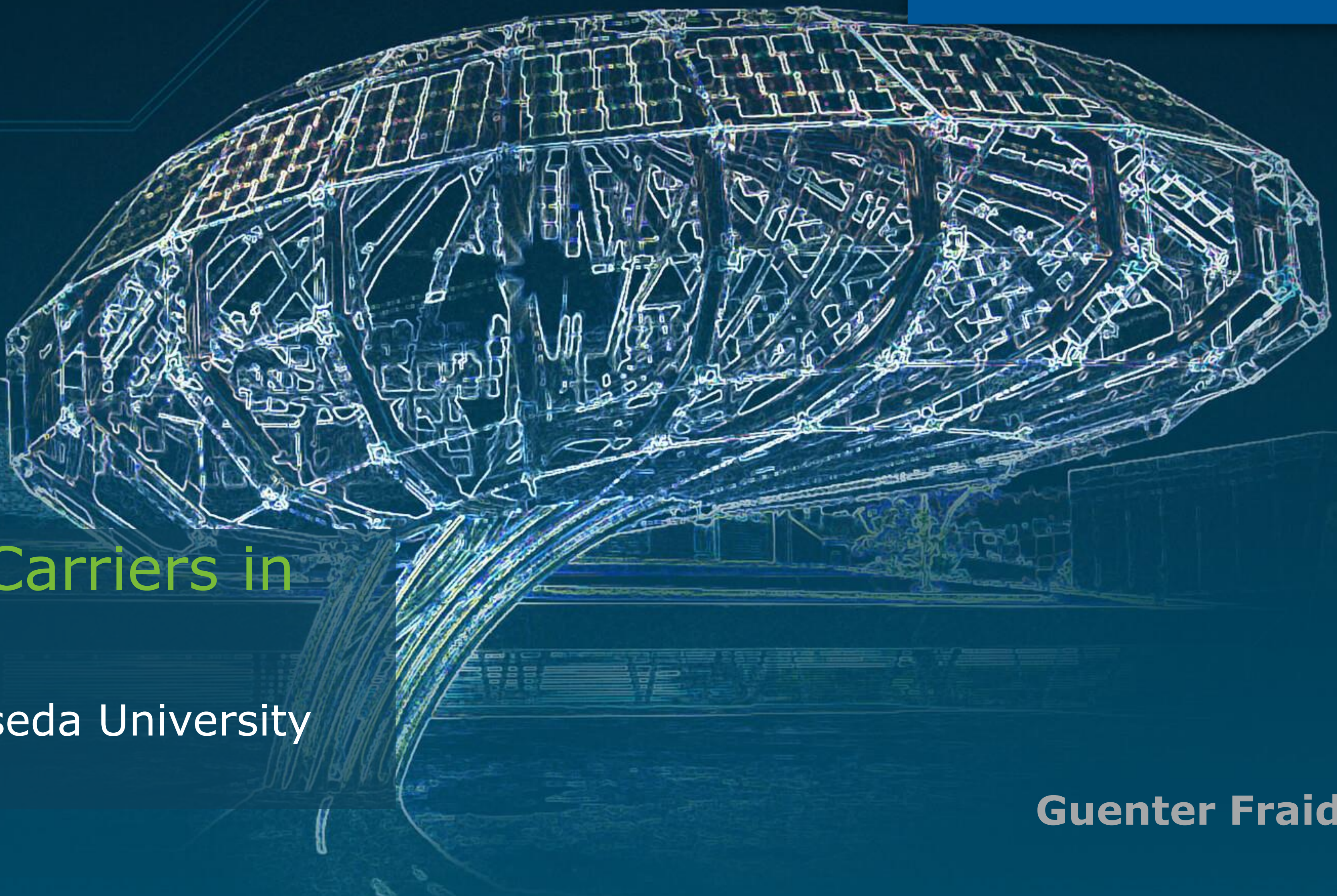


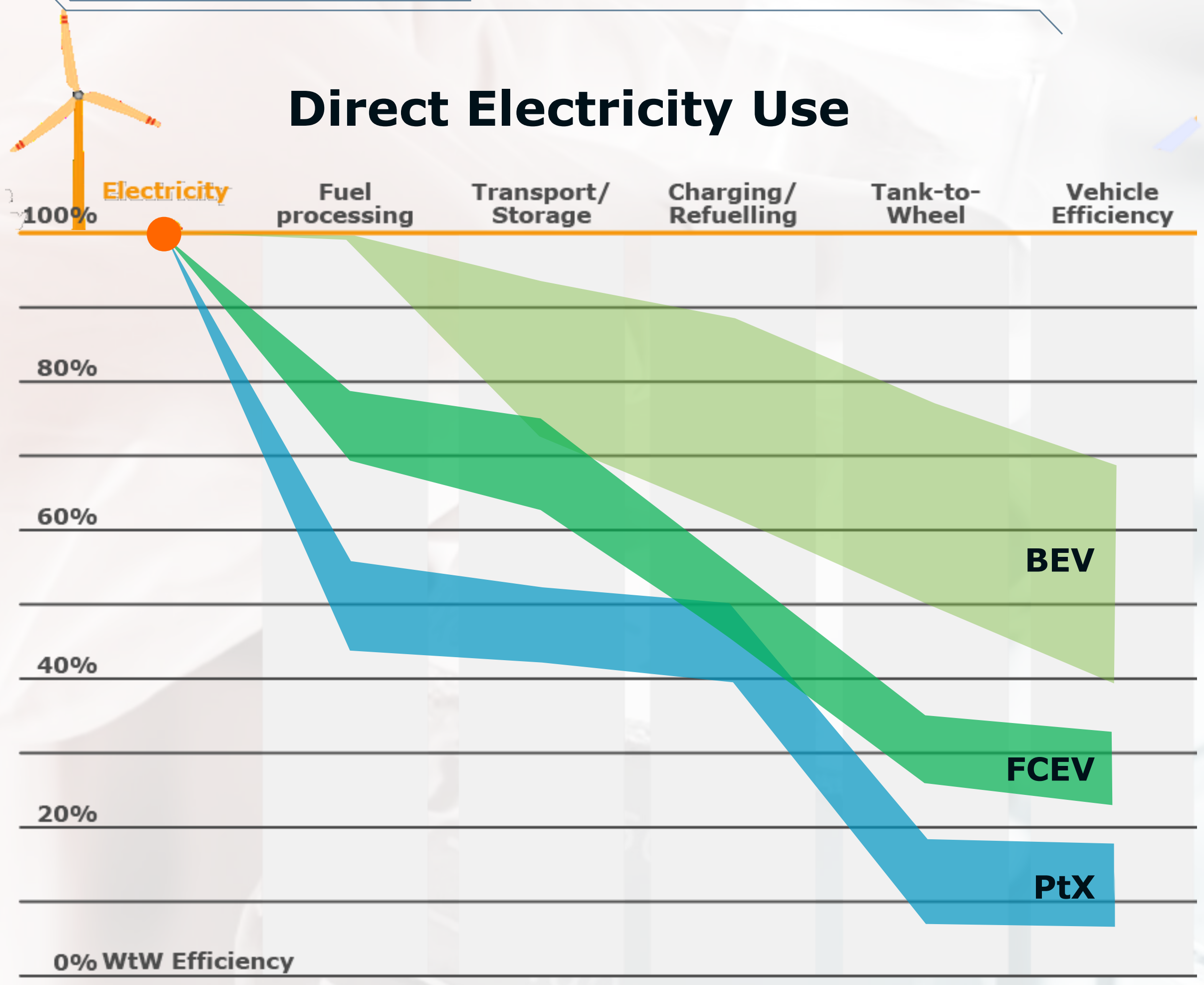
Future Energy Carriers in Passenger Cars

Joint Symposium Waseda University
May 20th, 2019

Guenter Fraidl

Actual & Future Challenges Passenger Car

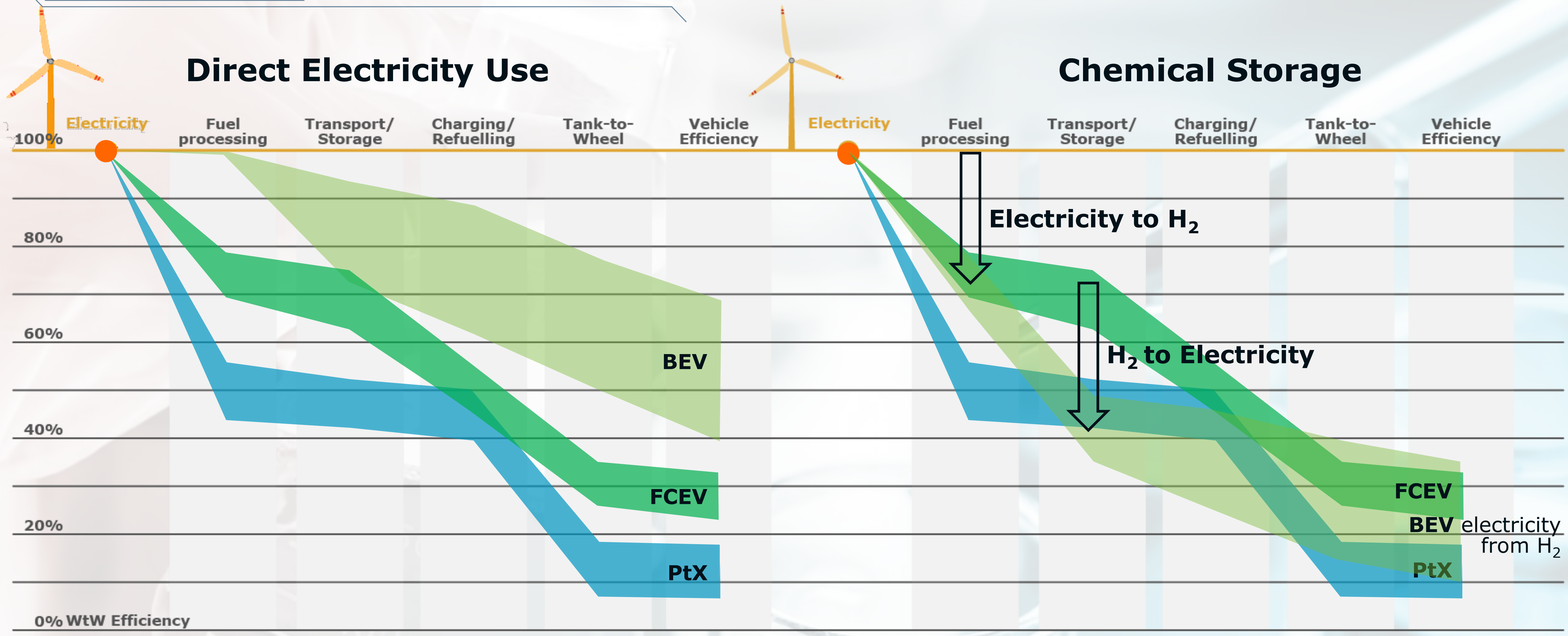
Efficiency Chain of Different Energy Carriers



Source: AVL Energy Consulting Services

Efficiency Chain of Different Energy Carriers

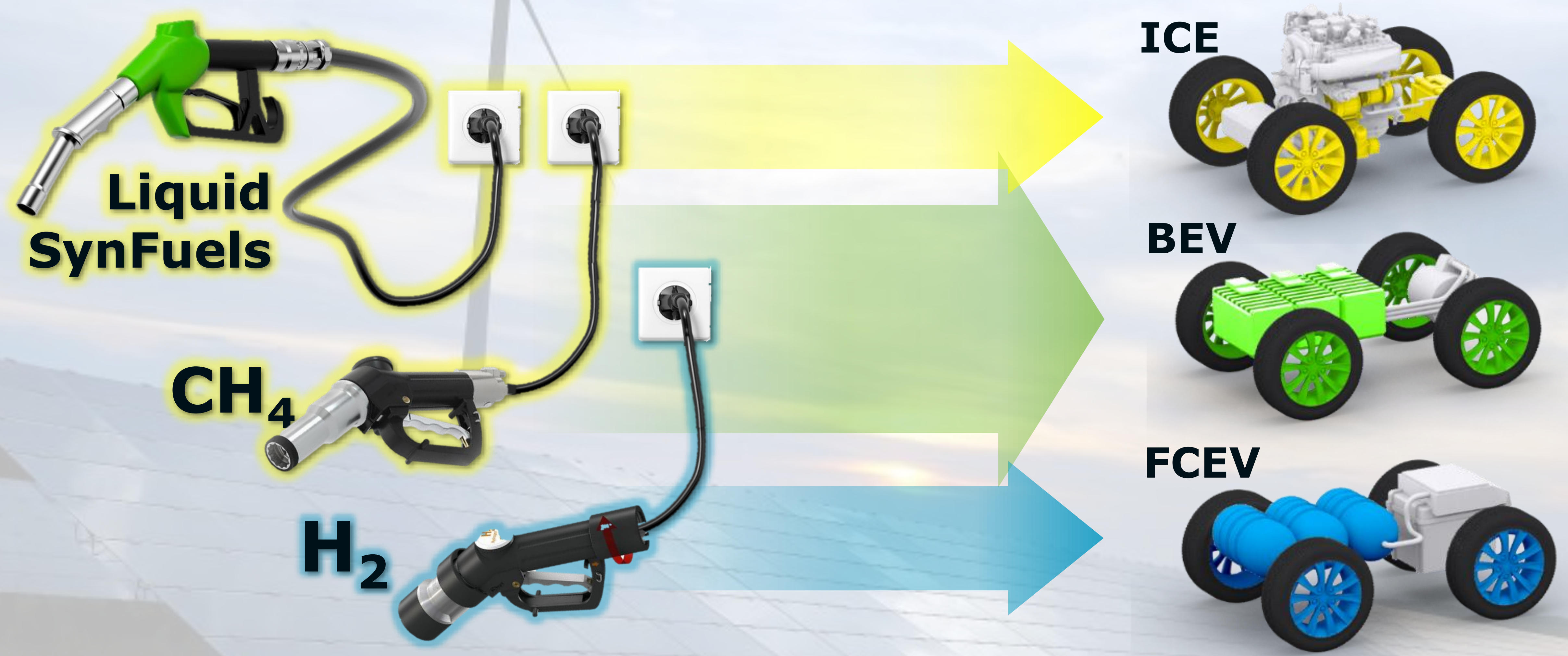
AVL



Source: AVL Energy Consulting Services

Chemical Energy Carriers enhance the Powertrain Competition

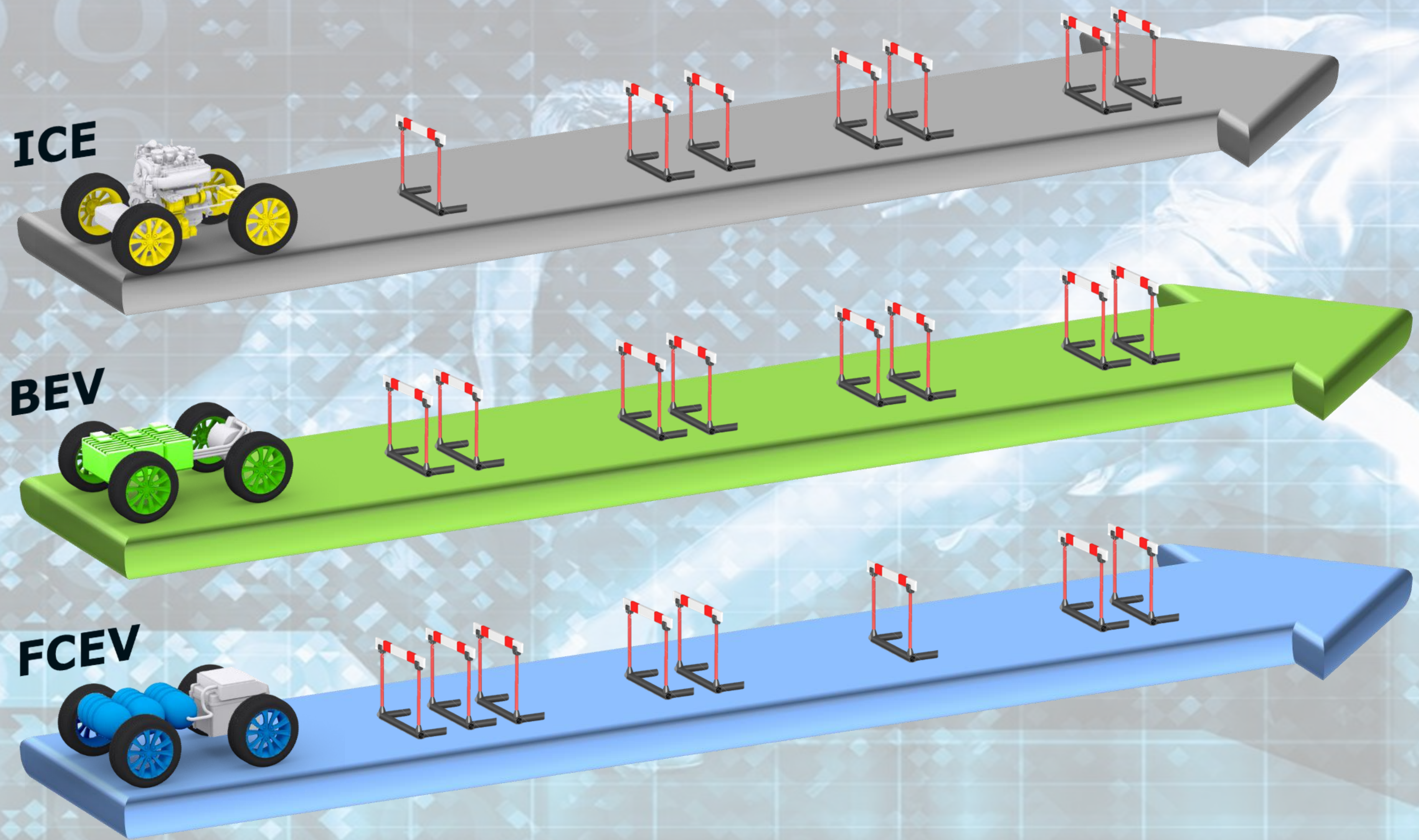
Chemical Energy Carriers



Chemical Energy Carriers enhance the Powertrain Competition

Photo: FAZ

Powertrain Competition
Challenges for Individual Technologies

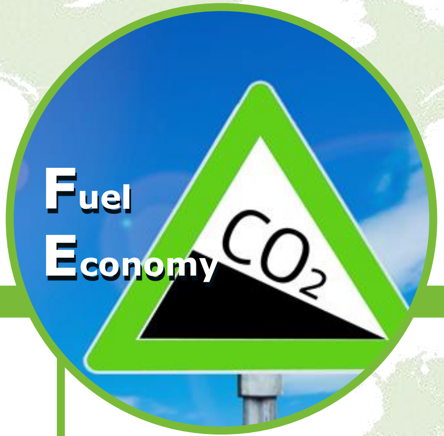


ICE Challenges

ICE

- EU7, CN7, LEVx
- RDE
- OBD

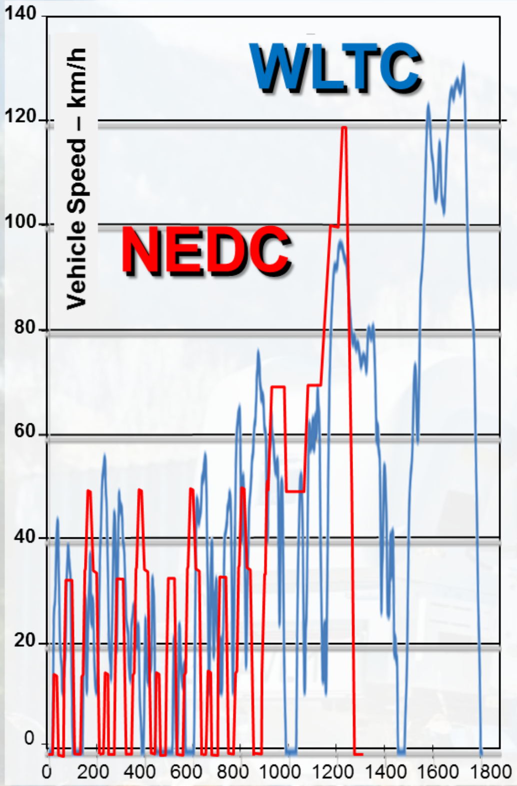
- Access Restrictions
- Extended ICE City Ban
- Complete ICE Ban ?

