuming the vehicle would learn over lifetime the specific user behavior

What is the further fuel efficiency potential if more information about the planned vehicle use between two different charging events, independent of the number of cycles and driving profiles between the charging events, is known

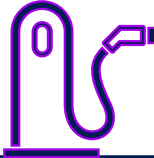
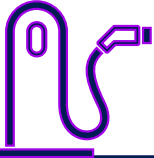
Learning Powertrain Intelligence – REEV Operating Strategy

Assessment of a Learning Operating Strategy against Charge Sust. OS

Boundaries operating strategy assessment:

- Real driving data from a standard user, as he drove his car over a period between two battery charging events
- 5 days from one charging stop to the next one – no intermediate external charging
- Overall distance travelled is 513 km
- Based on available data, as calendar, ToDo list, usage scenario in the past, etc. the routes to be travelled are fully know

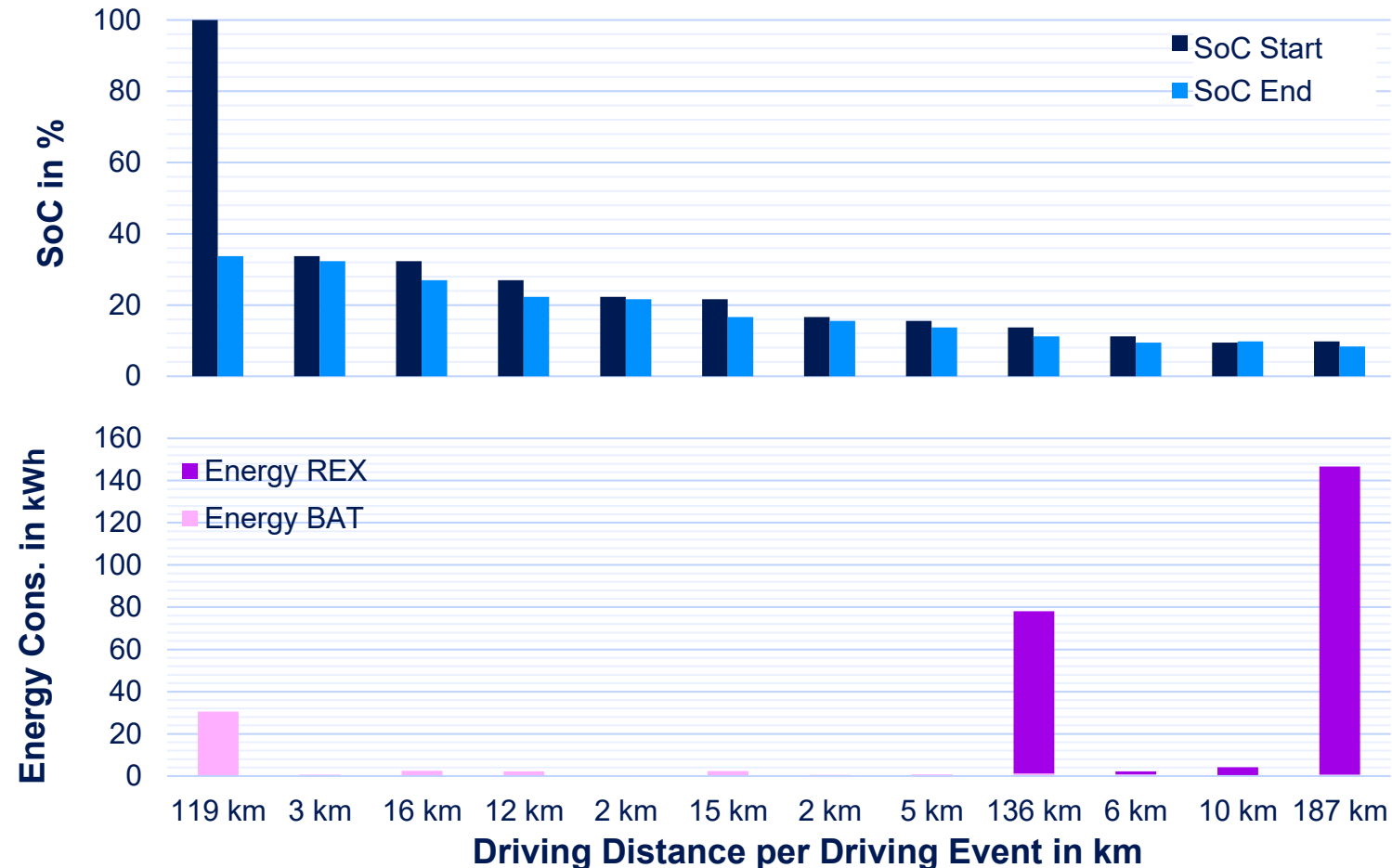
Day 1	Day 2	Day 3	Day 4	Day 5
Drive 1: 119 km	Drive 1: 16 km	Drive 1: 15 km	Drive 1: 136 km	Drive 1: 187 km
Drive 2: 3 km	Drive 2: 12 km	Drive 2: 2 km	Drive 2: 6 km	
	Drive 3: 2 km	Drive 3: 5 km	Drive 3: 10 km	



