March. 2nd, 2023, WAAI-2023

# Evolution of vehicle NVH requirements and solutions in the era of Sustainability and electrification

Dr. Davide Caprioli, Head Acoustic and Thermal Management

# Agenda

Autoneum at a glance

New BEV architecture and acoustic performance trends

Sustainable products for BEVs

Key takeaways

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Autoneum at a glance

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Sustainable products for BEVs

Key takeaways

## Autoneum. Mastering sound and heat.

# Autoneum at a glance

Supplier of 60 electric models worldwide

**1804**

CHF million revenue in 2021

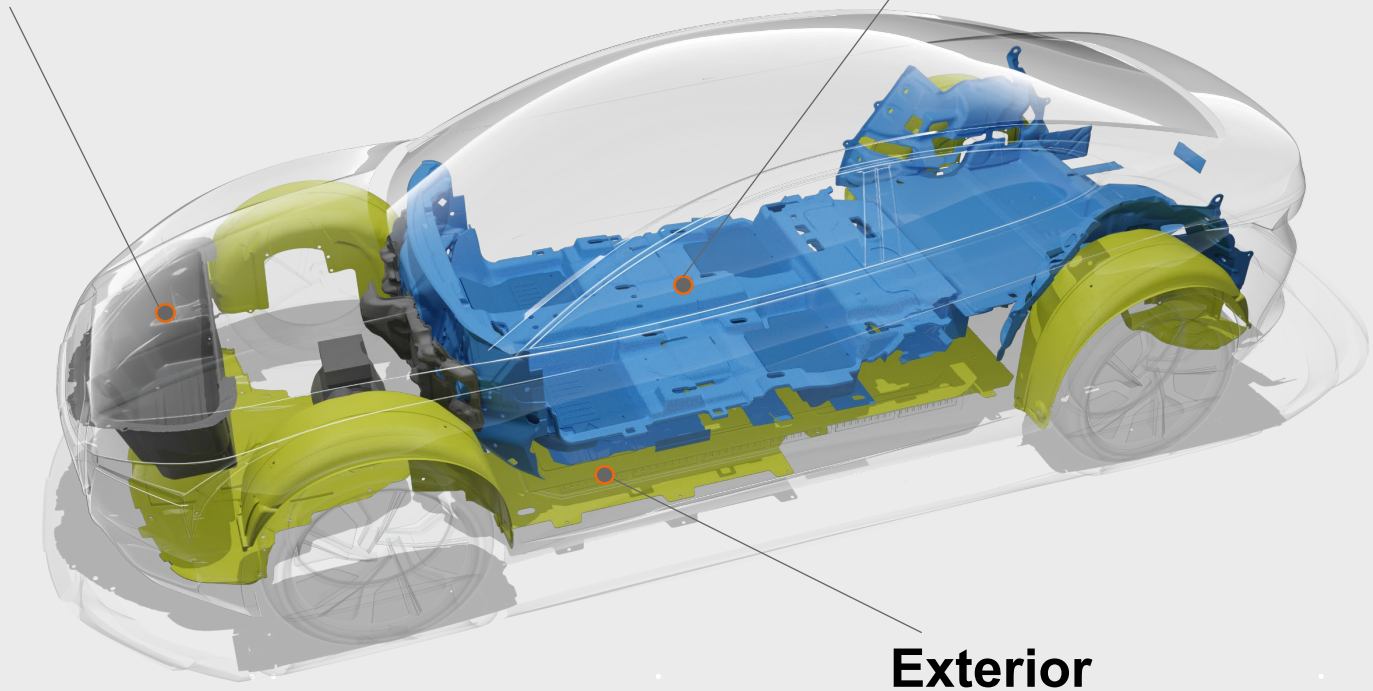
**53**

53 production facilities worldwide

Stock-listed company (SIX Swiss Exchange)

**24**

Represented in 24 countries



# Agenda

Autoneum at a glance

**New BEV architecture and acoustic performance trends**

Sustainable products for BEVs

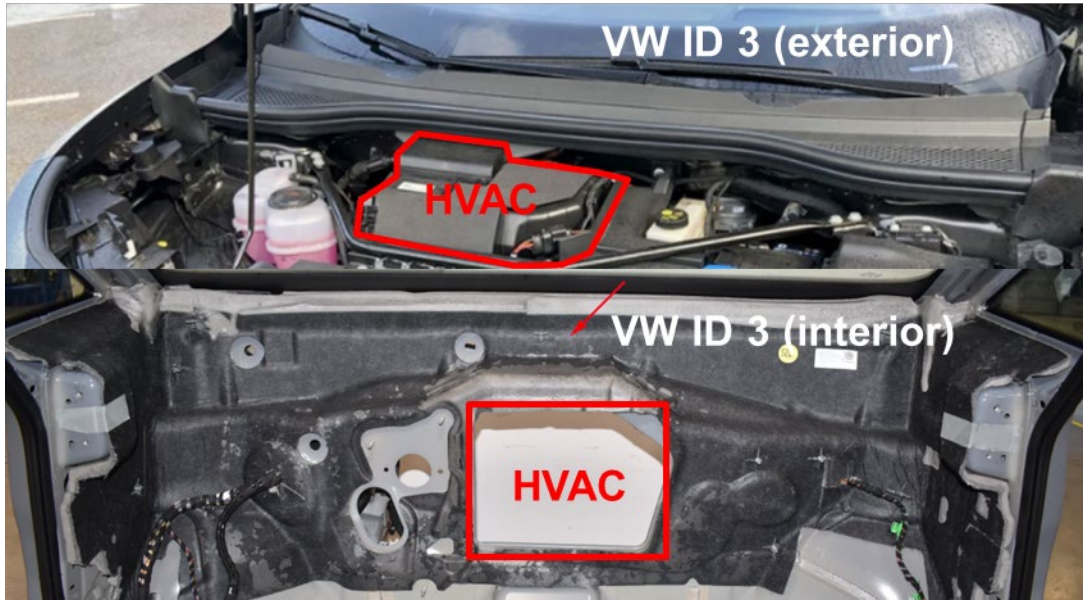
Key takeaways

## New BEV architecture

# Implications on interior dimensions

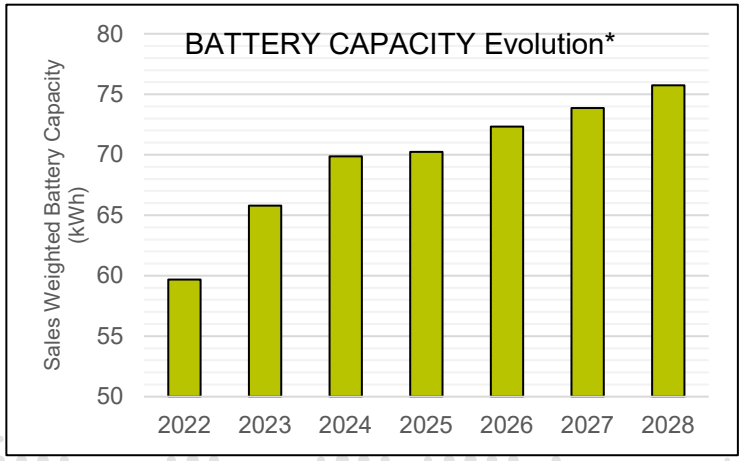
**New BEV architecture:**

- Longer wheelbase to accommodate larger floor battery
- Rear passenger moved towards the trunk
- HVAC pushed towards the E-motor bay
- No need for tunnel (no exhaust line)




**To be considered:**

- Potential weakening of the dash insulation because of the HVAC ingress in the E-motor bay
- Packaging space on the floor is reduced
- Different acoustics and thermal management due to the main floor battery and rear powertrain
- Rear passengers closer to rear wheels




Source: Hyundai Kia

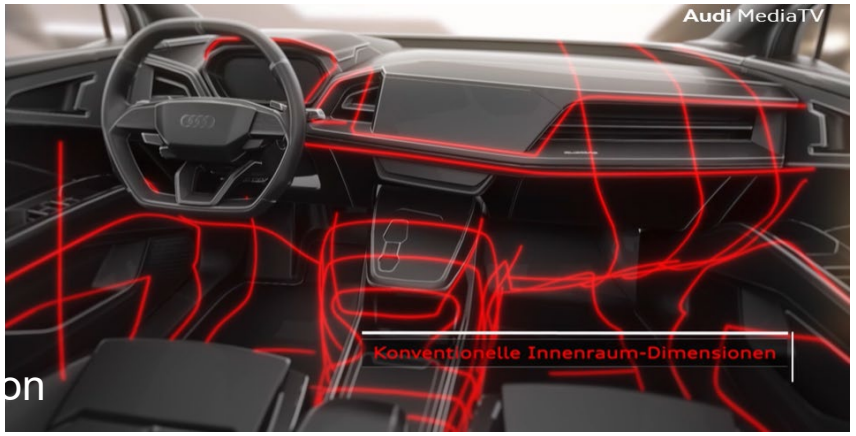
*IHS Database 2022 February

## New BEV architecture

# Implications on interior design

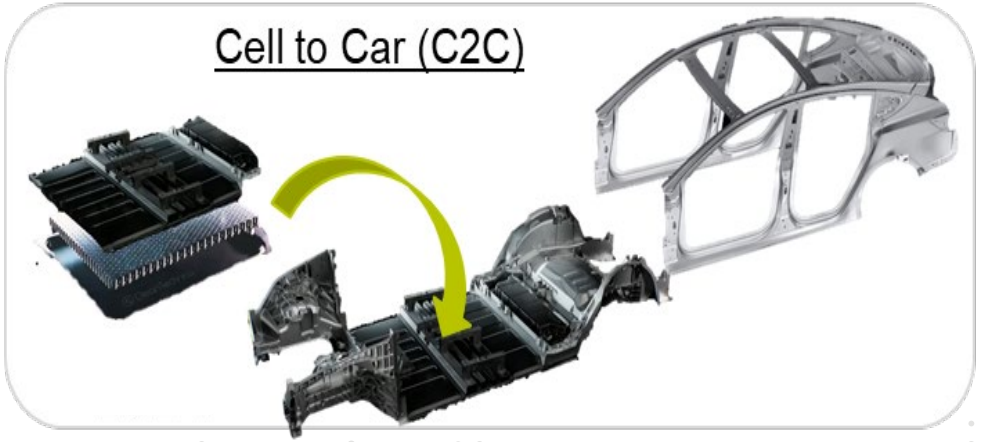
**Interior trim design:**

- Slimmer instrumentation panel & console reduce their own acoustic masking
- Local NVH treatment around HVAC required
- For ergonomics and safety reasons, larger crash padding on lower dash
- Larger carpet surface on the dash area