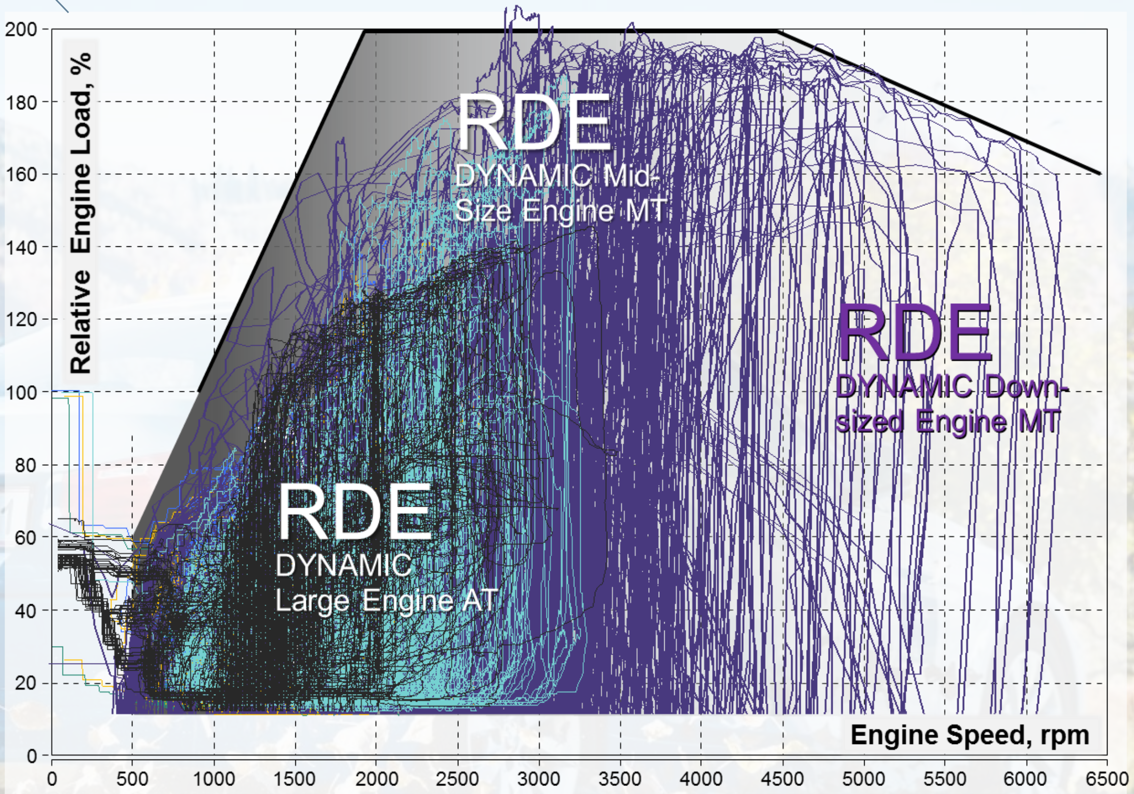


- Tank to Wheel CAFE
- Real World FE
- Lifecycle CO_2

- Boundaries
- Additional Pollutants
- Lifetime Compliance

IMPACT OF RDE (Real Driving Emission)





R
D
E

From EXACTLY REPRODUCIBLE TESTCYCLE towards STATISTICAL PROPABILITY

→ Paradigm shift in development towards virtual testing

ICE Technology:

On the way towards

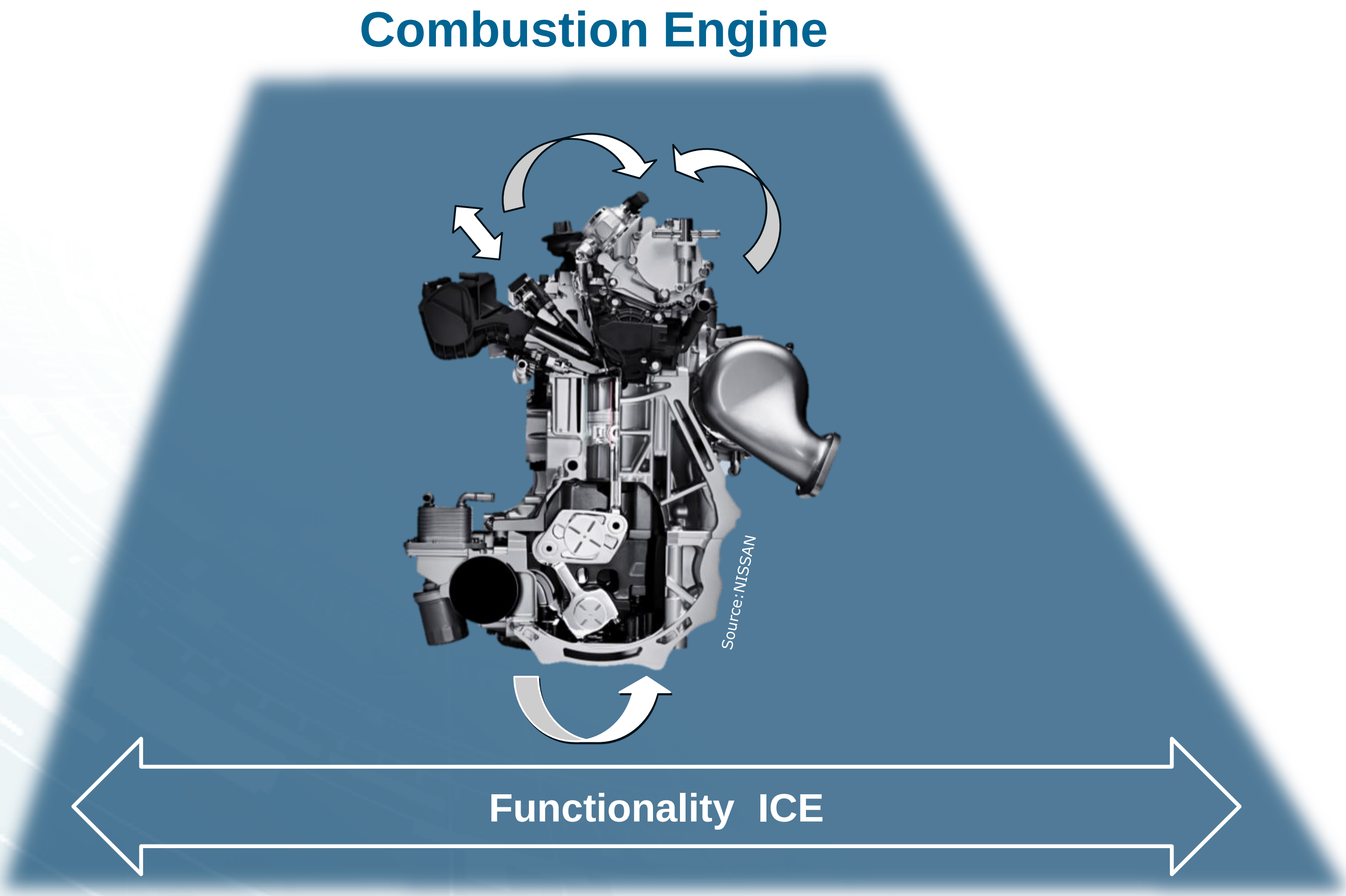
50%

> ~~45~~ % Max. Efficiency and

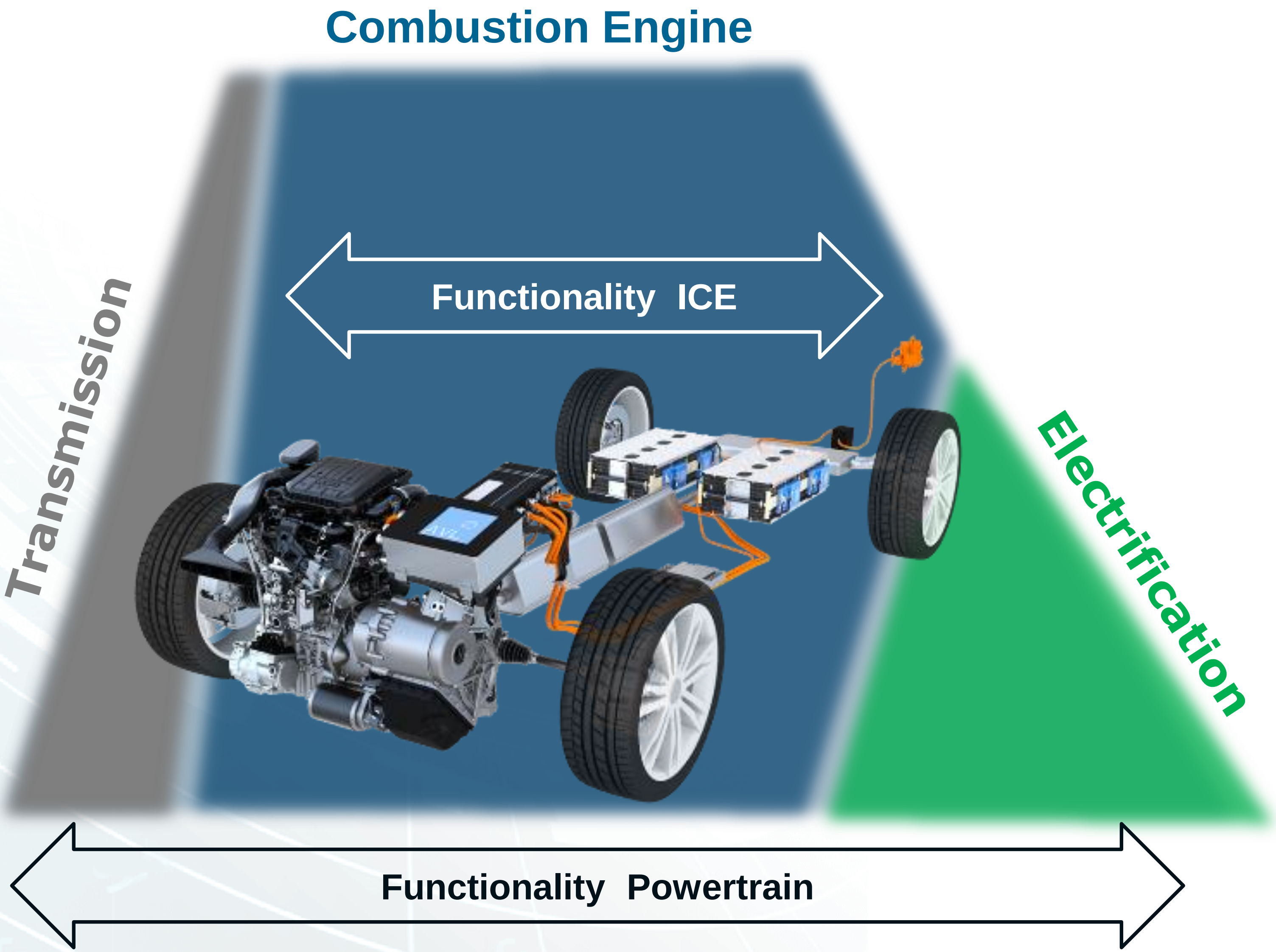
“Zero Impact Emission”

utilizing synergies with electrification

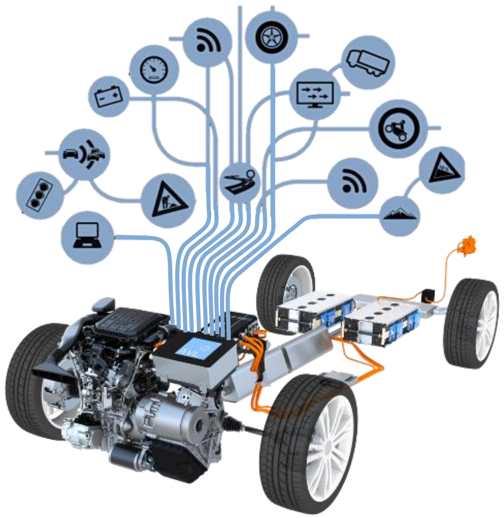
From "Fully Flexible Combustion Engine"



From "Fully Flexible Combustion Engine" to "Fully Flexible Powertrain"

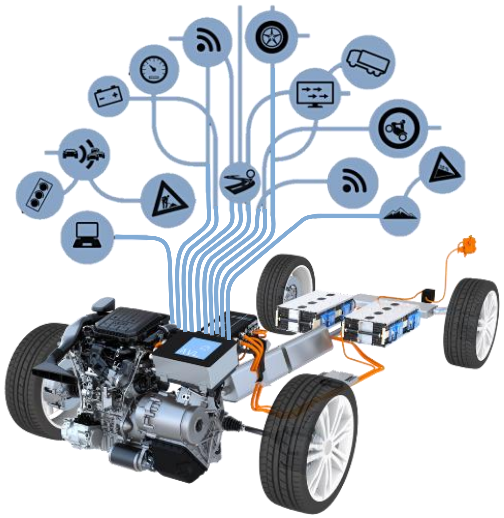


ICE 4.0



Hybri[redacted]
Connected
➔"Fully Flexible Powertrain"

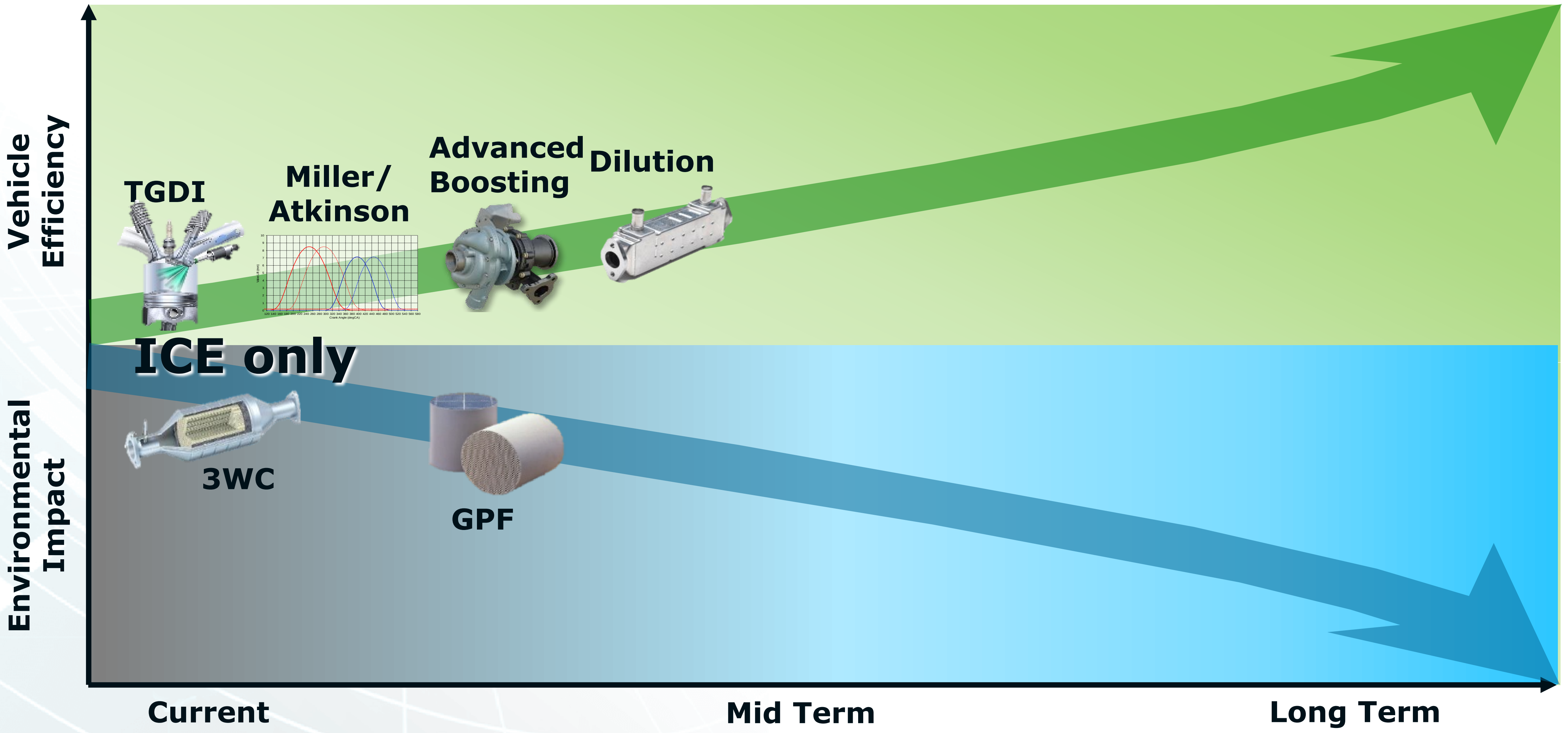
ICE 4.0



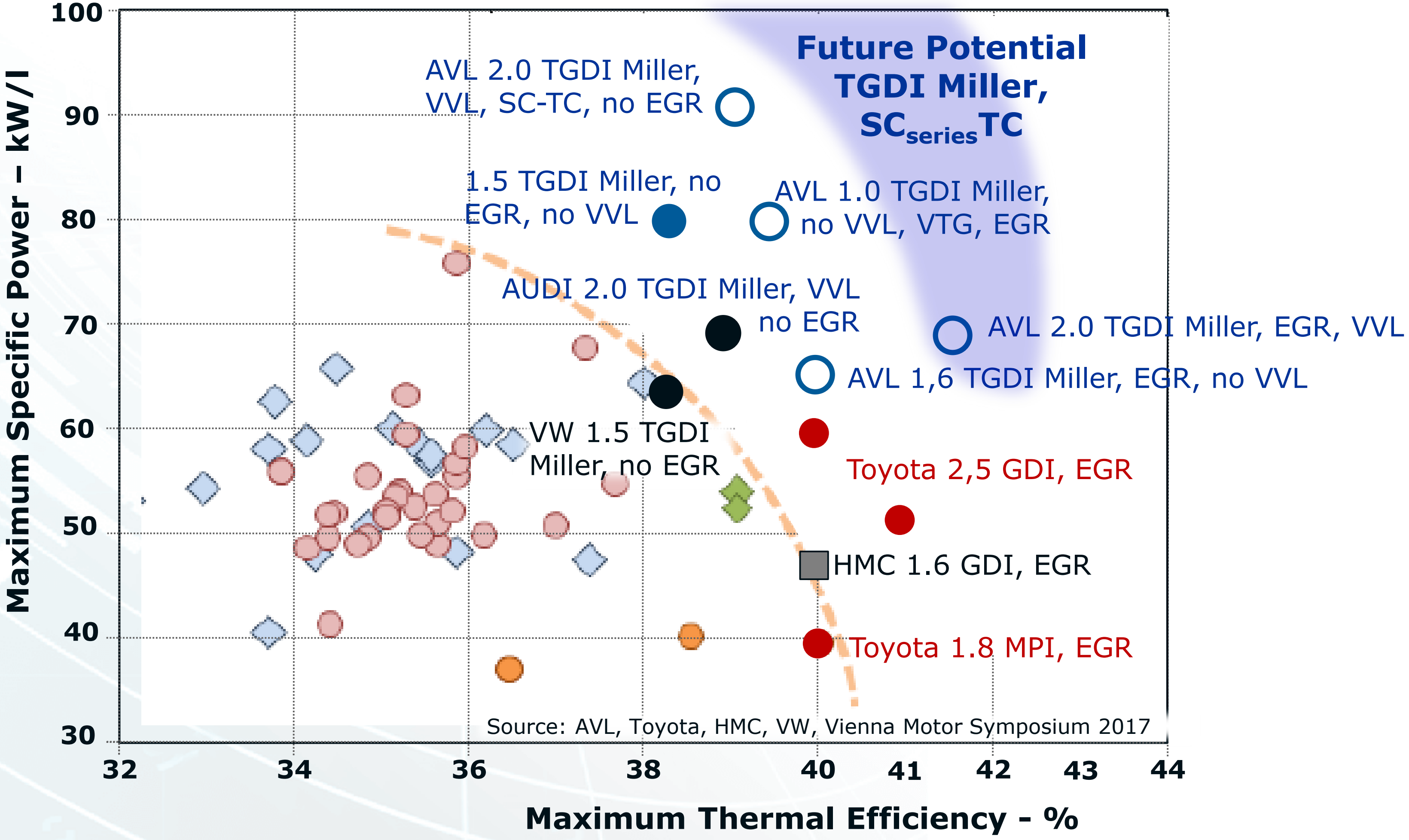
Hybri[redacted]
Connected

➔"Fully Flexible Powertrain"

