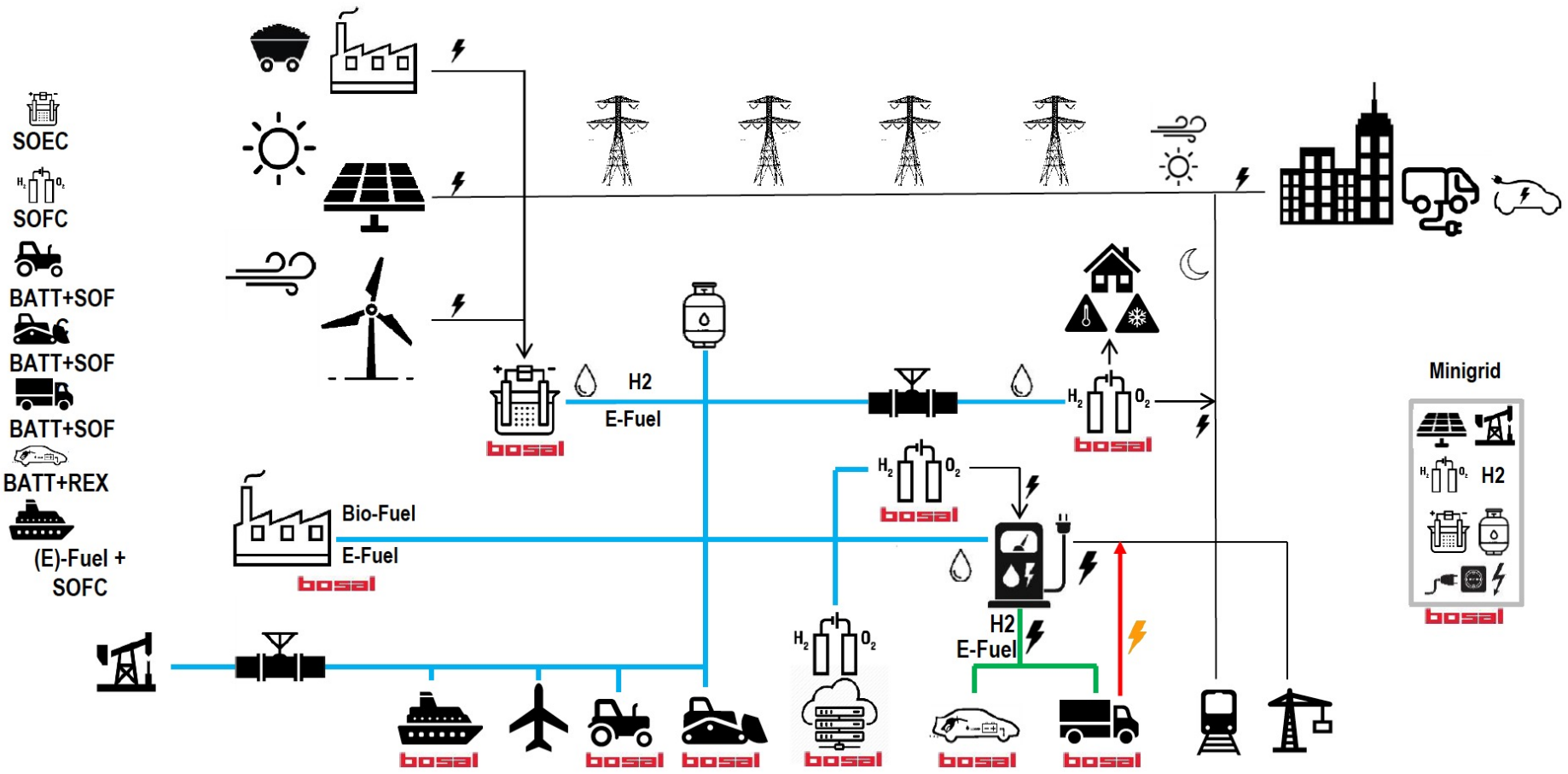
bosal :group

Mobility vision
PC & LCV

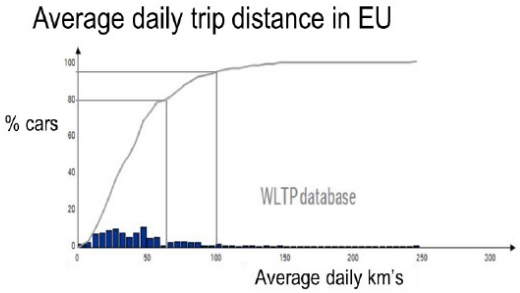
Energy meeting Mobility.

