Global Emission Scenarios & Future PassCar Powertrain Trends

Waseda Symposium
November 11, 2021

Dr. Guenter FRAIDL

The Automotive World is Changing

Much quicker than we have assumed in the past

CORONA
Acts as fire accelerator for the Technology Transformation

Financial impacts → OEM change from Technology Diversification towards BEV Focus

Flashlight on PassCar Global Trends*)

- **Clear intent to become environmental leader ("Green Deal", "Fit for 55"), focus on Tank to Wheel CO_2, e-fuels not focus for PassCar**
- **Political Dogma to push BEV by CO_2 legislation (-55% by 2030, -100% by 2035)**
- **Pollutants - EU7: from irrational 1st CLOVE proposal towards more realistic approach, but NGO´s push for lower limits**

- **Official focus on electrification, however balancing environmental aspects with economy ➔ both BEV+HEV**
- **Enormous technology catch-up and targeting technology leadership**
- **Still various new ICE under development - DHE**) and DHT***)**
- **New push for H_2 ICE**

- **Environmental policy is completely changing both regarding ICE and electromobility**
- **From ignoring environ-mental aspects towards overemphasize BEV**
- **Political intention towards electromobility to be matched with infrastructure and customer challenges**

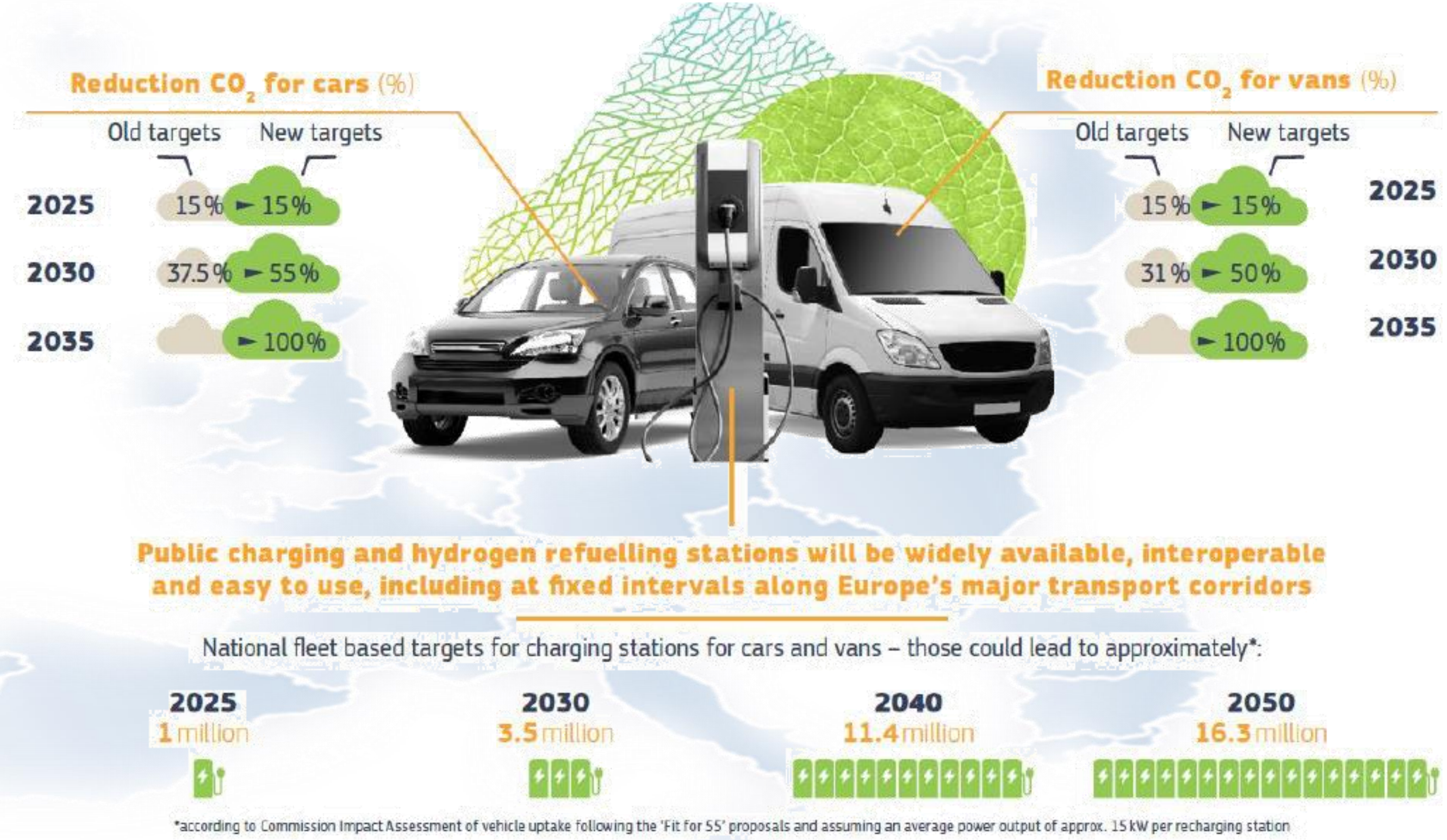
*) European Perspective, **) Dedicated Hybrid Engines, ***) Dedicated Hybrid Transmissions

Different political priorities – Europe on economically risky path

Make Transport Greener (07/2021)
Current Situation in Europe – **Fit for 55**

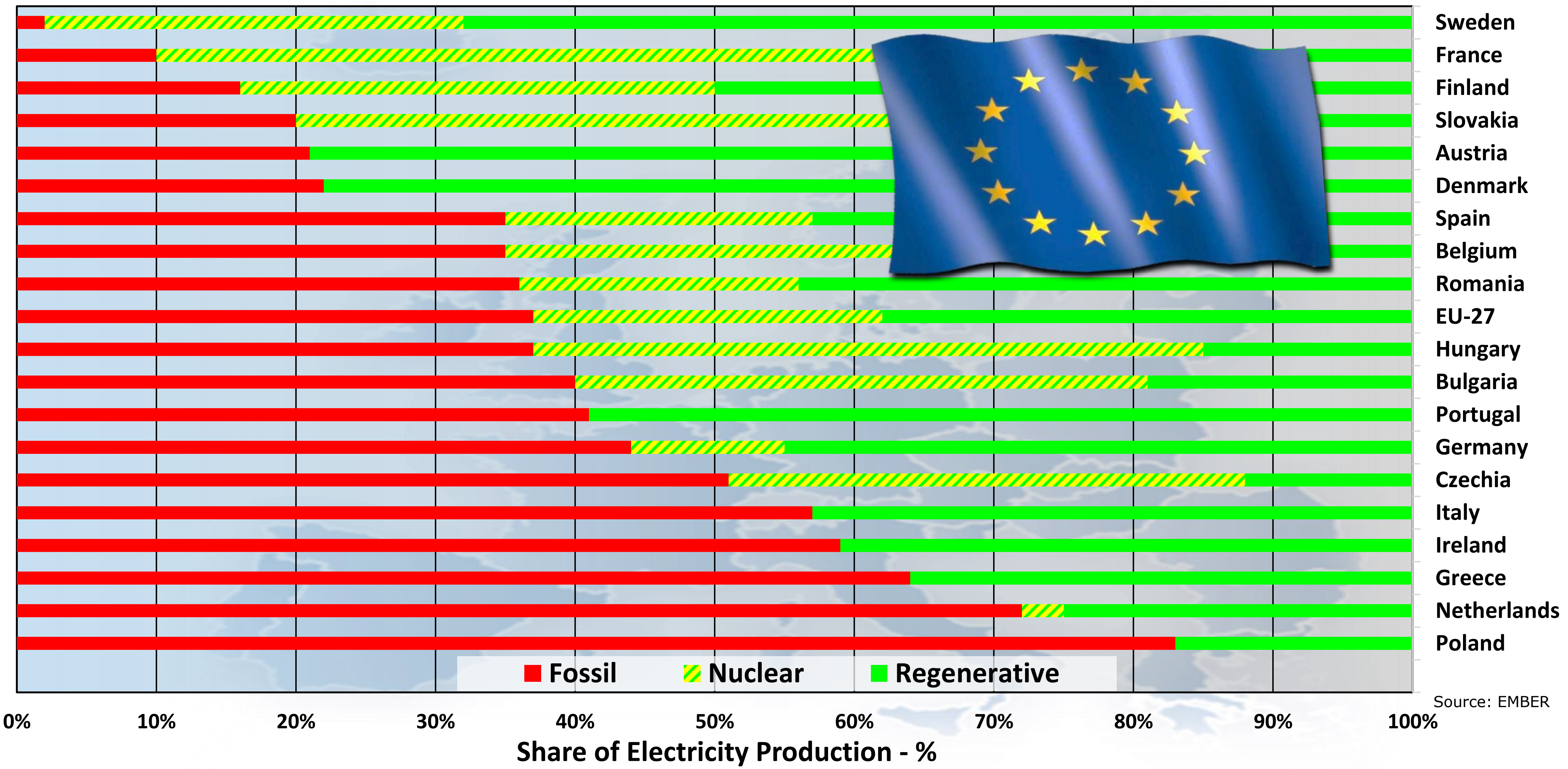
More ambitious CO_2 emissions standards for new cars and vans to help grow the number of zero- and low-emission vehicles on European roads.

Binding requirements for the rollout of public charging and hydrogen refuelling stations for cars, vans and trucks.

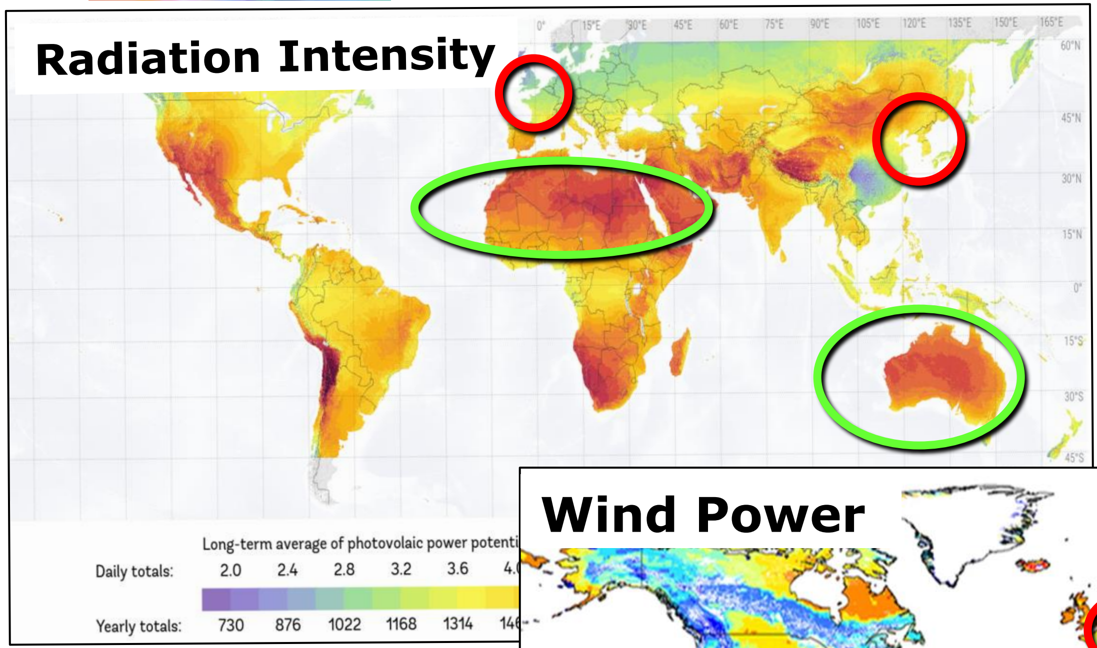


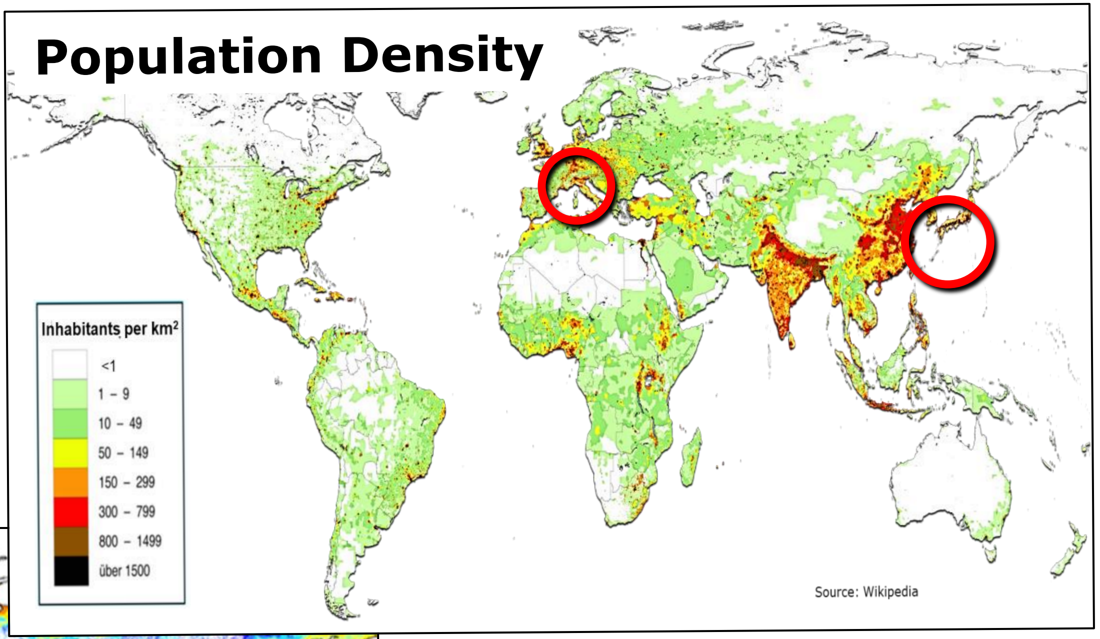
Source: Make Transport Greener Factsheet, European Commission, 14.07.2021

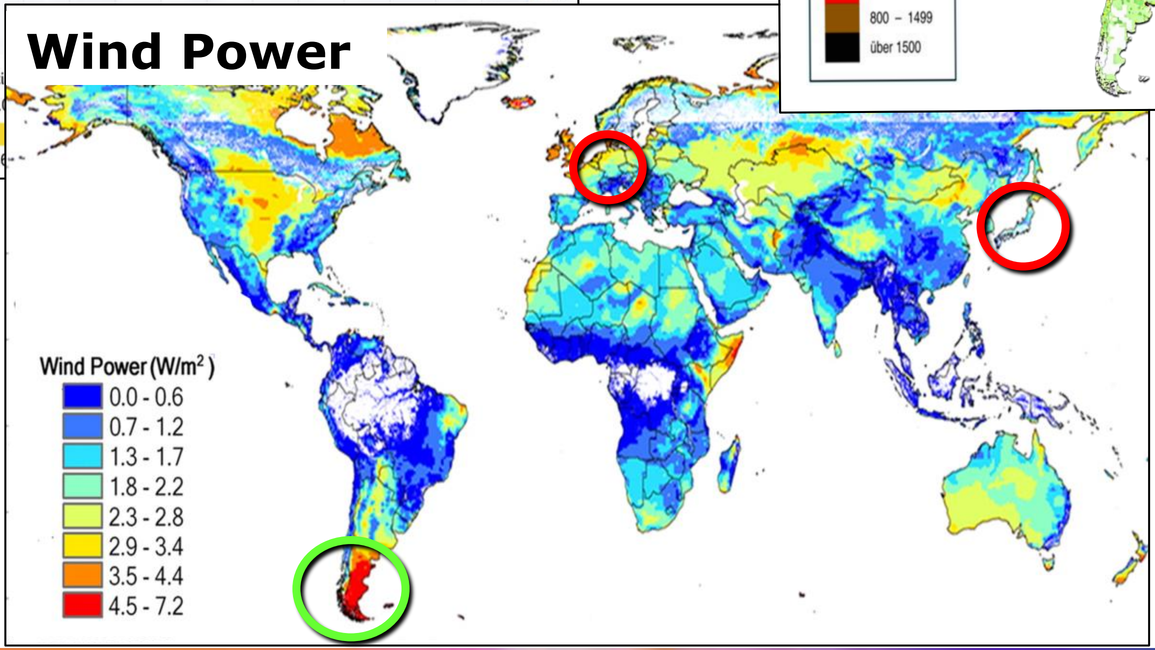
Primary Energy Scenario EUROPE



Prerequisites for Efficient Regenerative Energy Production







Neither Europe nor Japan offer favorable boundaries for regenerative energy production ➔ Import of green energy requires chemical energy carriers