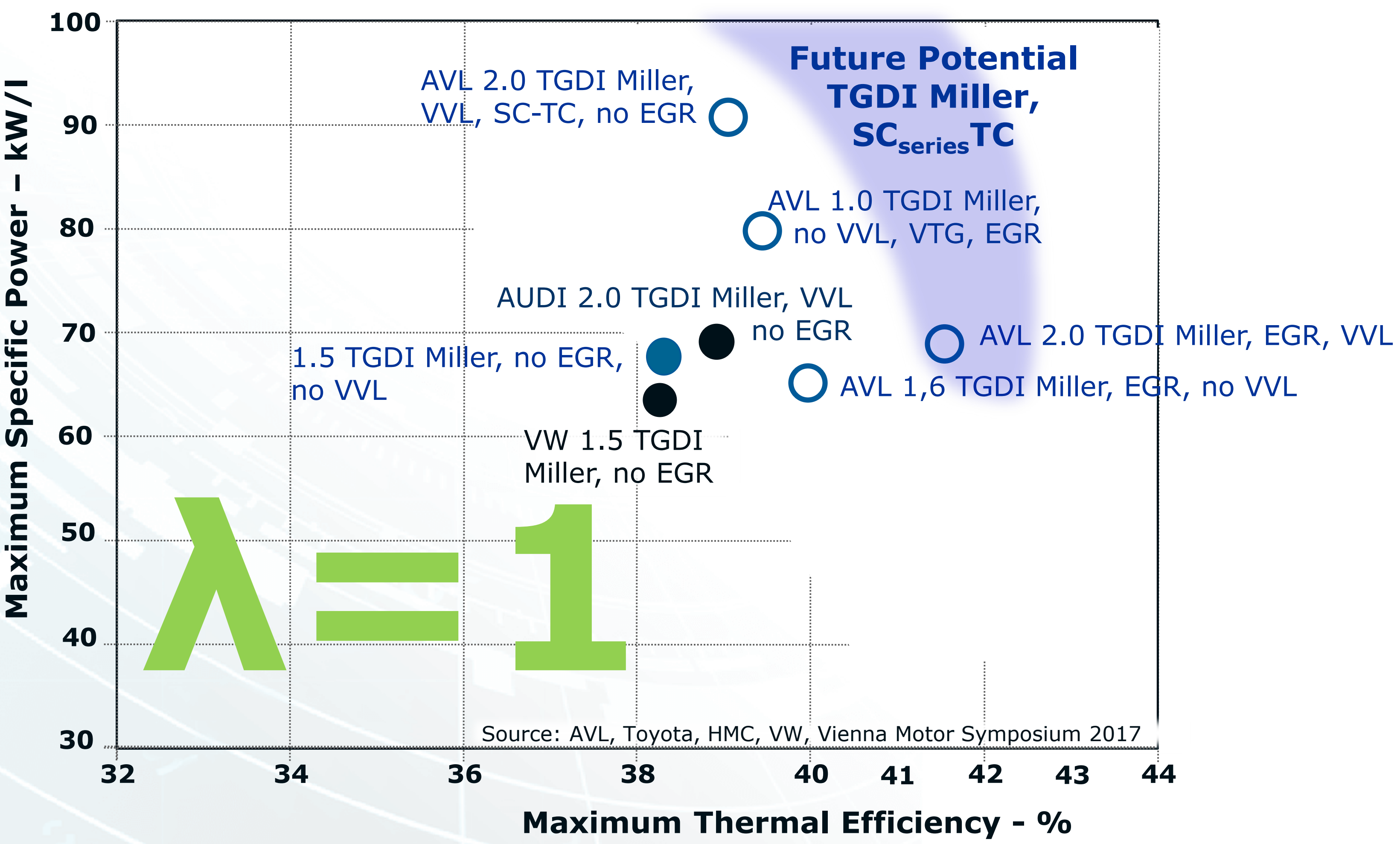
Technology Roadmap Gasoline Engines



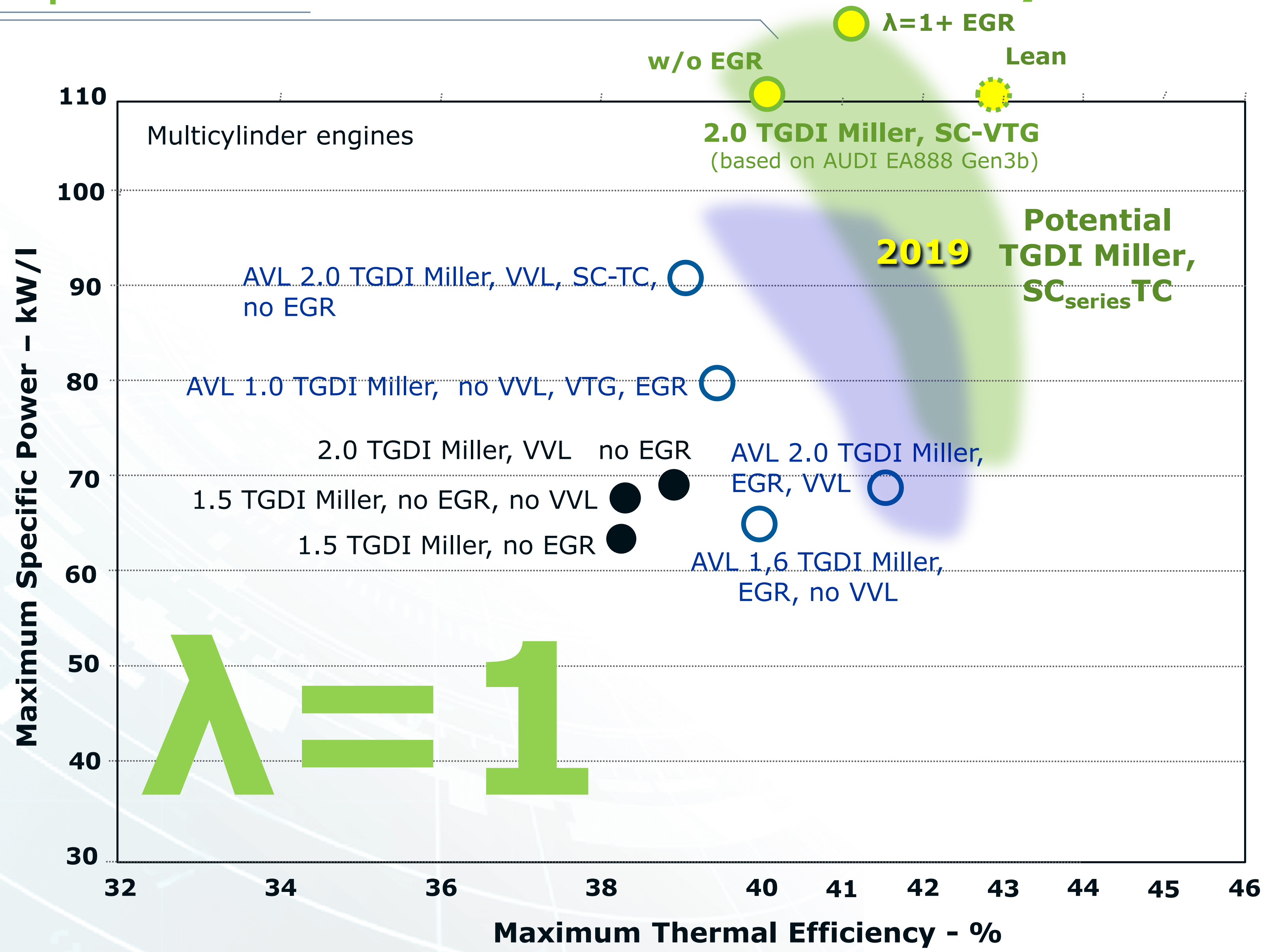
Trade-off between Max. Efficiency and Max. Specific Performance – **Status 2017/18**



Trade-off between Max. Efficiency and Max. Specific Performance – **Status 2017/18**



Trade-off between Max. Efficiency and Max. Specific Performance – **Status 05/2019**

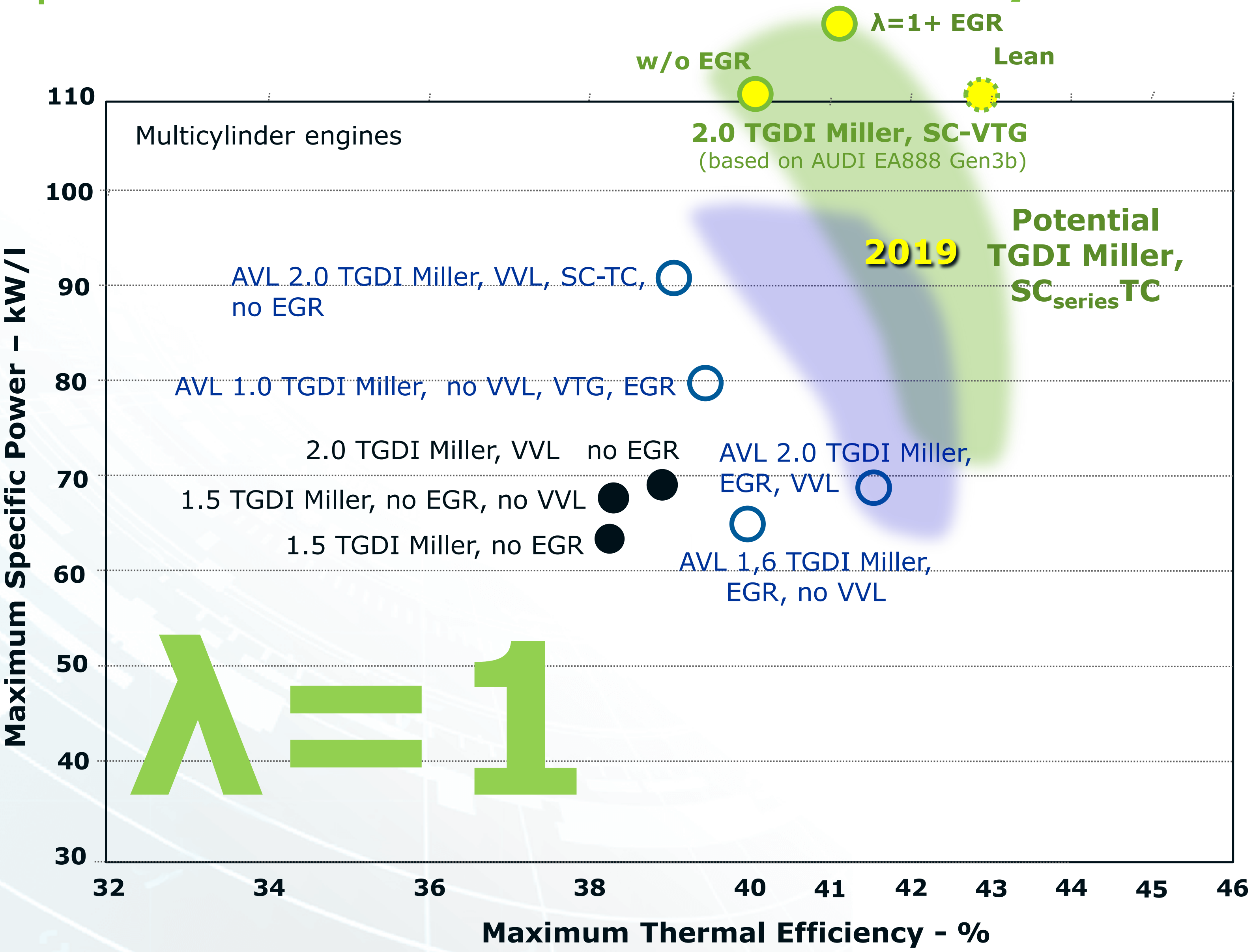


118 kW/l

with Advanced Charging & Cooled EGR

without Water Injection

Trade-off between Max. Efficiency and Max. Specific Performance – **Status 05/2019**



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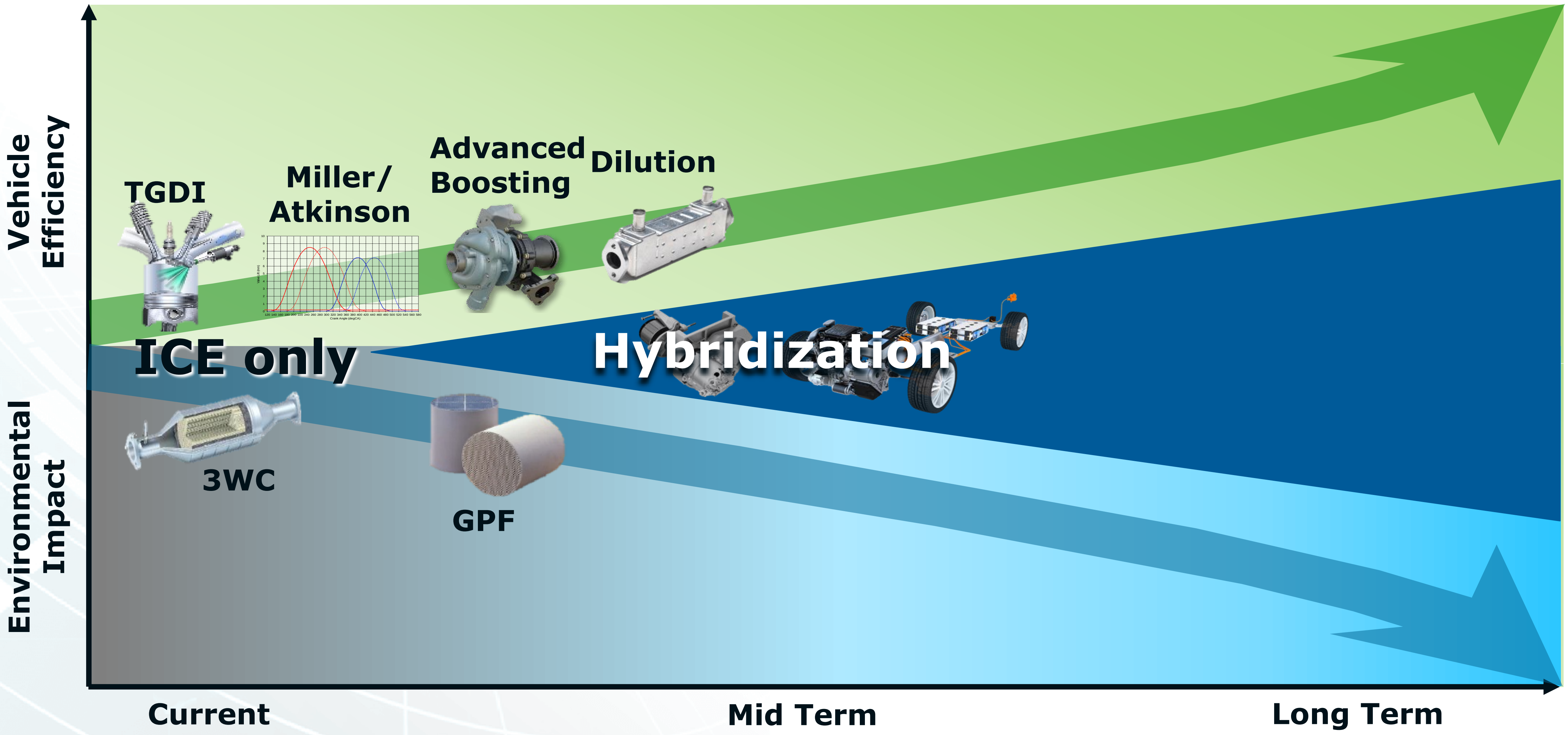
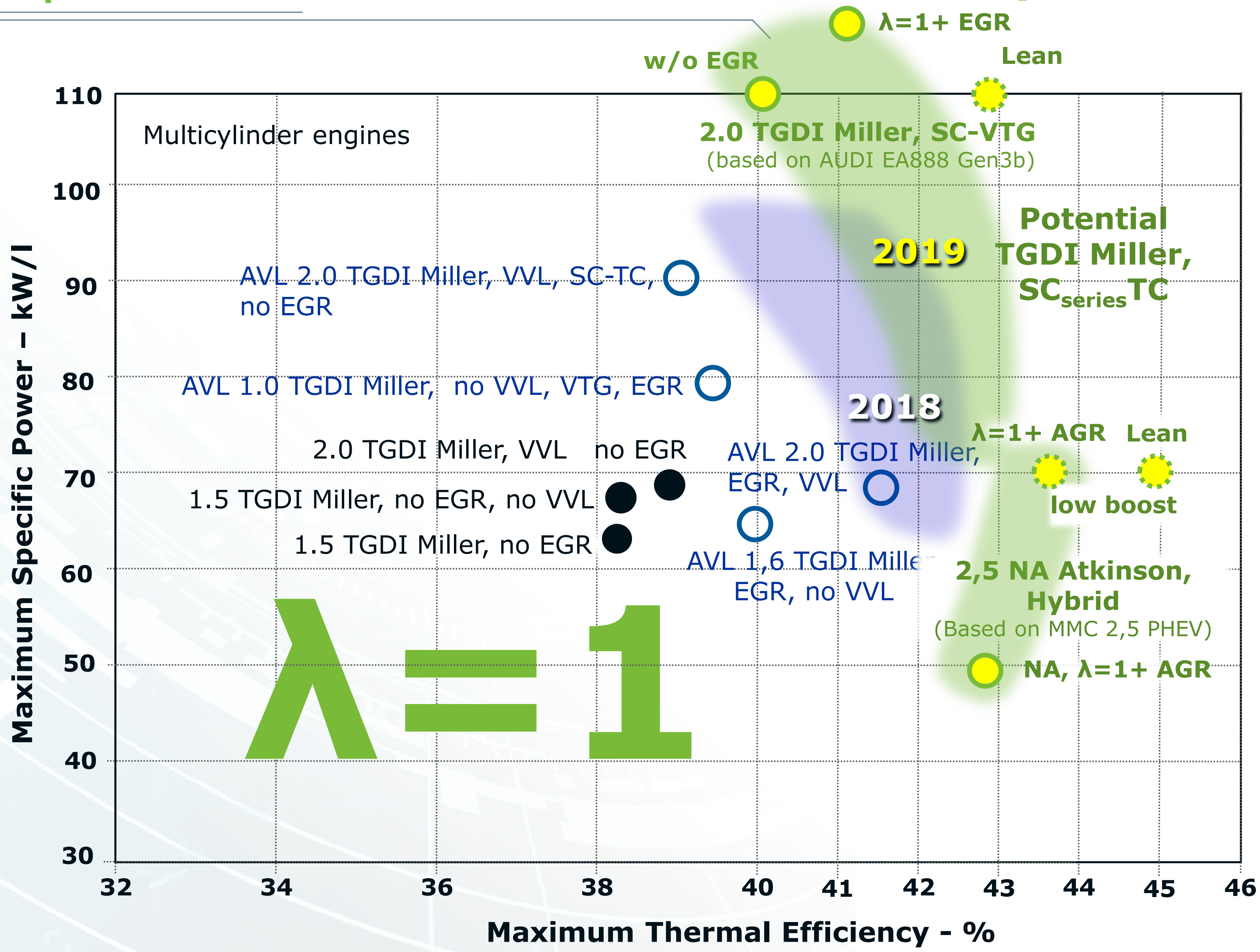
Technology Roadmap Gasoline Engines