**Battery design and integration:**

- Engineering paradigm #1: battery separated from the main floor by an air gap
- Engineering paradigm #2: main floor is the battery lid in “cell-to-car” approach
- Increase of body acoustic insulation on the floor in the area of the battery
- High floor / cable temperature (especially during charging)

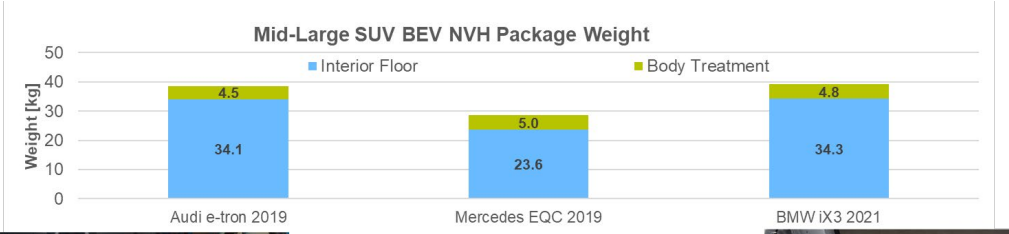


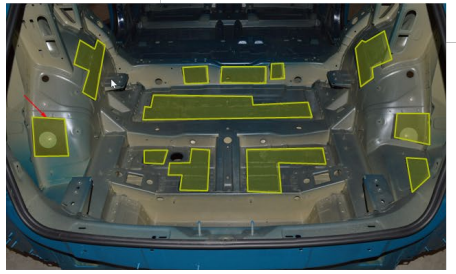
## New BEV architecture

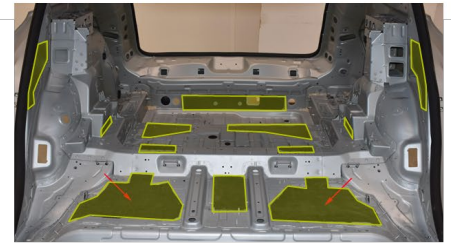
# Implications on interior sound comfort

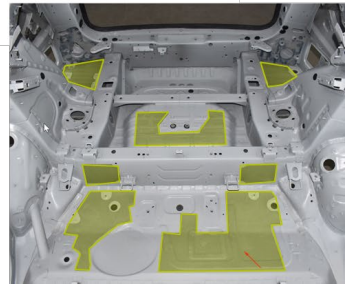
**Trunk acoustic requirements:**

- 85% of new BEVs will have a rear E-powertrain
- Dual motor mostly with 40/60 front/rear power distribution
- Rear trunk well with large flat walls enabled by the absence of exhaust line is acoustically critical
- Tire noise is not masked by E-powertrain noise

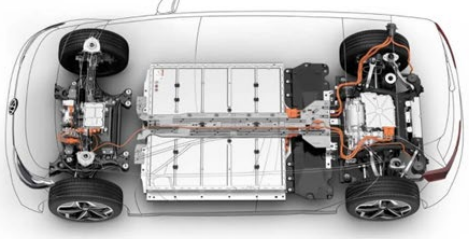






VW ID 3

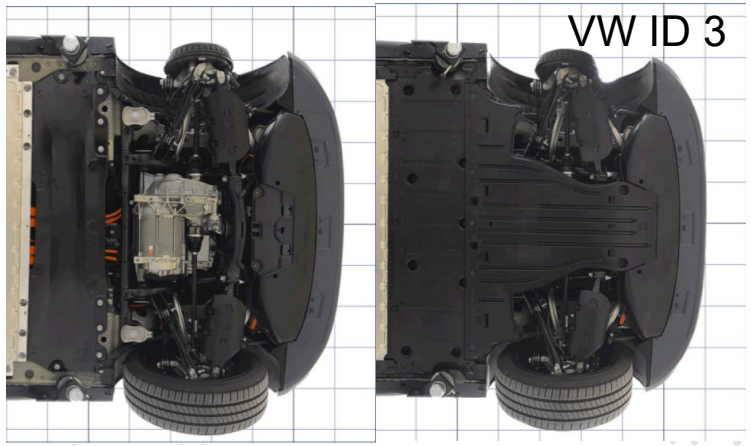


85%
RR or AWD

VW ID Life

15%
Only FRT

Toyota bZ4X



# New BEV acoustic sources

# Main contributors

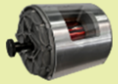
**BEVs present a new paradigm of NVH comfort:**

- New balance of sources contribution
- How to express the new concept of sound quality for BEVs?

**New Noise Sources**

**Electric motors Maxwell forces**

- Tonal orders
- Resonances by the breathing mode of stator (4.5-5.5kHz)



**High rotating speeds**

- Whining noise Resonances for frequencies ≥700 - 1.7kHz

**Power/control electronic and air cooling**

- Switching noise very annoying in audible range
- Range > 5kHz

**Other electrified systems**

- Acoustic sources not correlated with e-motor speed / engine load

**No Masking**

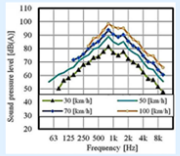
**Aerodynamic noise**

- Other noise sources become more predominant

**No Masking**

**Road noise**

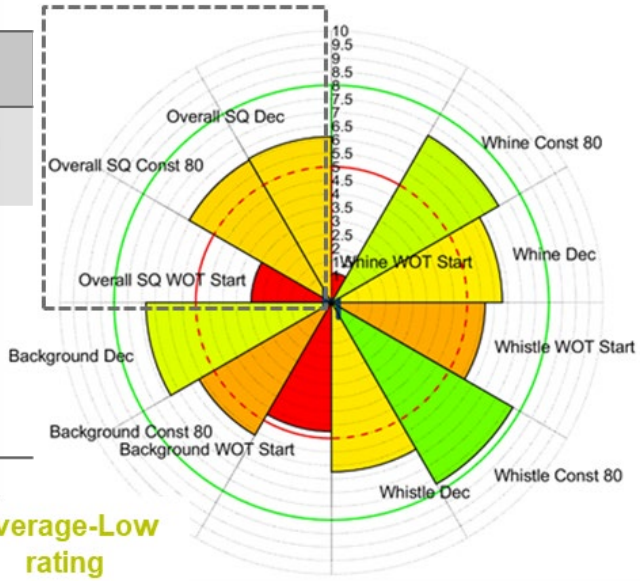
- Tire airborne peak contribution in average around 800-2000 Hz



**Specialized press review Mercedes EQS:**

- Very quiet – quieter than its rivals
- Very little whine from the electric motor at acceleration or deceleration
- Just a mild wind noise on the motorway
- Road noise is a distant background murmur

| BEV Powertrain related | | Other sources | Summary |
|---|---|---|---|
| **Whine** Noise | **Whistle** Noise | **Background** Noise | Overall Sound Quality |
| **Tonal** components in mid-freq e.g. **~400 – 4kHz**<br><br>Strongly related with speed | **Tonal** components in high-freq (e.g. > 4kHz)<br><br>Only mildly related with speed. | Broadband noise related to sources **not linked** to the e-drive (e.g. **tires**, **wind**). **Not tonal**. | Overall Sound Quality can be regarded as a **combination** of whine, whistle and background noise quality. |




Average-Low rating

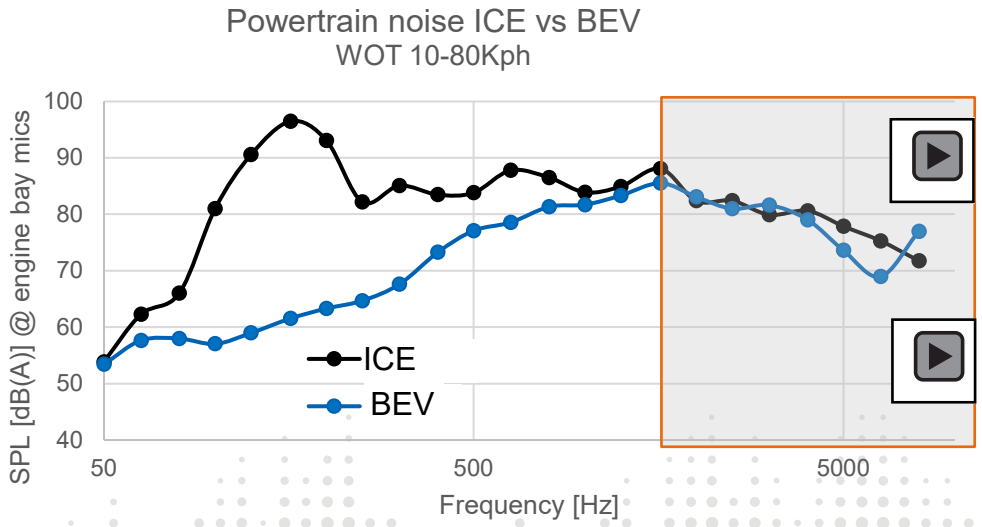
**Specialized press review e-tron:**

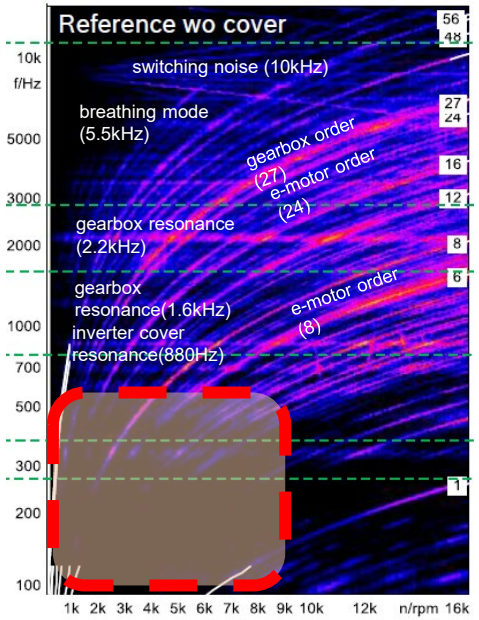
- Generates next to no wind noise on the move
- Road noise is also very well muted
- A quieter car than its rivals