Political Challenge of Synthetic Fuels – EUROPE

Political View

Inefficient option to elongate ICE life

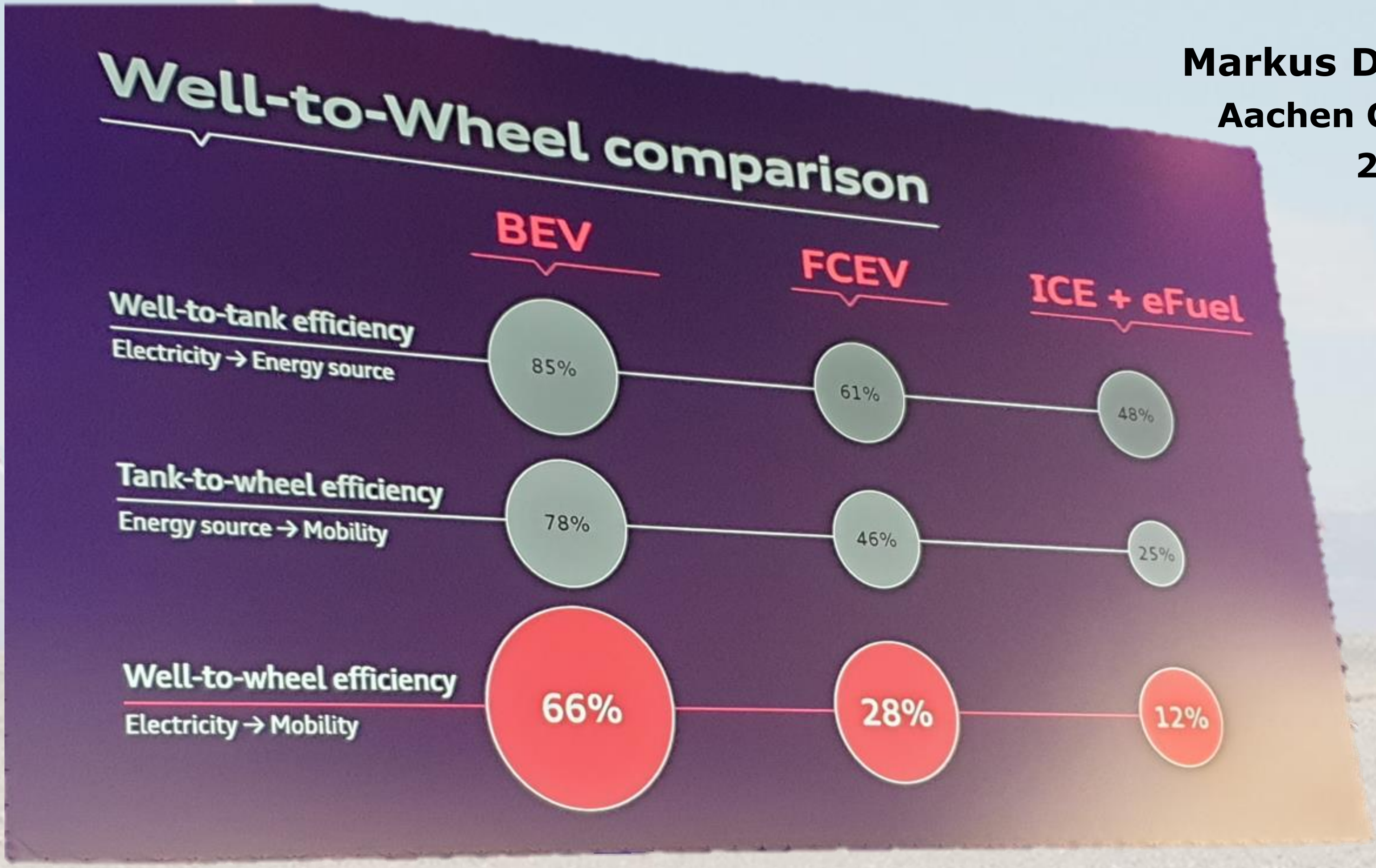
Competing with BEV only strategy

Technical Fact

Integral Part of Fully Regenerative Energy Scenario enabling access to renewable energy sources outside EU and large-scale storage of energy

Importance of e-Fuels to meet Paris Agreement not recognized neither by European, esp. German politics nor by public opinion
Announcements of ICE-ban compromise investment decisions

Efficiency in Applying Renewable Energy - AUDI View



Markus Duesmann
Aachen Colloquium
2021-10-05

This represents a quite common "Political View" on e-fuels in Europe

Efficiency in Energy Conversion of Renewable Fuels Germany vs. Chile

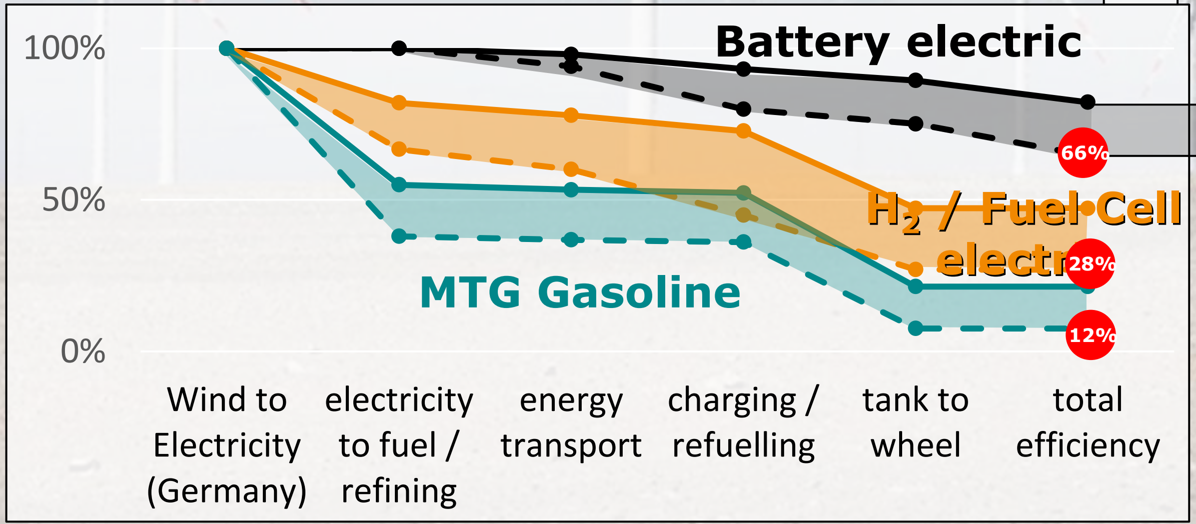
Both countries:

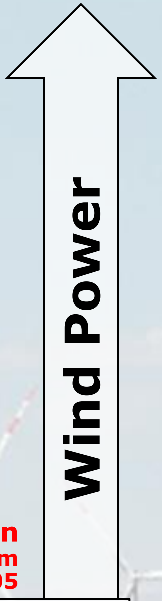
H_2 electrolysis efficiency: 67 – 82%

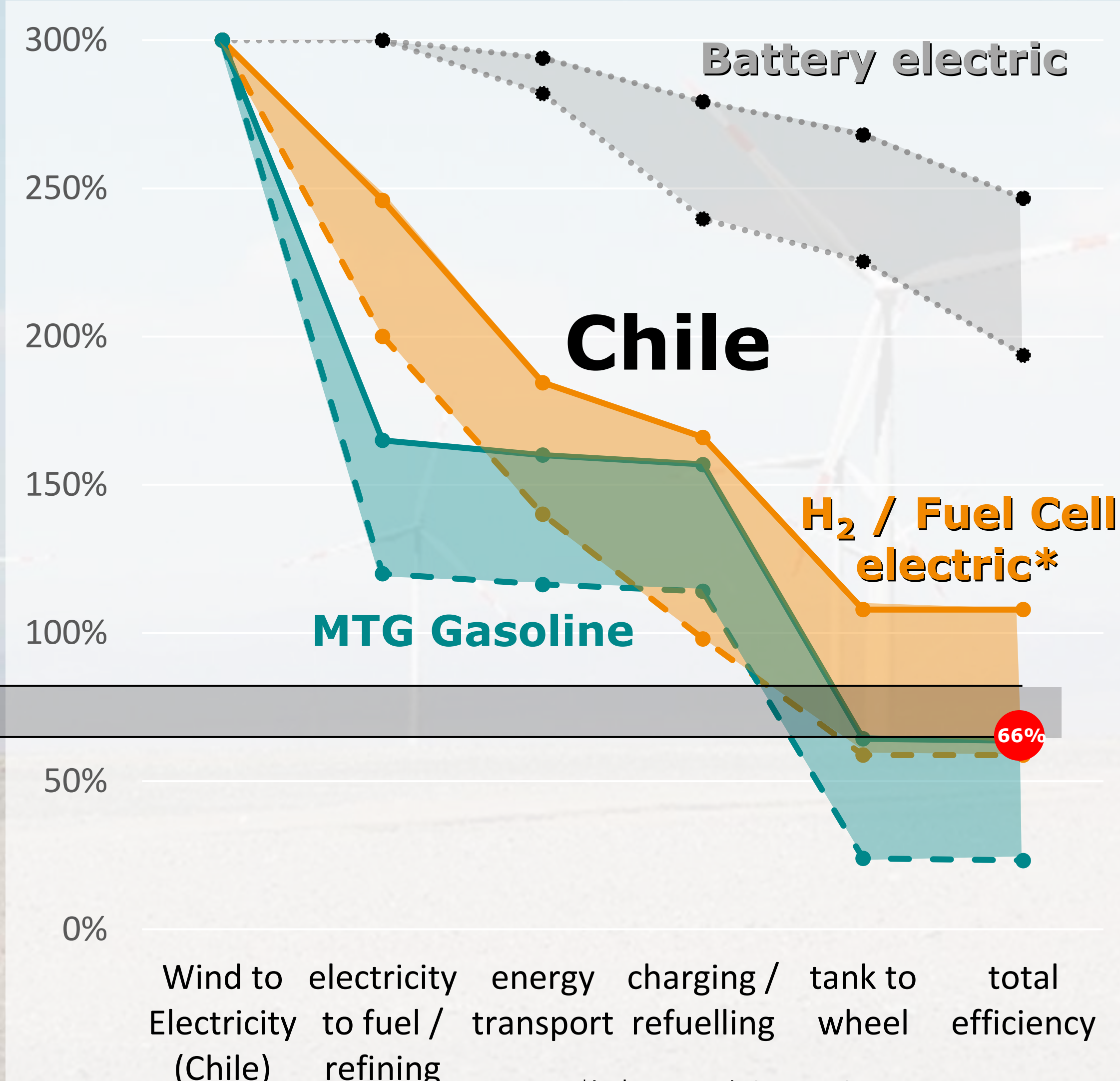
E-Fuel total process efficiency: 38 – 55%

Germany

Markus Duesmann
Aachen Colloquium
2021-10-05

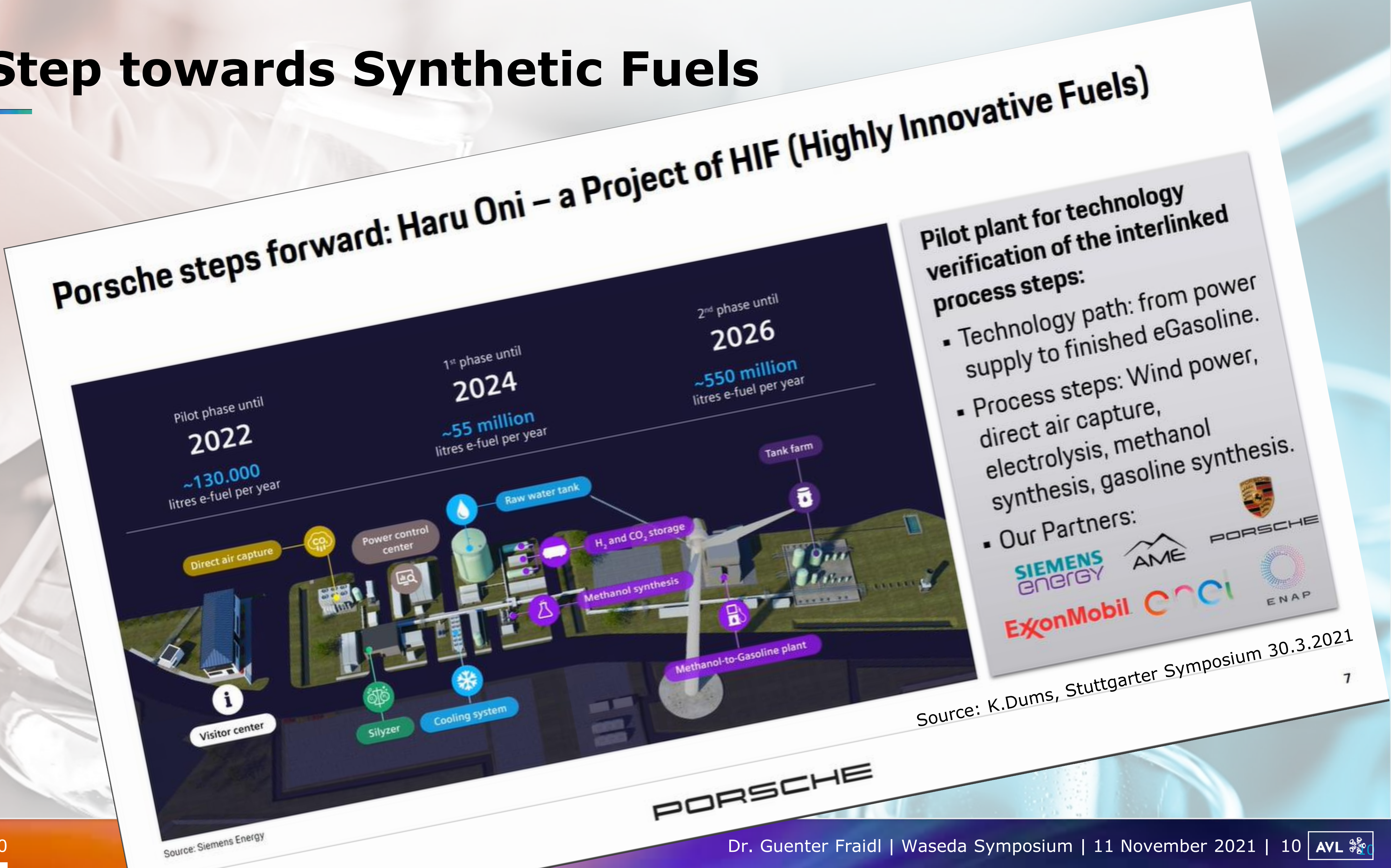






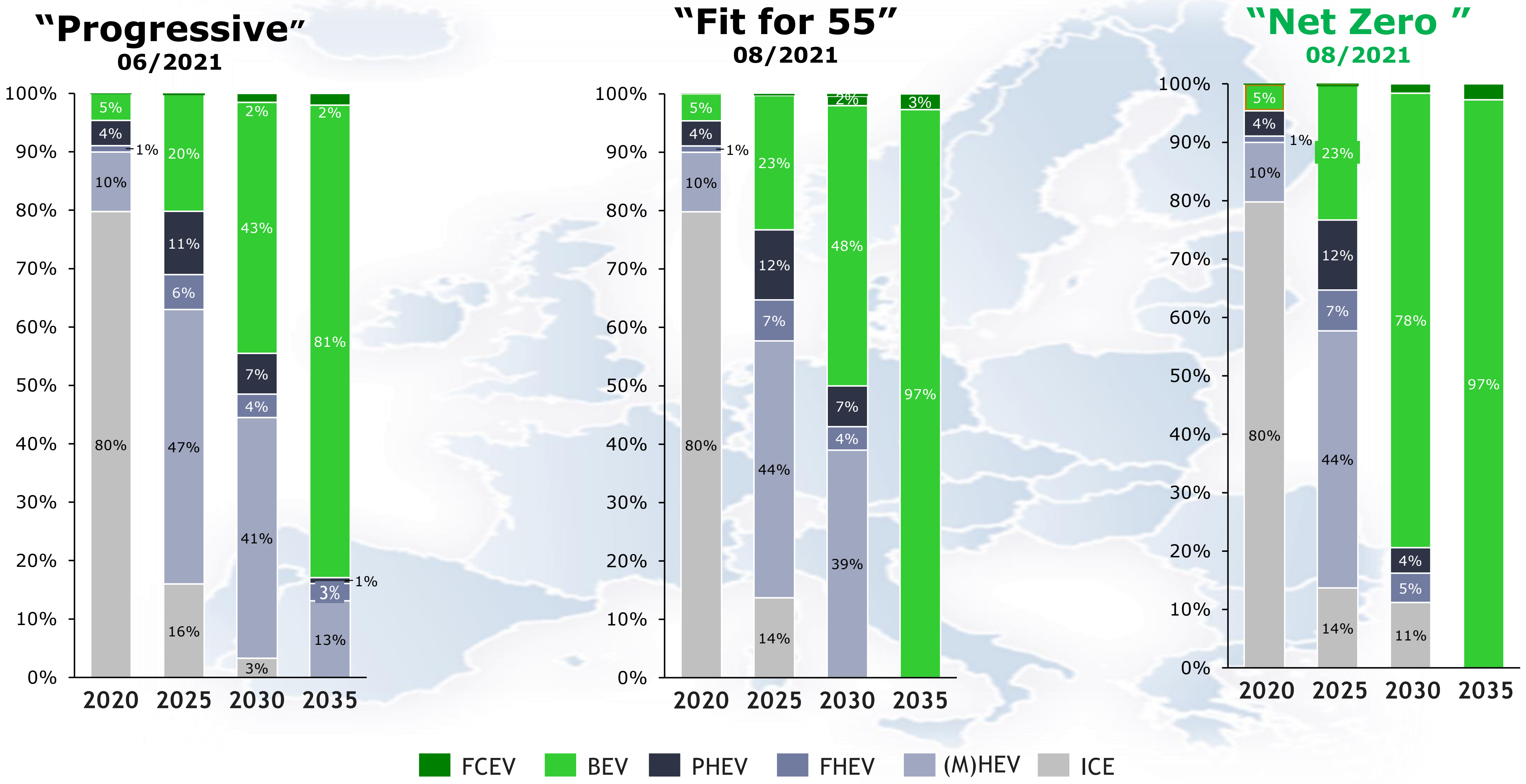
*incl. cryogenic transport

First Step towards Synthetic Fuels



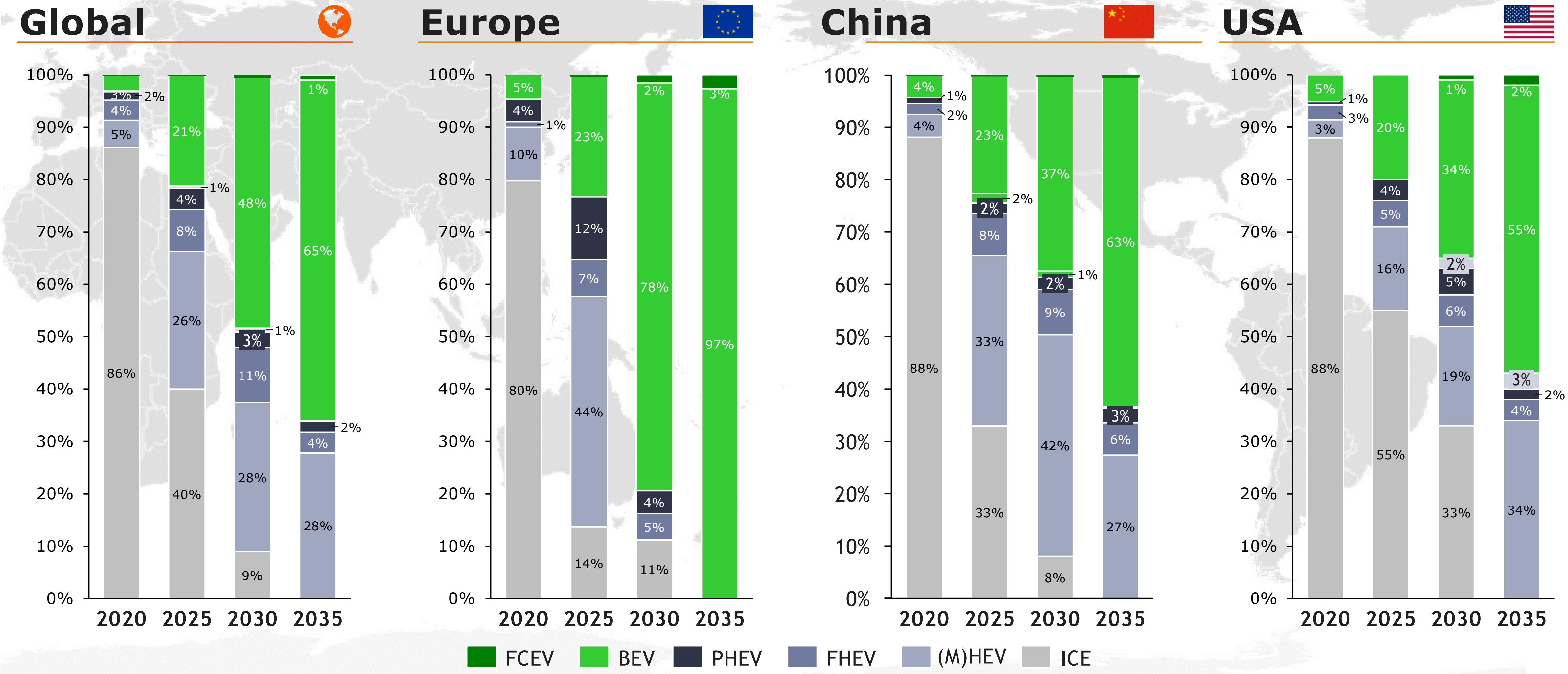
Source: K.Dums, Stuttgarter Symposium 30.3.2021