Trade-off between Max. Efficiency and Max. Specific Performance – **Status 05/2019**



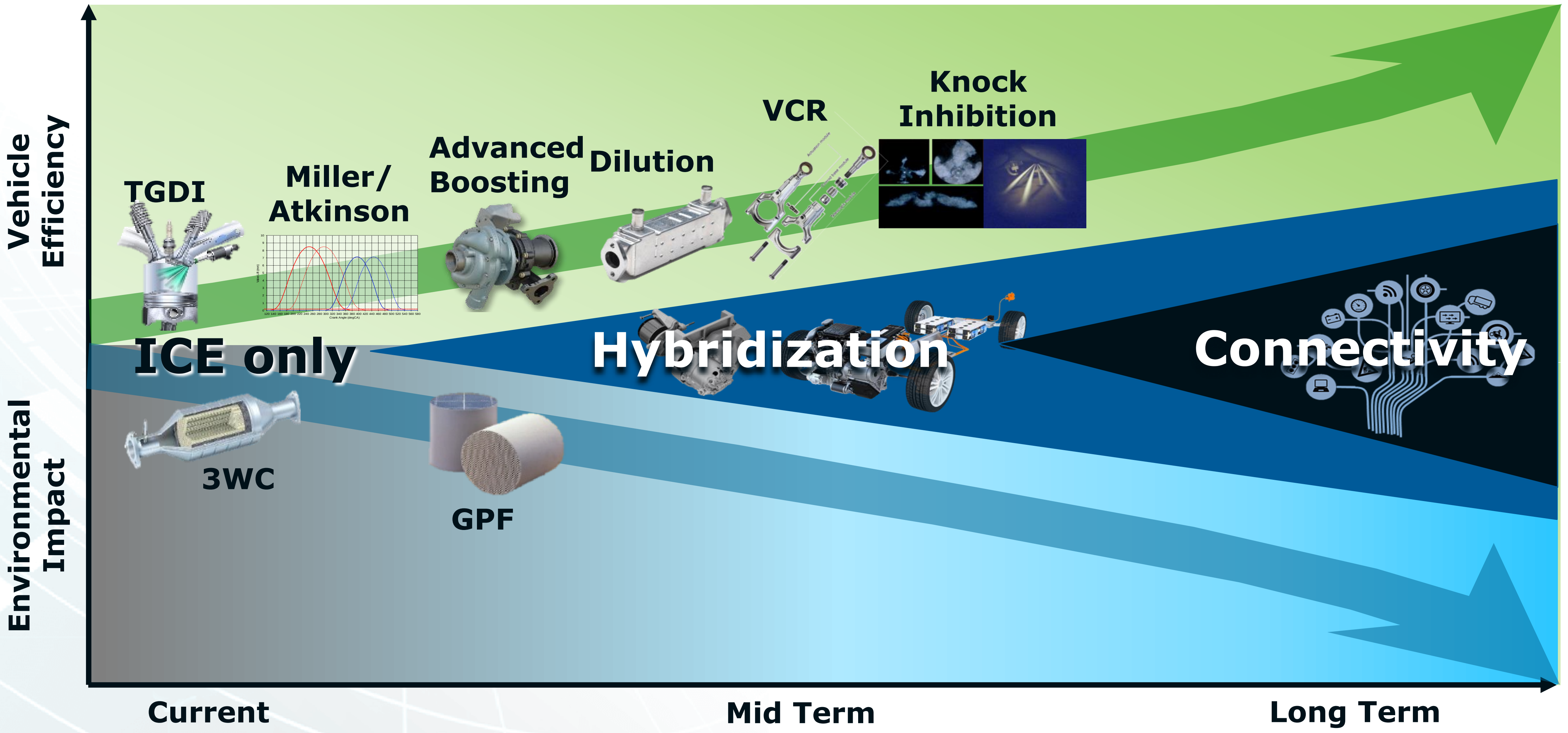
Naturally aspirated, λ=1:

BTE 42,8%
42 kW/l

Low Boost ,λ=1:

BTE 43,8%
70 kW/l

Technology Roadmap Gasoline Engines

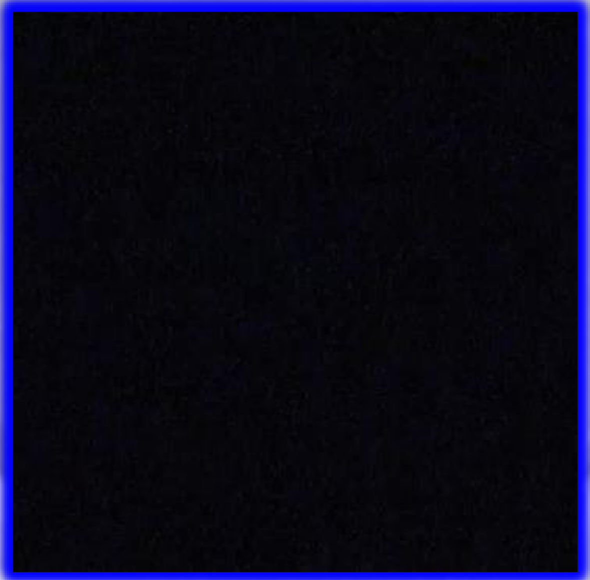


Standard versus Prechamber Spark Plug

Standard Spark Plug

Bottom View:

Intake

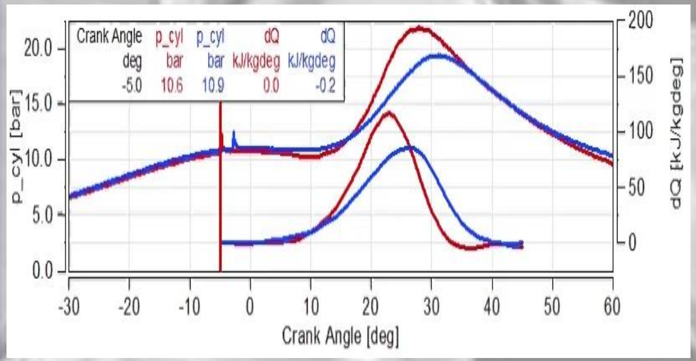


Exhaust

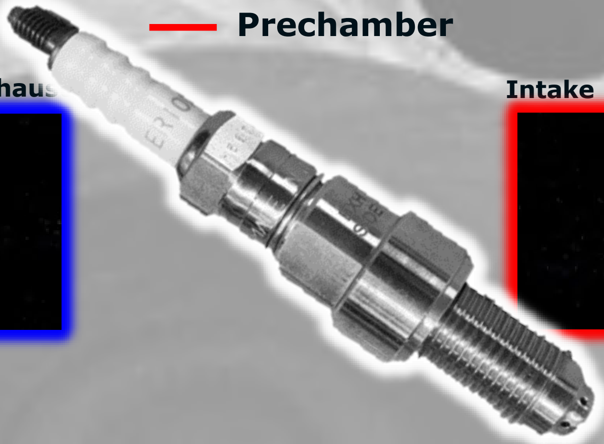
Intake

Side View:

Exhaust



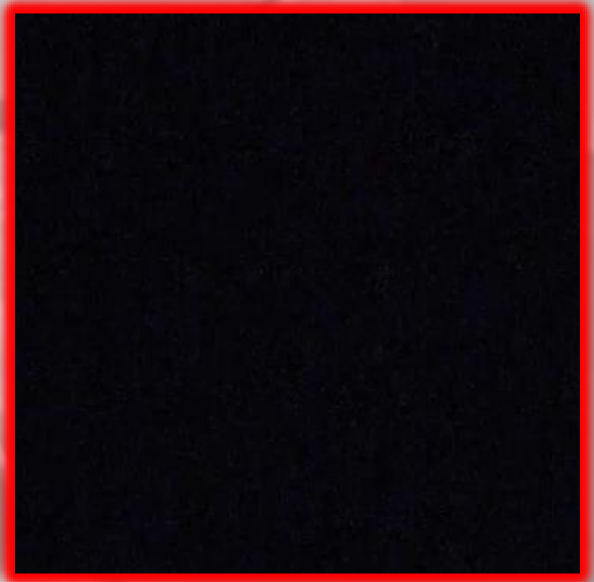
Standard
Prechamber



Prechamber Spark Plug

Bottom View:

Intake

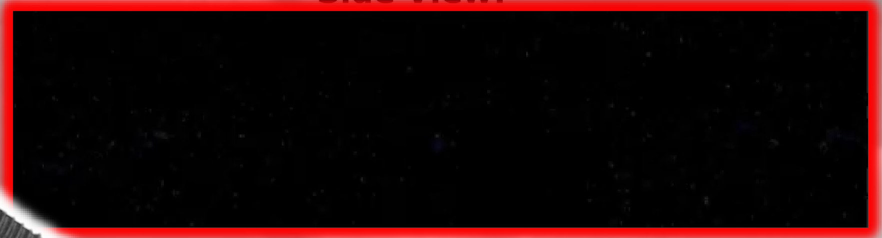


Exhaust

Intake

Side View:

Exhaust



ICE Technology:

On the way towards

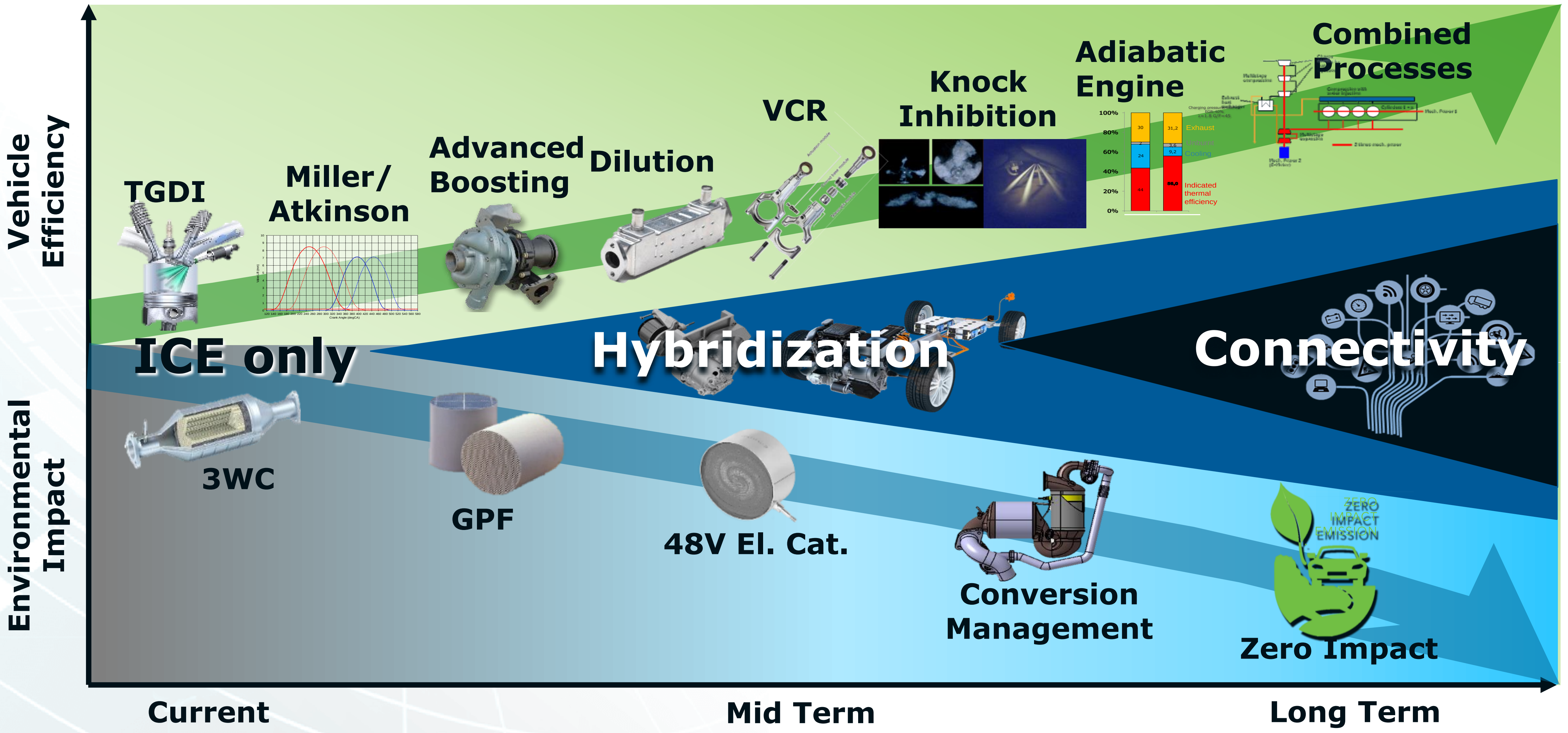
50%

> ~~45~~ % **Max. Efficiency** and

“Zero Impact Emission”

utilizing synergies with electrification

Technology Roadmap Gasoline Engines



Zero Impact Emission Operating Strategy

Cold Drive Off Predictive Cat-Heating System

Electric drive off + pure electric drive

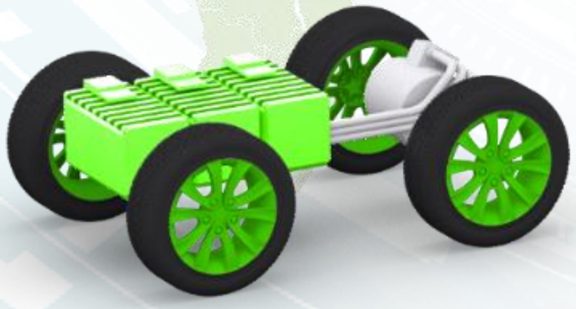
Torque Assist

Balanced SOC and operation strategy management

Maximized Emission Robustness

Challenges – BEV

Battery Electric



Lifecycle

- Primary Energy CO_2
- Battery Production
- Charging/ Operation Efficiency

Charging

- Infrastructure
- 800V / 350 kW
- Low Temp. Operation

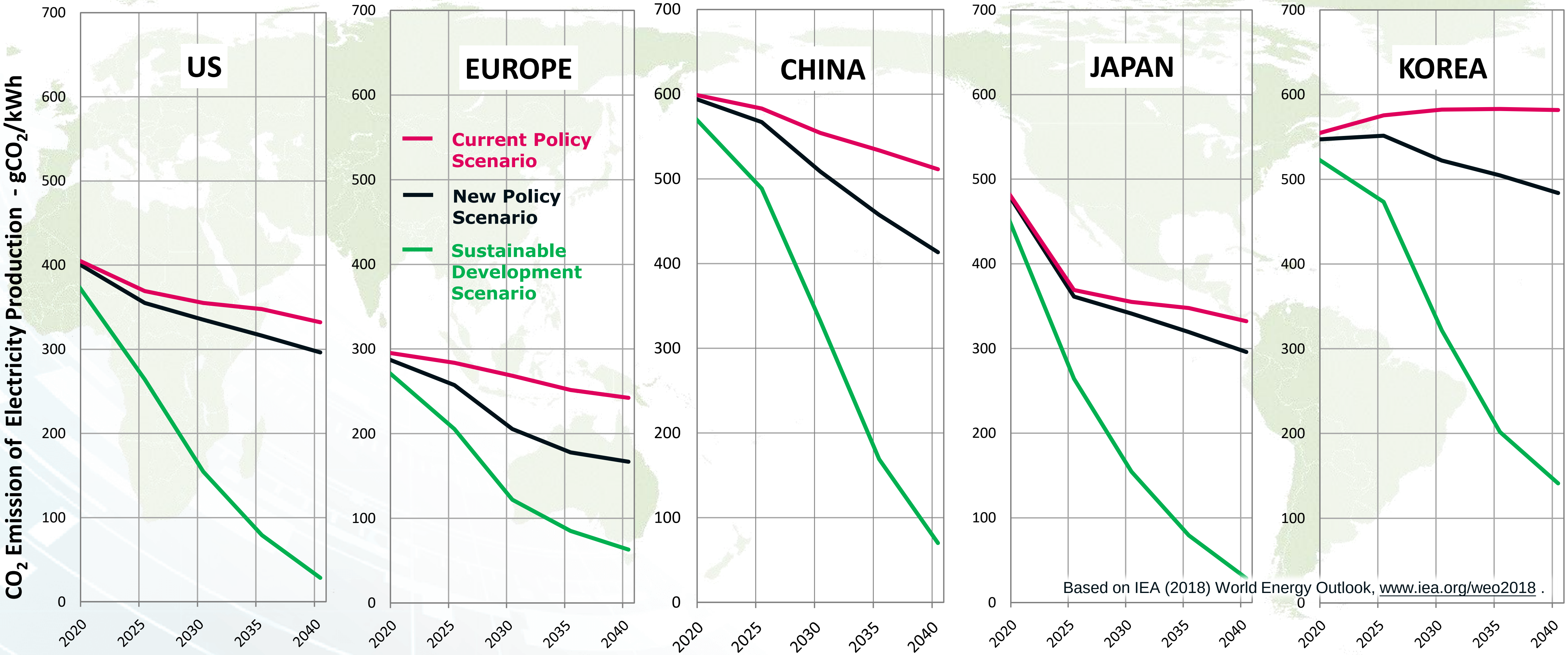
e-Range

- Comfort / Auxiliaries
- ADAS
- Thermal Management

Cost

- Scale Up
- Evolution of Technology
- Raw material hedging

Electricity Mix Prognosis (Energy Production)



Based on IEA (2018) World Energy Outlook, www.iea.org/weo2018 .