How much fuel consumption reduction can be achieved with such a maximum learning strategy compared to a standard charge sustaining strategy

Learning Powertrain Intelligence – REEV Operating Strategy

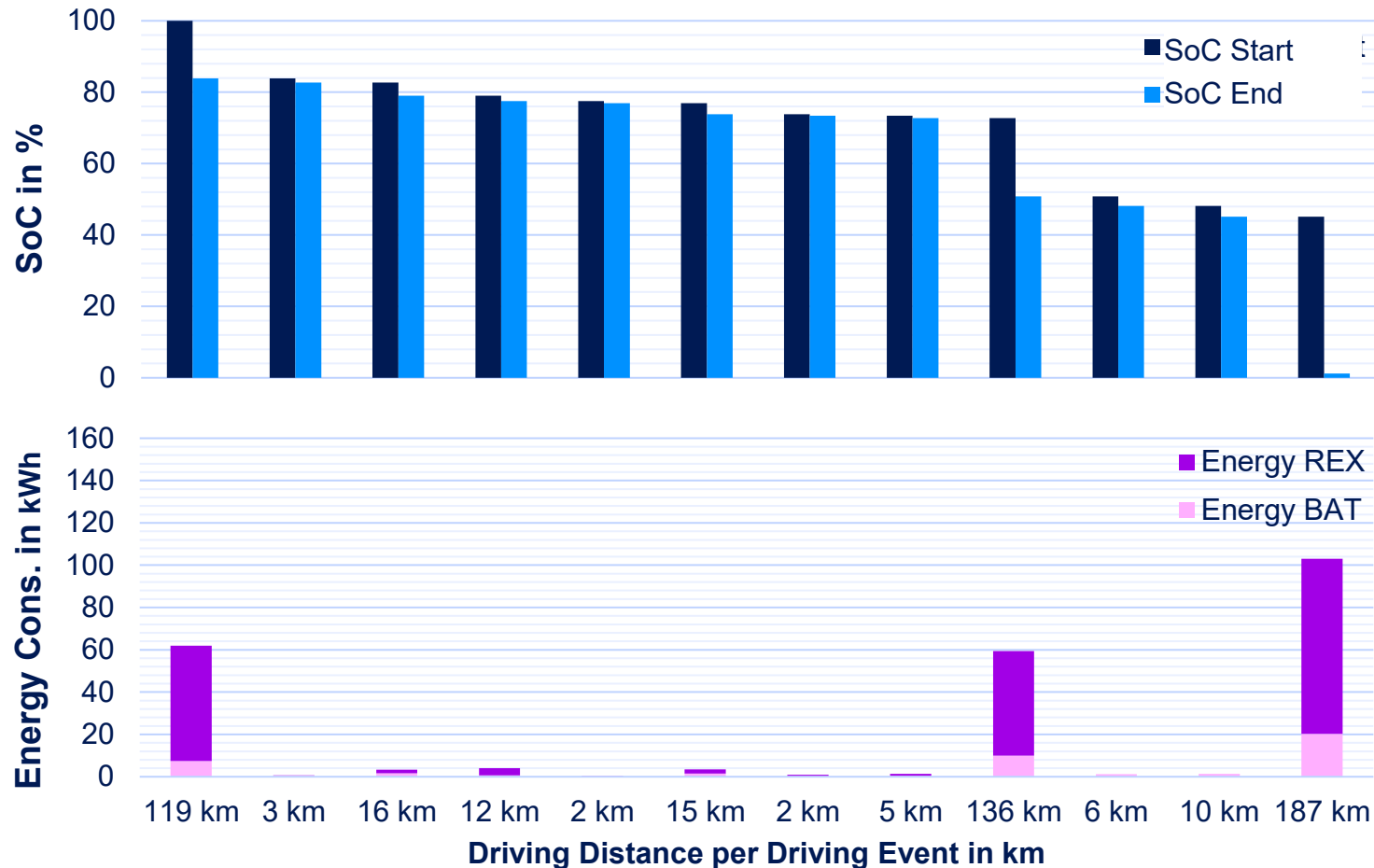
REx Fuel Consumption with Standard Charge Sustaining Strategy