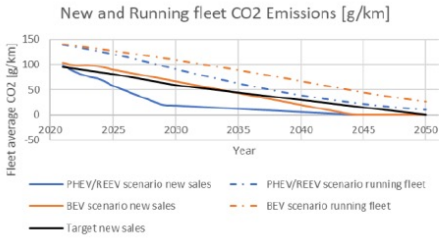


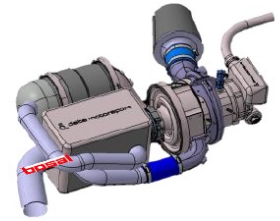
bosal : group

Executive Summary

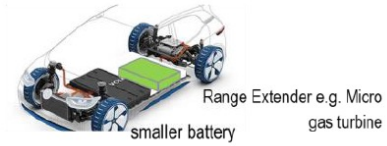
- BEVs with an electric range of >200 km are too expensive, too heavy, and have an over-designed battery pack for over 95% of the duty cycles.
- A fleet scenario with direct transition to pure BEVs with high range prevents reaching the target climate change objectives due to lack of sales & limited battery capacity.
- The combination of BEV and on-board charging:
  - •Reduces the battery pack by 75%
  - • Enables 95% of all duty cycles to be electric
  - • Provides full range with fast refilling times in current infrastructure
  - • Shares the battery production capacity with 4x more cars
  - • Enables higher sales resulting in fast implementation of ultra-low CO_2 cars to realize climate change objectives
- Re-thinking EVs (“Omtanke”) truly delivers the most cost-efficient, lowest TCO and lowest CO_2 solution for automotive







REEV



No space for ICE & exhaust

bosal : group

Outline

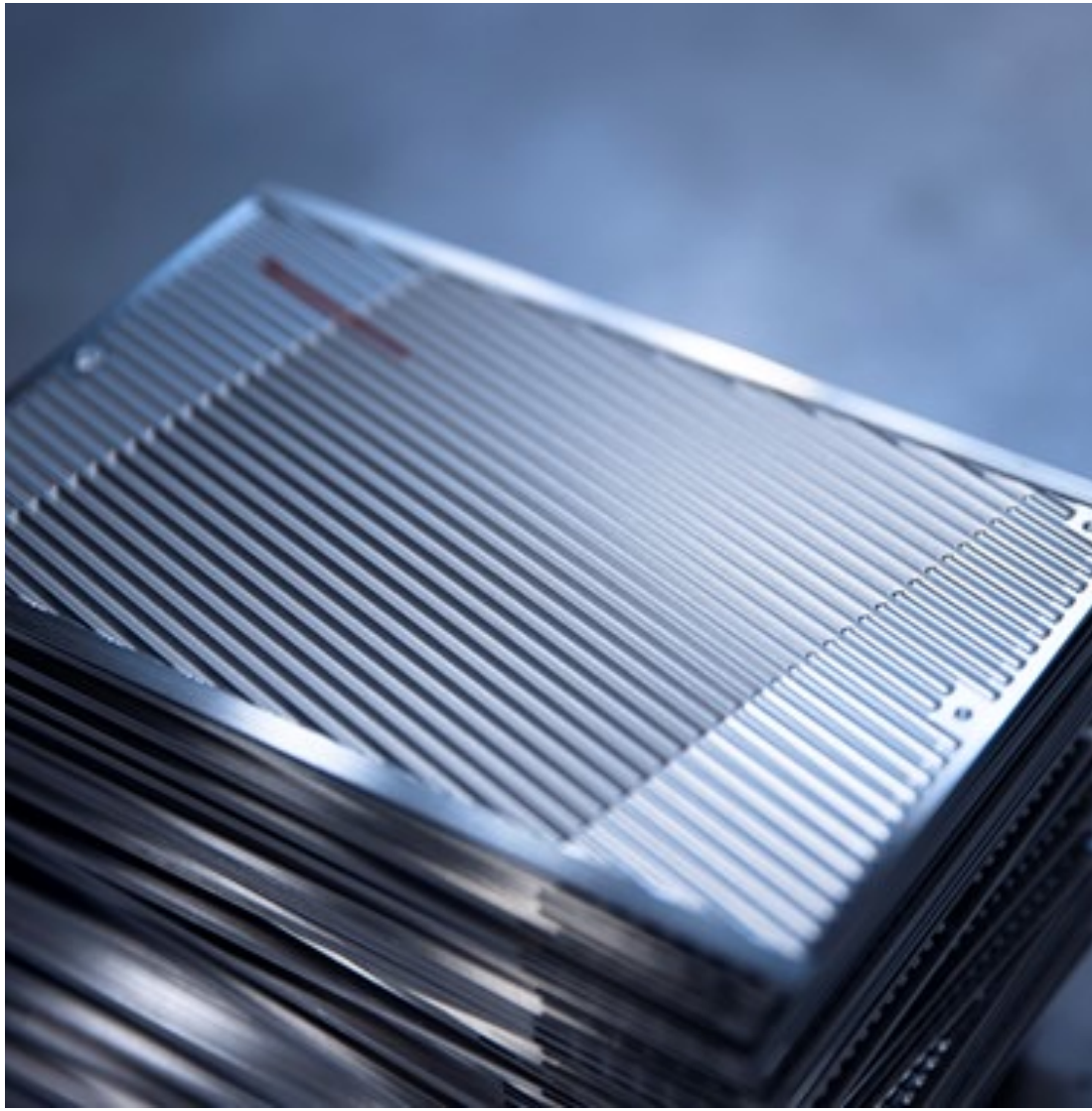
: CO_2 objectives, contributions & policies