Differentiated primary energy scenario in key areas for cell production

Electricity Supply Chain - Europe

EU28

Primary Energy Carrier
(incl. Upstream)

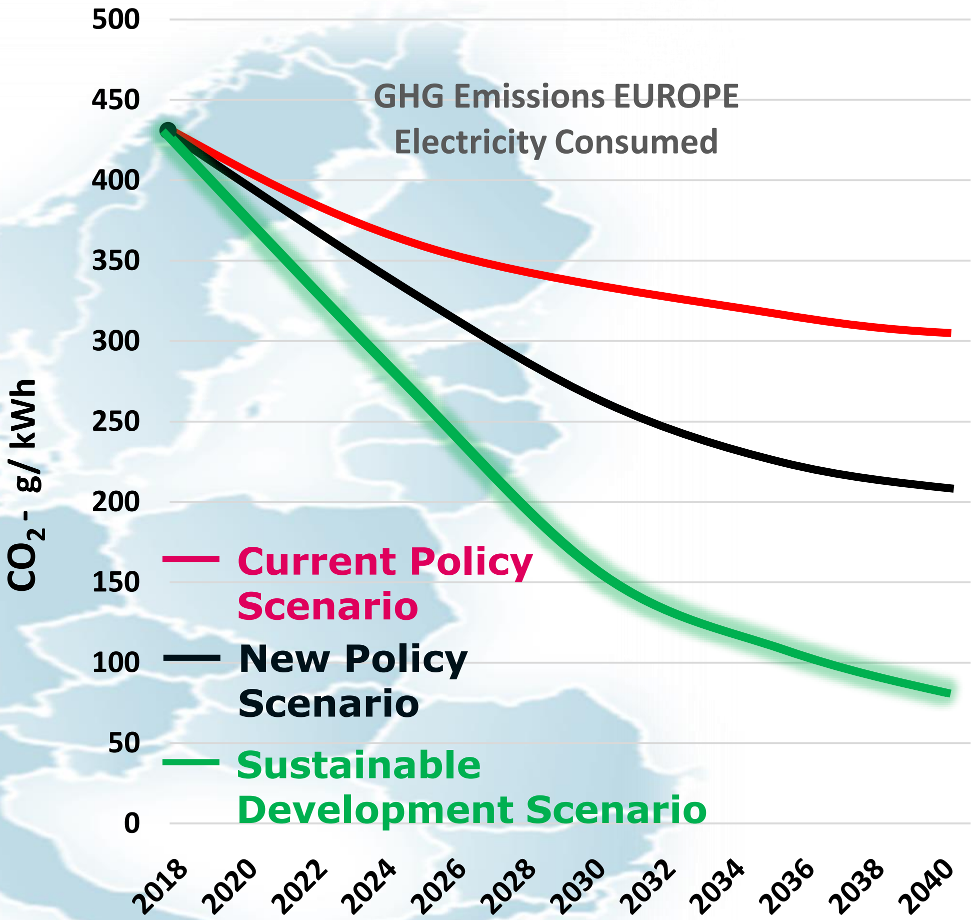
Electricity Production

340 gCO_2/kWh

Storage / Transport

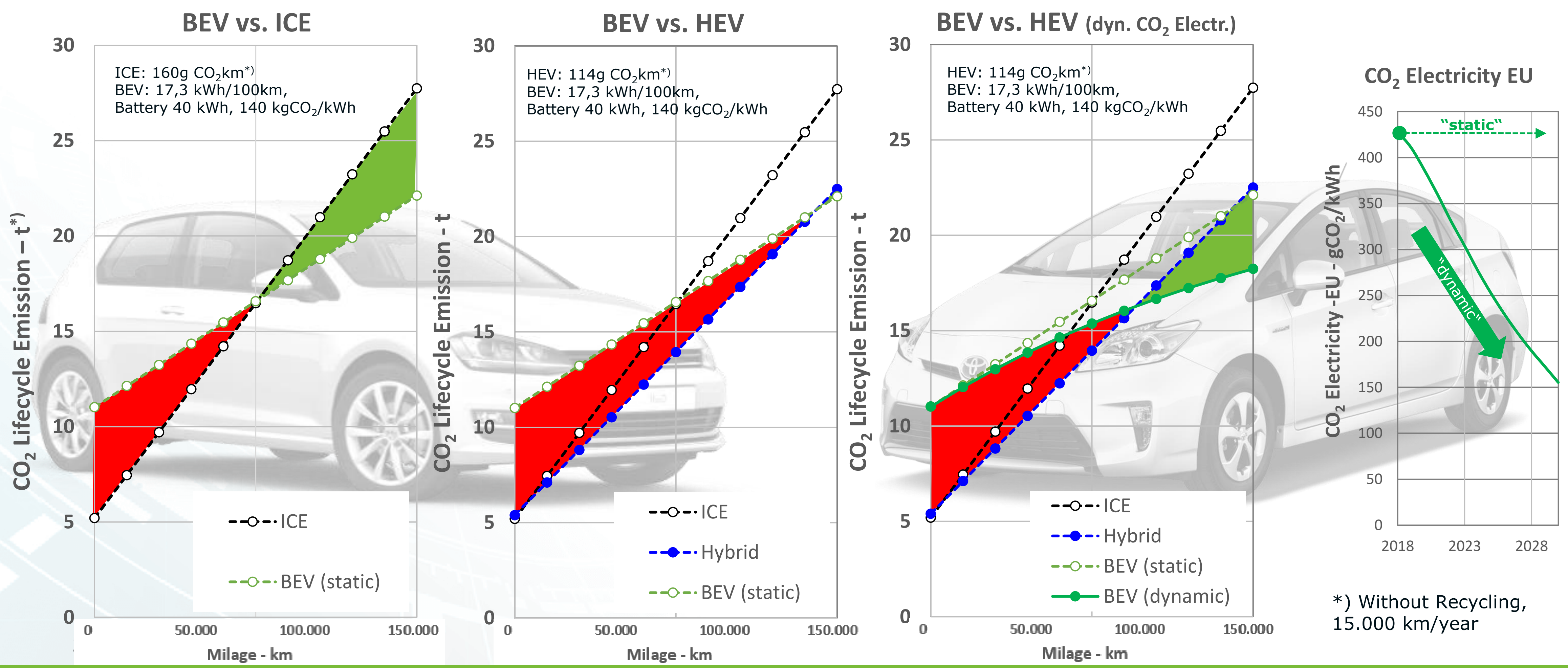
Electricity Consumed

428 gCO_2/kWh



Based on data from IEA 2018 and European Commission, Joint Research Center (JRC), July 2017

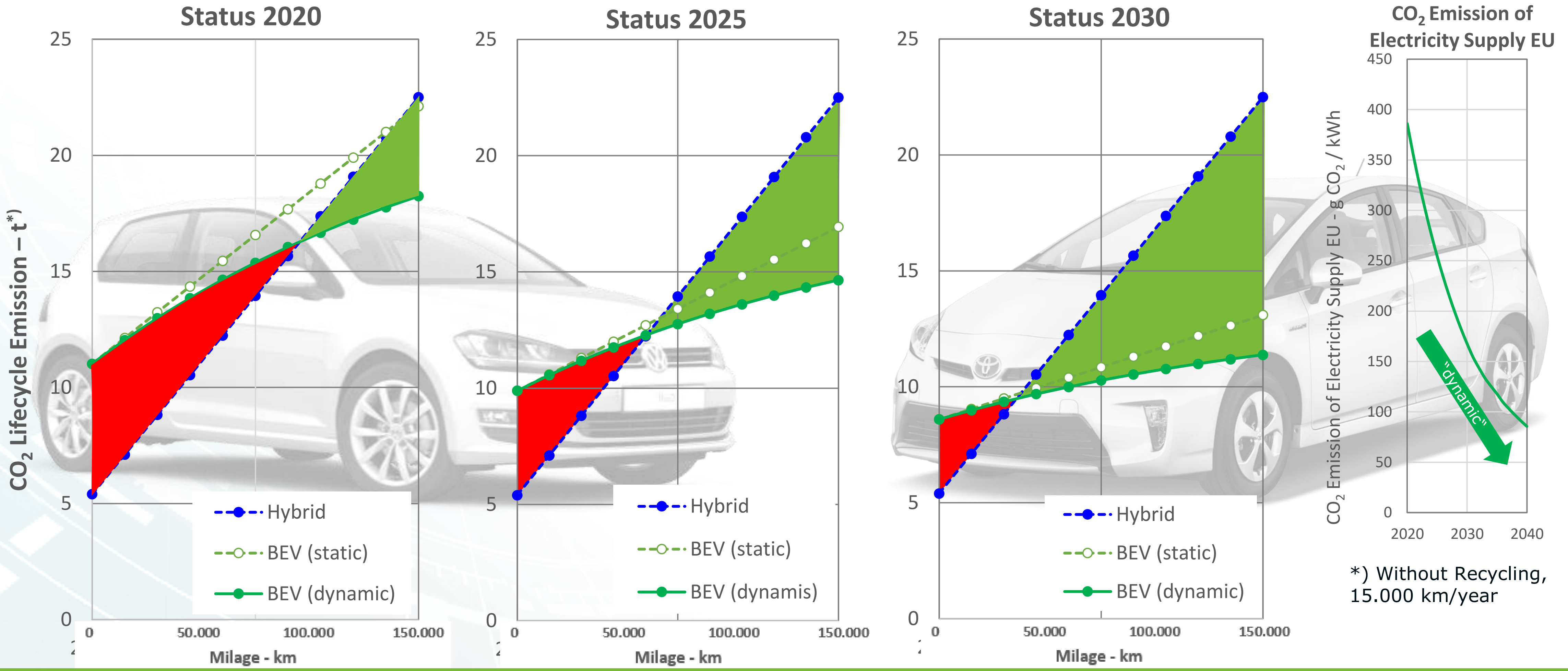
Lifecycle Emissions CO_2 (w/o Recycling)



*) Without Recycling,
15.000 km/year

BEV versus ICE lifecycle CO_2 relation strongly depends on boundaries

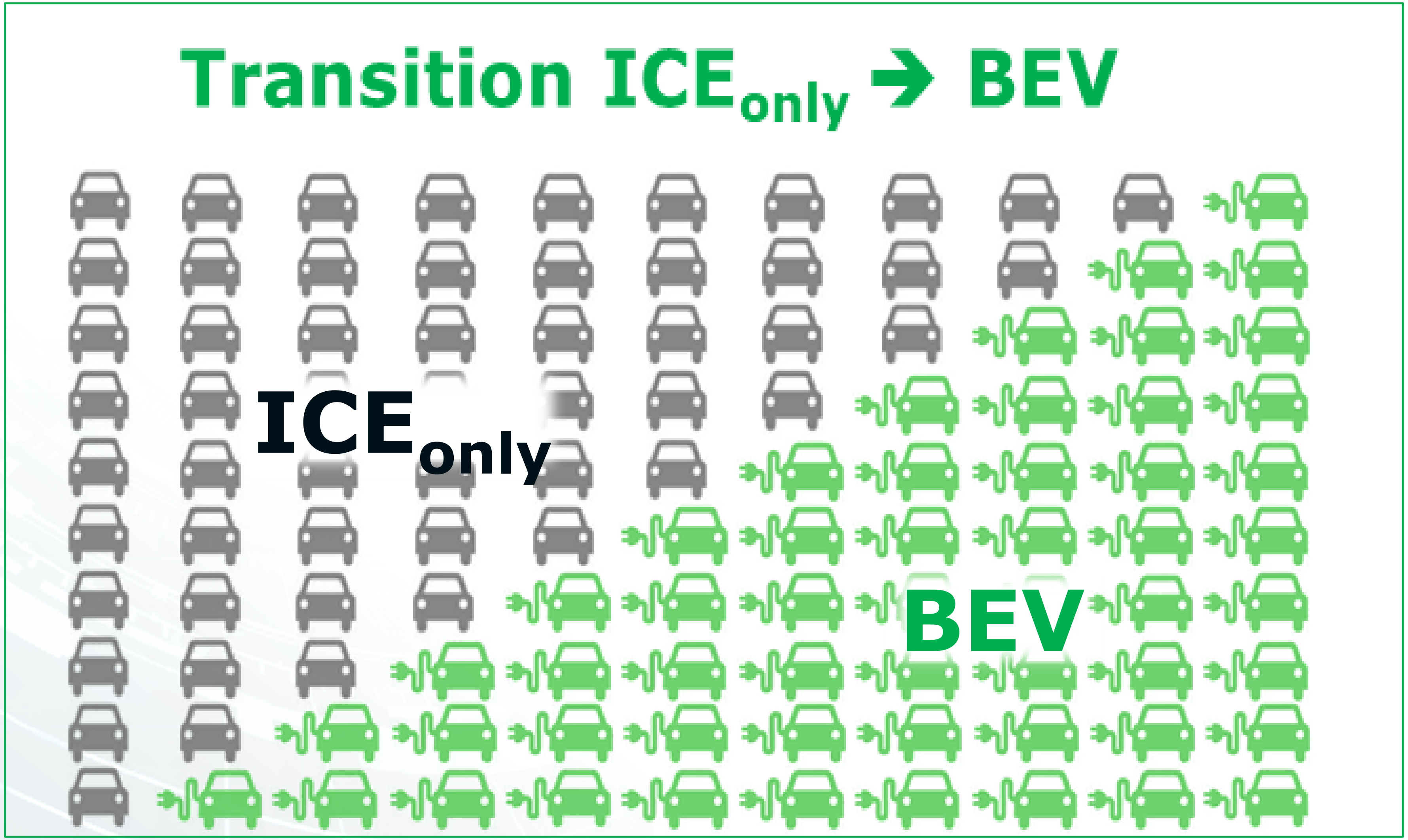
Lifecycle Emissions CO_2 (w/o Recycling)



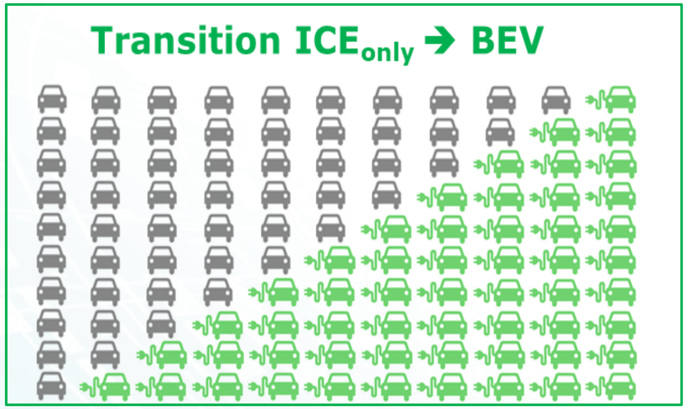
*) Without Recycling, 15.000 km/year

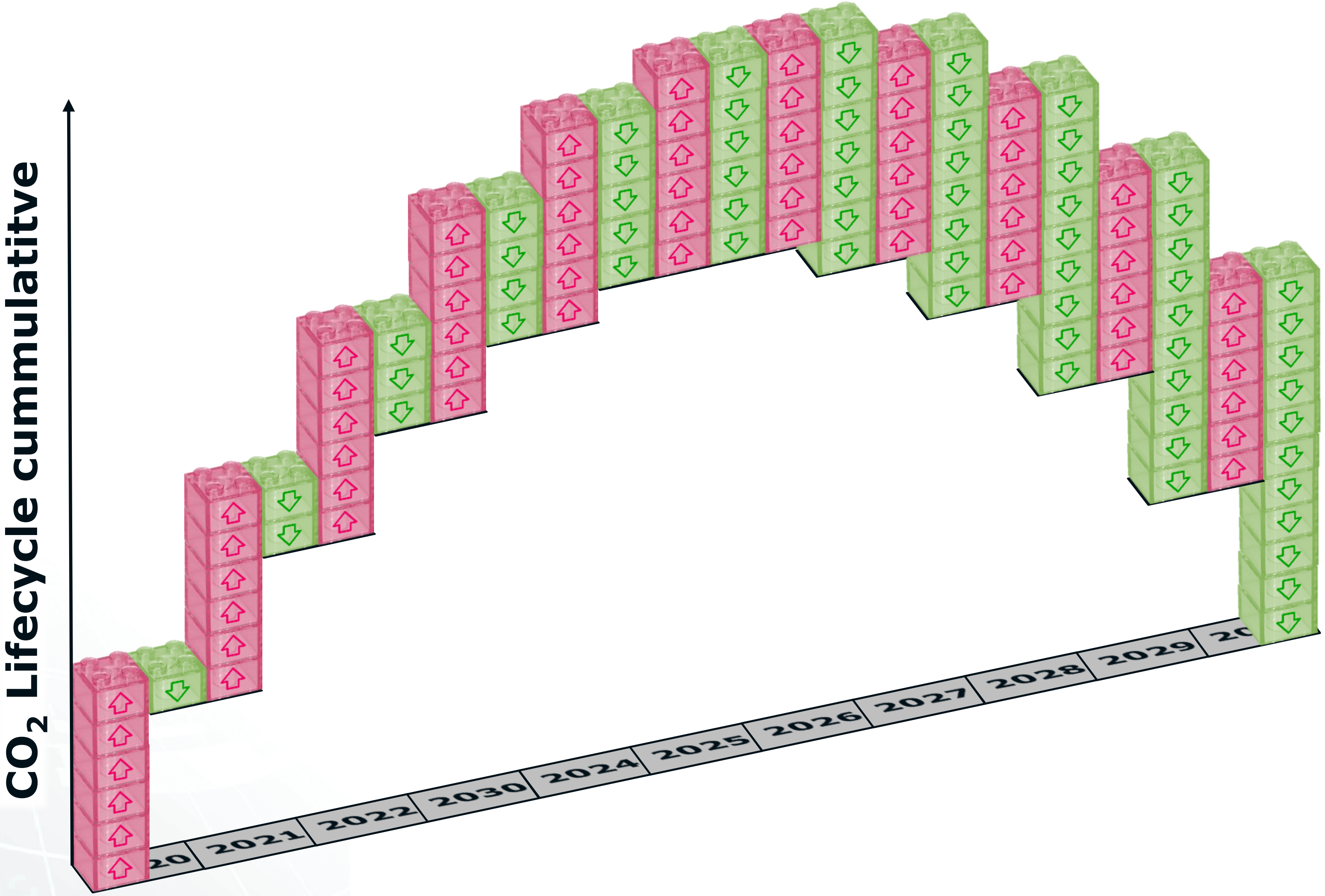
With later introduction, BEV becomes more attractive

BEV CO_2 Lifecycle – Cumulative



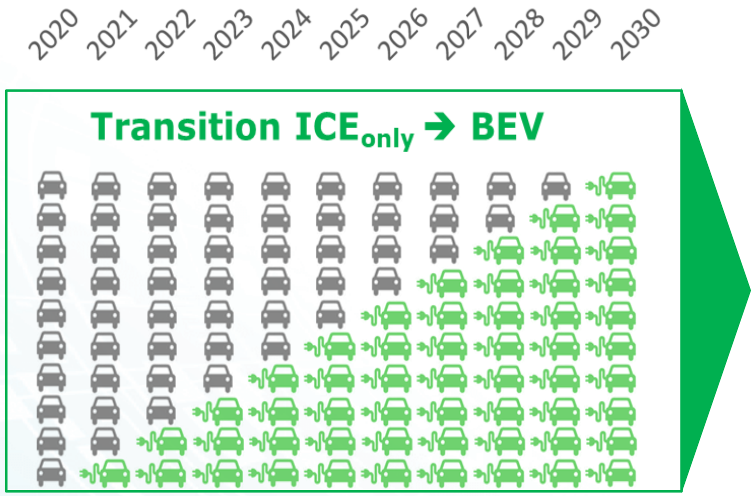
BEV CO_2 Lifecycle – Cumulative



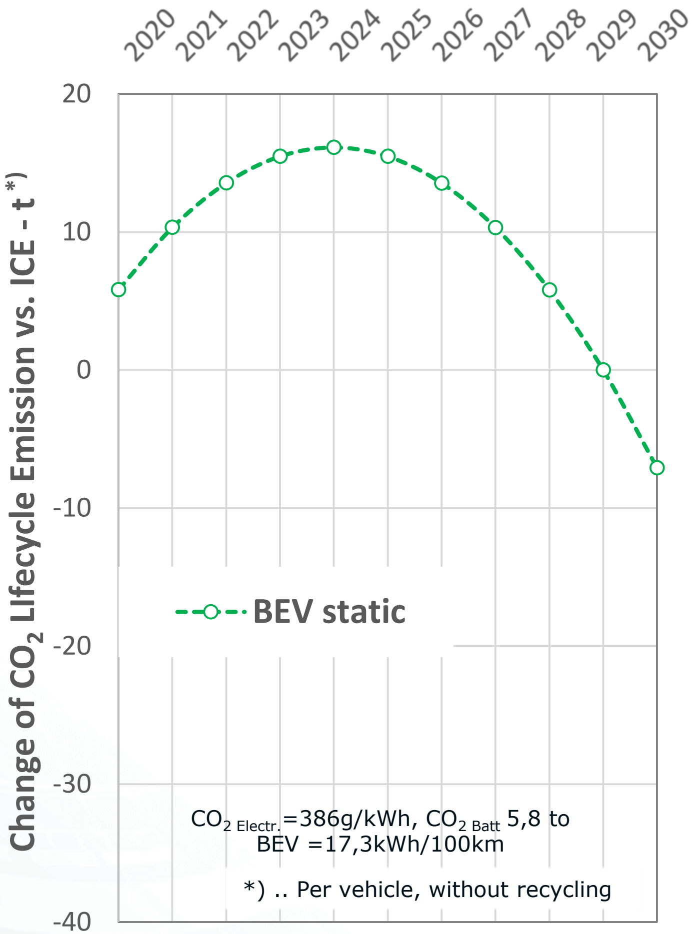


CO_2 Impact of New Technology Introduction

Replacement of ICE_{only}



Impact on Lifecycle CO_2 *)