Technology Outlook EUROPE - Different Scenarios

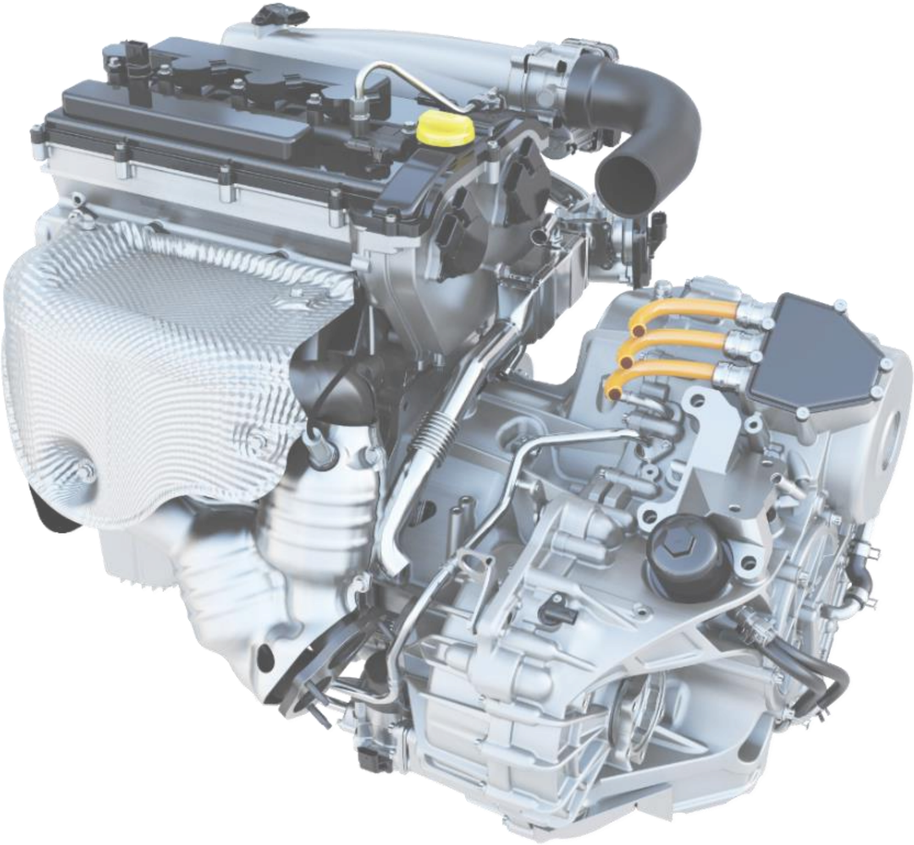


Net Zero Scenario – Regional Powertrain Split (08/2021)

Getting closer for "Net Zero" in 2050 would entail a steep ramp-up of BEV sales until 2035 – e.g. to close to 97 % in Europe

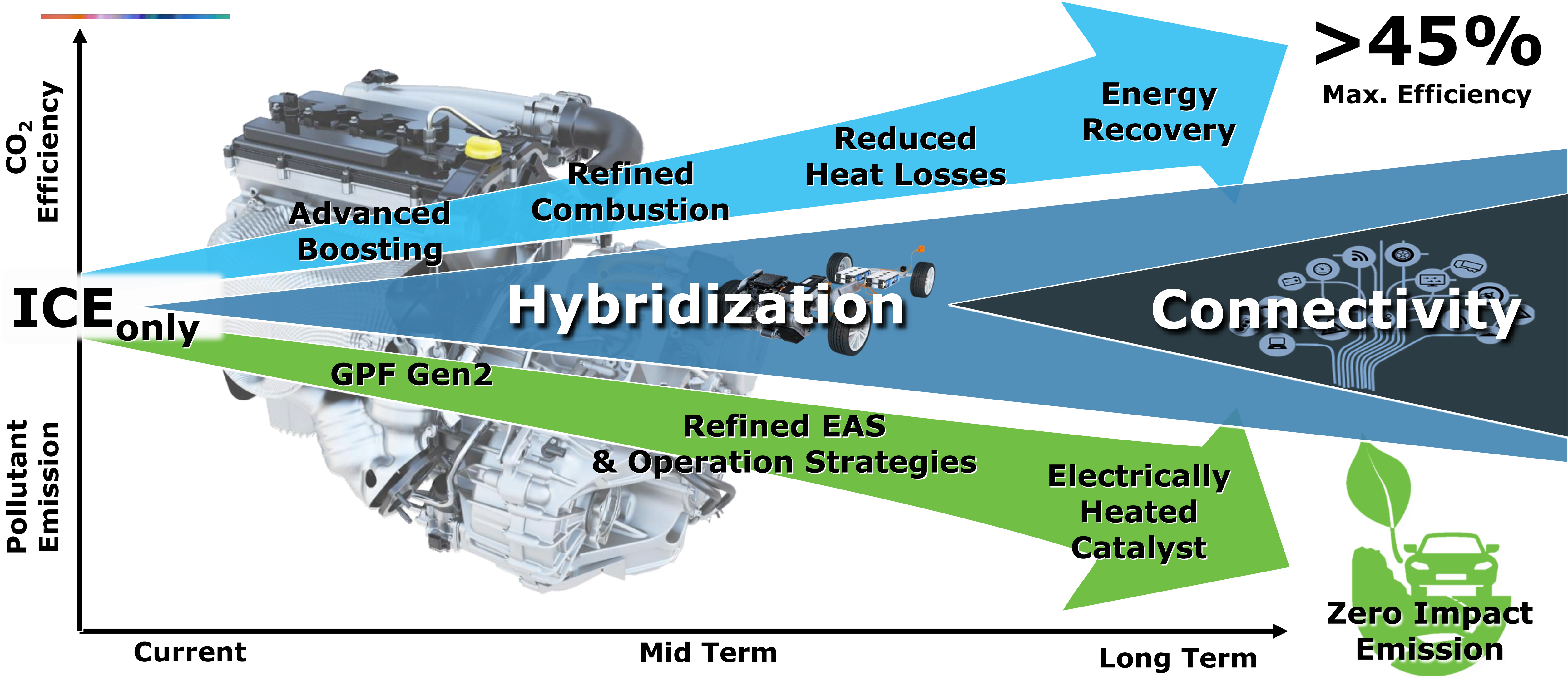


Technology Options

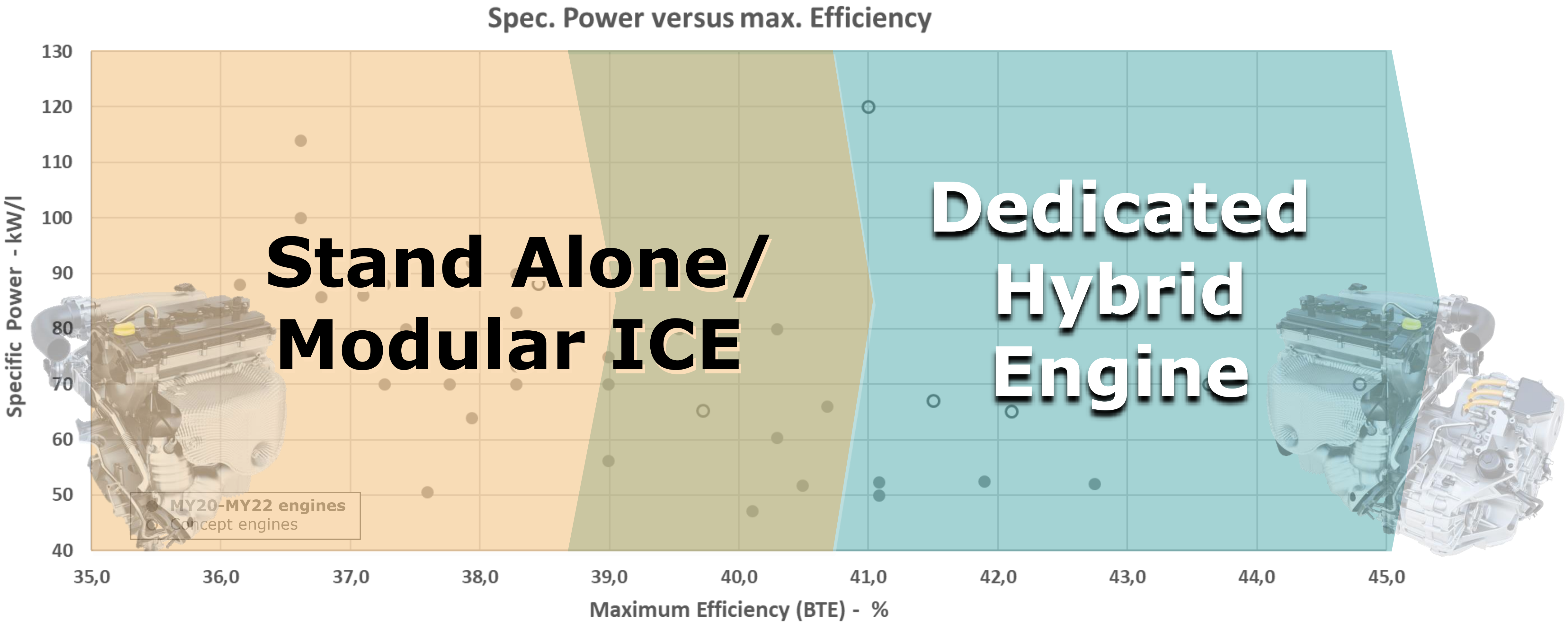


ICE/Hybrid

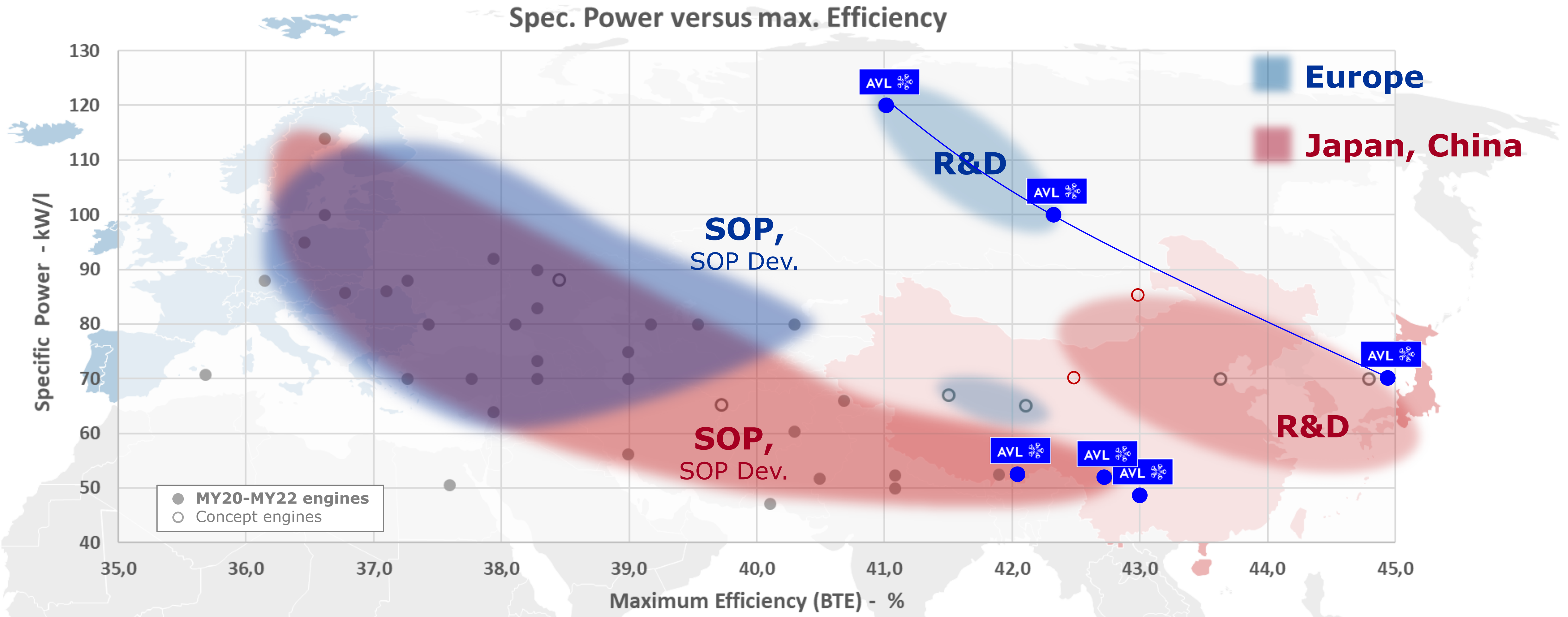
Transformation of the ICE



Gasoline Engine Development Trends
Performance vs. Efficiency



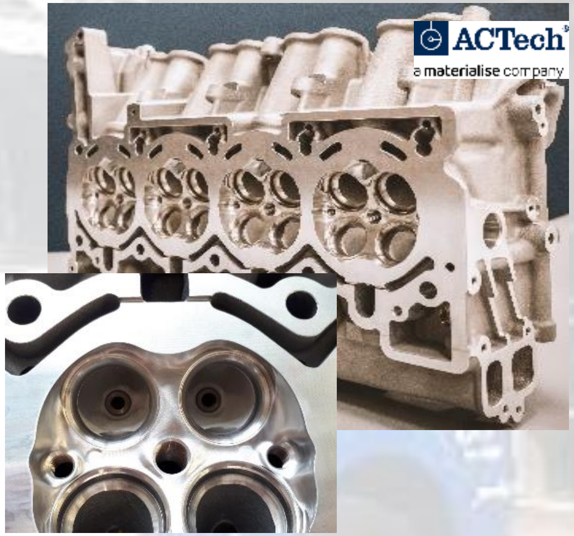
Gasoline Engine Development Trends
EUROPE versus ASIA



Europe is applying same base ICE´s both for stand alone and with Hybrid, Asia is adding new DHE`s

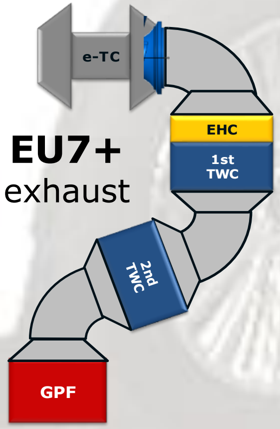
Series/Parallel PHEV Demo with DHE*) - 45% Peak Efficiency

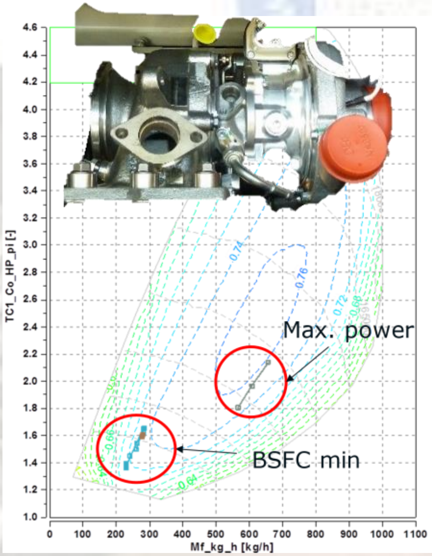
- 2,5l I4 TC; up to 70 kW/l
- Cooled coated exhaust manifold
- Compression ratio >16:1; polished piston crown
- New cylinder head with 3 spark concept
- Atkinson cycle
- Cooled LP EGR
- Friction reduction
- E-TC with optimized efficiency
- Engine min. BSFC <190 g/kWh
- HV battery; plug-in capability
- Series / parallel operation
- Zero Impact Emission exhaust system