: Must-plug-in LEV & their impact on fleet CO_2

: Must-plug-in PHEV vs. REEV

: Micro gas turbine REEV

: Conclusions

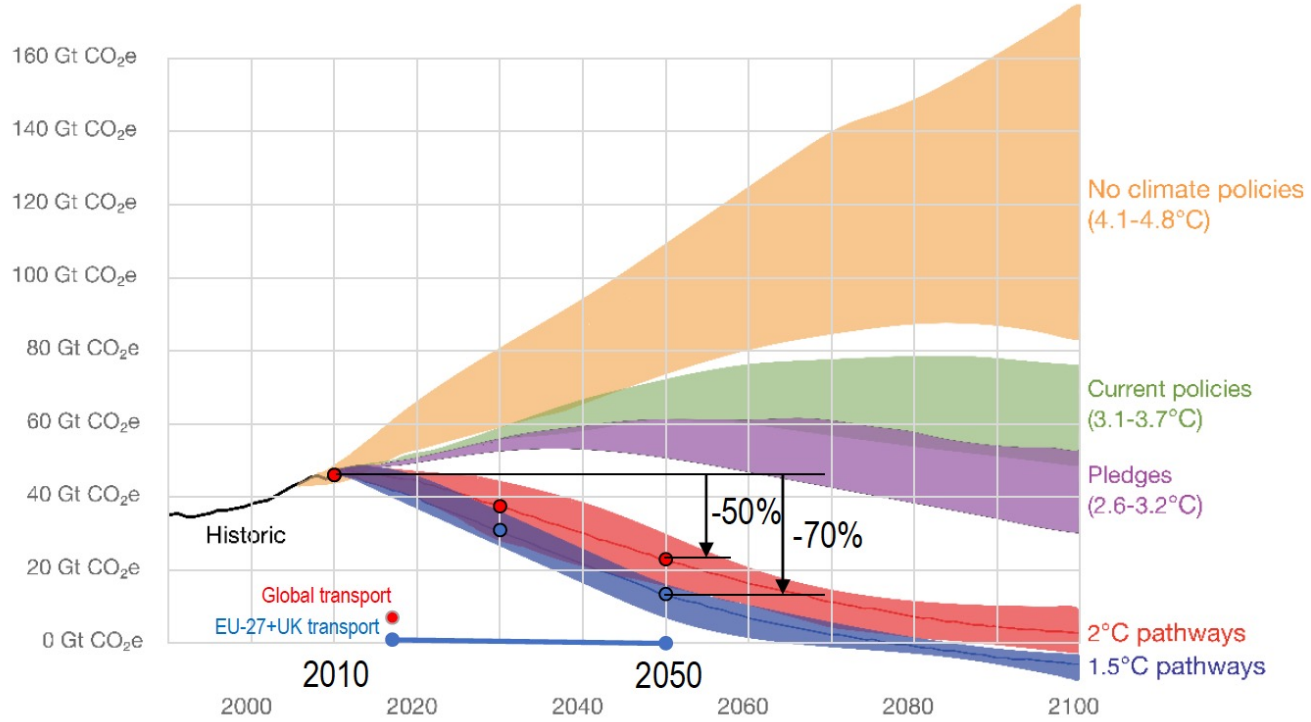


bosal : group

: CO_2 objectives, contributions & policies

Paris Agreement: CO_2 pathways towards +1,5°C and +2°C in 2100

- +1,5°C : 70% reduction of CO_2e[1] emissions by 2050
- +2,0°C: 50% reduction of CO_2e[1] emissions by 2050
- EU Green deal : climate neutral by 2050 (going further than the rest of the world)