CO_2 Impact of New Technology Introduction

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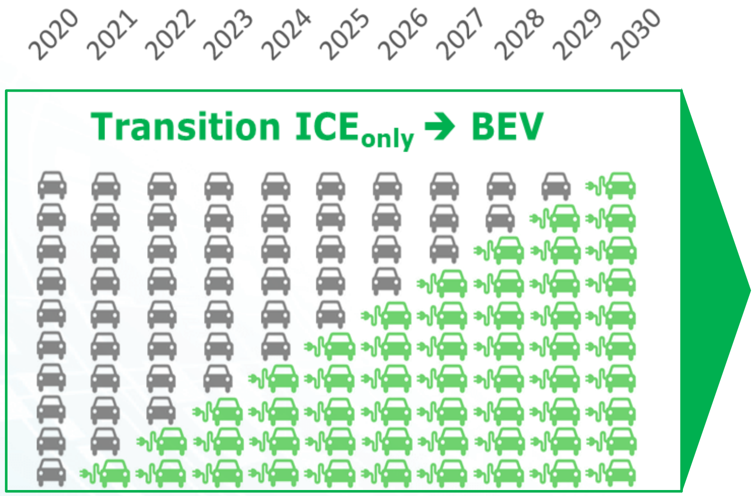
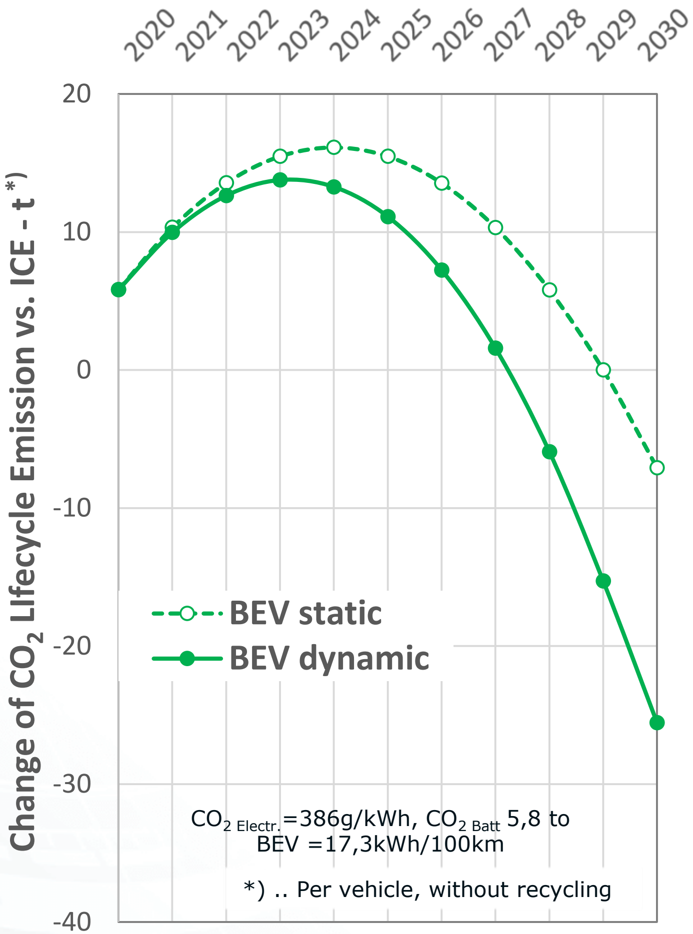


Impact on Lifecycle CO_2*)



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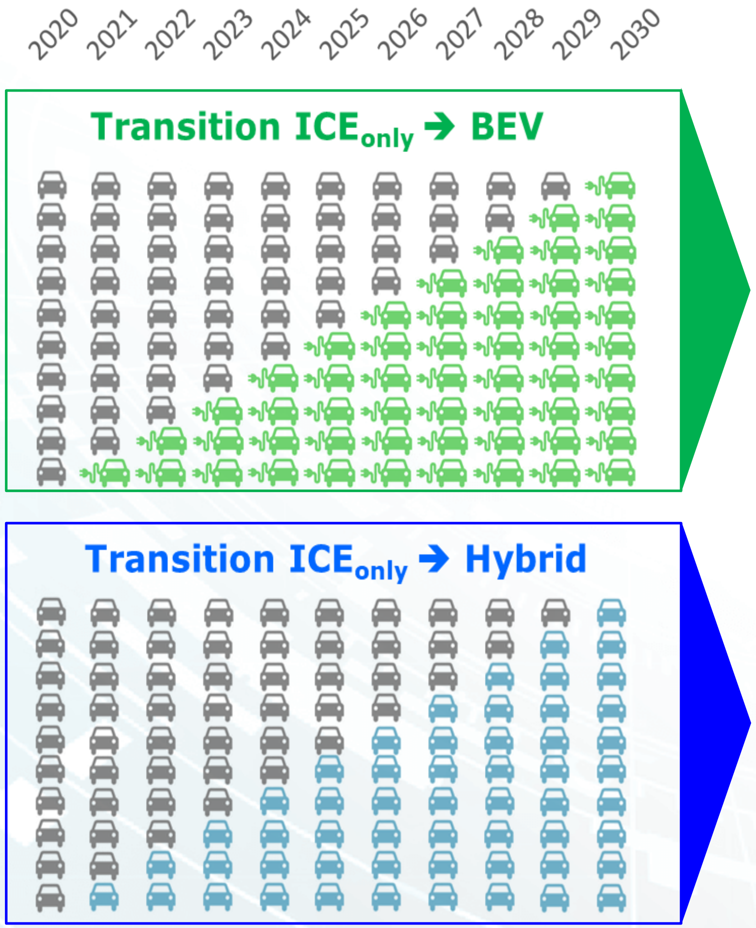

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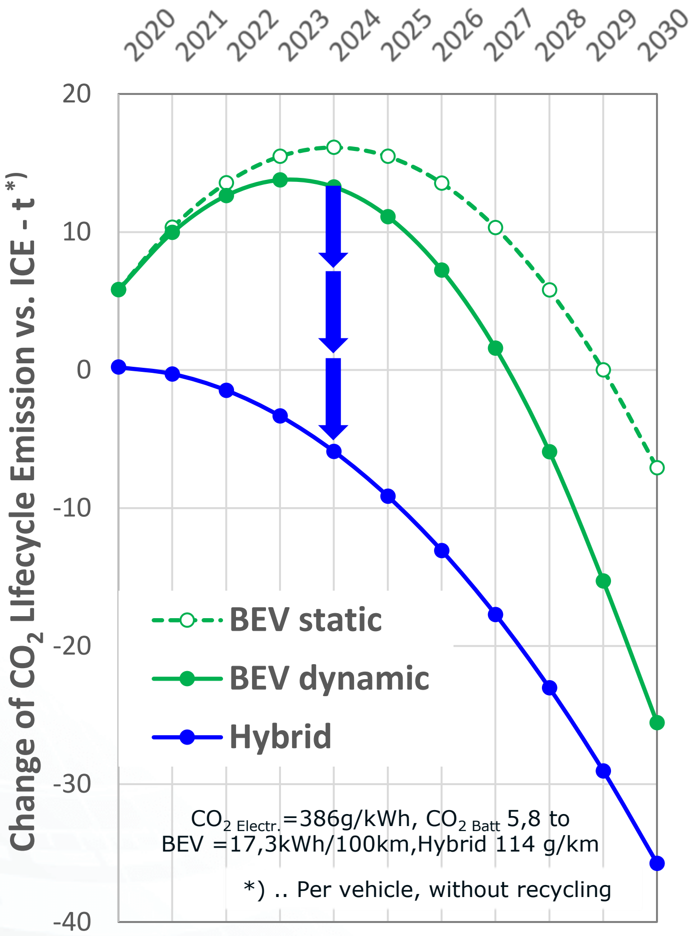

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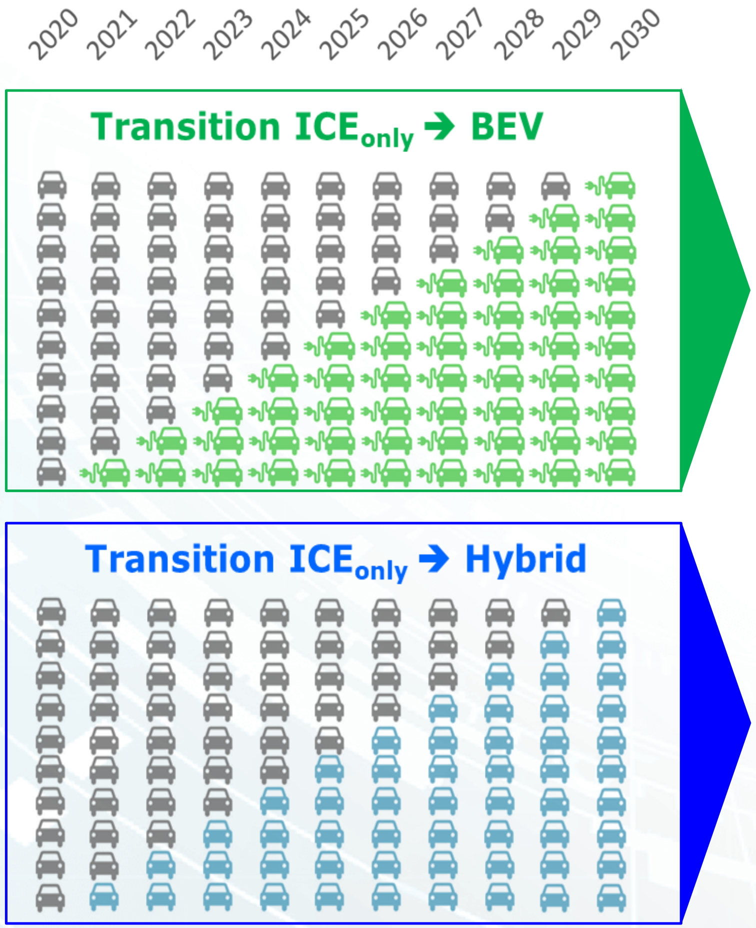
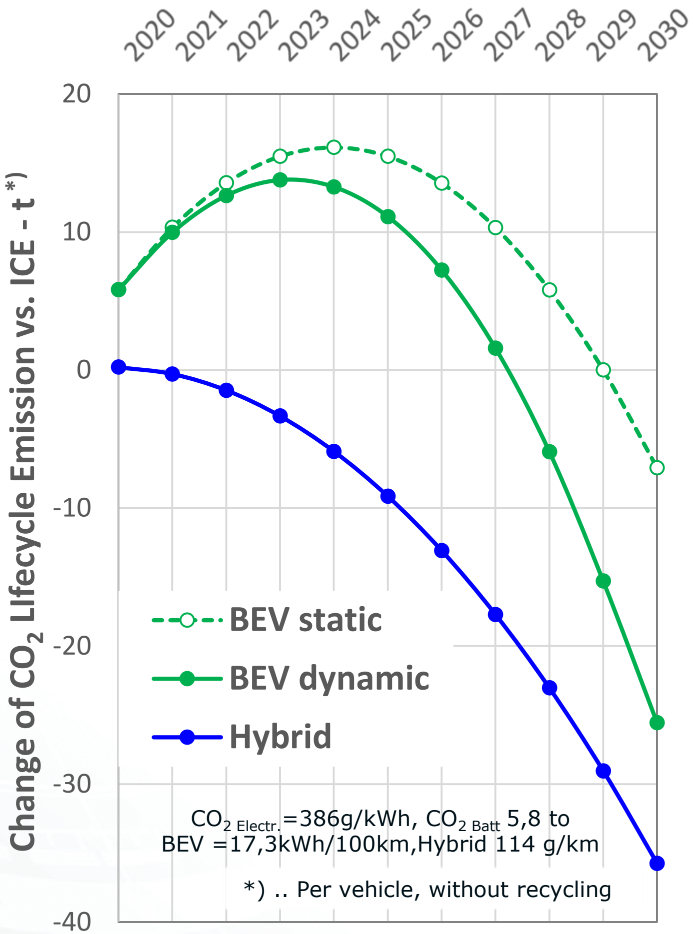
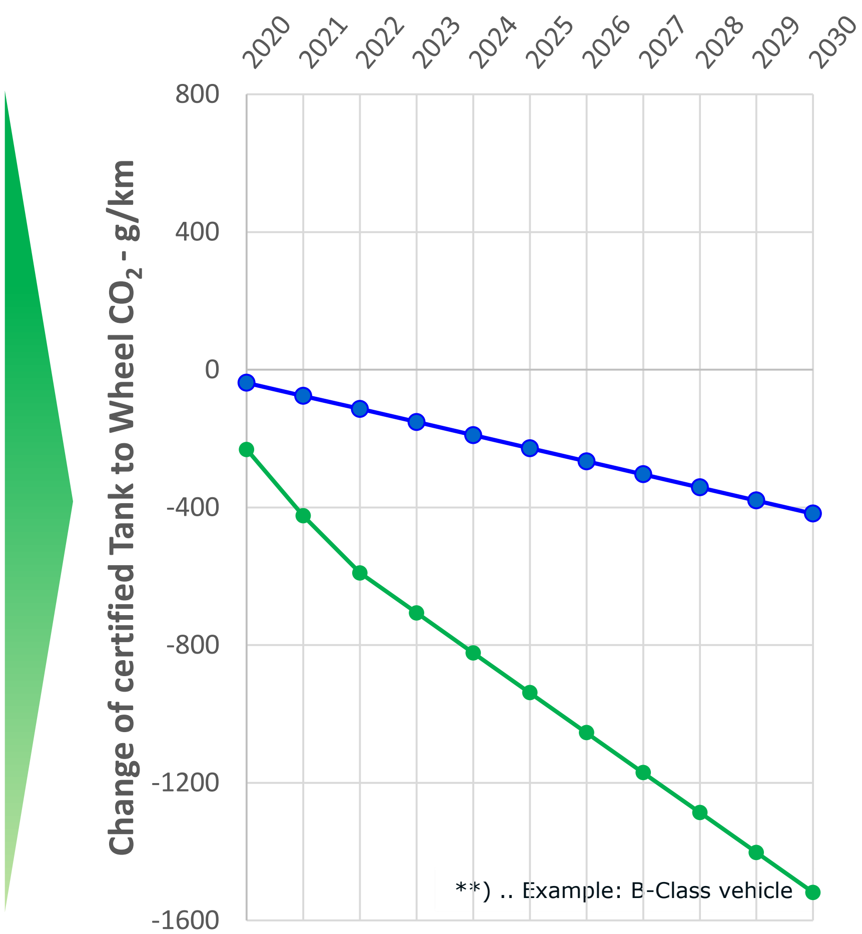


Impact on Lifecycle CO_2*)



Impact on Certified CO_2**)

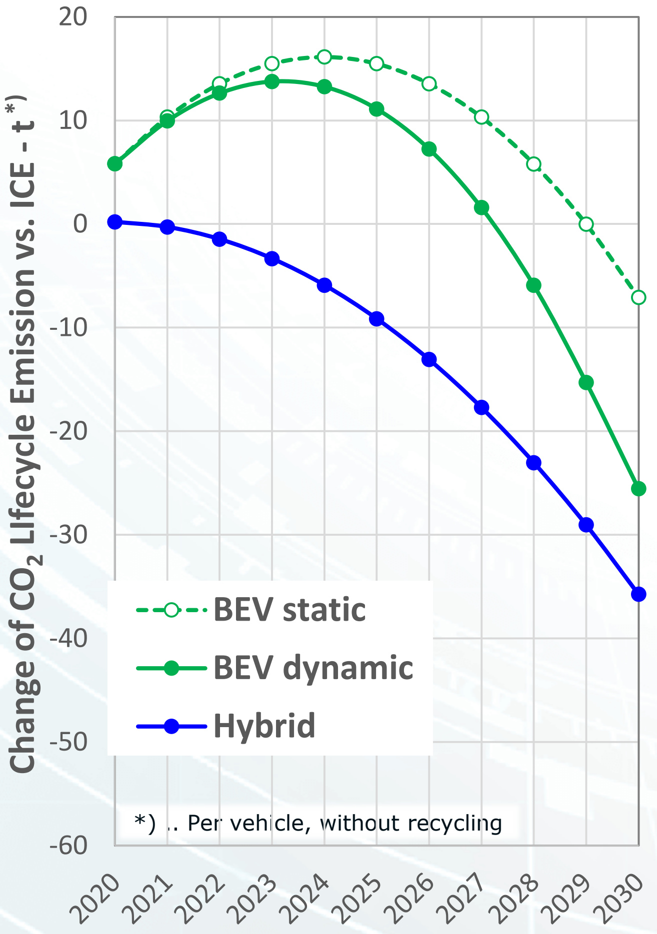


Current Tank to Wheel Legislation is just focused on BEV introduction

CO_2 Impact of New Technolgoy Introduction

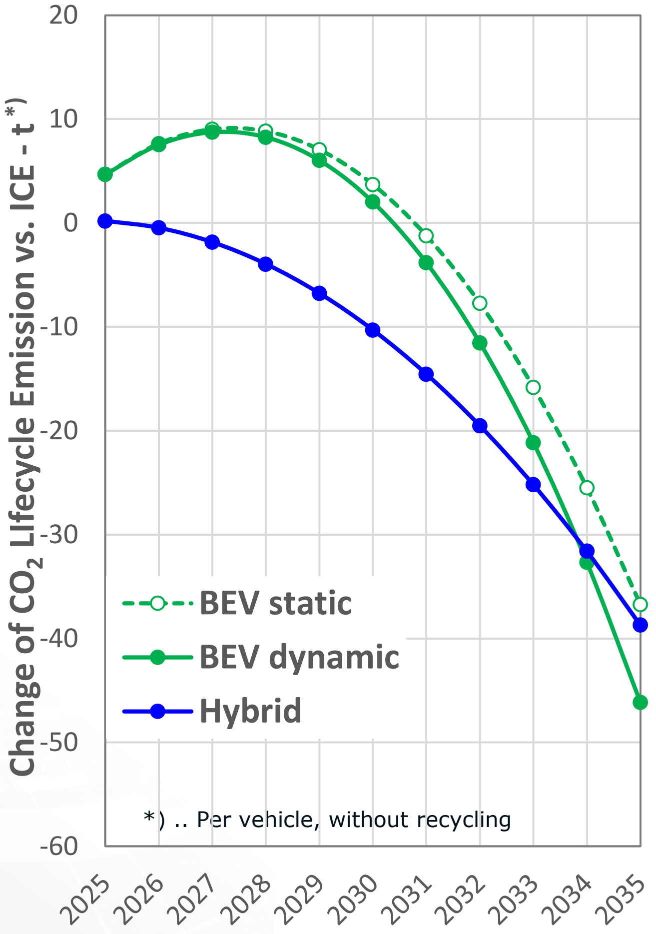
Starting Point 2020

$CO_{2\ Electr.}$ = 386g/kWh, $CO_{2\ Batt}$ = 5,8 to
ICE = 160 g/km, Hybrid 114 g/km