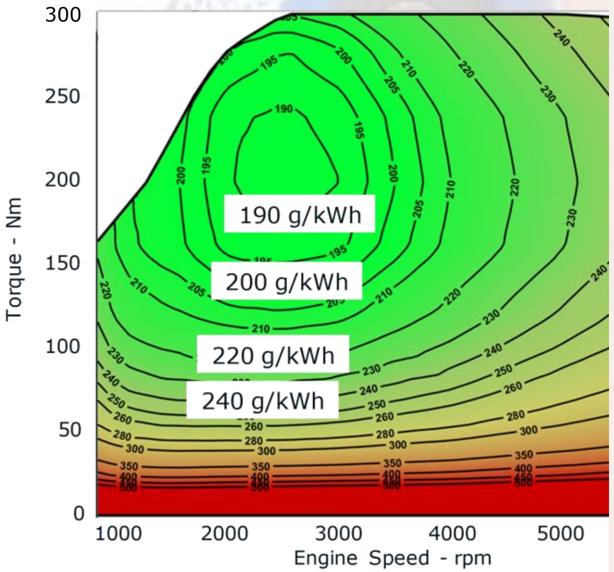


Freudenberg Sealing Technologies

Garrett ADVANCING MOTION

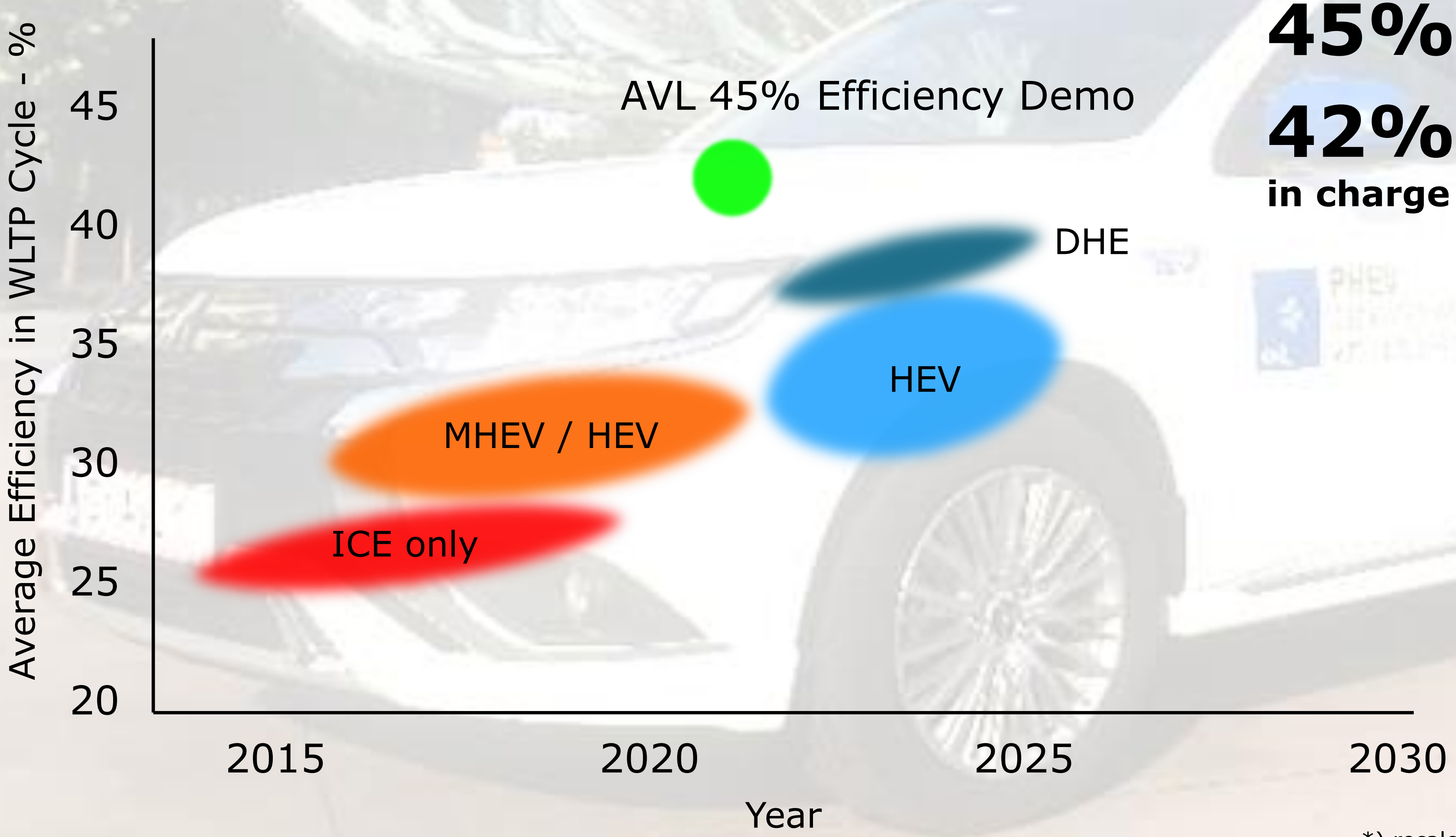






*) Dedicated Hybrid Engines

Dedicated Hybrid Engine - Average ICE Efficiency in WLTP



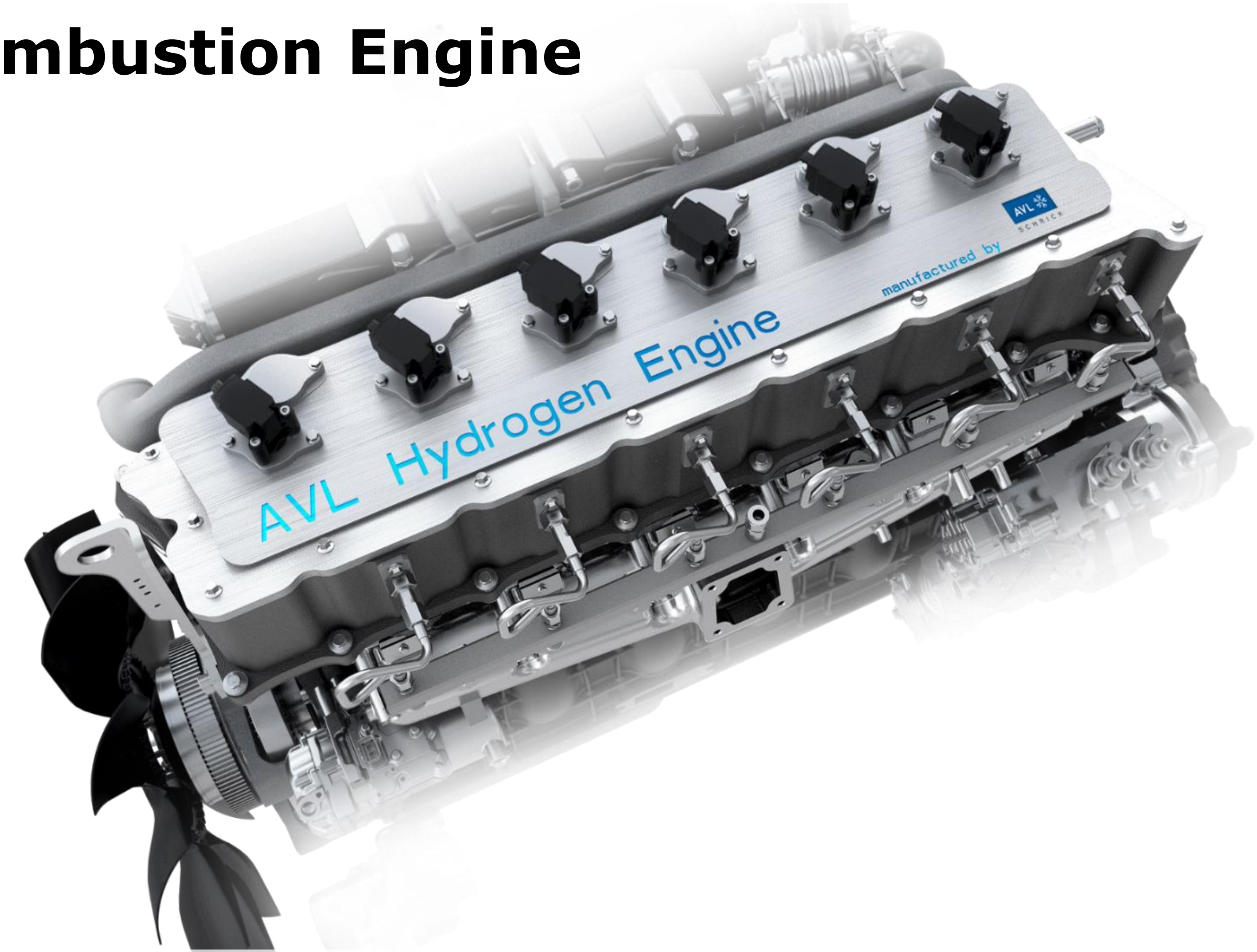
45% **max. efficiency**

42% **avg. in WLTP**

in charge sustaining mode*)

*) recalculated based on validated baseline simulation

Hydrogen Combustion Engine



H_2-ICE has started with commercial vehicles – proceeding with PassCars ?

Hydrogen Internal Combustion Engine

Current Global H_2-ICE activities: OEMs and Suppliers

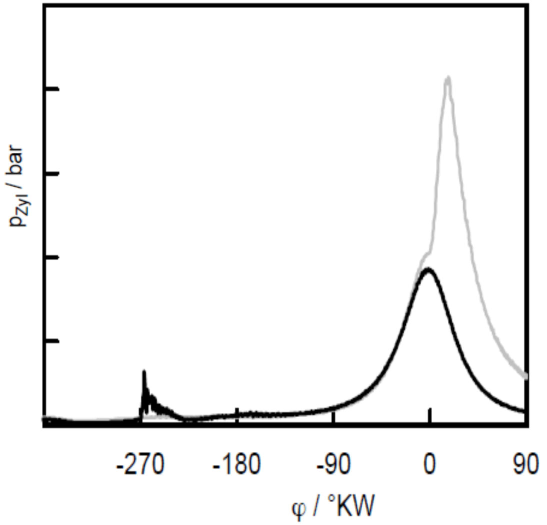
	US	Europe	India	China	Japan
PC H_2-ICE	No activities	Growing interest	No activities	Advanced projects	Advanced / Racing projects
Bus & Truck H_2-ICE	No major H_2-ICE activities	Global epicenter of H_2-ICE (11-13l engines) Fleet-CO_2 reduction as driver (-30% in 2030)	First H_2-ICE activities on OEM side ARAI starting to investigate H_2-ICE	Growing interest in H_2-ICE technology Still focus on CH_4/Methanol	As hydrogen is a major pillar in future energy policy strong interest in H_2-ICE
NRMM H_2-ICE	No activities	High interest	No activities	No activities	High interest

H_2-ICE has started with commercial vehicles – proceeding with PassCars ?

Hydrogen Internal Combustion Engine

H_2 Engine Operation Challenges

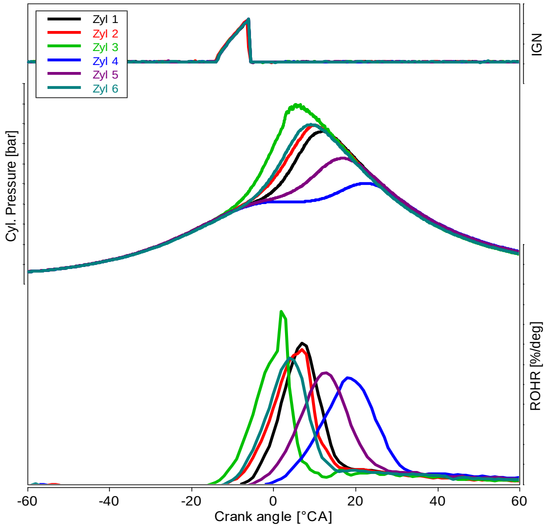
Backfire



Backfire into suction path

- inflammation during suction phase on hot sources
- occuring for PFI concepts

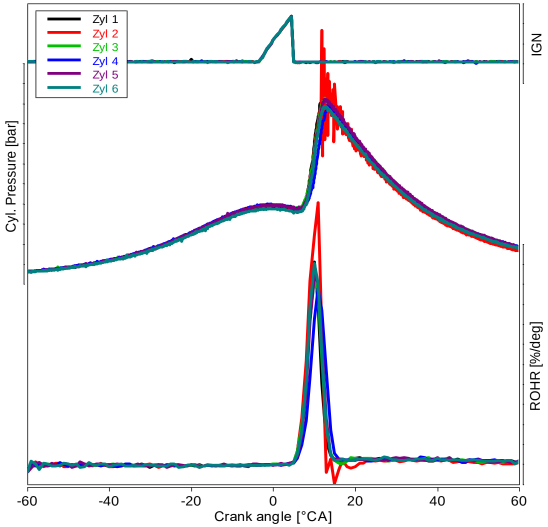
Pre-Ignition



Pre-Ignition

- H_2 molecule highly reactive
- weak ignition sources may serve sufficiently for IRC

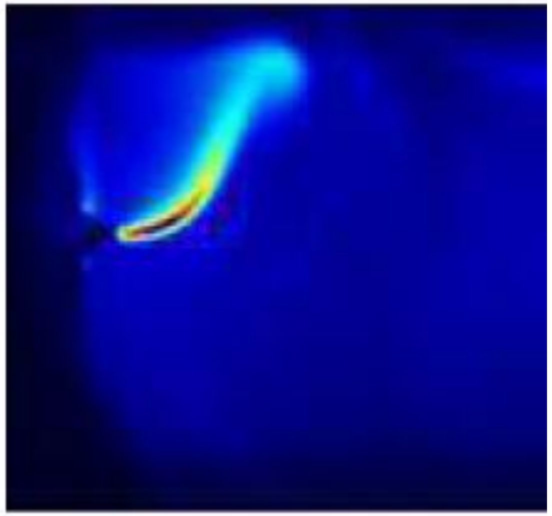
Knocking



Knock

- H_2 molecule highly reactive
- especially prone to knocking in stoichiometric conditions

DI Injector Leakage



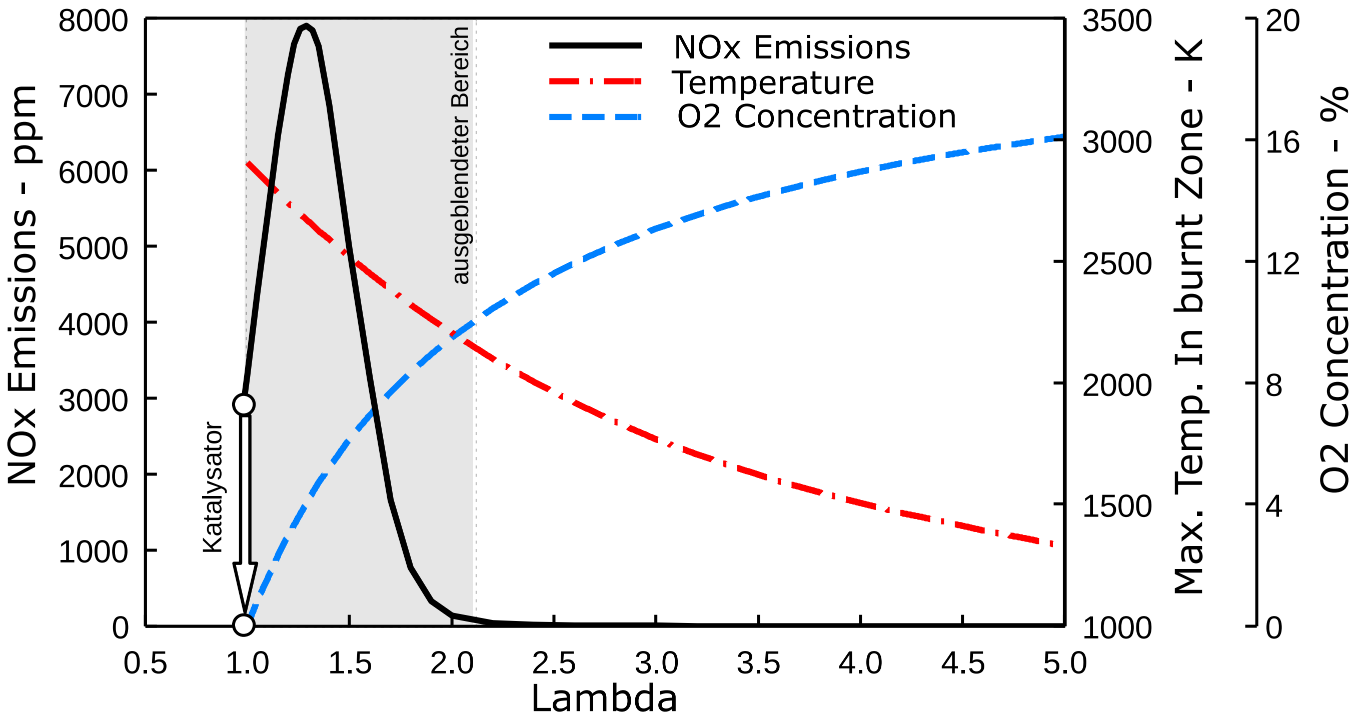
Hydrogen DI Injector Leakage

- small H_2 molecule
- no lubrication capability
- issue for DI inj. tightness/lifetime

Hydrogen Internal Combustion Engine

H_2 Engine Emission Behavior – Concept Idea with TWC only

- Example: Emission behavior of a H_2 ICE with external mixture formation
- No carbon based emissions except for lube oil origins (detection level)
- Noteworthy NO_x emissions at $1.0 \leq \lambda \leq 2.1$ → operation strategy that avoids this area