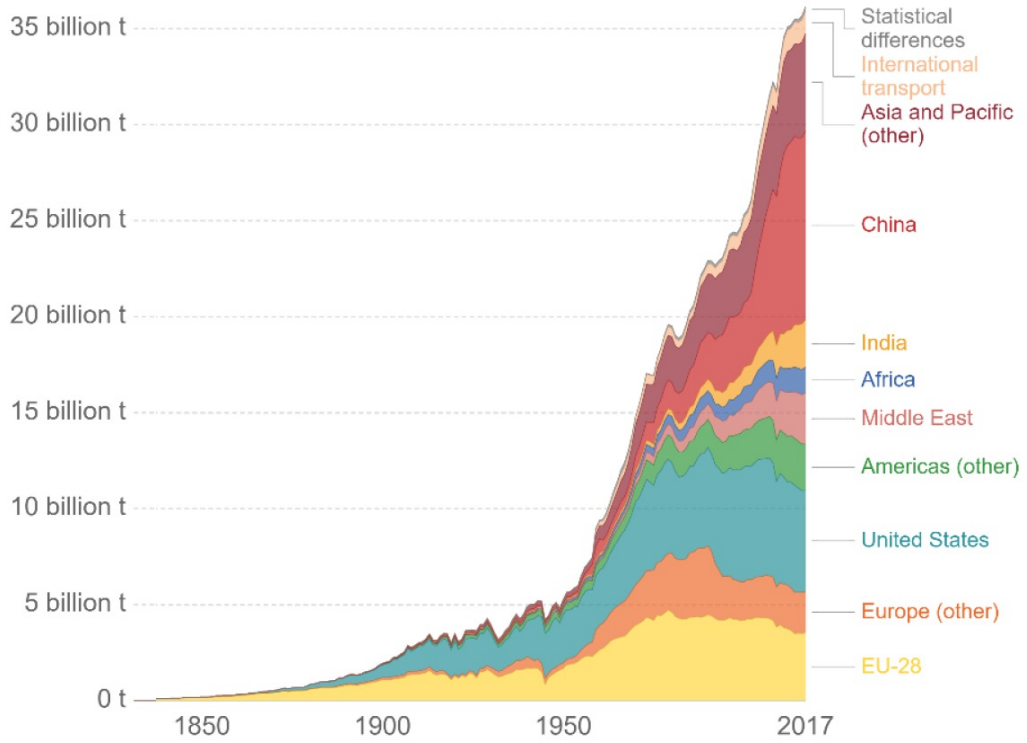
[1] CO_2e : CO_2 equivalents accounting for global warming potential: 35GT CO_2, 8Gt eq. CH_4, 3Gt eq. N_2O in 2010

Source: Oxford University https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions