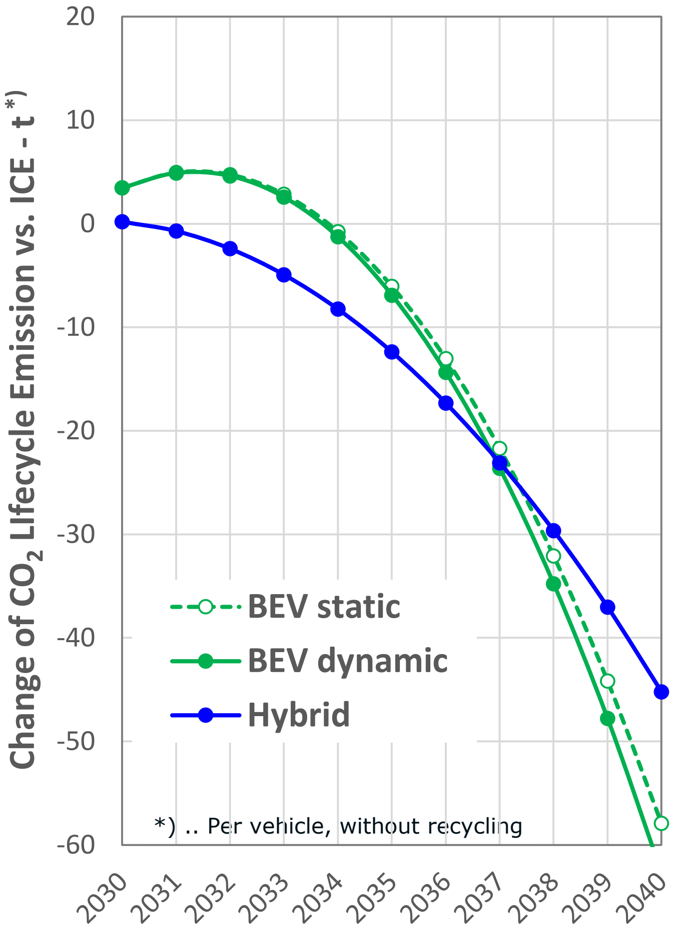
Starting Point 2025

$CO_{2\ Electr.}$ = 259g/kWh, $CO_{2\ Batt}$ = 4,7 to
ICE = 150 g/km, Hybrid = 102 g/km

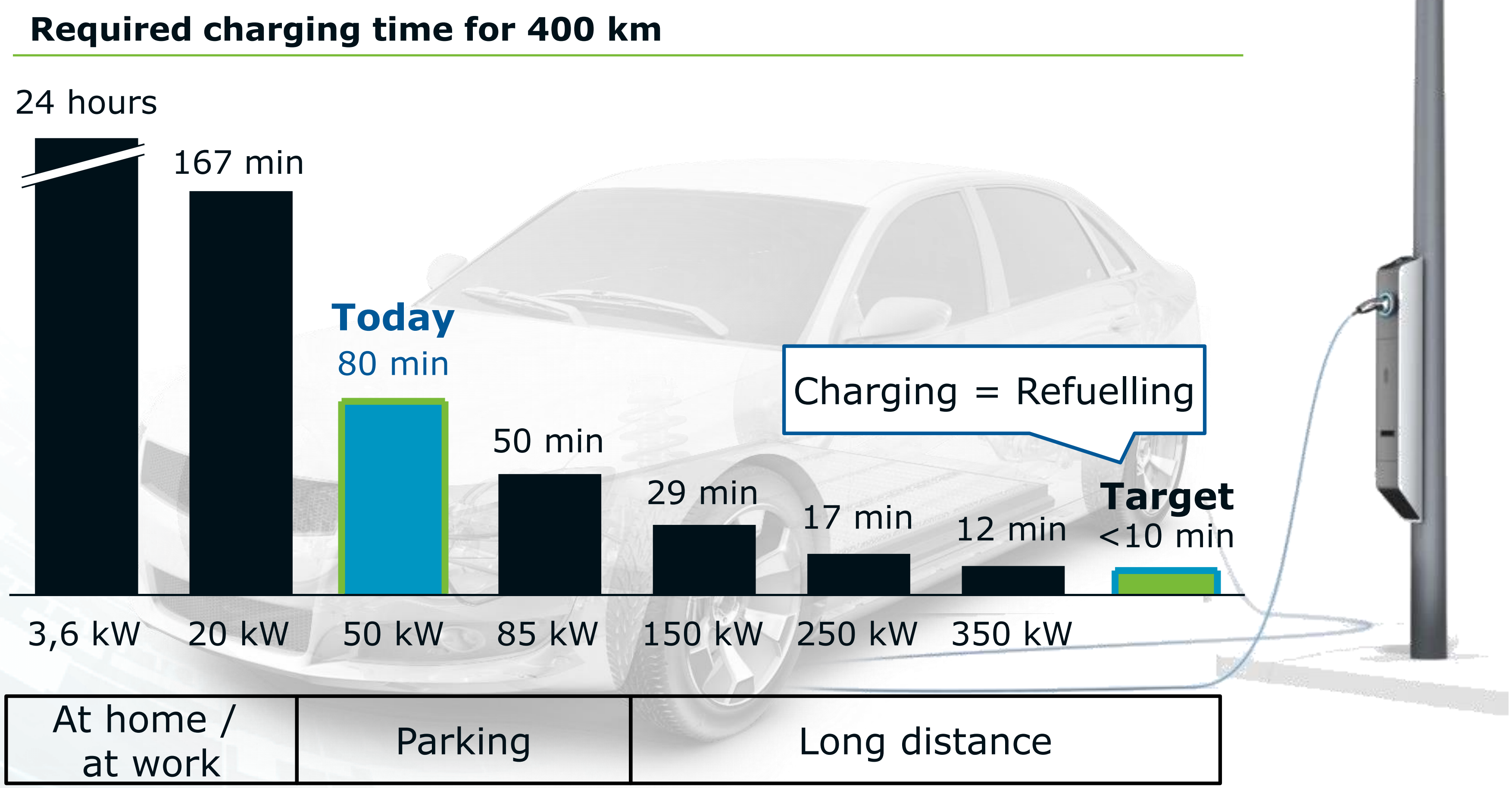


Starting Point 2030

$CO_{2\ Electr.}$ = 162g/kWh, $CO_{2\ Batt}$ = 3,5 to
ICE = 141g/km, Hybrid = 87 g/km

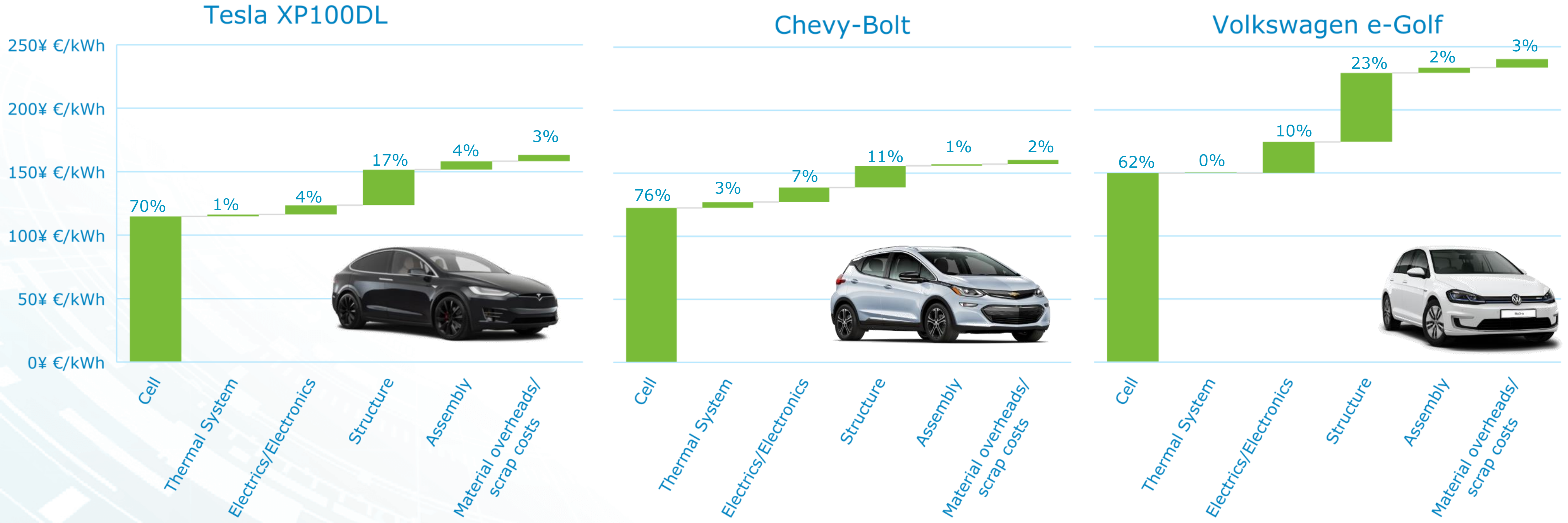


Required Charging Time for 400 km Range



Source: AVL, Strategy Engineers, Audi, bimmertoday

Cost Split of Selected Battery Systems

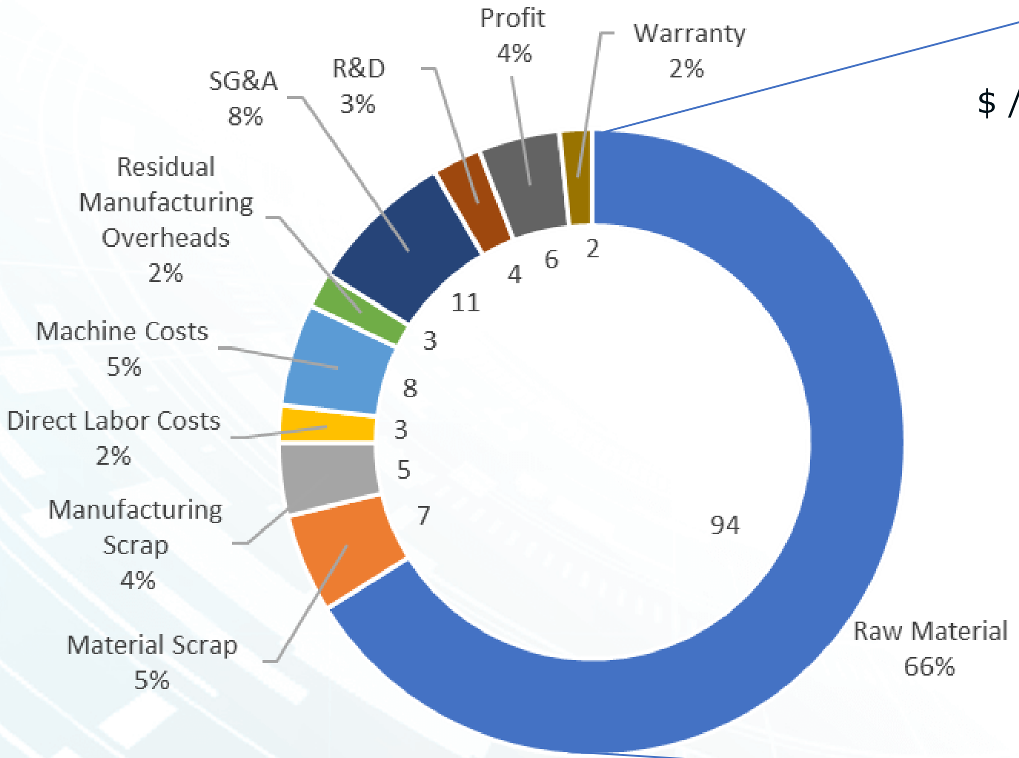


Source: AVL cost analysis in Series Battery Benchmark Program

Cell costs will remain dominant cost contributor for vehicle batteries

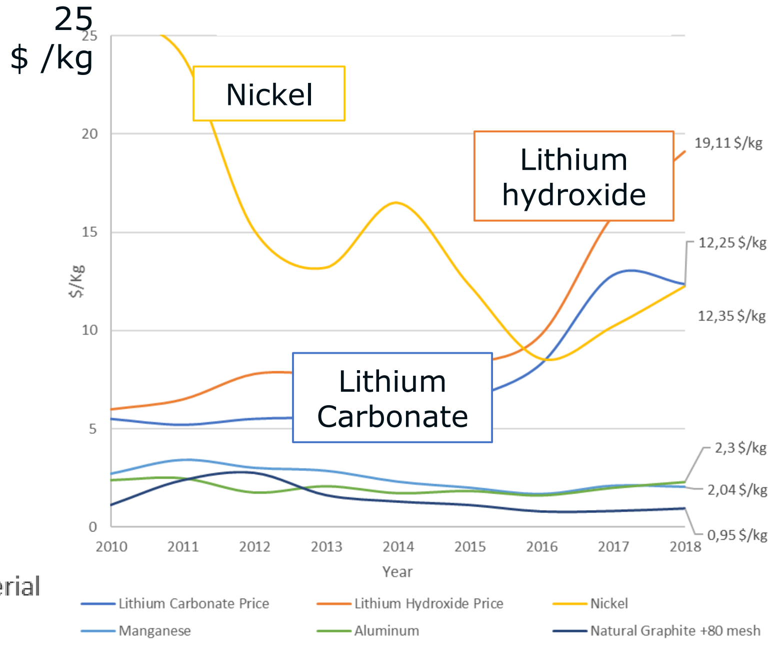
Battery Cell Cost Influencer

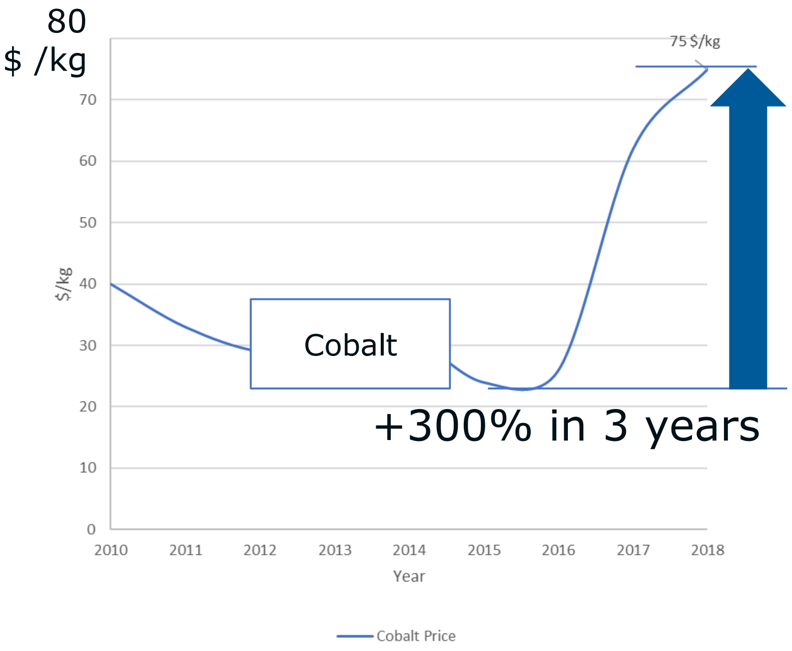
Cost Break-Down Automotive Battery Cell:



Battery Cell Costs, Source: AVL internal analysis

Prices Raw Materials:

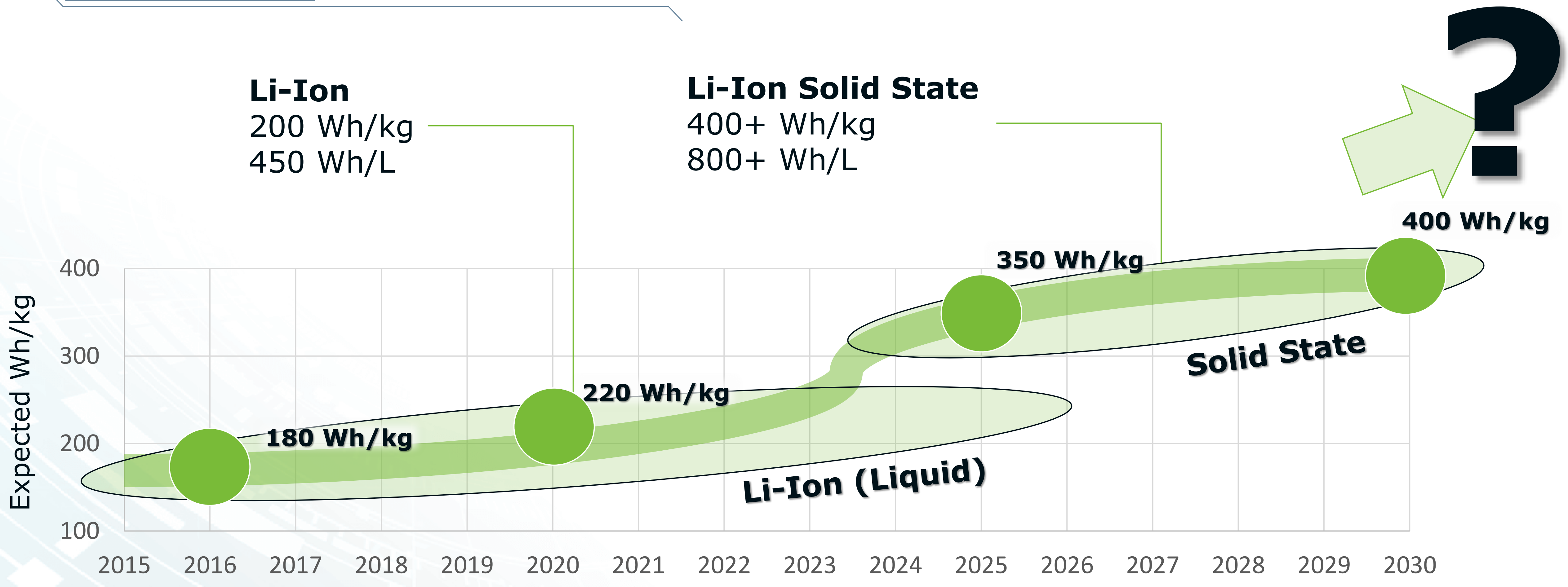




Source: SMM Prices 12.09.2018

2/3 of cell cost influenced by raw material price, which is highly fluctuating today

Battery Cell Technologies 2015 - 2030



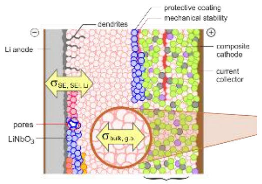
Trend Highlights – Electrification 2020+

Predictive Controls

✓ Quickly available solutions

400V? 800V?

✓ Trickling down from performance segment



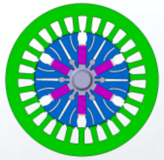
Solid-state cells?