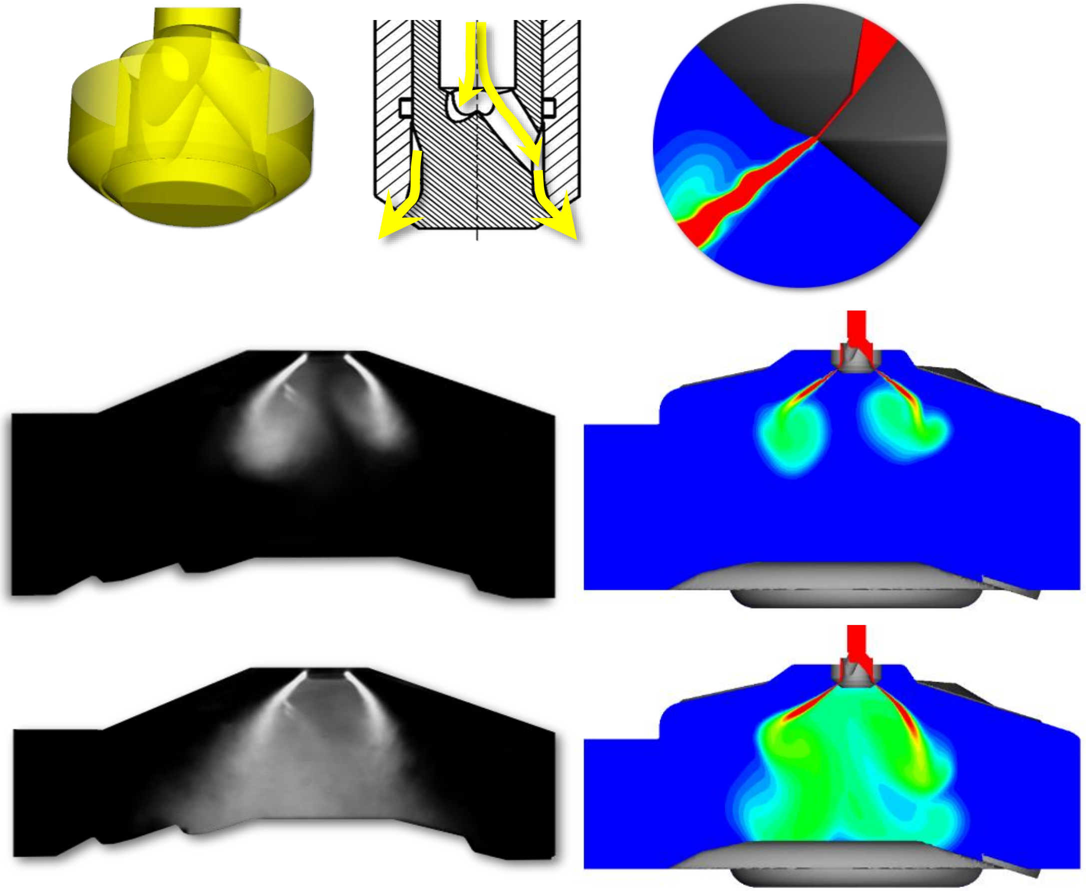


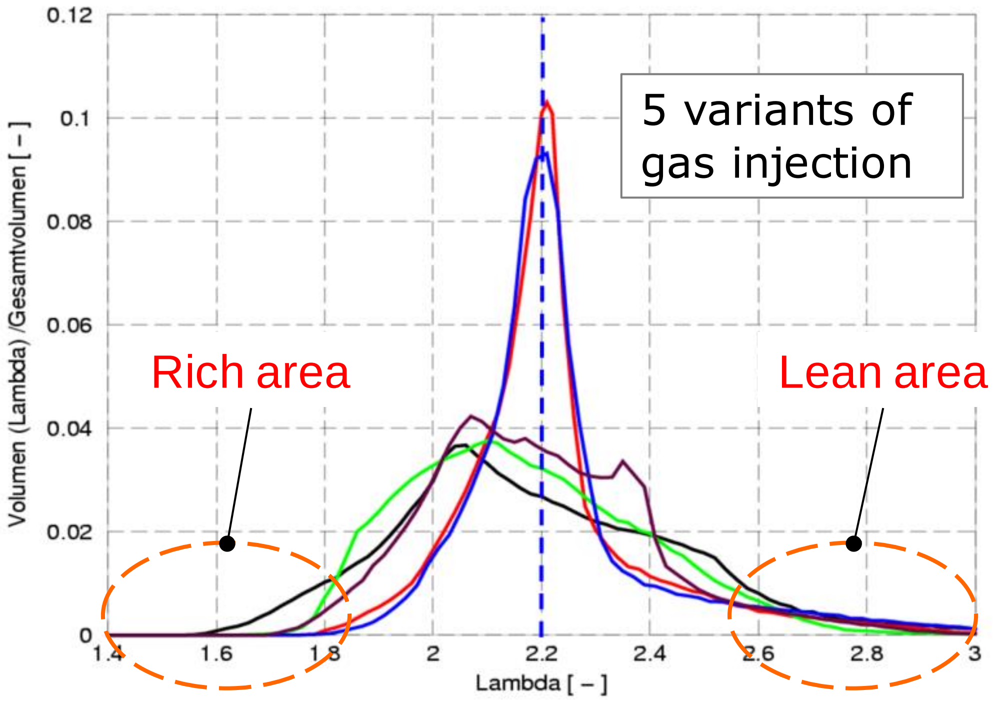
- ➔ Lean operation at part load (no NO_x-formation with lambda > 2)
- ➔ Switching to lambda = 1.0 at higher loads (conventional TWC after-treatment possible)
- ➔ could help avoid additional NO_x after-treatment
- ➔ Potential to meet SULEV emission standard

Source: Eichlseder, H.; Klell, M.: „Wasserstoff in der Fahrzeugtechnik – Erzeugung, Speicherung, Anwendung“, ISBN 978-3-8348-0478-5, Vieweg+Teubner, 2008

Hydrogen Internal Combustion Engine

Example: CFD Simulation of Mixture Preparation with H_2 DI

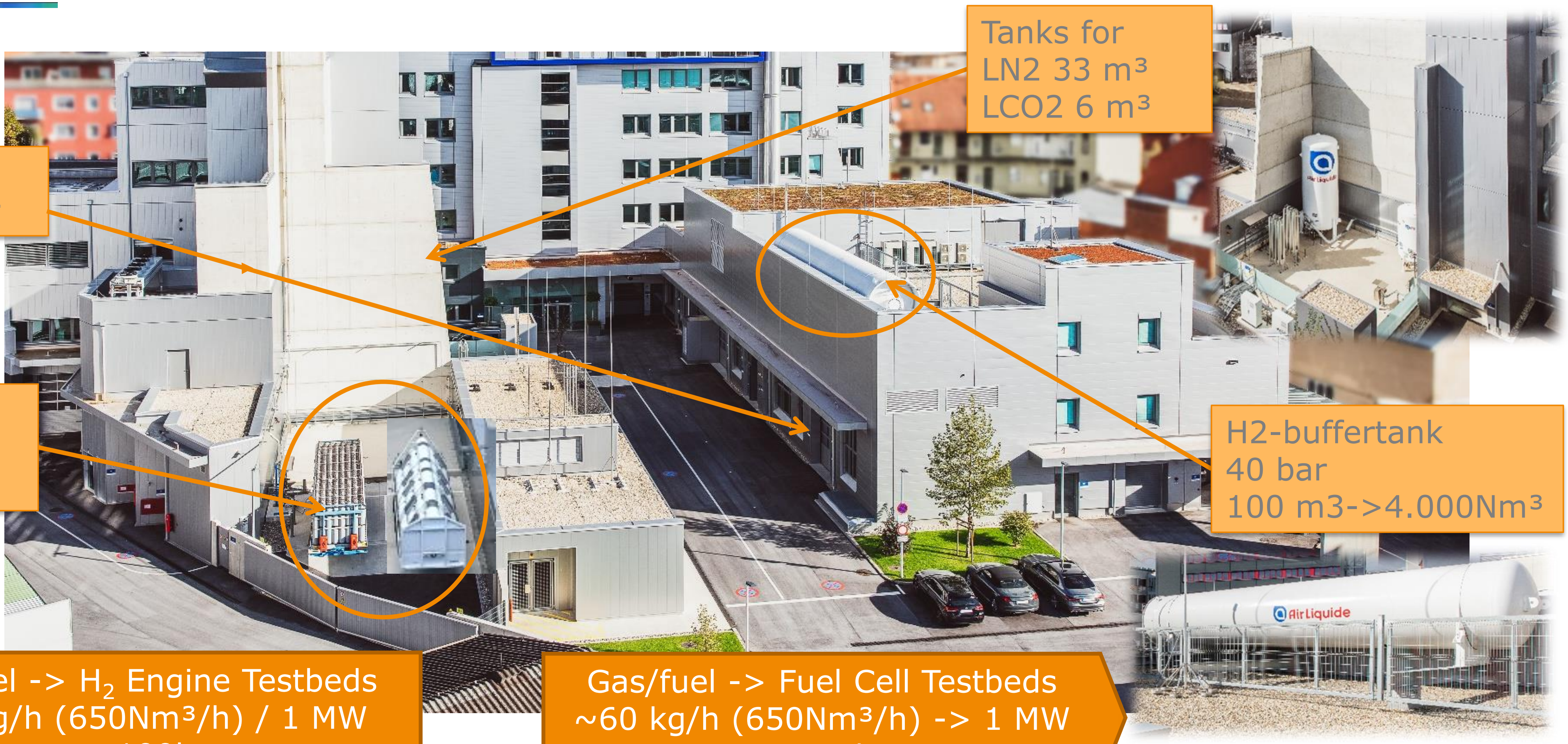




H_2 DI: Mixture preparation is key to low NO_x/efficient comb.

- Gas Jet Formation
- Multiple Gas Jet Interaction
- Interaction Gas Jet(s) vs. Air Charge Motion
- Interaction Gas Jet(s) vs. Surrounding Walls
- CFD Setup & Verification

Hydrogen Center Graz



Tanks for
LN2 33 m³
LCO2 6 m³

FuelCell
Testcenter

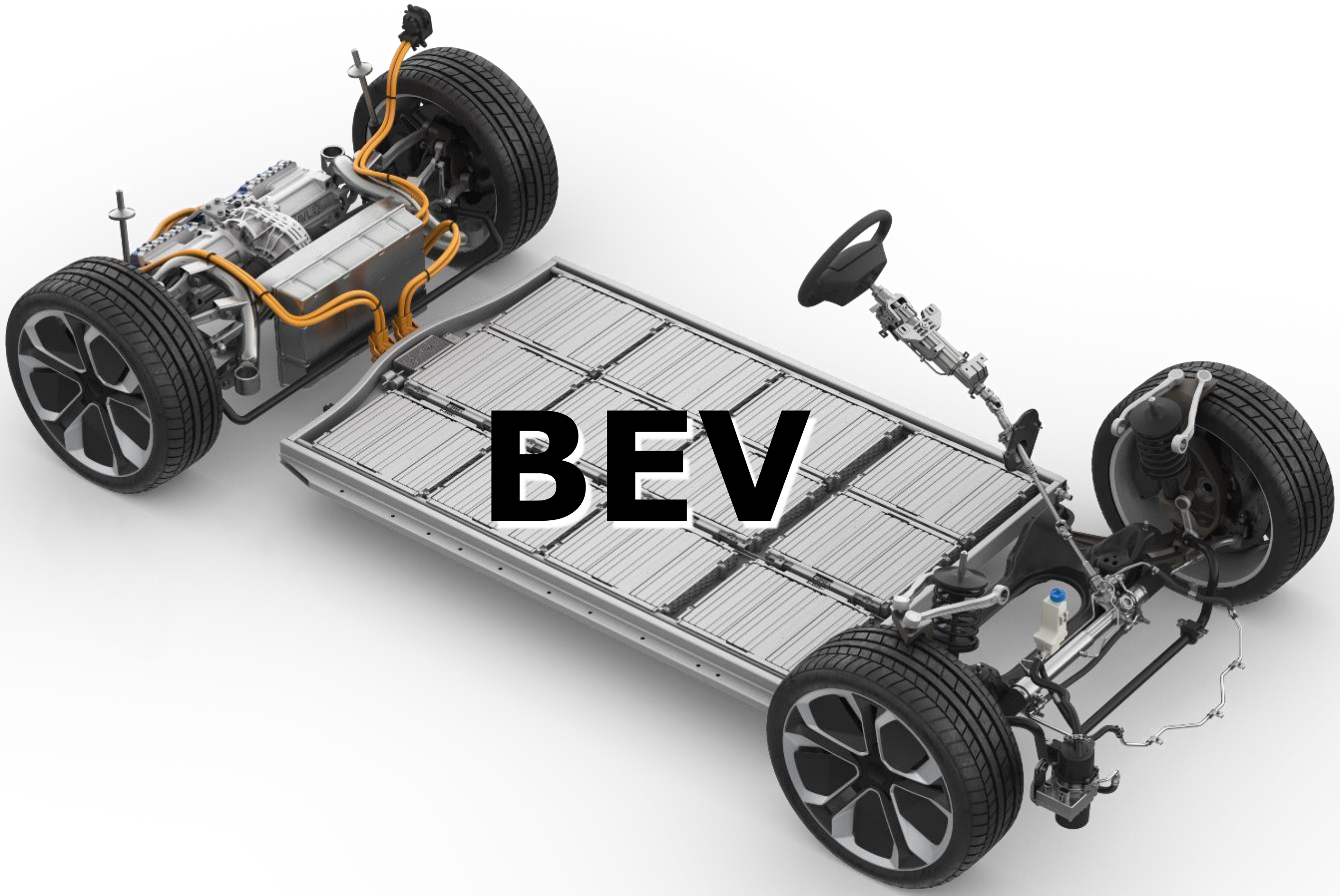
H2-Trailer
200 bar
4.000 Nm3

H2-buffertank
40 bar
100 m3->4.000Nm³

Gas/fuel -> H_2 Engine Testbeds
~60 kg/h (650Nm³/h) / 1 MW
max 100bar

Gas/fuel -> Fuel Cell Testbeds
~60 kg/h (650Nm³/h) -> 1 MW
max 40bar

Technology Options



eCarTec Award 2012:

Bavarian State Award for Electric Mobility

Winner in the category “Drive Technology, System Electrics, Testing Systems”: Coupe 800 – AVL Software and Functions GmbH

Press Release eCarTec, Munich in October 2012

eCarTec
AWARD WINNER

AVL pioneering 800V since 2011 – 1st award already 2012

Innovative Efficiency Improvement of Electric Vehicle

2012/2012
Pioneering 800V

2019 SOP

2021 SOP

2021 Advanced
AVL R&D

Integrated Dual SiC-Inverter

w/ common DC-Link & interleaving

Performance | Compact

800 V technology

for high performance, fast charging

Performance | Efficiency | Compact

Dual motor & dual transmission

enables torque vectoring

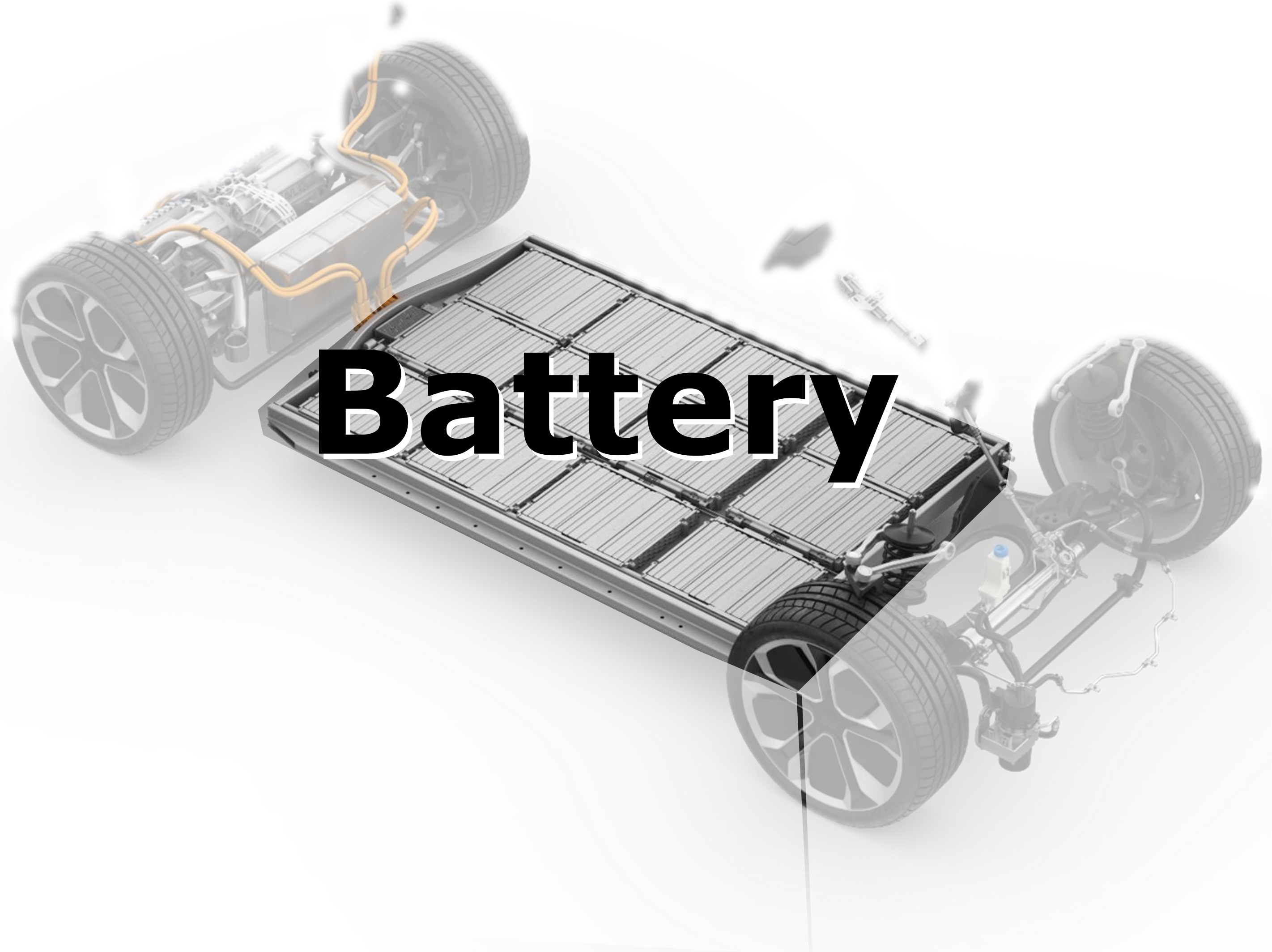
Performance

30.000 rpm direct oil cooled E-Motor

provides reduced weight, volume & high cont. power

Performance | Efficiency | Compact

Technology Options



Battery Future Challenges

Range & Performance

Performance @ charging & driving

High installed energy & reduced weight

Safety

No safety concerns for any electric vehicles

Cost Optimization

Product Costs
Time2Market
Lifecycle

Battery Solutions

Range & Performance

Cell2Pack & Cell2Chassis

Optimization of Thermal System

Safety

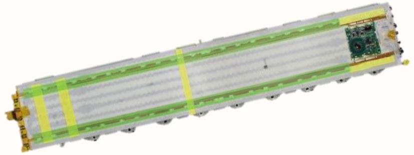
Thermal Runaway Analysis to achieve "no thermal propagation"