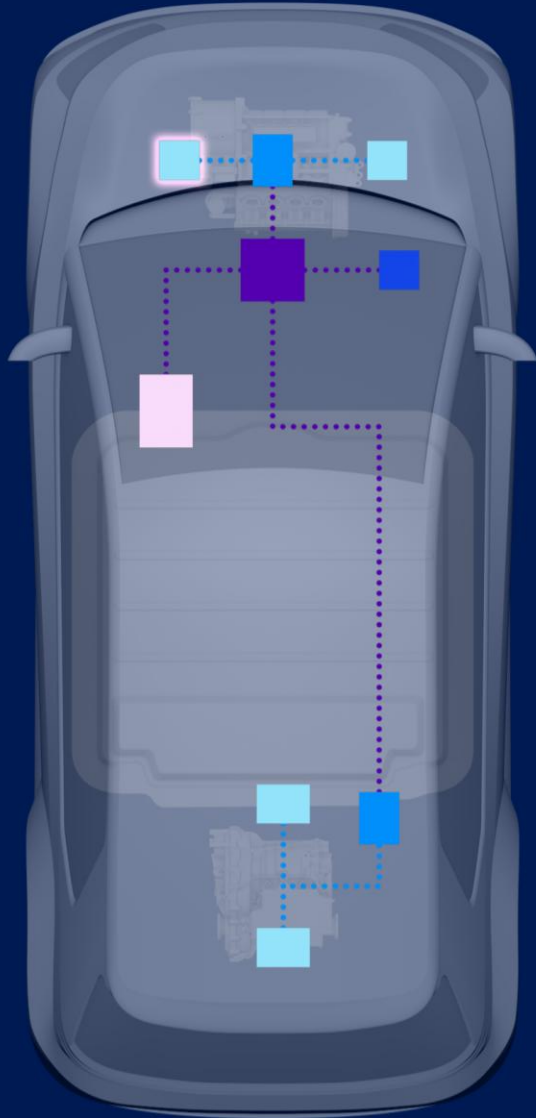
- SoC minimum at ~10% - REX will start automatically
- Optimization avoids REX use through short driving trips (NVH and efficiency)
- First long drive will be done completely electric, based on strategy electric first until SoC min. is achieved
- **REx energy demand at 228 kWh (26,6l gasoline fuel)**

Learning Powertrain Intelligence – REEV Operating Strategy

REx Fuel Consumption with Machine Learning & Multi Route Prediction



- SoC minimum at ~10% - REX will start automatically
- Optimization avoids REX use through short driving trips (NVH and efficiency)
- REX will be activated whenever meaningful from efficiency, NVH and general driving behavior – priority is not anymore pure electric driving from start until SoC ~ 10%
- **REx energy demand at 196 kWh (22,8l gasoline fuel)**



Take Away / Next Steps

- A **horizontal positioned ICE**, derived from a vertical purpose ICE, offers huge advantages in package, cost and NVH when having a BEV vehicle platform
- **Hyper REEV** emotionalizes battery electric vehicles by the help of a real, not artificial, ICE sound
- **ML based REEV operating strategies** do offer a significant fuel consumption reduction during a REEV operation
- If **single routing is known** before start of the single drive, a further fuel efficiency increase is achievable
- **Full knowledge about planned drives**, for instance between two charging events, will offer a huge fuel efficiency increase

AI based REEV operating strategies, trained with a lot data available from the vehicle, user, etc. can offer a huge fuel consumption reduction and help to reduce HW cost – more to come...

Let's REEV it up...

Marc Sens (Senior Vice President Research & Technology)

IAV GmbH

Carnotstraße 1, 10587 BERLIN (GERMANY)

Phone +49 162 244 61 84

marc.sens@iav.de

www.iav.com

**Many thanks to all contributing IAV
colleagues!**

Dr. Alexander Fandakov, Joerg
Mickeleit, Tiam Tahmasebi Dezfouli,
Maik Dam Linh Nguyen, Patrick
Stracke