## New BEV acoustic sources

# E-powertrain

- Noise spectra relevant in higher frequency range compared to ICE – focus above 500-700 Hz
- Very tonal frequencies highly disturbing:
  - E-motor orders: e.g. 6th, 12th, 56th order
  - Gearbox orders (whining & 23rd order) and resonances (>700 Hz)
  - Switching noise tonal components (> 5KHz)

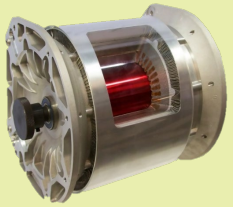



Example of eAxle
SPL @1m distance on engine testbench (run up 50% load)

Internal Combustion Engines highest emission range

**Electric motors Maxwell forces**



**High rotating speeds**

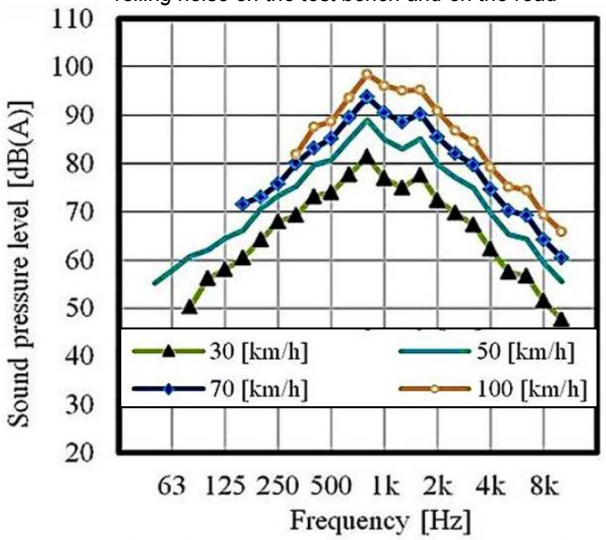
**Power/control electronic and air cooling**

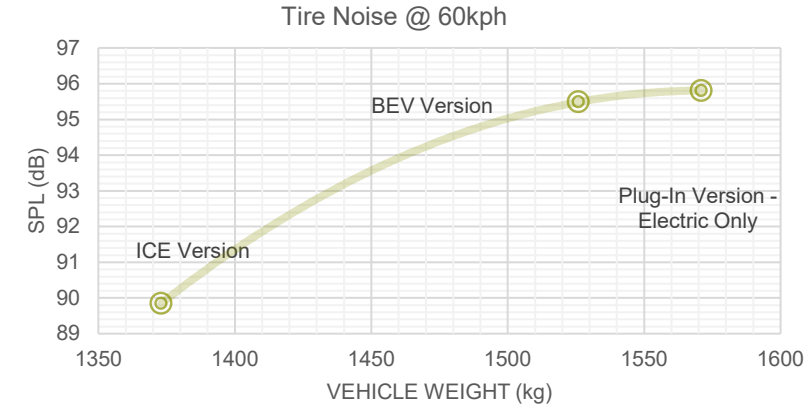
## New BEV acoustic sources

# Road noise

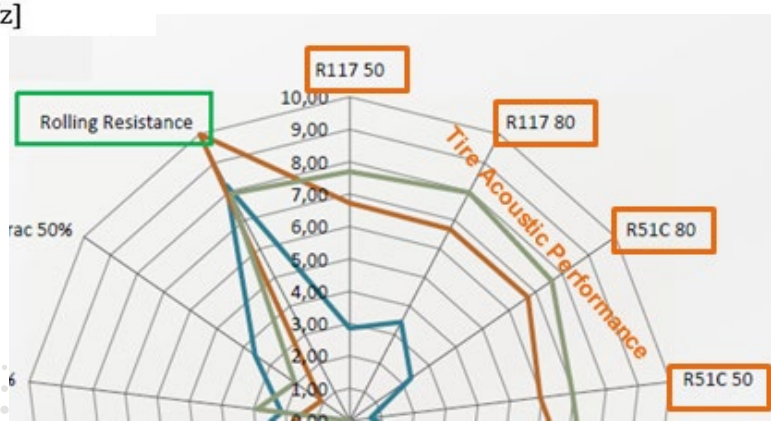
- Noise emission of tires strongly correlated with vehicle speed and impacted by tires width and vehicle weight:
  - Airborne peak contribution in average around 800-2000 Hz
  - Structure borne contribution in the 150-250 Hz
- BEV vehicle weight in average 4-600 kg higher than reference ICE requiring wider tires ➔ increased contribution
- Tires designed for low rolling resistance (higher drive range) are not the best in class for noise emission

*FKFS 2014 Paper - Comparison of vehicle rolling noise on the test bench and on the road*




*Source: Autoneum Benchmarking*




*FKFS 2014 Paper - Comparison of vehicle rolling noise on the test bench and on the road*

# Performance analysis – road noise and powertrain noise filtering

**BEV NVH performance evolution through benchmarking:**

- Noise filtering performance by reciprocal transfer functions ➔ influencing factors:
  - Bare body insulation (BIW thickness, windows thickness, battery position,..)
  - Interior NVH package design (packaging space, coverage, cut outs, pass-through)
  - Exterior NVH package (underbody panels and WOL)

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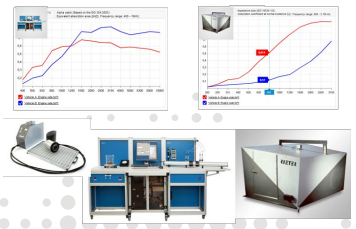
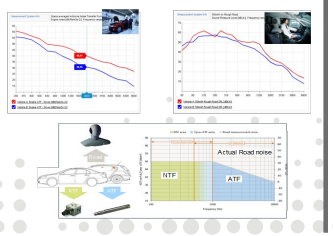
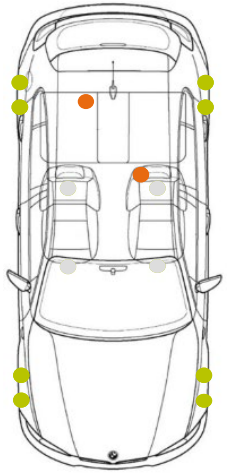
Global service to OEMs (Europe-Market)

Components benchmarking



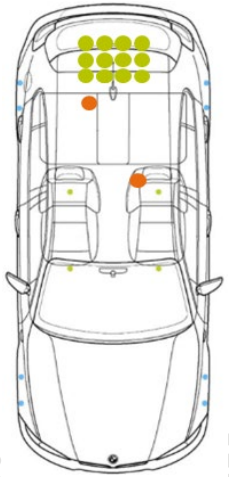
Vehicle benchmarking



- Noise source locations *i*
- Aquisition points at tire - road contact patch *j~8*

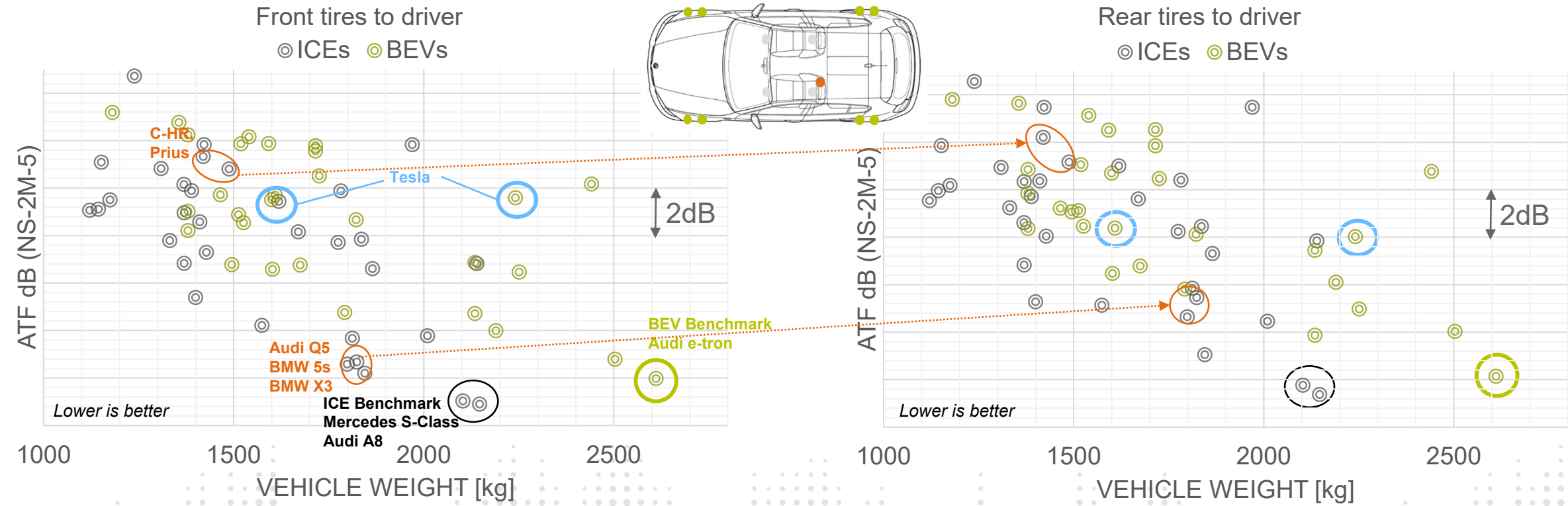
$$\frac{P_j}{\dot{Q}_i}$$ *Average* ***1-4 kHz***



- Acquisition points on powertrain inert surfaces *j~50*

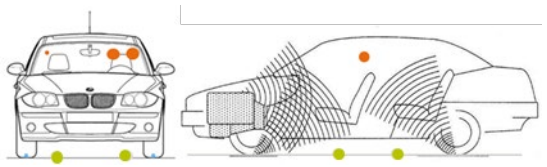
# Performance analysis – road noise filtering

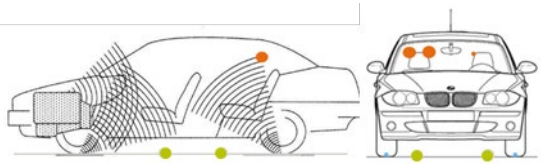
- Best-in-class BEVs with SUV open trunk body style are as good as best-in-class premium sedans with a closed trunk
- In new BEVs,  rear tire noise is better filtered by NVH package than front tires (generally opposite behavior on ICE cars)
- Acoustic glazing & improved door seals completes standard NVH package (efficient for both rolling and aerodynamic noise)