bosal : group

: CO_2 objectives, contributions & policies

Annual CO2 emissions by world region

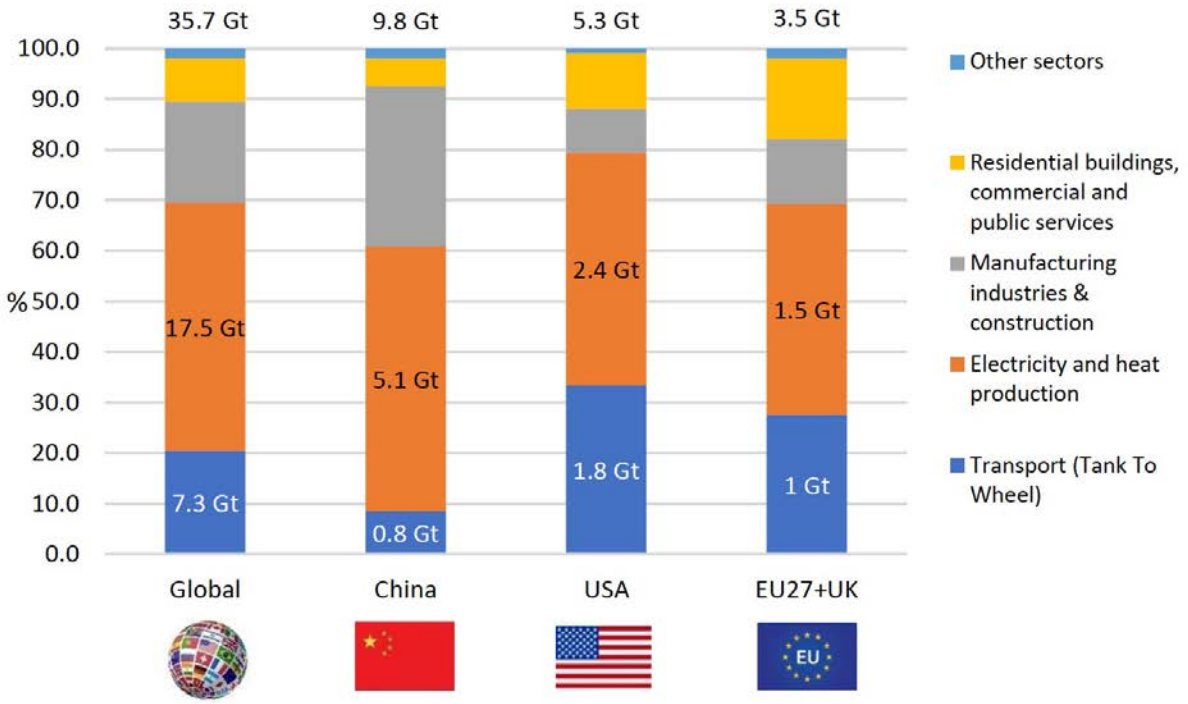


- Asia, North America & Europe emit the most
- Historically, USA, EU27+UK and China contributed the most
- Developing countries have limited contribution
- EU Green deal ambitions may help compensate for developing countries

bosal : group

: CO_2 objectives, contributions & policies

CO_2 emissions from transport and other sectors



- Transport is responsible for 20% of global CO_2 emissions
- Transport includes road, rail, aviation & waterways.
- EU : 28% due to transport 1Gt
  - 72% from road = 0,7 Gt
  - O,4 Gt PC + 0,1 Gt LCV
  - PC fleet EU27 + UK
    - 268 million vehicles
    - Average age 10,8 years
    - Average growth 2% over past 5 years
    - Average 13.000 km/car/year

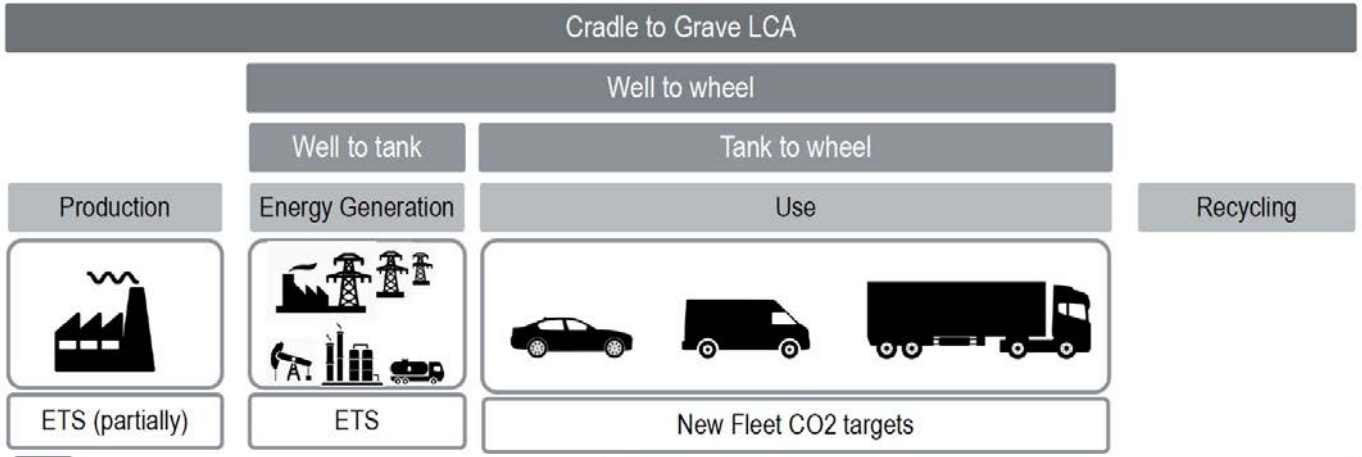
bosal : group

: CO_2 objectives, contributions & policies

EU27 + UK

CO_2 policy making in Europe

Transport is targeted more than other sectors.