Cost Optimization

Derivative Development Process

AVL battery innovation center: Combination of functional and process development

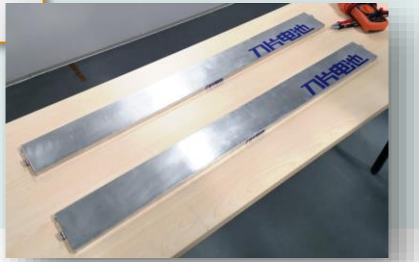
Cell 2 Pack Concept BYD Han vs. Tesla


Model 3 75 LR 2017

Han 82kWh, 2020

	Cell	Module	Pack	Chassis
TESLA – Model 3 75 LR 2017	21700 (Cyl.) **NCA/G** 242 Wh/kg, 683 Wh/L	1150 cells **4 modules** 203 Wh/kg, **453 Wh/L**	160 Wh/kg 230 Wh/L **Grav. C/P 64%** **Volum. C/P 34%** 79,2 kWh	*Dedicated Platform*
BYD – Han 82kWh, 2020	Prismatic “Blade” **LFP/G** 165 Wh/kg, 448 Wh/L	No module	140 Wh/kg 237 Wh/L **Grav. C/P 85%** **Volum. C/P 53%** 82 kWh	*Dedicated Platform*

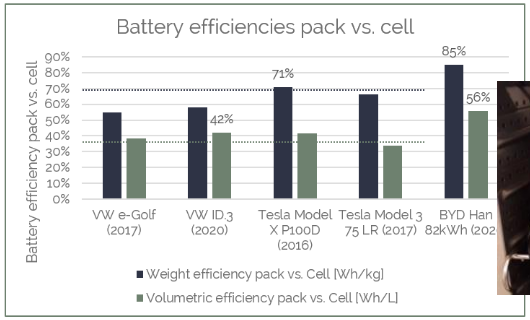


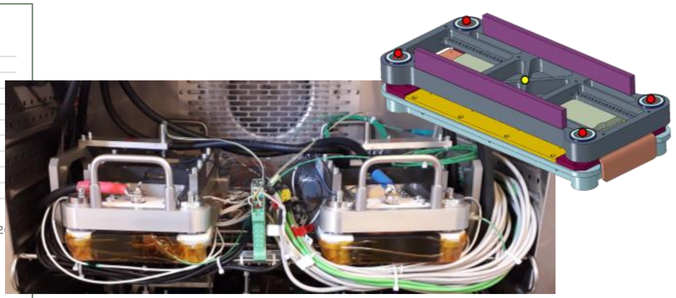

C/P…Gravimetric ratio: Weight of cells/Weight of pack (in %); **Pictures:** AVL Series Battery Benchmark, www.tesla.com, www.electrive.net

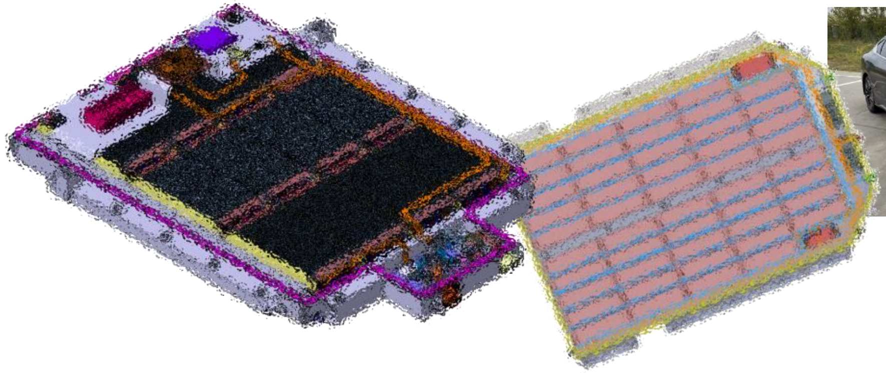
Optimization of Volumetric and Gravimetric System Efficiency

Technical Advantages

AVL Activities







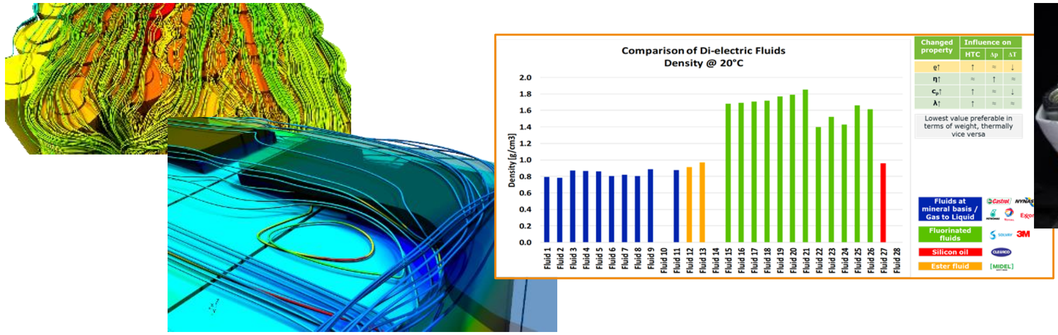
- Simplifying battery pack by reduction of "overhead" in battery system to **maximize gravimetric** and **volumetric energy density**
- **Reduction** of **battery system costs**

- Cell characterization including **swelling & breathing measurement** to derive validated **swelling & breathing simulation** model characteristics
- **Design solutions** for **optimized cell integration** and combined approach of battery **system development** & **vehicle integration**
- **Concept and series development** of cell2pack battery systems

- **Development cell2pack battery** incl. built for **demonstrator** vehicle (cyl. cell)
- **Concept development** including design & simulation study (prism. And pouch cell) – **212Wh/kg 76,7% Grav. ratio**
- **Benchmark Program** of BYD Han battery system at AVL China

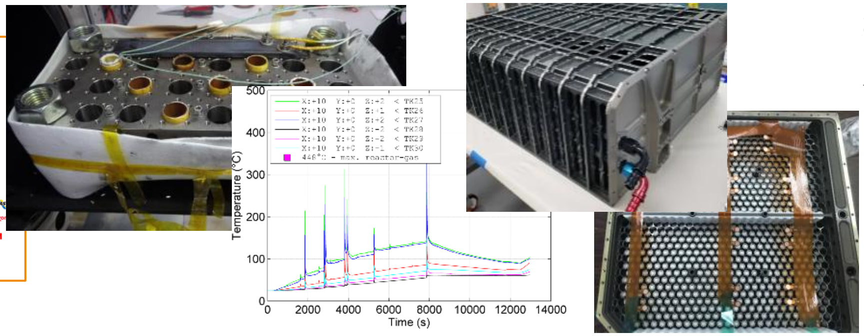
Battery Cell Immersion Cooling

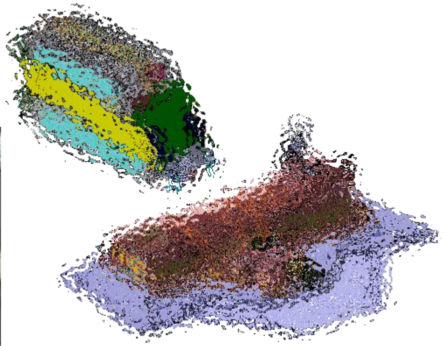
Technical Advantages



- **Direct heat removal** on **cells** and **contactors / busbars** (lower thermal resistance between cells and coolant)
- Possibility to run **higher C-rates** (e.g. in fast charge)
- **Increased safety** in comparison to water/glycol cooling

AVL Activities





Design, **development, optimization** and **validation** of **high-performance battery systems** with immersion cooling incl. proposal for sub-components (cooperation with cooling media supplier) – for **all three cell formats**

- **SOP dev' and small series production** of HEV sports-car project (cyl. cells)
- **Battery development** and **built** of 3 **BEV-demonstrator**
- **Concept projects** with OEMs and Tiers (cyl., pouch and prism. type cells)

Battery Solutions

Safety

Thermal Runaway Analysis to achieve “no thermal propagation”

Thermal Runaway, New Regulation

EU* | Japan | Korea | USA | China | India

UN GTR No.20 (EU*, Japan, Korea, USA, China)

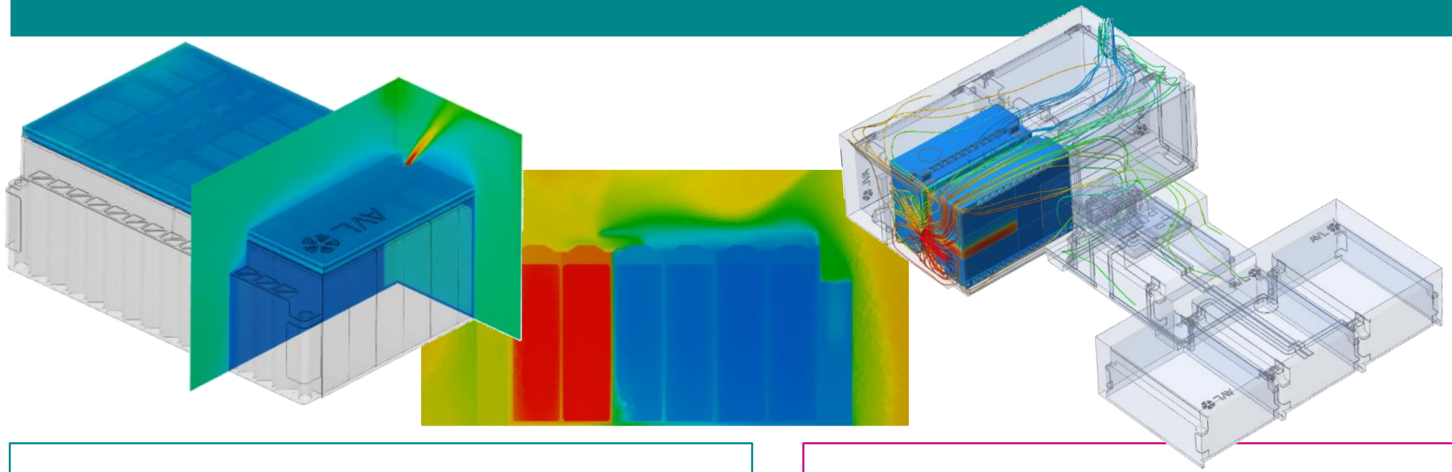
The new **GTR20 regulation** requests a period of 5 minutes between the warning of thermal runaway and the safe escape of passengers

Managing Thermal Runaway

Technical Requirements

- **Thermal Propagation** requirement in GTR or GB
- Ensuring safe escape time for passenger
- Expensive tests with limited possible insight for design optimization

AVL Activities



Simulation methodology using cell test results for module and pack simulation

Prediction of propagation time and risk assessment of

- Fire / ignition / explosion
- Arc formation

- **Design optimization** to delay propagation to over 20mins up to **"no thermal runaway"**
- Simulation correlation with test results for **rout cause** analysis of propagation test

Battery Solutions

Cost Optimization

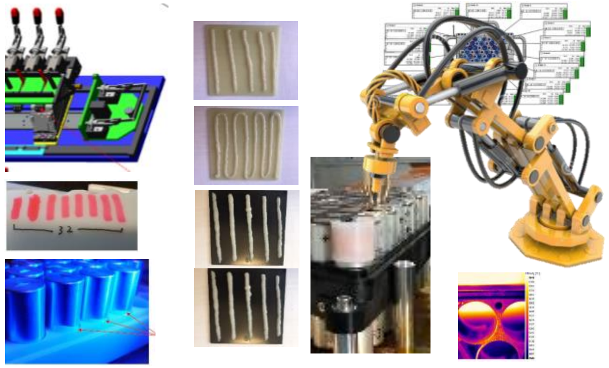
Derivative Development Process

AVL battery innovation center:
Combination of functional and
process development

Combination of Battery Function and Process Development

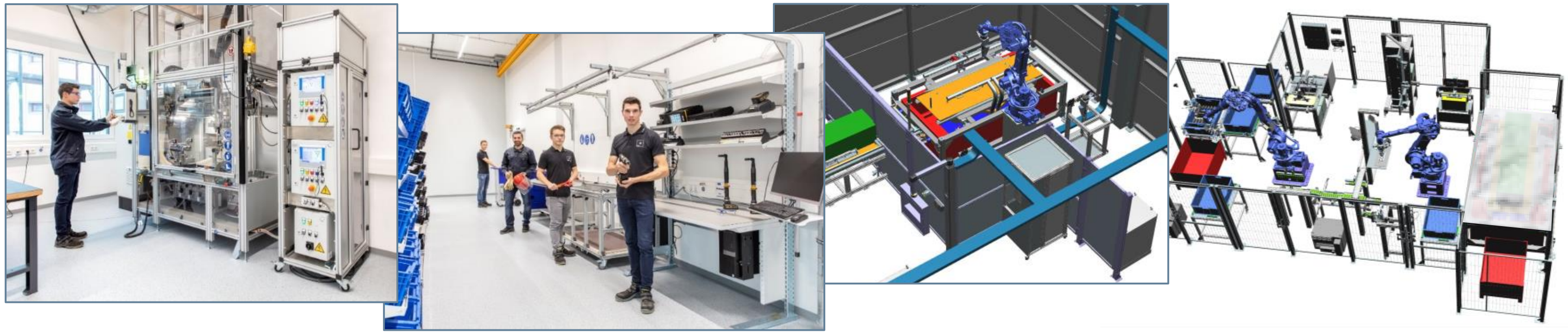
Cost Optimization

Technical Advantages



- **Considering multiple manufacturing variables** to achieve **competitive product attributes** under **time-to-market** requirements
- **Design for Manufacturing** and development of **innovative production processes** to further reduce product costs

AVL Activities: AVL Battery Innovation Center (SOO Q2/21)



- Full functional understanding of **special characteristics** and their transfer to **controlled processes** for modules & packs
- **Process readiness** in sync with **product readiness** with AVL **design for assembly** and **design to cost** activities
- Highly flexible assembly of battery prototypes & pilot production within a **fully industrialized environment**
- Including **robot stations** for: **Cell stacking, gluing & welding**

Technology Options

Charging

What should charging be?

Swiss Knife of Charging

SIMPLE

QUICK (5 min)

Convenient

Focus: Smart | Quick | Robust

Charging Standards

CCS1

CCS SAE COMBO

Chademo (phasing out)

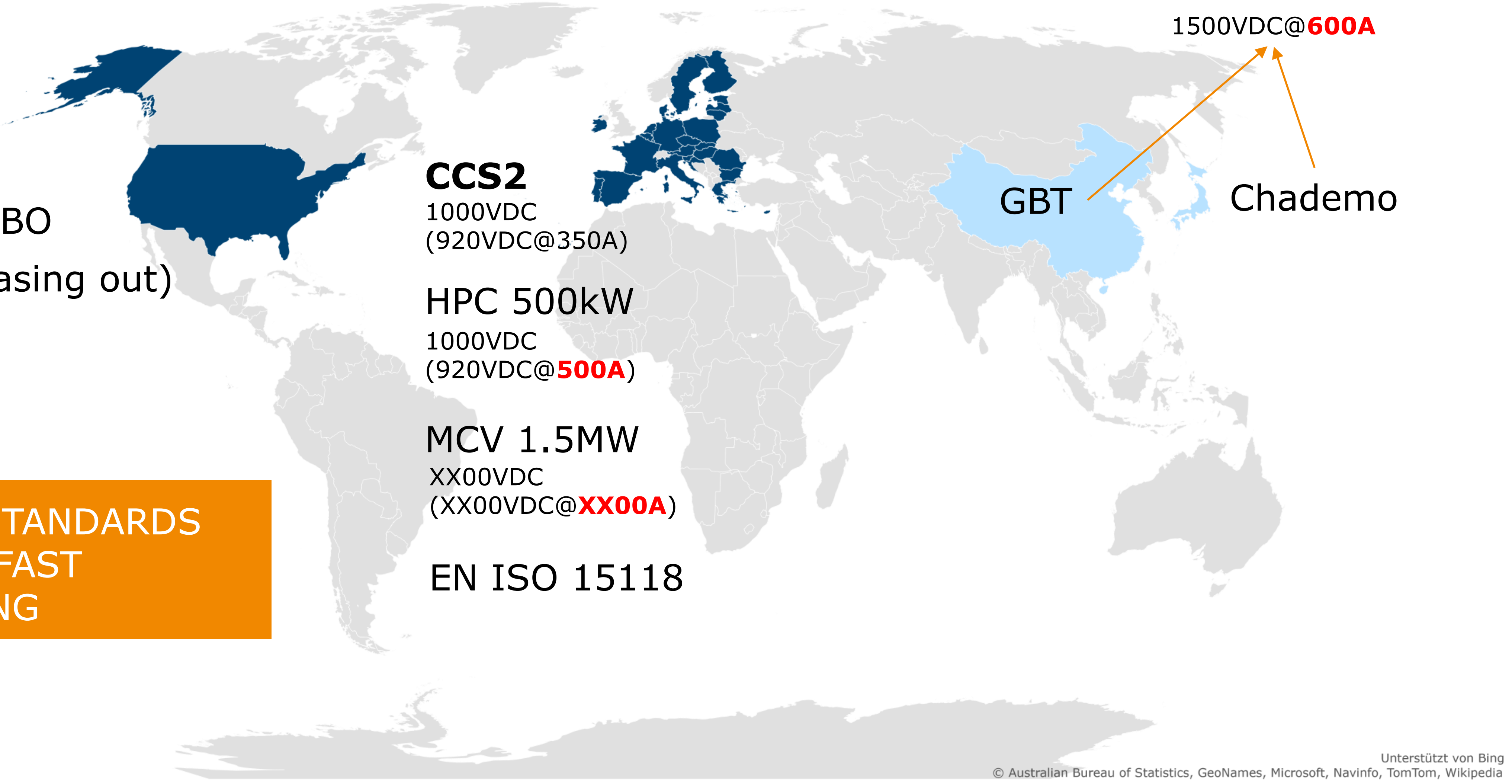
CCS2
1000VDC
(920VDC@350A)