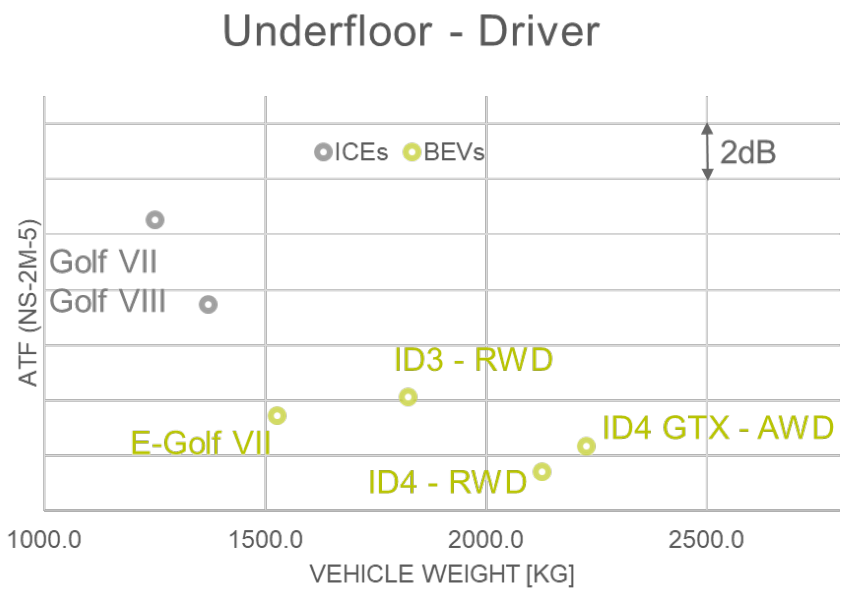
## Vehicle benchmarking

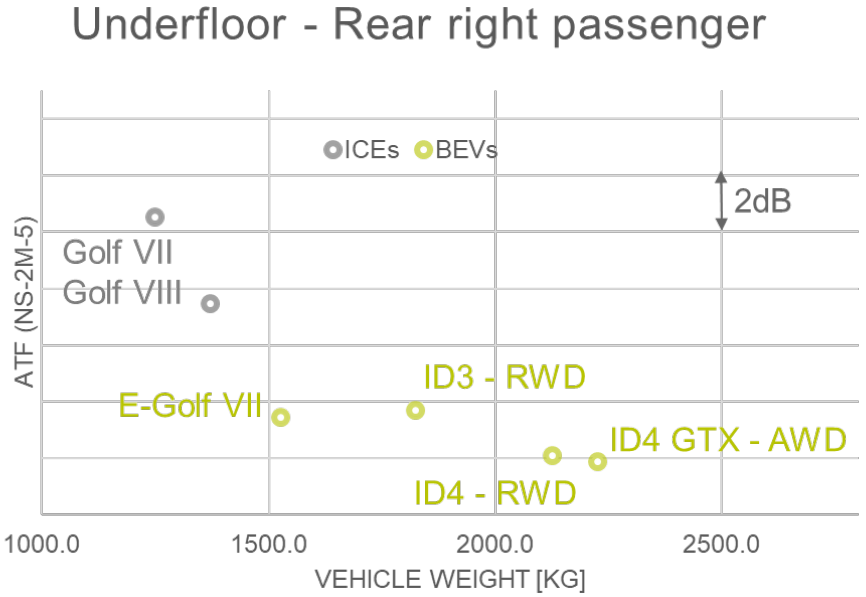
# Performance analysis – Floor In-situ Insulation - VW fleet evolution

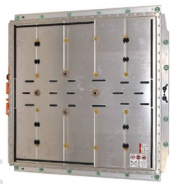


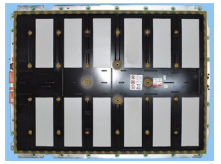


- On its own, a 500 kg battery, offers about +10dB insulation to the floor in a coupled room testing set up
- Measuring the floor transparency at vehicle level, we can observe the impact of improved NVH filtering performances (with similar NVH concepts in the interior) given by different battery weights and integration levels



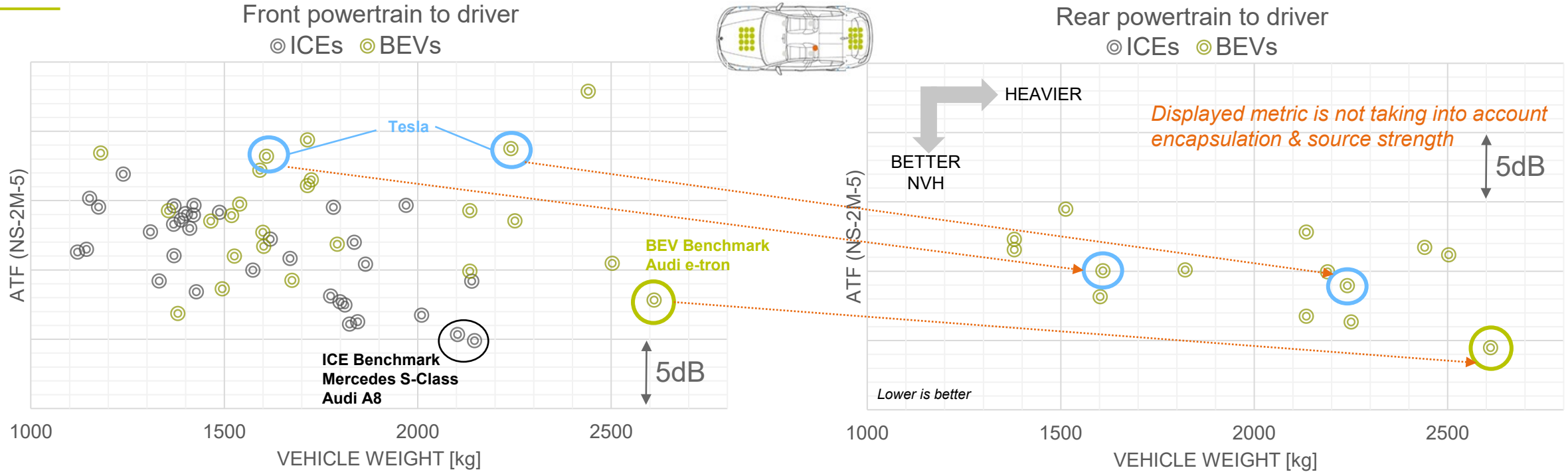





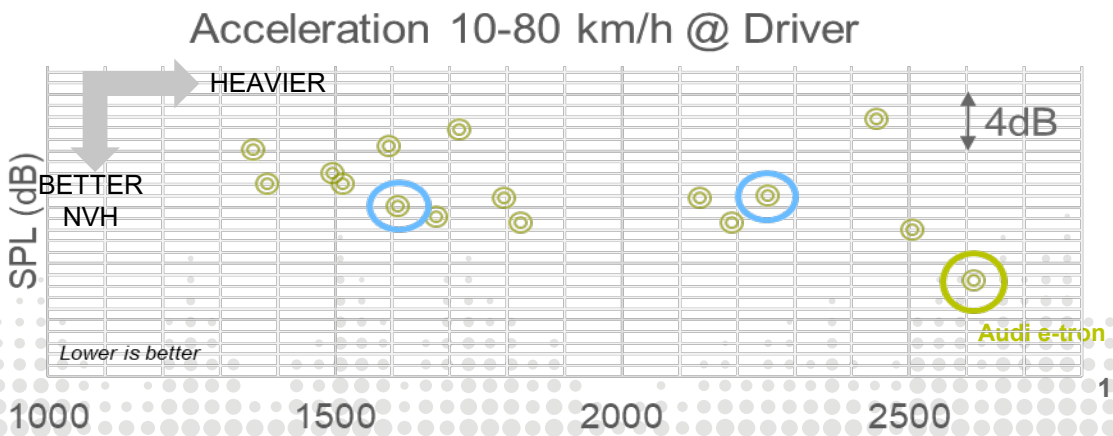
| WV E-Golf | WV ID.3 | WV ID.4 (/GTX) |
|---|---|---|
| 36kWh - >318kg - >1.9m Length | 55kWh - 350kg - 1.5m Length | 82kWh - 491kg - 1.8m Length |

# Performance analysis – powertrain noise filtering






- NVH package design & transmission path adopted at rear end allows for higher noise filtering vs. front powertrain
- Displayed metric is not taking into account encapsulation & source strength
- WOT in most cases display similar trend than ATF of rear powertrain ➔ guided by higher source strength