✓ 2025 in low power or long range EV

€

Cost Trends: Battery & Fuel Cell

✓ High reduction potential seen

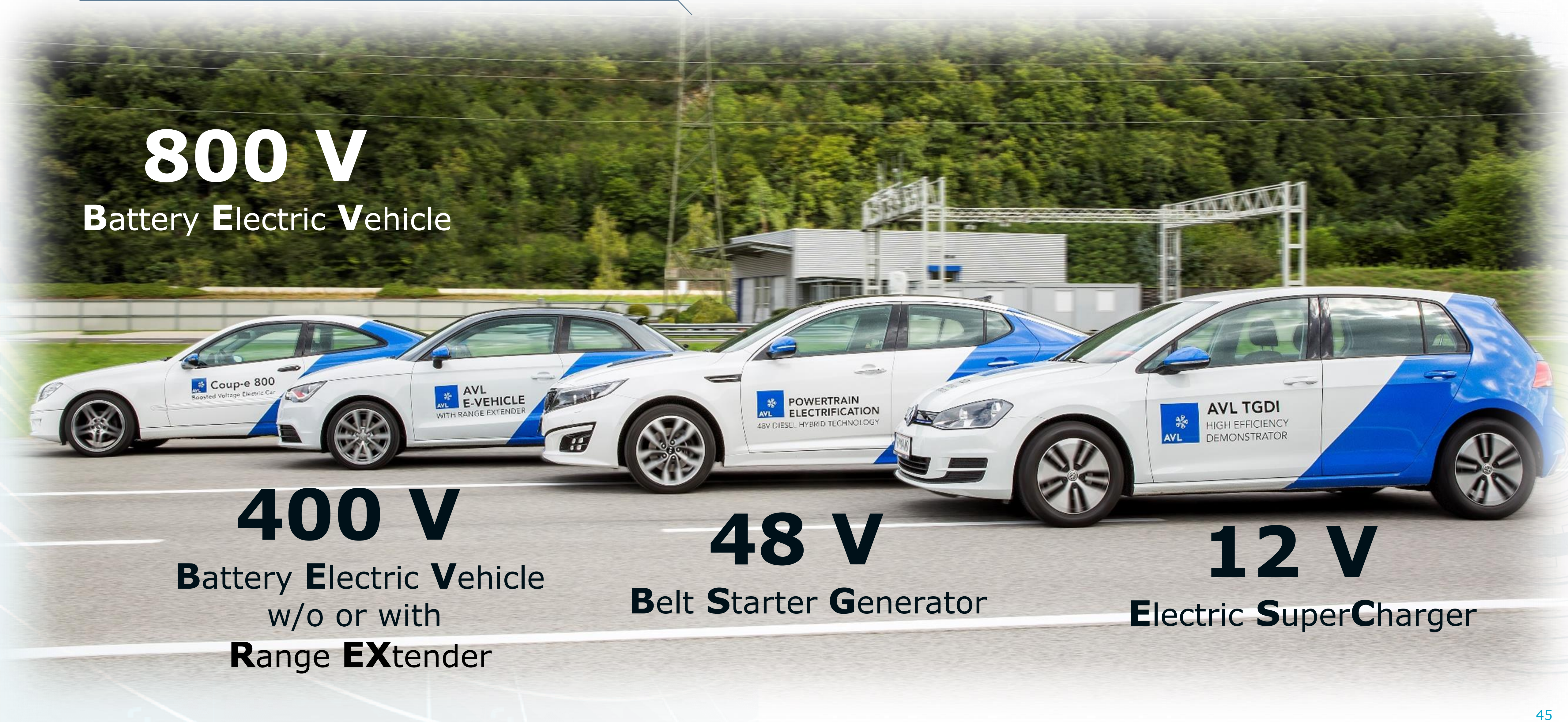


High speed Axles

✓ 2022+ in first EVs +30.000 RPM

- **Optimization of existing layout / elements ongoing:** No revolutionary base tech in next 10 years
- **Common to elements development:** Reducing or eliminating cooling needs for improved efficiency
- **Cost advantages by rolling out in larger scales**

Rightsizing the Electrification



800 V

Battery **E**lectric **V**ehicle

400 V

Battery **E**lectric **V**ehicle
w/o or with
Range **EX**tender

48 V

Belt **S**tarter **G**enerator

12 V

Electric **S**uper**C**harger

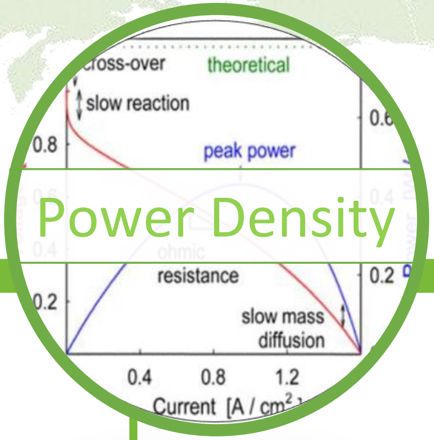
Fuel Cell Powertrain - Challenges

Infrastructure

- Increased coverage
- Standards for Trucks
- Renewable Hydrogen

Cost

- Pt Reduction
- Performance Increase
- Cheaper Materials



Power Density

- Volume Reduction
- Weight Reduction
- Power Density increase

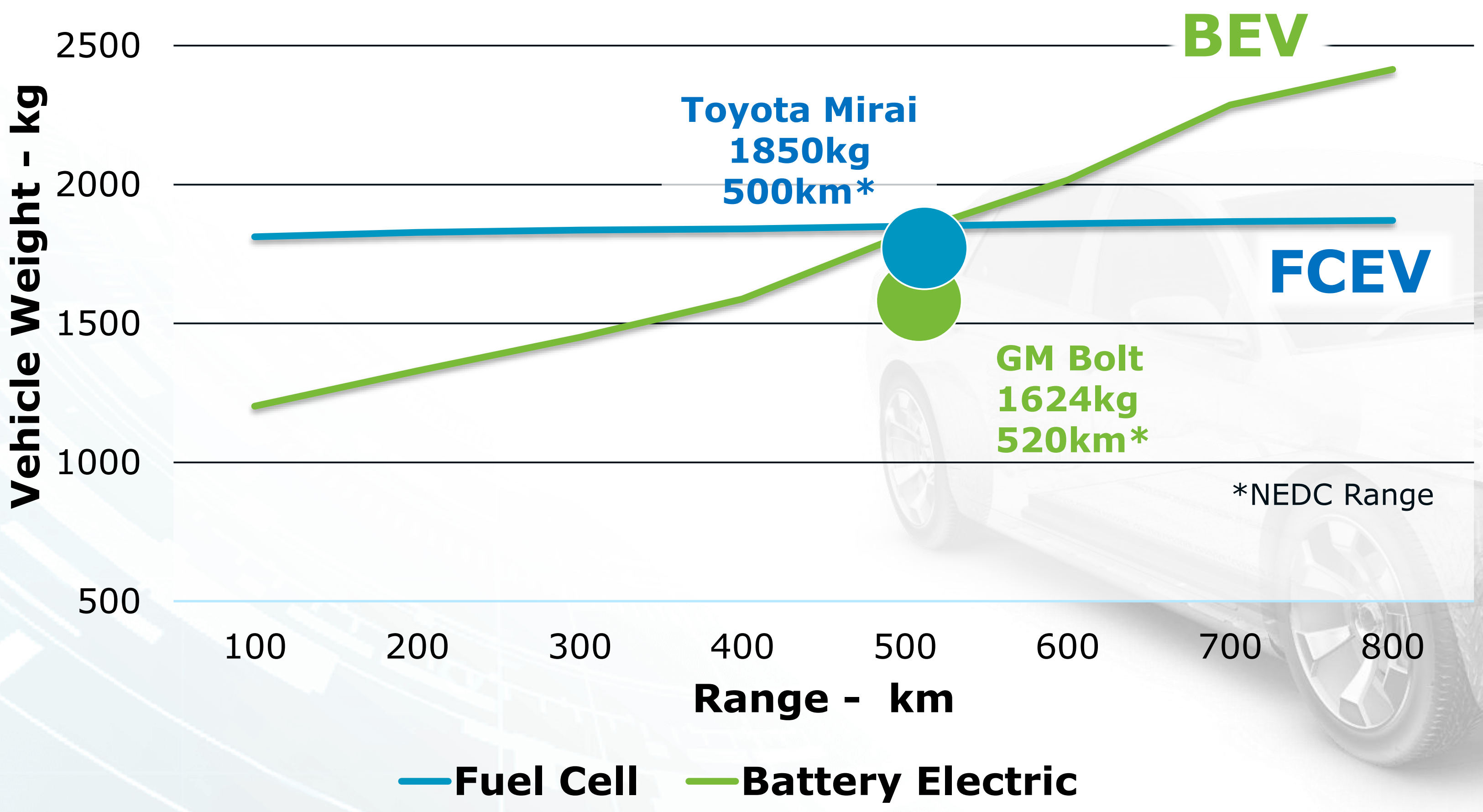
Temperature

- Increased Op. Temperature
- Stability Low Temperature
- Freeze Start up Robustness

Durability

- Better Materials
- Operation Strategies
- Requirements for Commercial

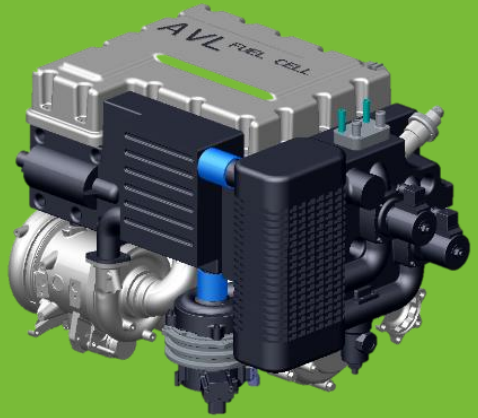
Range Impact on Vehicle Weight



Types of Fuel Cells

AVL

PEM
(Emission free)



PEM Fuel Cell Engine
20-150 kW

H_2

SOFC
(Pollutant free, only CO_2 emission)

SOFC APU/Range Extender
3-30 kW

SOFC Stationary Power Generator
kW-MW

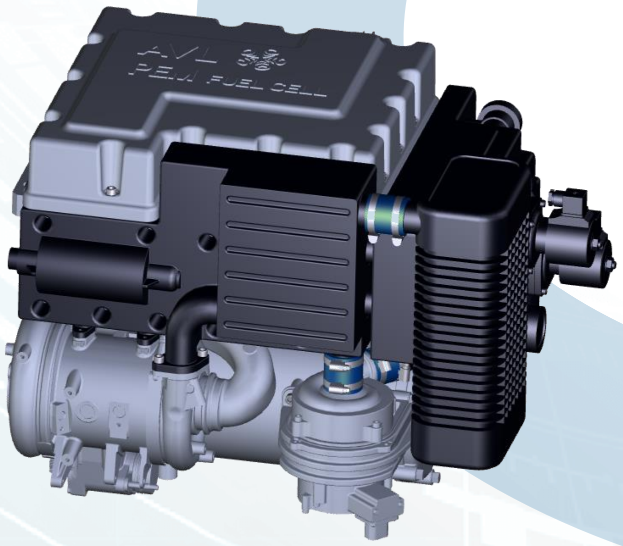
DIESEL | GASOLINE | CNG | e-Gas | LPG | H_2 | Ethanol | Methanol

AVL PEM Fuel Cell Plug-In Concept Car

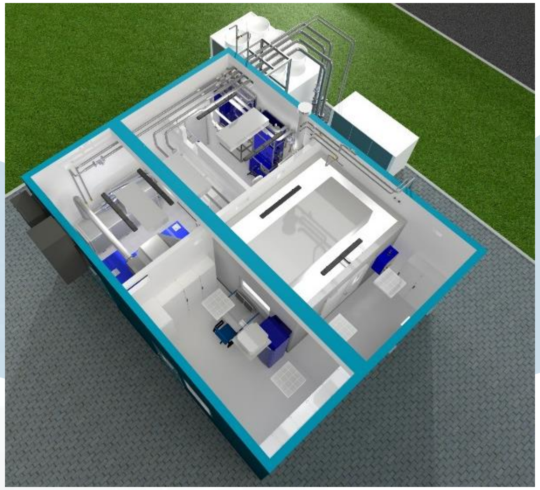
Vehicle Concept

- 55 kW PEM Fuel Cell System
- 10 kWh Battery
- ~5 kg H_2 for >600km range

AVL Fuel Cell Engine



Advanced Testing

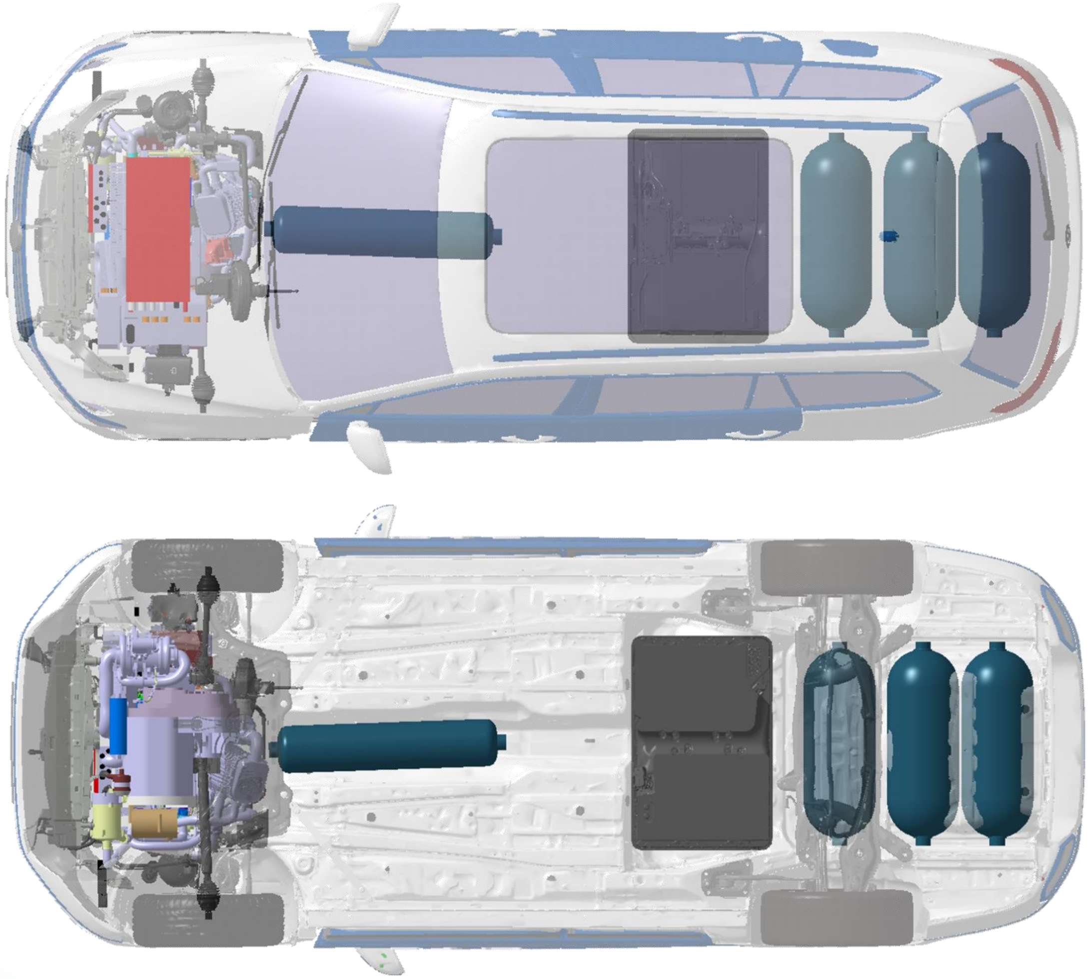


- **Integrated Fuel Cell System + e-drive design (125kW)**
- **Advanced diagnostics (THDA)**
- **New boost converter with integrated inverter for air compressor**
- **Passive anode recirculation**
- **HiL methodology for FC calibration**

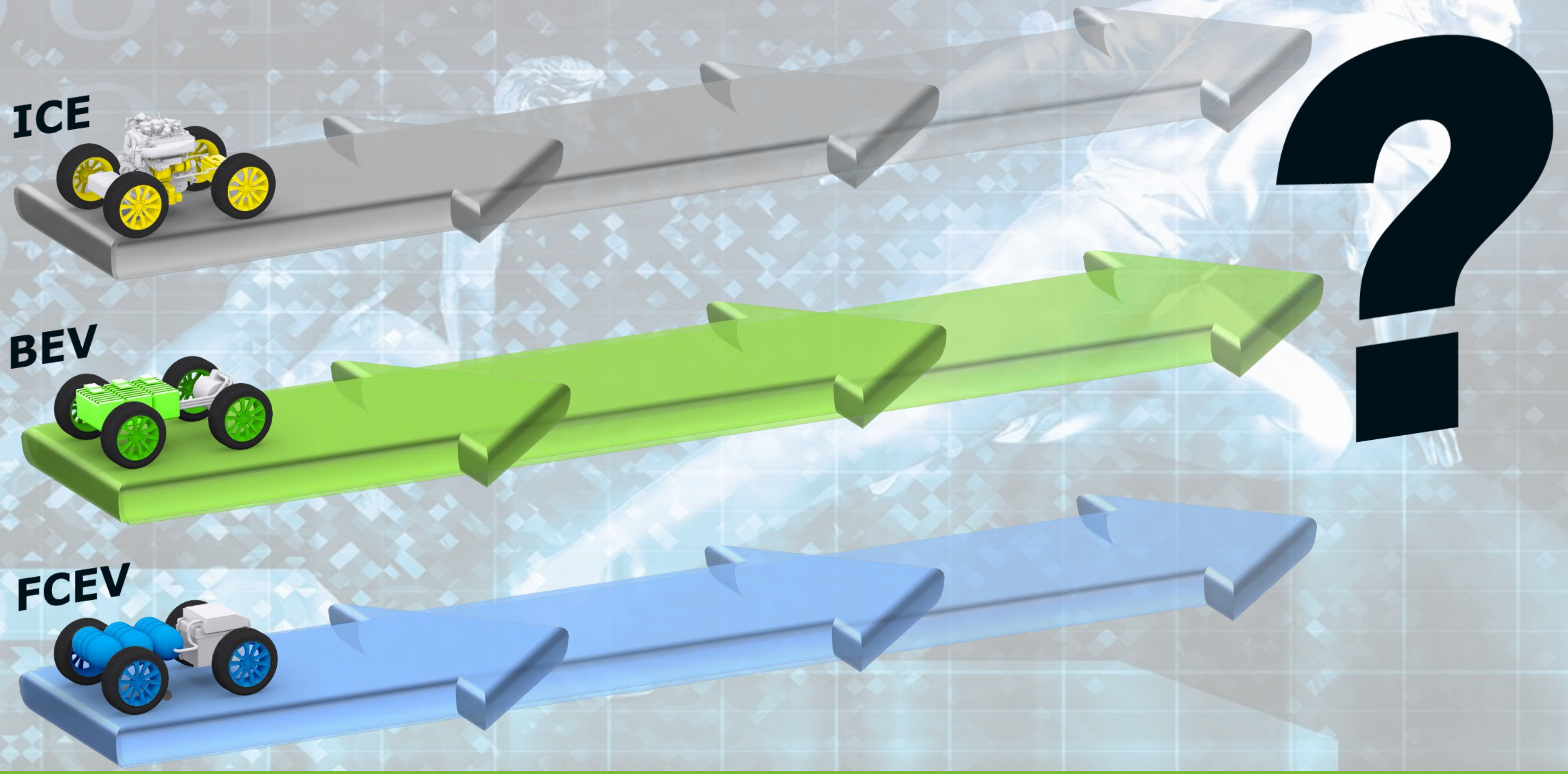
AVL Plug-In FUEL CELL Concept car

Vehicle specifications

Vehicle platform	VW Passat GTE
Vehicle curb weight	1746 kg
Vehicle gross weight	2182 kg
Battery size	9.9 kWh
Battery power	85 kW
Battery weight	125 kg
Fuel cell system power	~55 kW
e-drive power	100 kW
Hydrogen tank capacity	5.3 kg
Number of tanks	4
Hydrogen refilling time	approx.3 min
Hydrogen consumption	0.8 kg /100 km
Driving range	>600 km



Powertrain Competition



SUMMARY

- In spite of a strong trend towards BEV, a variety of different energy carriers will remain long term
- The ICE has the potential for ”Zero Impact Emissions“ with regard to pollutants, applying e-Fuels even for CO_2
- Both BEV and Fuel Cell are still far away from being CO_2 neutral due to high primary energy CO_2
- Even within raising BEV shares, the ICE will remain an essential part of global powertrain portfolio even long term

Thank You

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