HPC 500kW
1000VDC
(920VDC@**500A**)

MCV 1.5MW
XX00VDC
(XX00VDC@**XX00A**)

EN ISO 15118

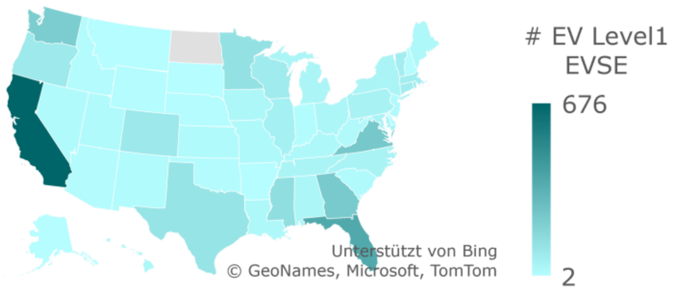
ChaoJi 900kW
1500VDC@**600A**



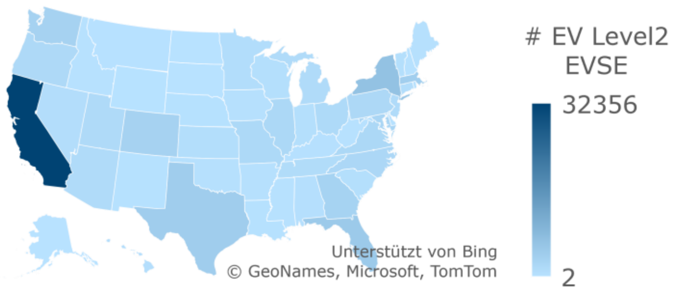
2 MAJOR STANDARDS FOR DC FAST CHARGING

Charging Trend – US Station Locator

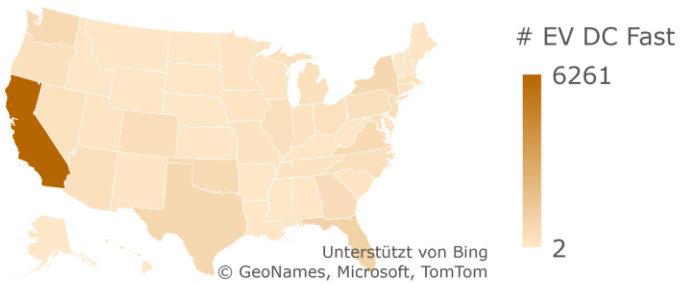
Level 1 AC Charging



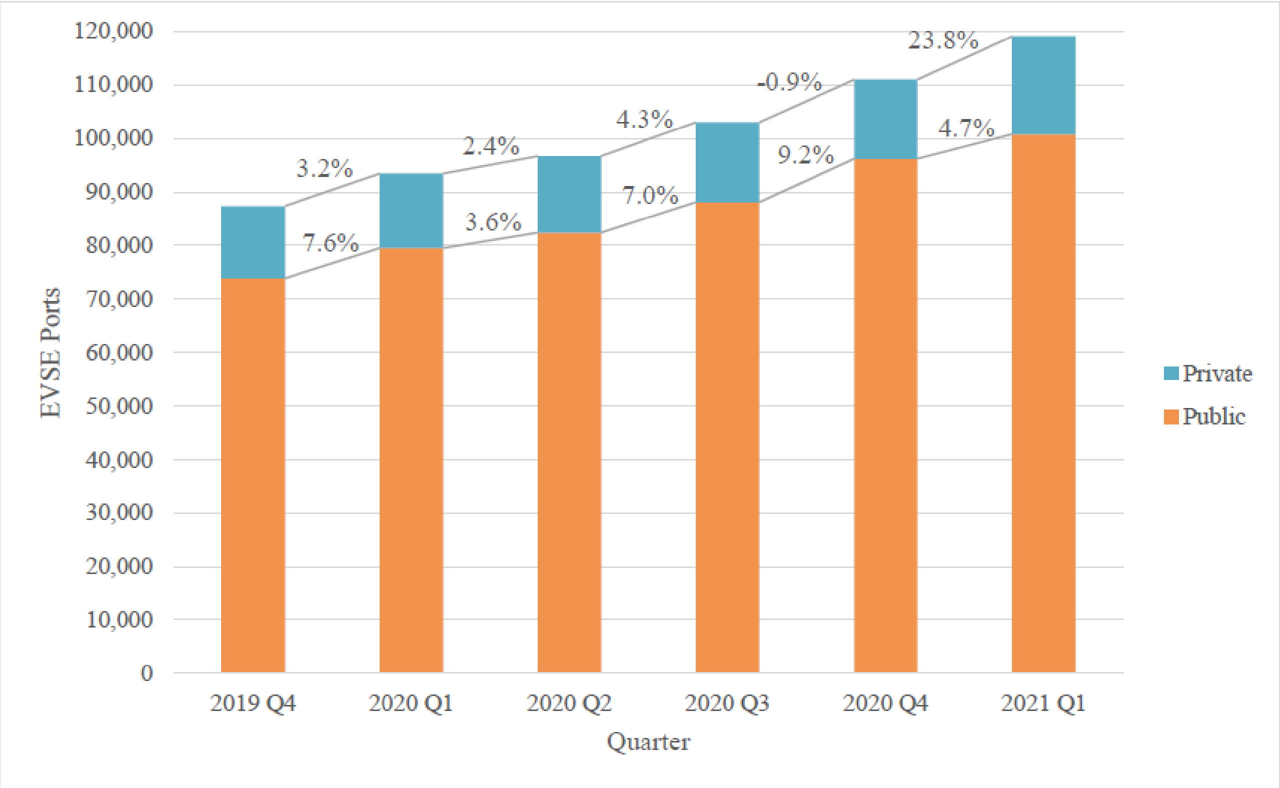
Level 2 AC Charging 7,2 - 20kW



DC Fast Charging



Public Charging Infrastructure



"Private" charging infrastructure for fleet purposes

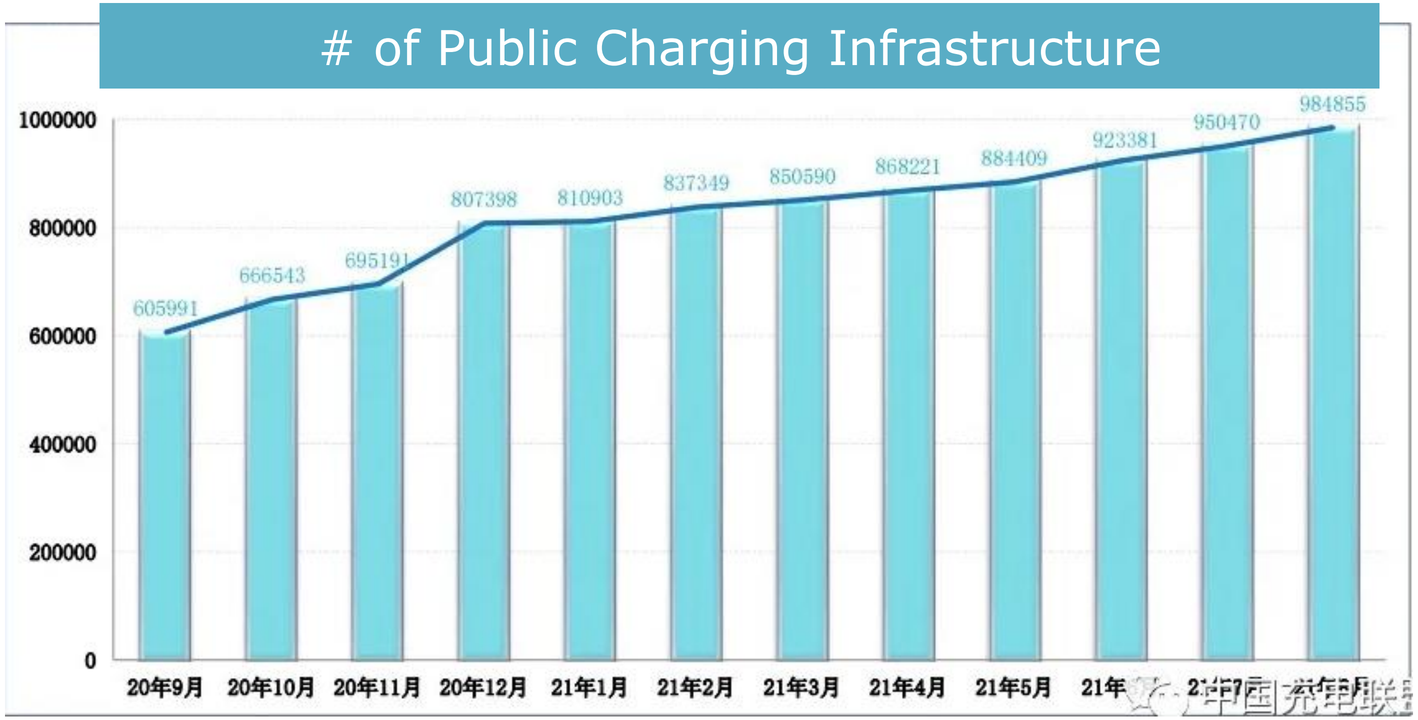
https://afdc.energy.gov/files/u/publication/electric_vehicle_charging_infrastructure_trends_first_quarter_2021.pdf

Charging Trend – CN

China Electric Vehicle Charging Infrastructure Promotion Alliance

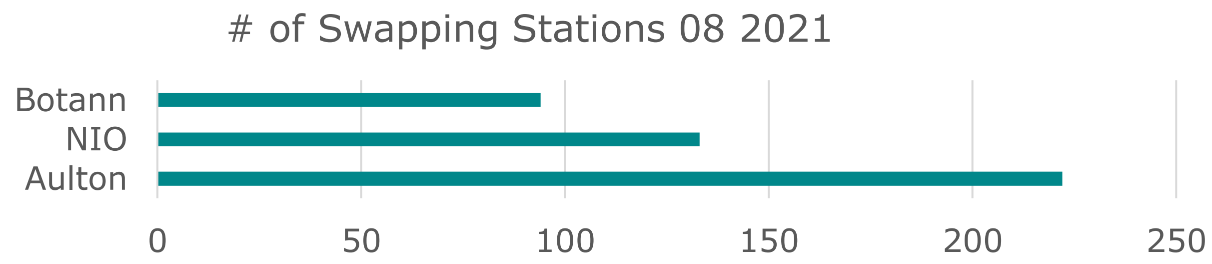
Public Charging Heat Map 08/21

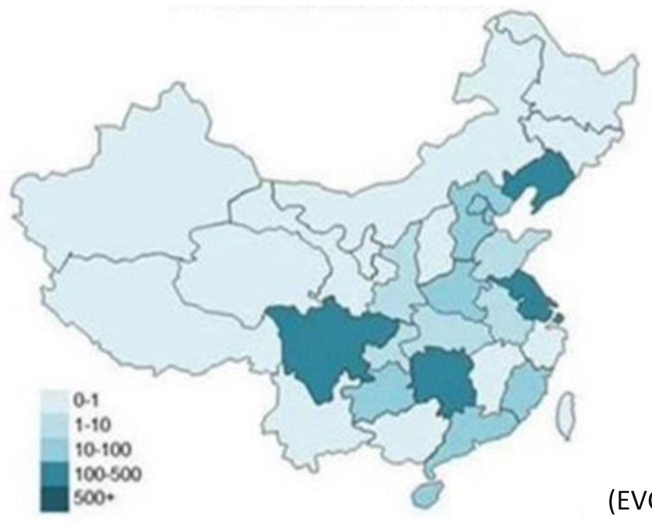
# of Charging Stations 2.015.000



https://mp.weixin.qq.com/s/V-TiOxfRpTwuuYefagKcGg

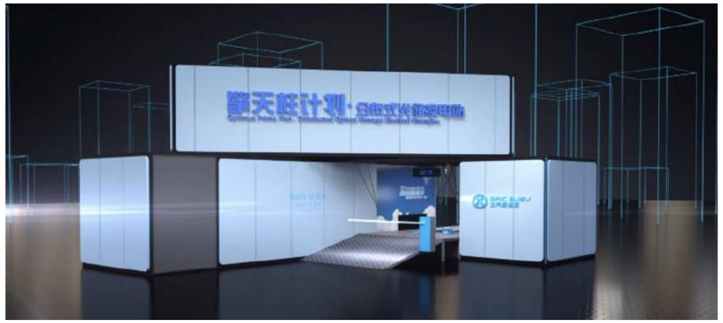
Charging Trend – CN
Battery Swapping Stations





(EVCIPA)

By 2020, NIO had established 178 battery-swap stations across the country in 64 different cities in the eastern part of China. The stations cover two major highways between Beijing-Guangzhou and Beijing-Shanghai. Their plan is to reach 500 battery-swap stations by the end of 2021.
By June 2020, NIO had completed more than **700,000 battery swaps**.

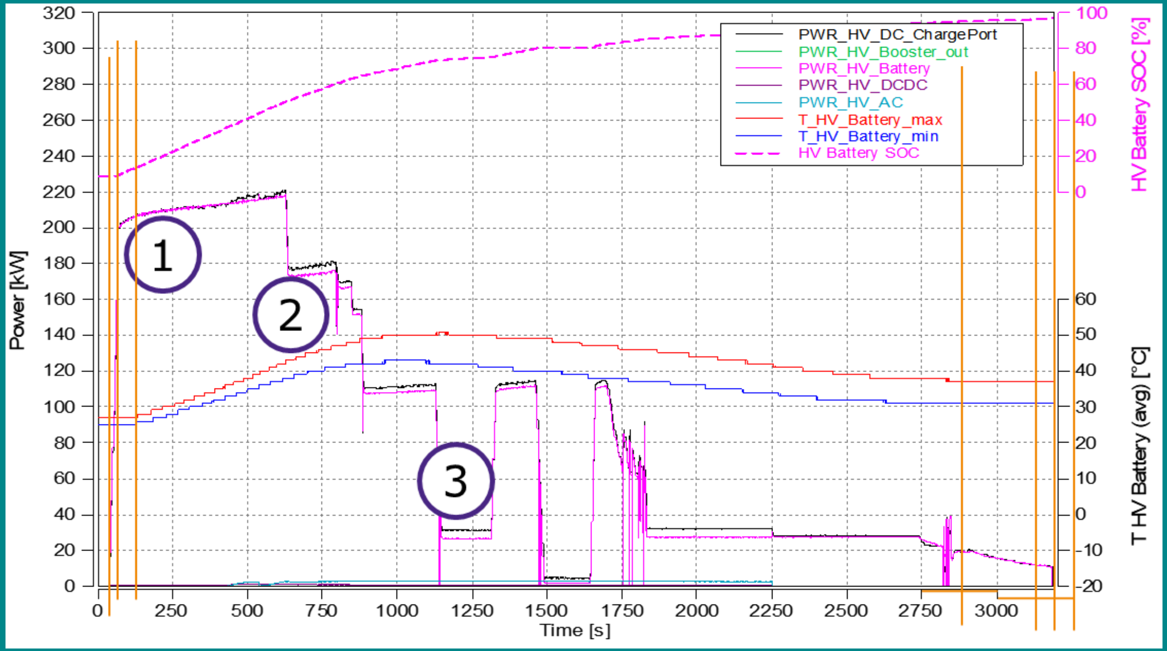


Link: https://www.bjev.com.cn/html/charge-transfer.html

BAIC/BJEV plan to invest more than 10 billion yuan **($1.4 billion) to build 3,000** battery-swap stations capable of serving 500,000 electric vehicles by the end of **2022**

On February 2 2021, Geely completed and put into service its first 10 smart battery-swap stations in the Chongqing Expressway Service area. Each new energy vehicle requires just **60 seconds** to complete battery-swapping. Geely is planning to build 35 battery-swap stations in Chongqing alone, rapidly **expanding** by an additional **100 in 2021 and 200 in 2023**.