# Agenda

Autoneum at a glance

New BEV architecture and acoustic performance trends

**Sustainable products for BEVs**

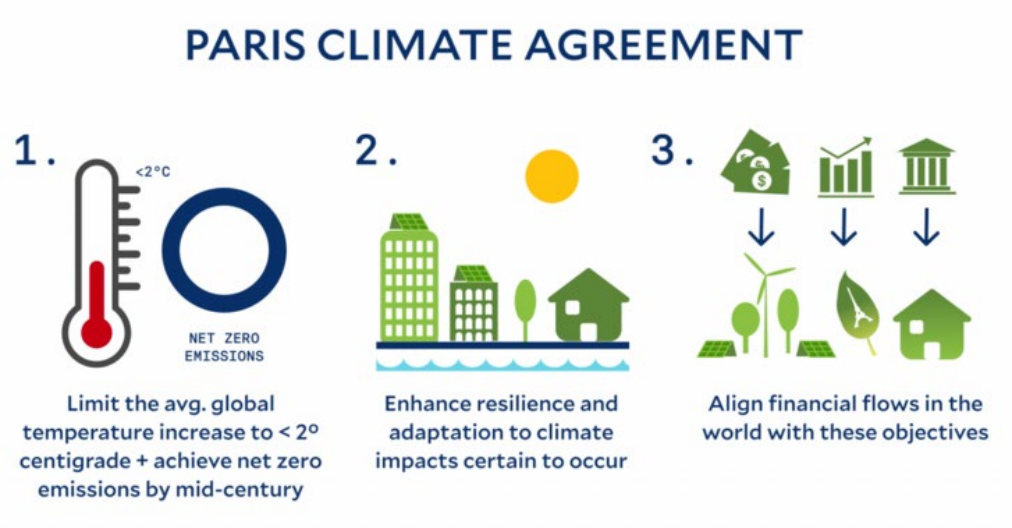
Key takeaways

## Sustainability in the automotive industry

# Need for action

### Fight against climate change

Decarbonization, energy saving




Greenhouse gas emissions reduction until net zero

### Stop pollution of the environment, preserve resources

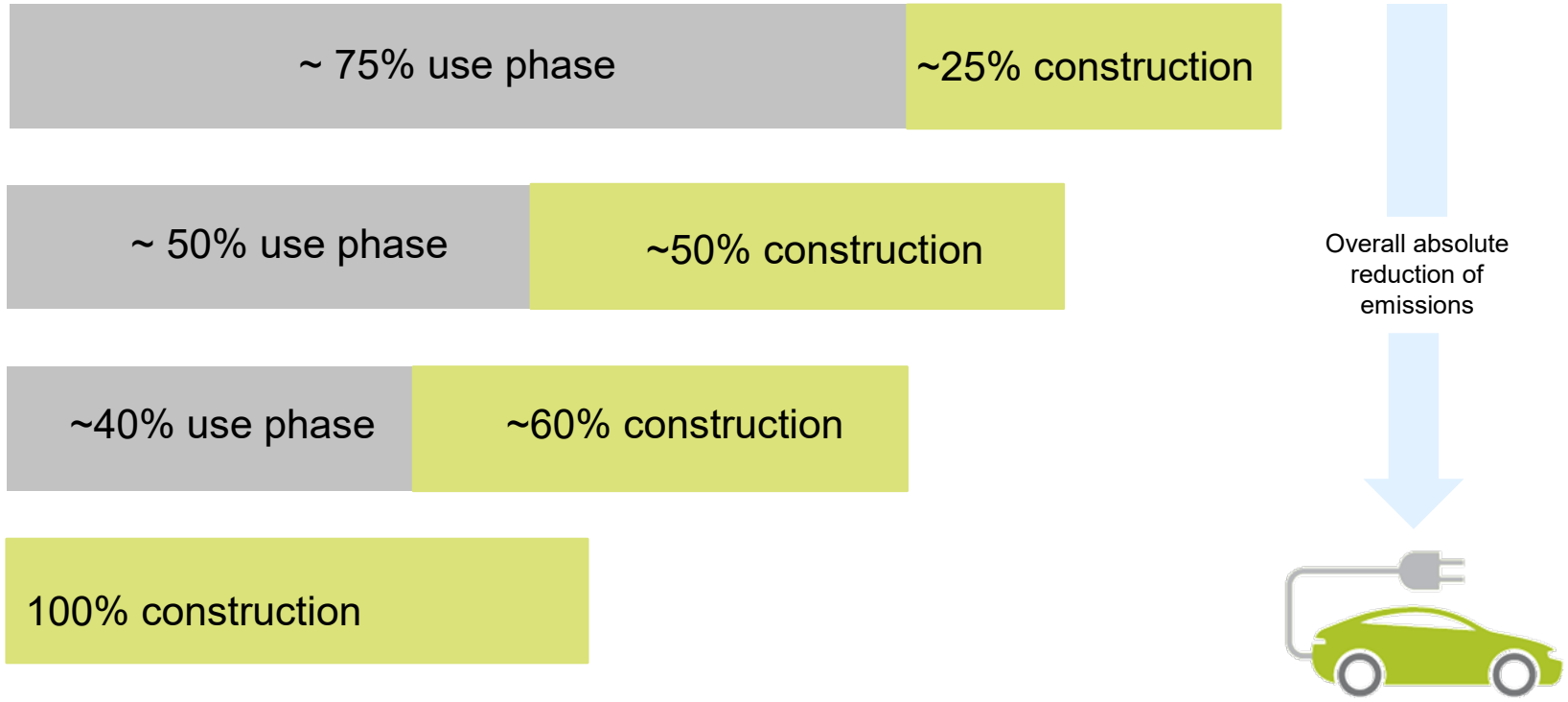
Health, biodiversity, resources depletion, forest


- Material compliance
- Reduce waste and water consumption
- Circular economy

## Sustainability in the automotive industry

# Supply chain sustainability key for electric cars

**$CO_2$ emissions breakdown** of a typical car in use phase and construction (manufacturing and material)




- For electric cars, CO2 emissions in the use phase are significantly reduced compared to ICEs.
- To further improve the carbon footprint, material production emissions must also be reduced.

## Sustainability in the automotive industry

# Source of $CO_2$ emissions* in Autoneum

**Scope 3**
Indirect emissions in the value chain of the reporting company

> 80% of total emissions for Autoneum

> 60% coming from purchased materials

**Scope 2**
Indirect emissions from purchased energy

**Scope 1**
Direct emissions

- Collecting primary carbon intensity factors is key to assessing and tracking improvement: This is still a challenge for the automotive industry to overcome.
- High quality “Cradle-to-Gate” product carbon footprint need to be developed all along the supply chain.

*According to Greenhouse Gas Protocol

## Sustainable product portfolio

# Sustainability throughout the entire product life cycle

**End of life**
- Easy to dismantle
- Mono-materials

End of life

Raw materials

**Raw materials**
- Recycled instead of virgin
- Thermoplastic
- Low carbon footprint
- Mono-material or easy to separate constructions

Production

**Production**
- Low energy process, renewable resources
- Minimum waste generation
- Waste recycling

Delivery

Use

**Use**
- Lightweight design
- Thermal insulation
- Aerodynamic

**Autoneum** focus on reduction of SCOPE 3 emission – LCA analysis of products according to **Cradle to Gate** boundary

**OEMs** currently require:

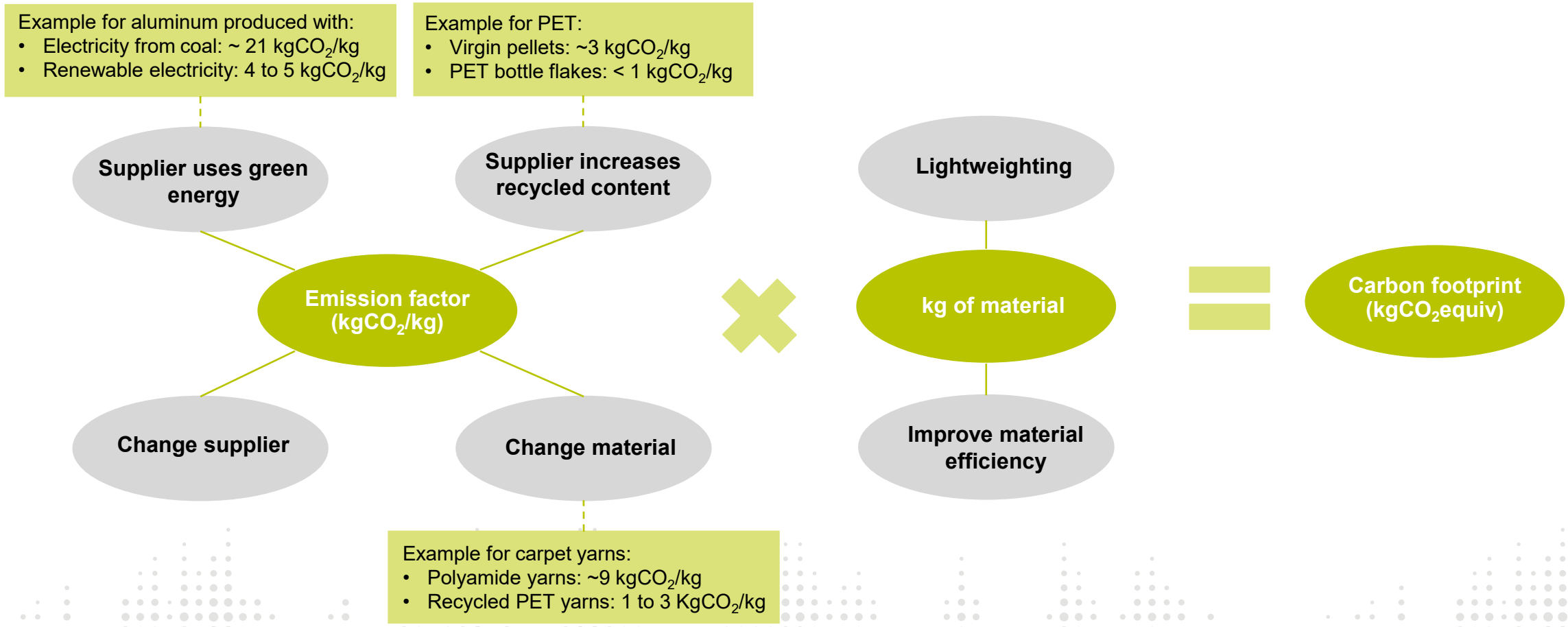
Min % Recycled Content

Max carbon footprint value (cradle to Gate)

Recyclability @ End of life

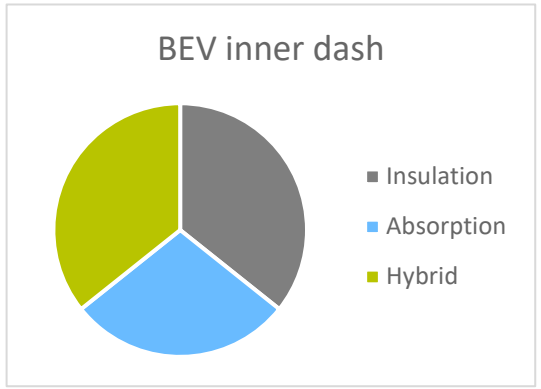
## Impact and key levers for improvement