: CO_2 objectives, contributions & policies

Conclusions

- 1,5°C – 2°C global warming pathways require 50-70% CO2 reduction by 2050
- Significant CO2 contribution from developed regions China, USA & EU
- Transport sector responsible for 20% of CO2 emissions globally
- Road transport responsible for 70% total transport CO2 emissions
- EU Green Deal = Carbon neutral by 2050 (more ambitious than the rest of the world)
- Transport legislation is limited to:
    - New fleet; delayed impact due to average car age of approx. 11 years
    - Tank-to-Wheel
- Tank-to-Wheel more penalized than Well-to-Tank

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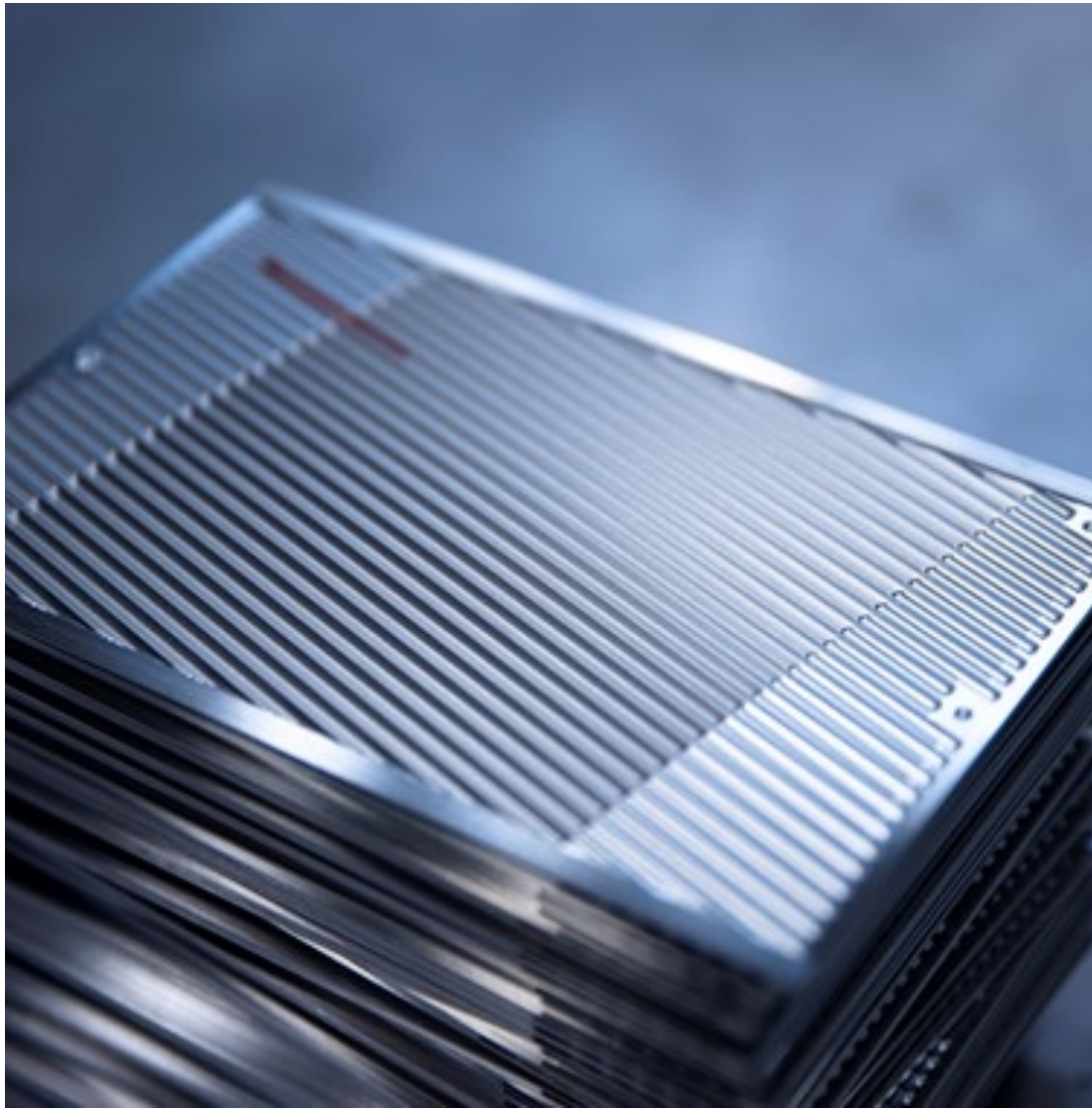