Charging Benchmark

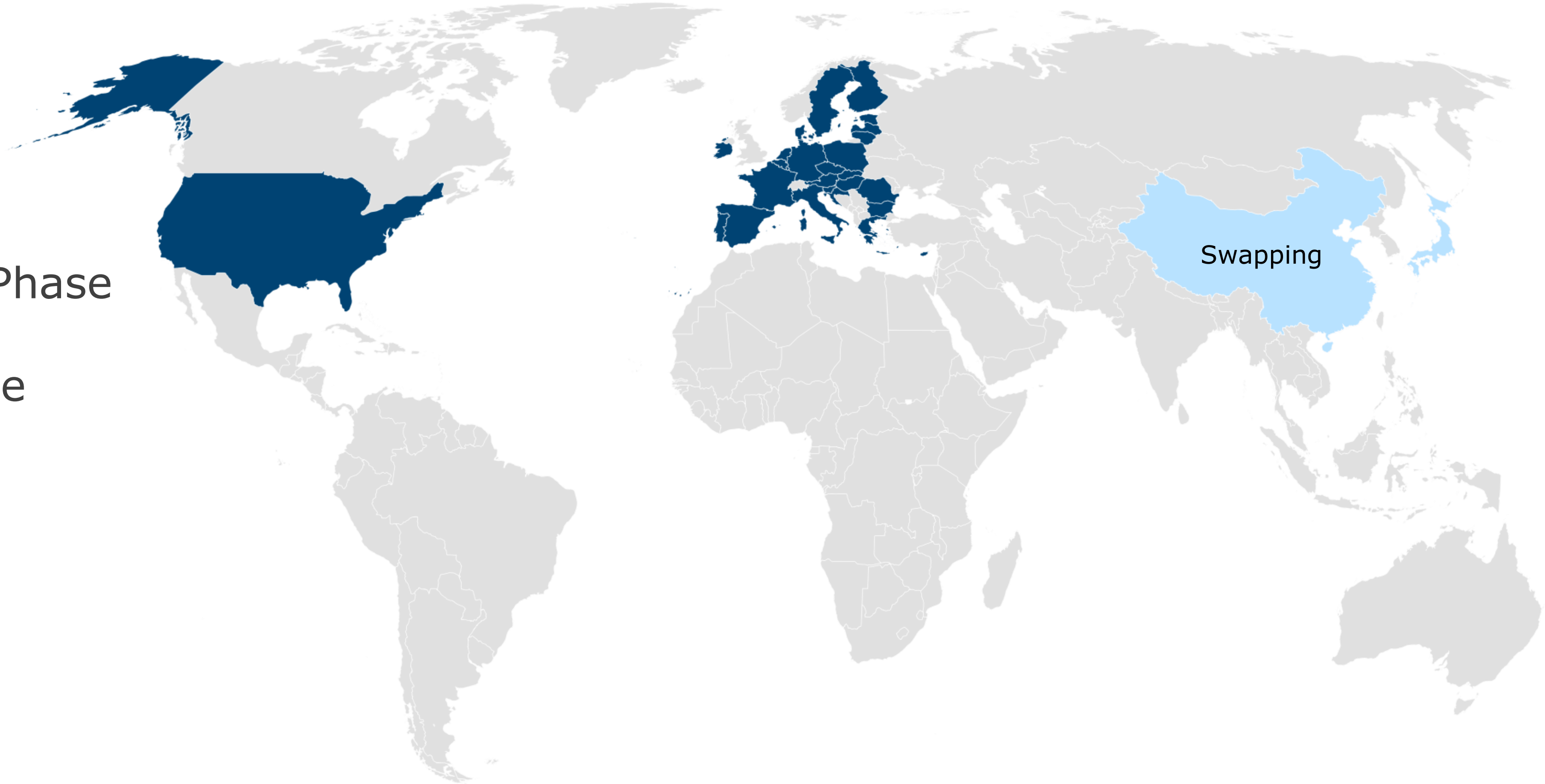


Taycan: 18km/min
IONIQ 5: 20km/min

Better driving efficiency enables better km/min value for the consumer.

→ Charging time - km /min will become the "magic number"

Charging Trend Summary



AC Charging

- 6-7kW Single Phase
- 22kW 3 Phase
- 20kW DC-Home

DC Charging

- 920VDC
- 500A

MAXIMIZE km/min

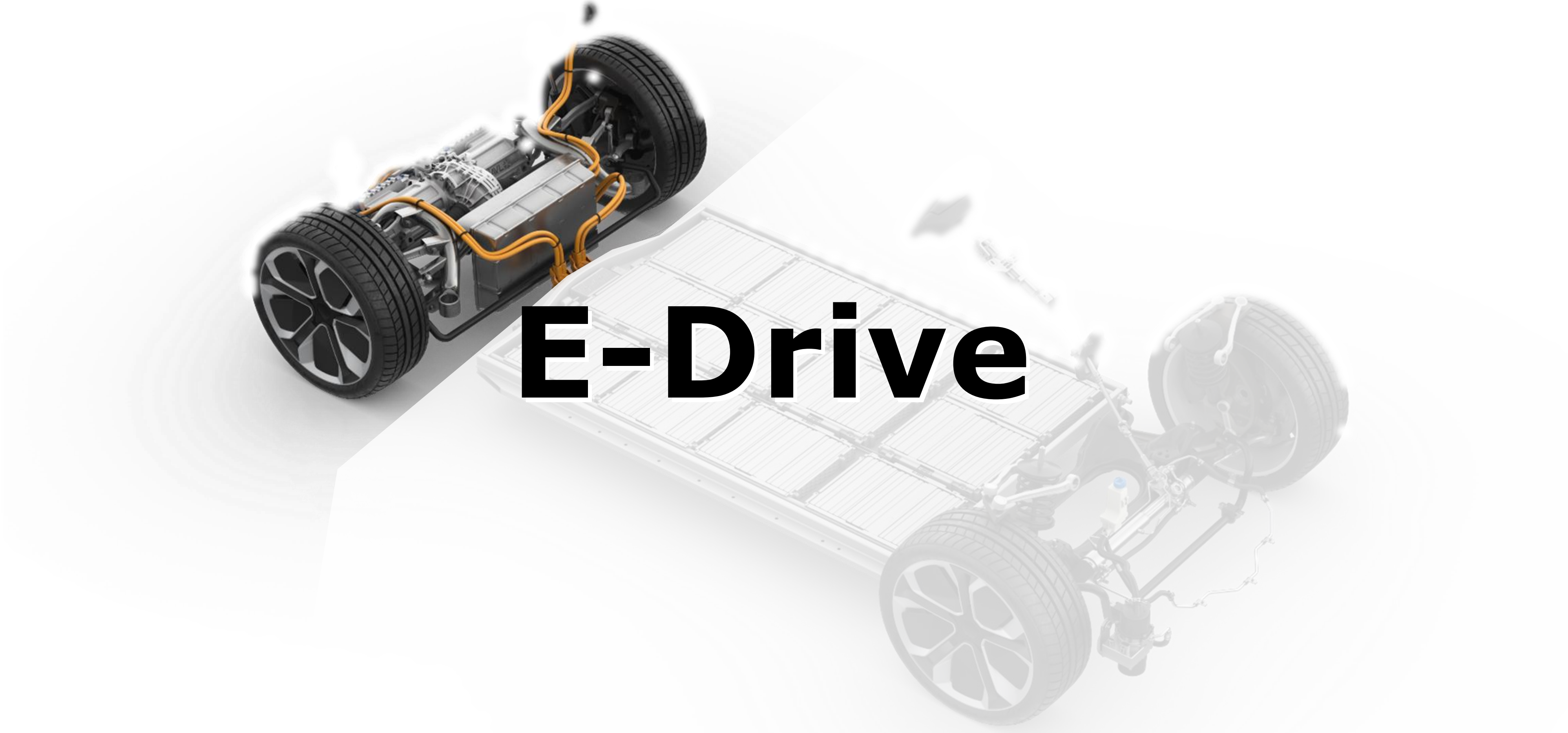
Wide Range Voltage

Driving Efficiency

Predictive Energy Management

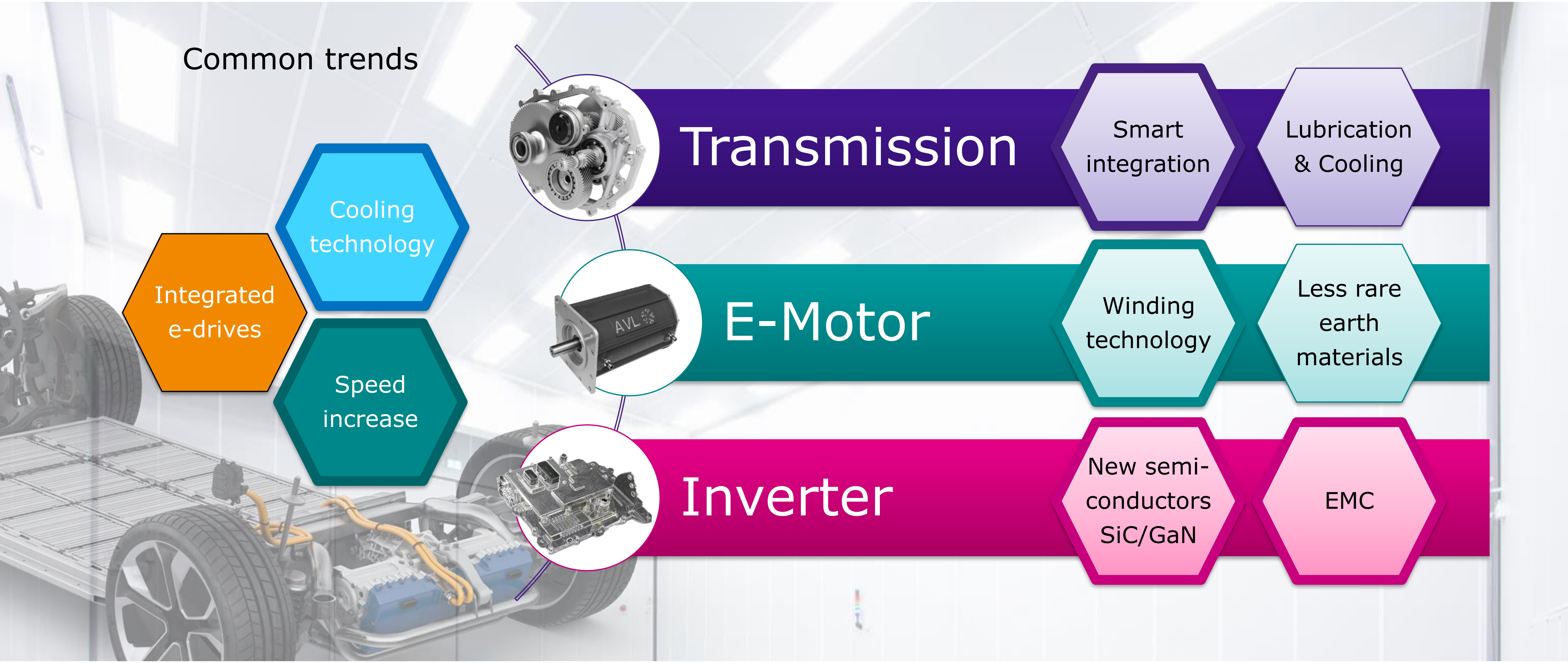
Charging Speed

Technology Options



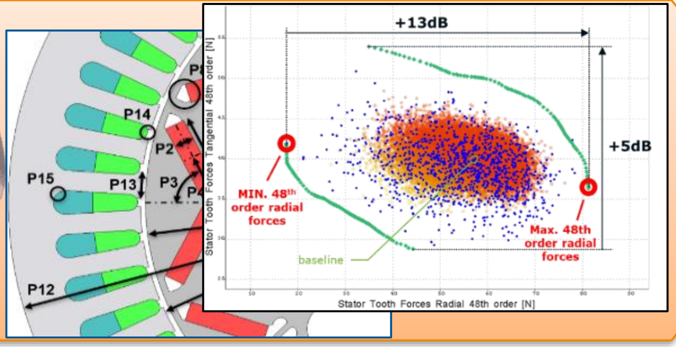
E-Drive

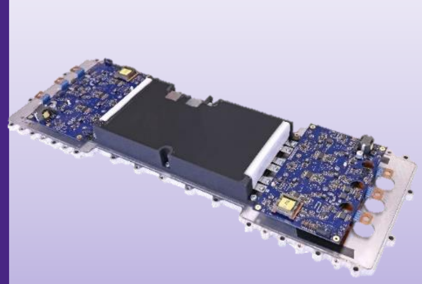
Electric Drive Unit Technology Trends

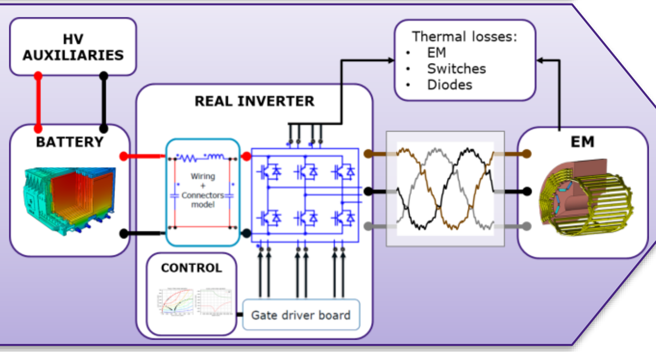


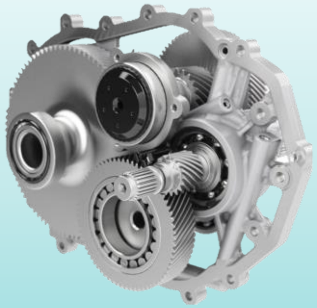
EDU Efficiency Development

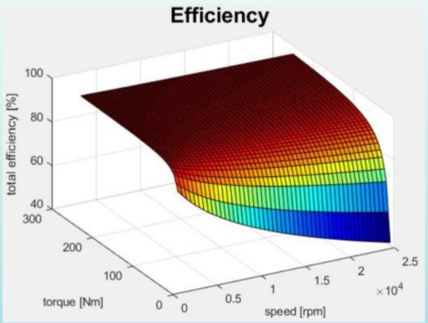
Multi Domain & Multi Objective Optimization





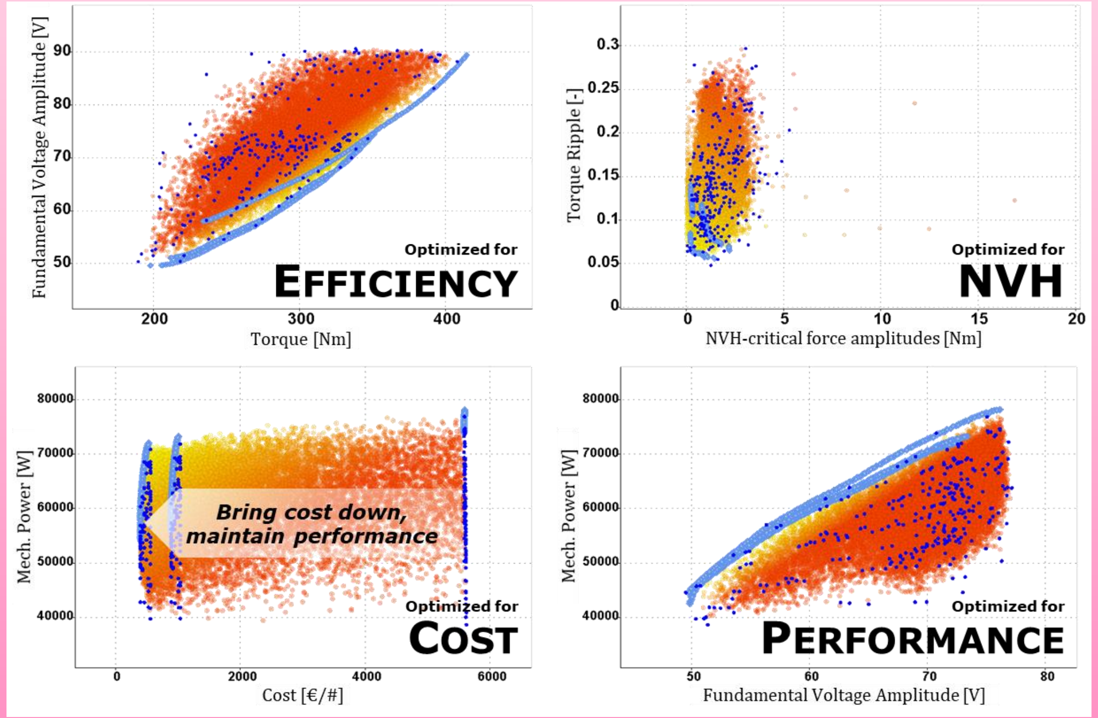






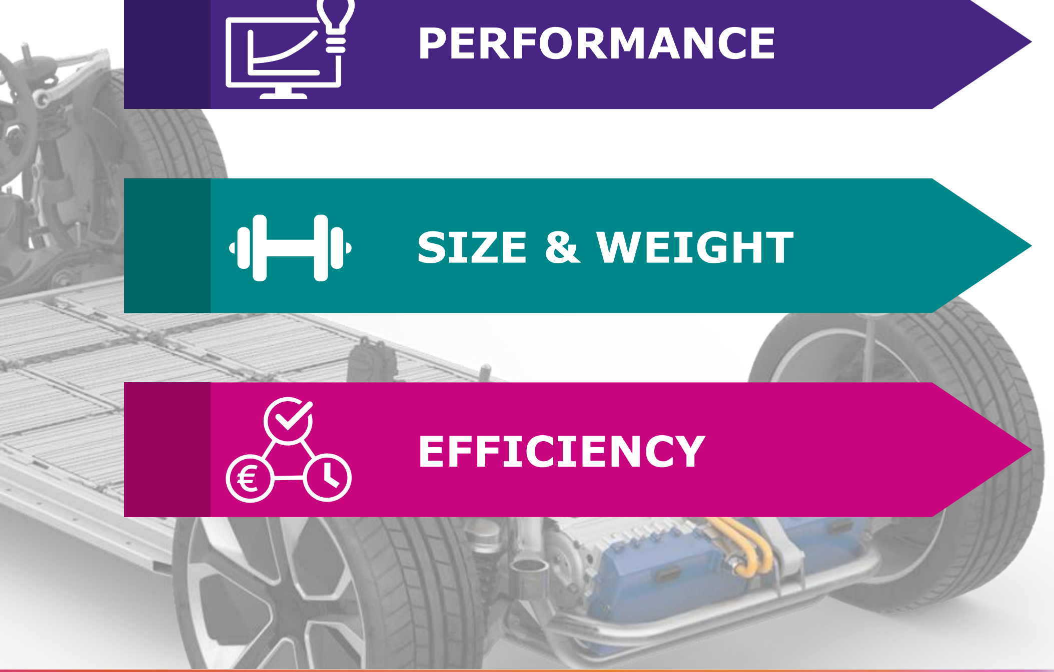
E-Axle System Optimization/Calibration

EDU optimization by combining all three individual development processes into one big multi domain & multi objective optimization



How to Tackle Today's E-Drive Challenges

E-drive technology is driven by:



- **COST**
- **PERFORMANCE**
- **SIZE & WEIGHT**
- **EFFICIENCY**

AVL's response:

New semiconductors
for **compact design, superior performance & efficiency**

High-speed e-motor
as enabler for **lower cost & higher power density**

High integration
allowing **compact design, robustness & further cost reduction**

Direct oil-cooled e-motor
for **optimized continuous high power** at compact design

EMC simulation & optimization
ensures **reliability, cost & weight optimized designs**

Holistic software approach
by **processes & methods** to ensure **safe & secure turnkey solutions**

How to Tackle Today’s E-Drive Challenges

Shaping the Electrification Transformation Across All Applications

How to Tackle Today's E-Drive Challenges

Design to Function

Design to Cost

Design to CO_2

Thank you

www.avl.com