# Scope 3: sustainable supply chain and design



# New acoustic products for BEVs

## Acoustic concepts vs sustainability

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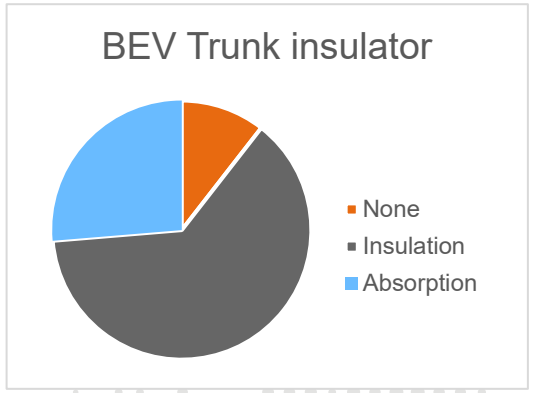
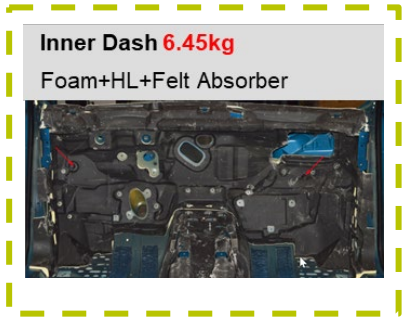
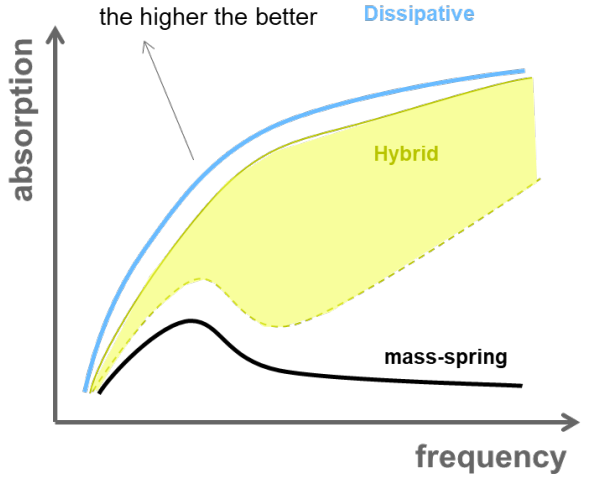
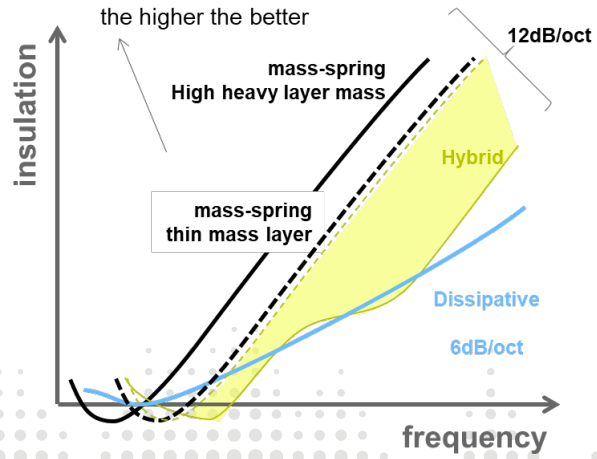
EU Market 2017-22