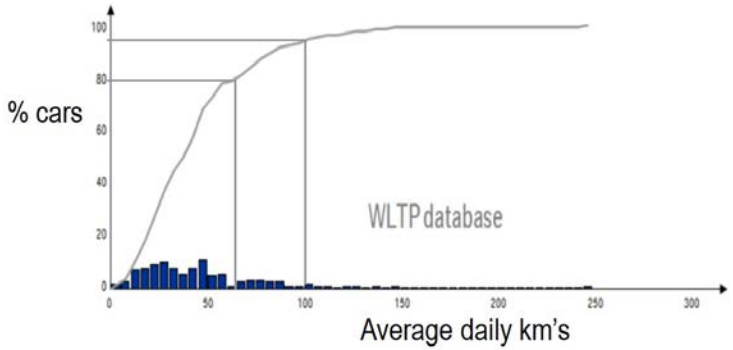
bosal : group

: Must-plug-in LEVs & their impact on fleet CO_2

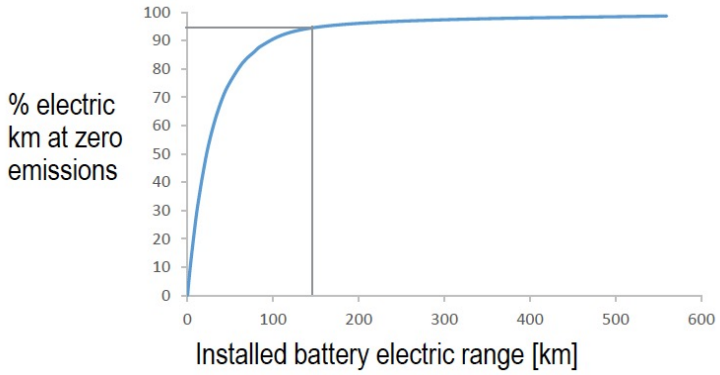
EU27 + UK

How European cars are used

Average daily trip distance



Utility factor of properly used plug-in vehicles

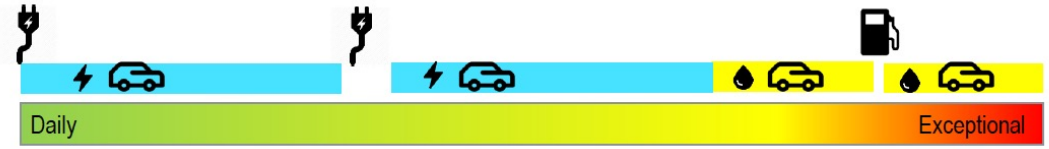


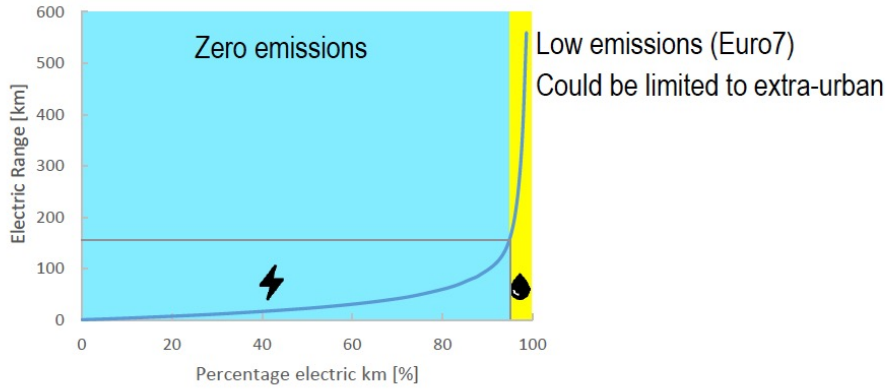
- 80% of cars drive less than av. 65 km/day
- 95% of cars dive less than av. 100km/day
- Plug-in Low Emission Vehicles (LEV) drive mainly electric when properly used; "must-plug-in"
- LEV with 80 km electric range allows for 87% of all kilometers to be electric (at zero emissions)
- LEV with 150 km electric range allows 95% of all kilometers to be electric (at zero emissions)

: Must-plug-in LEVs & their impact on fleet CO_2

Must-plug-in Low Emission Vehicles

- Must-plug-in daily
- Primarily a BEV (Battery Electric Vehicle); primary fuel = electricity
- Exceptional use of range extender; secondary fuel can be hydrocarbon (fossil/bio/synthetic) or hydrogen





LEV with 150 km electric range allows 95% of all kilometers to be electric at zero emissions