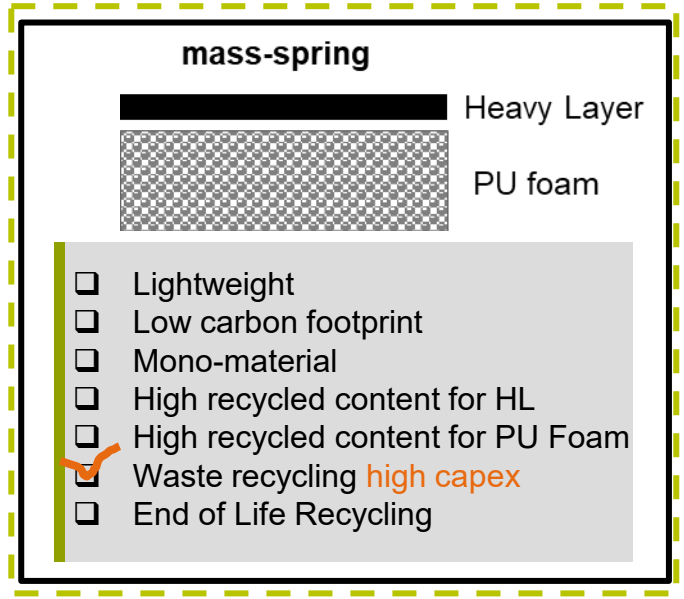


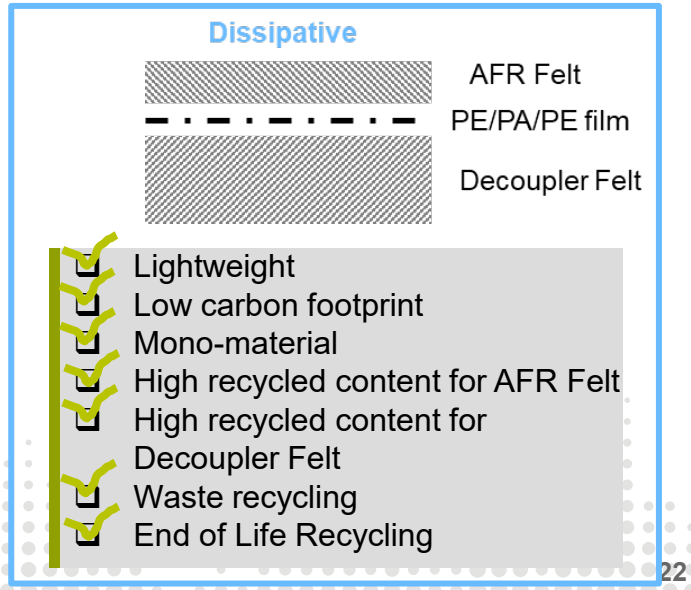







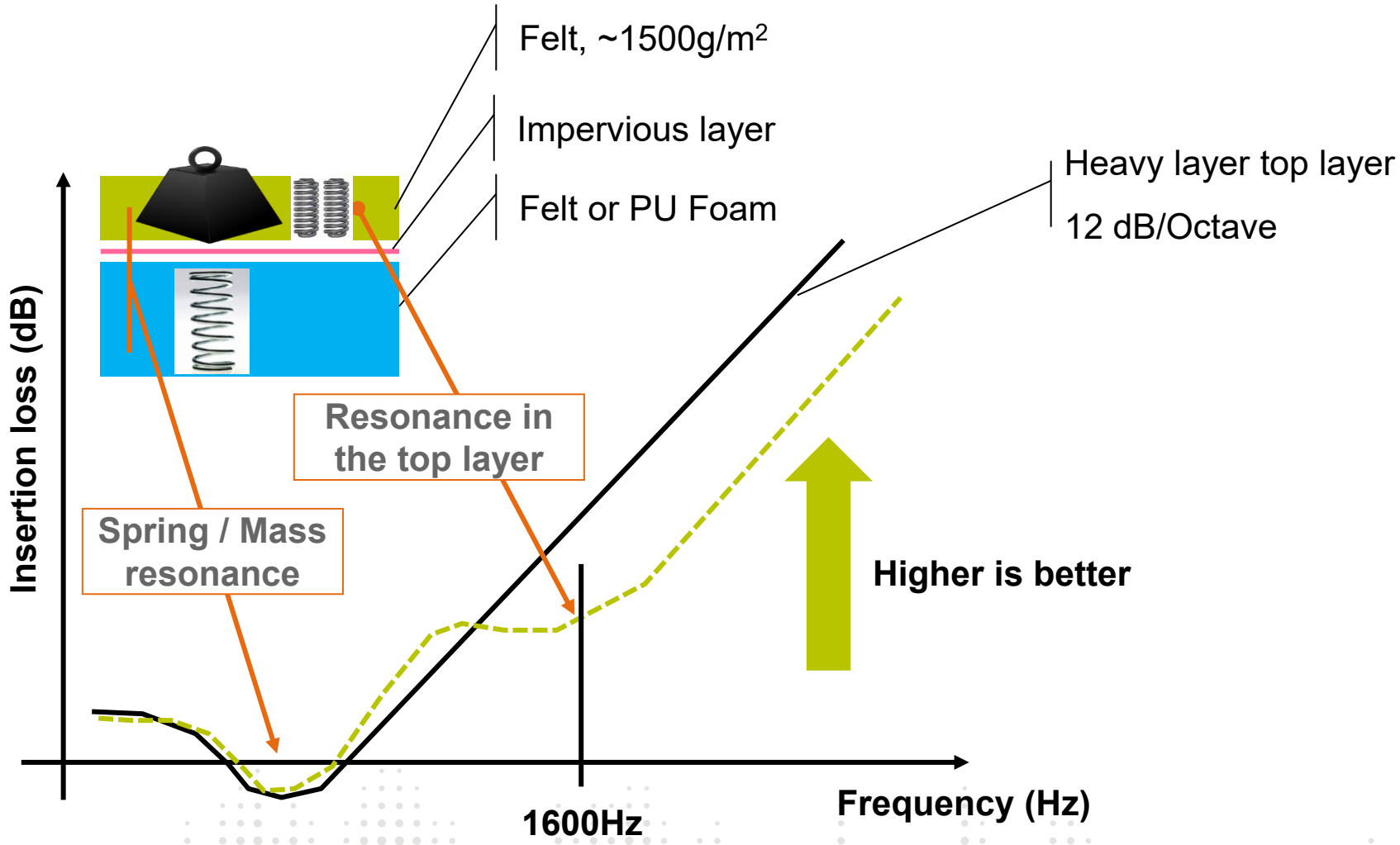



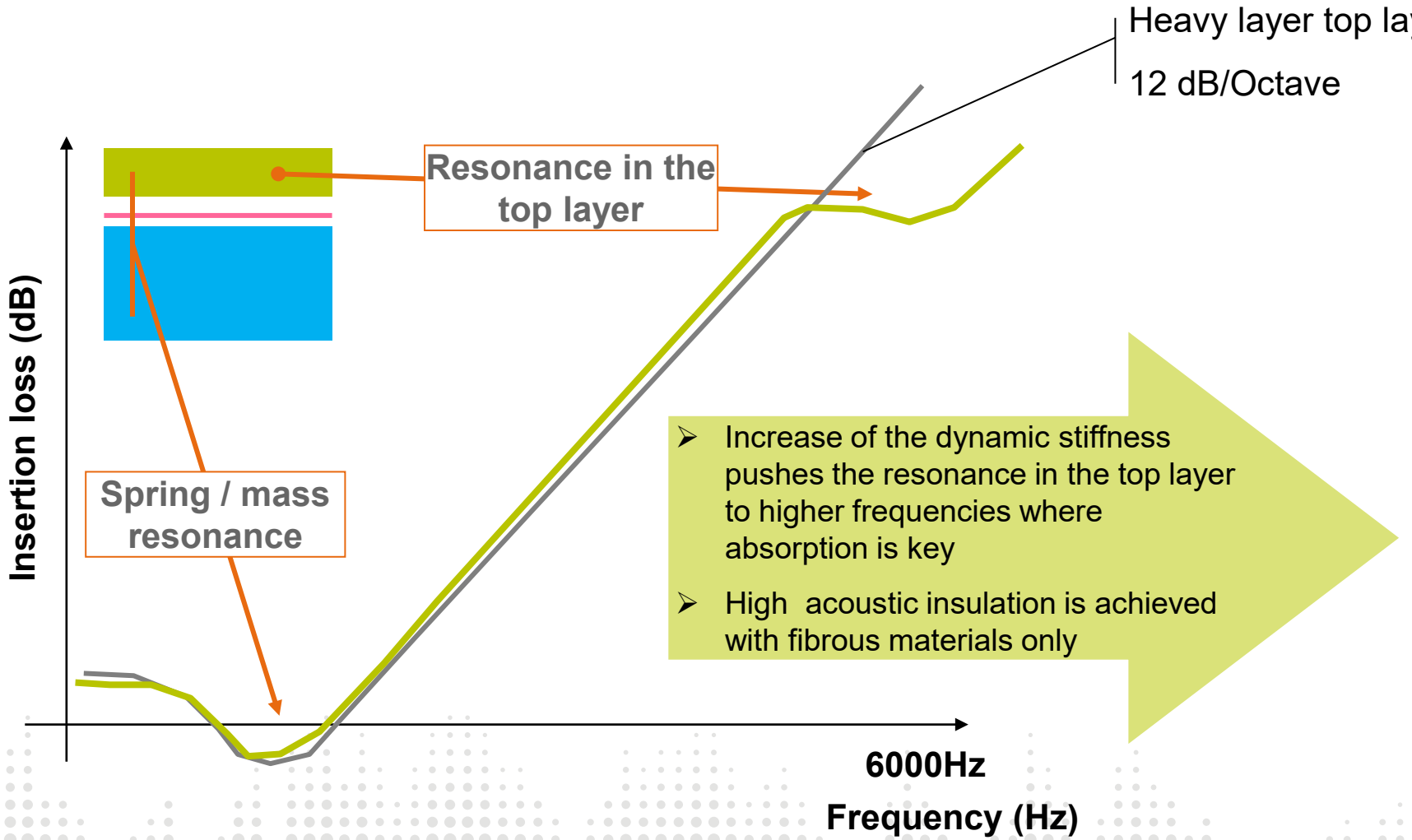



## New acoustic products for BEVs

# Typical lightweight construction acoustic insulation



# Autoneum innovation: Hybrid-Acoustics concept



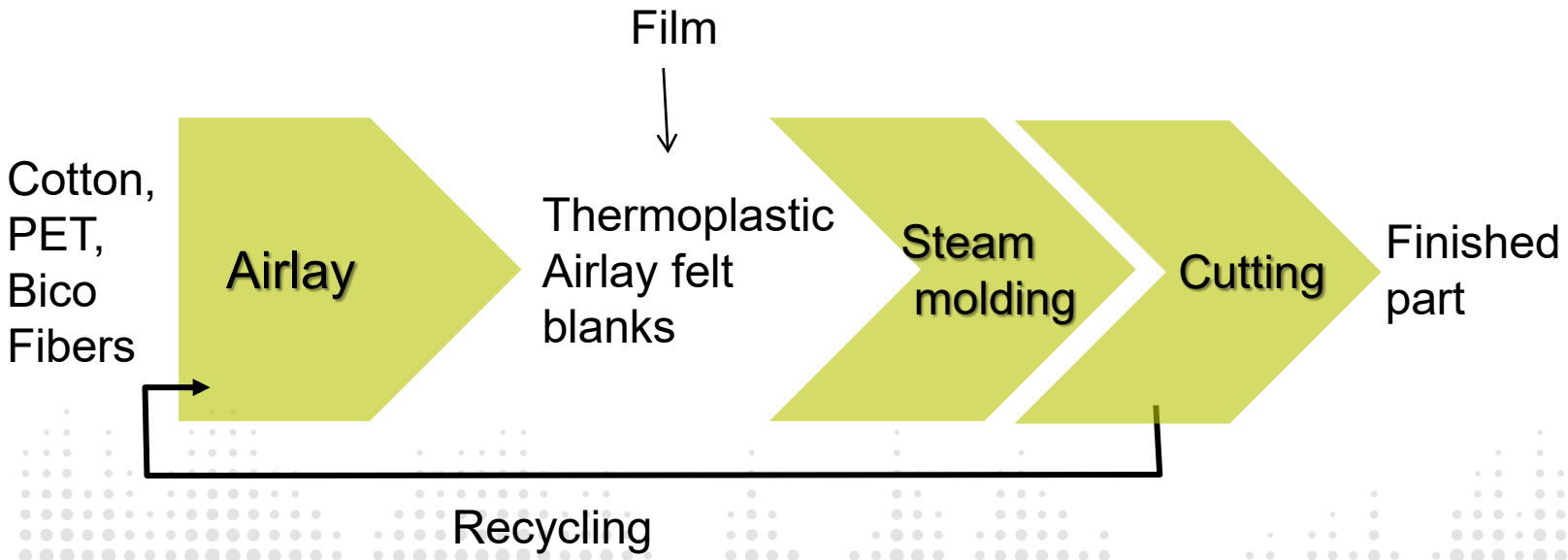
## New acoustic products for BEVs

# Hybrid-Acoustics ECO+ inner dash

A-Side:

B-Side

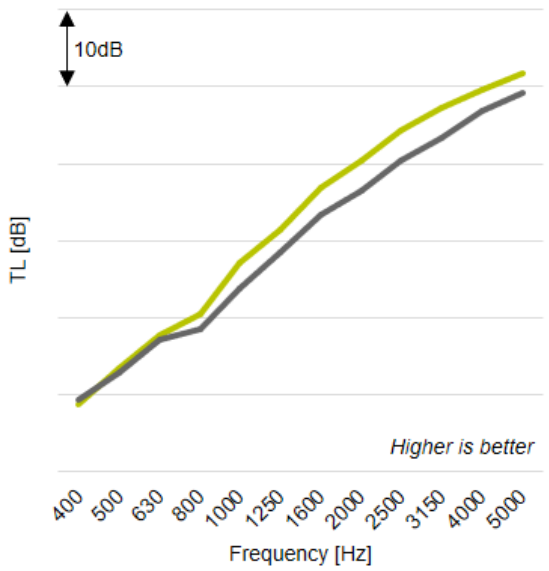
- ☑ High recycled content
- ☑ Thermoplastic material
- ☑ Low carbon footprint
- ☑ Mono-material
- ☑ Waste recycling
- ☑ Lightweight
- ☑ End of Life Recycling



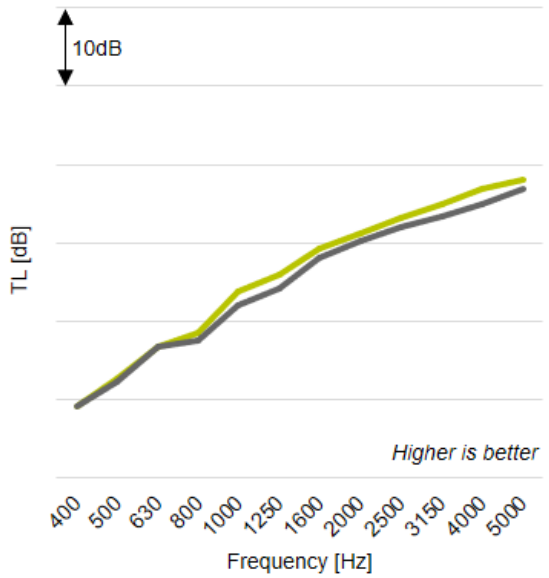
## New acoustic products for BEVs

# Hybrid-Acoustics ECO+ inner dash

**Sound insulation testing in all sealed condition**



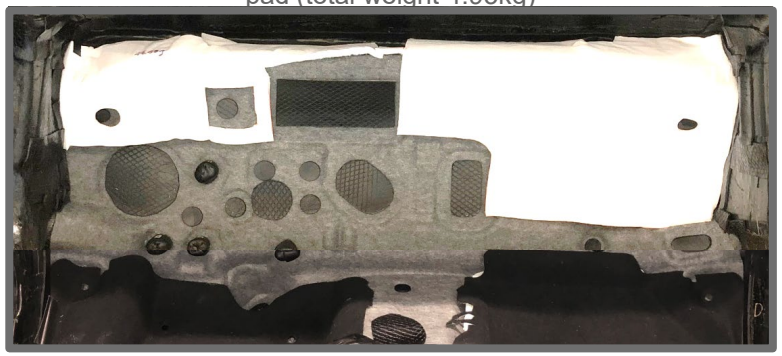

**Sound insulation testing in vehicle condition (incl. pass-throughs, HVAC, IP, etc.)**




Hybrid-Acoustics ECO+ 1500 / 1100 g/m2 (reference)
HL 2.0kg/m2 + PUR 60kg/m3 + PET 400g/m2 noise-absorbing pad

**Hybrid-Acoustics ECO+**
DSL 1500g/m2 + foil + felt 1100g/m2 (total weight 4.02kg)

**Heavy Layer + PU Foam**
HL 2.0kg/m2 + PUR 60kg/m3 + PET 400g/m2 noise-absorbing pad (total weight 4.95kg)

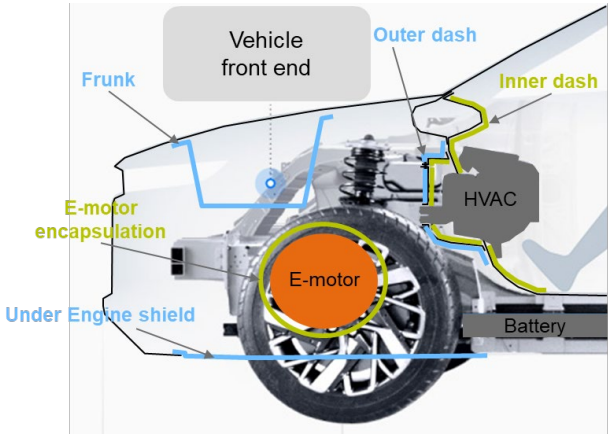


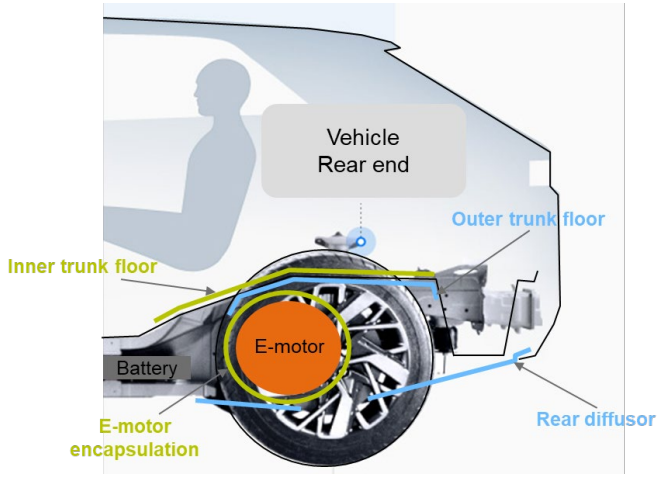
- The Hybrid-Acoustics ECO+ inner dash delivers higher performance than the HL-based inner dash, 20% weight reduction and is more sustainable
- Hybrid-Acoustics ECO+ technology is also applied to trunk floor inner and wheelhouse inner insulators of BEVs

# Acoustic products & engineering for BEVs

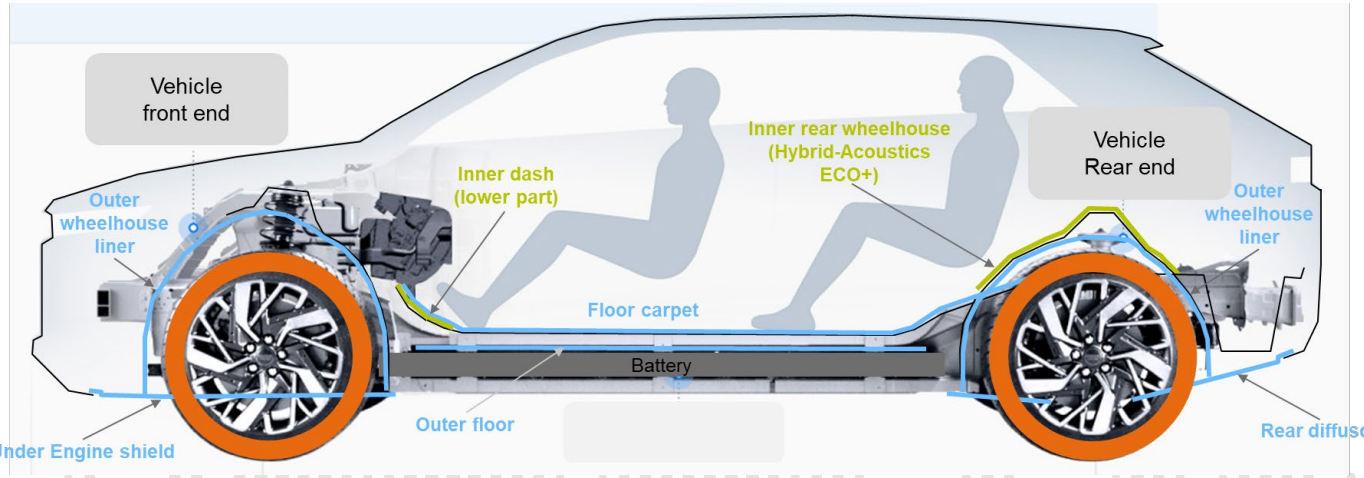
## E-powertrain and Rolling noise - Autoneum countermeasures

E-powertrain Noise




Rolling Noise



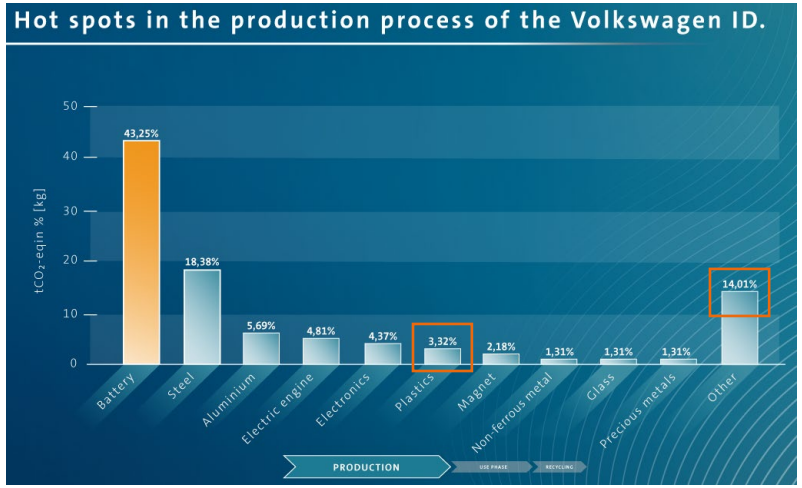

Hybrid layer
Absorbing layer

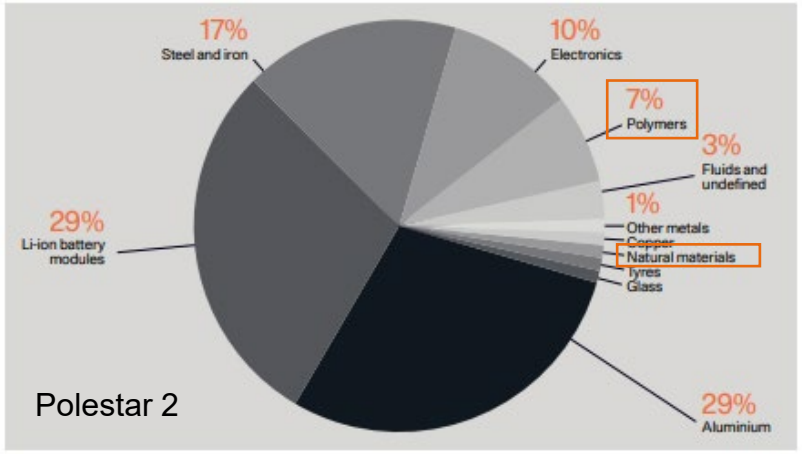
# Sustainability: driver for new mobility transformation

# Outlook

## Carbon Neutrality: the long path of vehicle carbon footprint reduction

*Source: From the well to the wheel. VW Website*



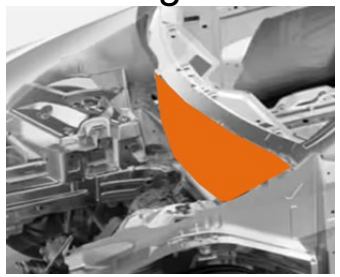




*Source: Life cycle assessment, Carbon footprint of Polestar 2 - Polestar Website*

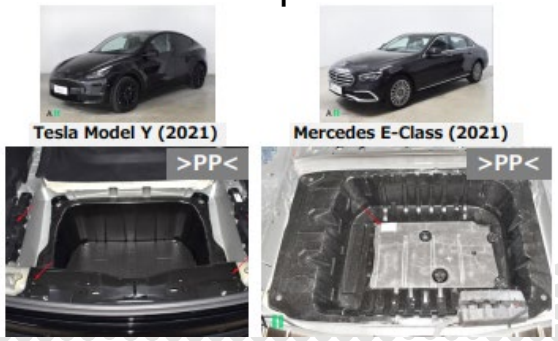
## Reduction of weight and of metals with high emission factor

Cell to Structure Battery Layout:

Injection molding Dash Panel:

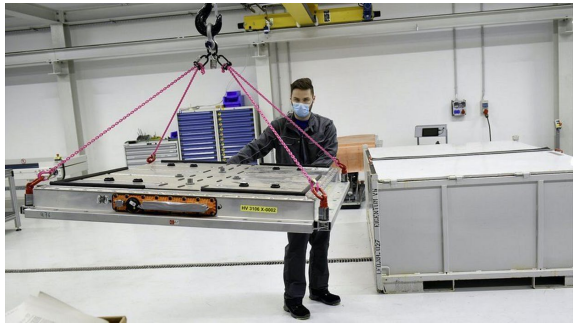


Rear Trunk floor panel in Plastic:




## Incoming ELV (2023) on Vehicle and Batteries:

Opportunity for Interior NVH to be dismantled and recycled:



Challenges in Functions & accessories integration:

- Strong eco-design rules for easy material separation
- Mono-Material Constructions

# Agenda

Autoneum at a glance

New BEV architecture and acoustic performance trends

Sustainable products for BEVs

Key takeaways

# Sustainable acoustic treatment for electric cars

## Key takeaways

| | |
|---|---|
| **New BEV platform** | Flatter floor and presence of a rear e-motor in 85% of the BEVs. Acoustics is strongly impacted by HVAC interface with dash, battery integration strategy and vehicle rear end design. |
| **Acoustic sources** | Low powertrain noise levels vs ICEs but with prominent medium to high frequency tonal noises. Rolling noise is more critical on BEVs due to vehicle weight, tire width and emphasis on rolling resistance reduction over acoustics. |
| **NVH treatment** | Autoneum benchmarking analysis shows that best-in-class BEVs have an improved sound package in the trunk aiming at reduction of both tire and rear e-powertrain noises. |
| **Sustainability** | Sustainable interior NVH solutions require lightweight, thermoplastic, recycled, and mono-material or easy to separate constructions. Hybrid-Acoustics concept supports this engineering paradigm. |
| **Outlook** | Sustainability requirements are enhanced with electrification: this will dictate further evolutions of NVH solutions in the direction of mono-material solutions, whose base materials shall be available in large quantities both in virgin and recycled versions |

Autoneum. Mastering sound and heat.