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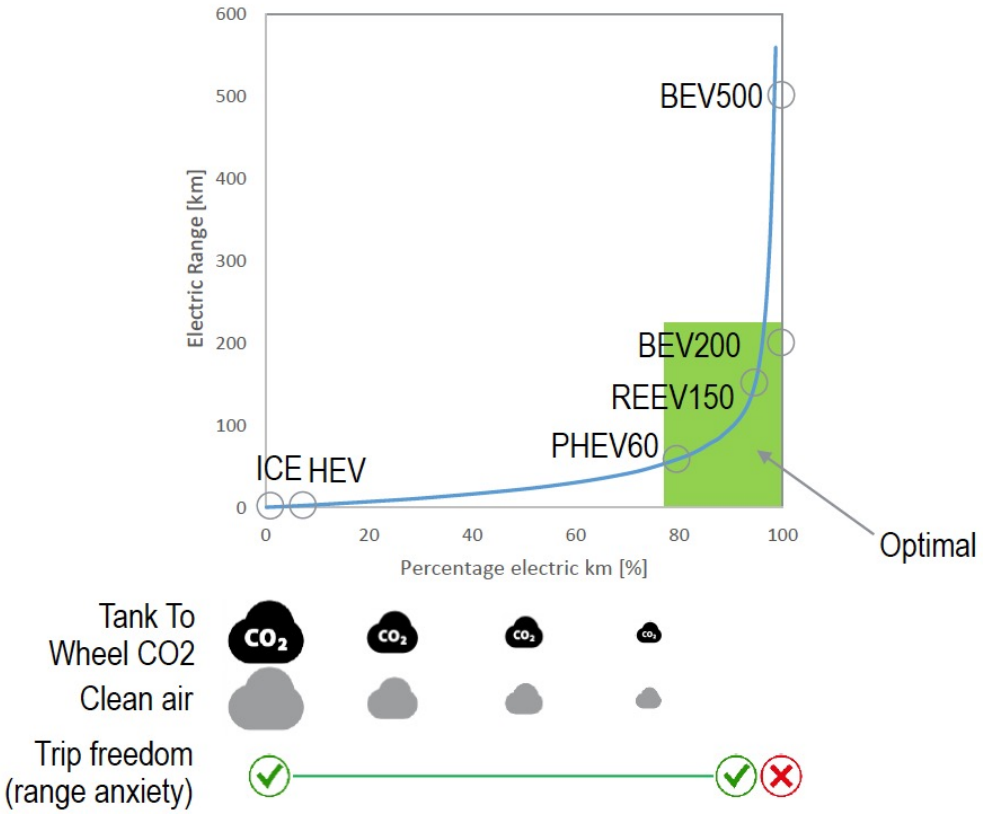
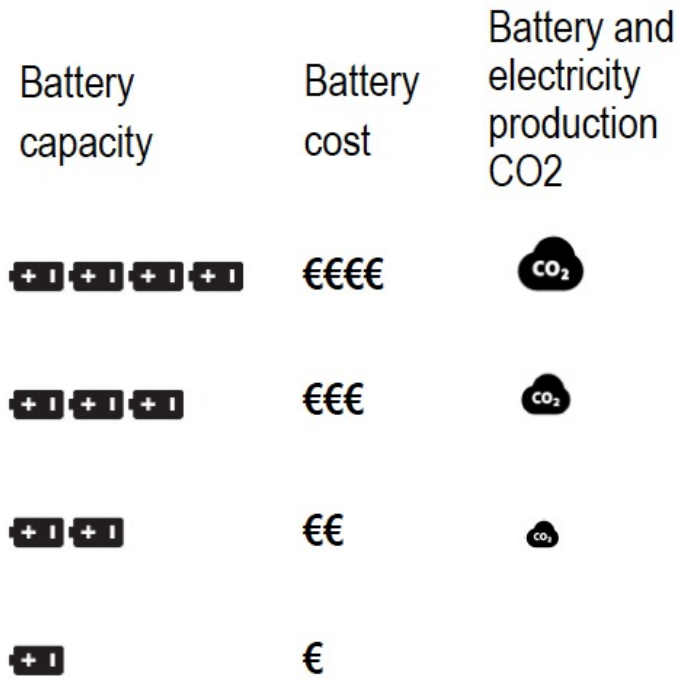
: Must-plug-in LEVs & their impact on fleet CO_2

Consumer vs. inhabitant expectations

Must-plug-in LEV (PHEV and REEV) offer the best trade-off

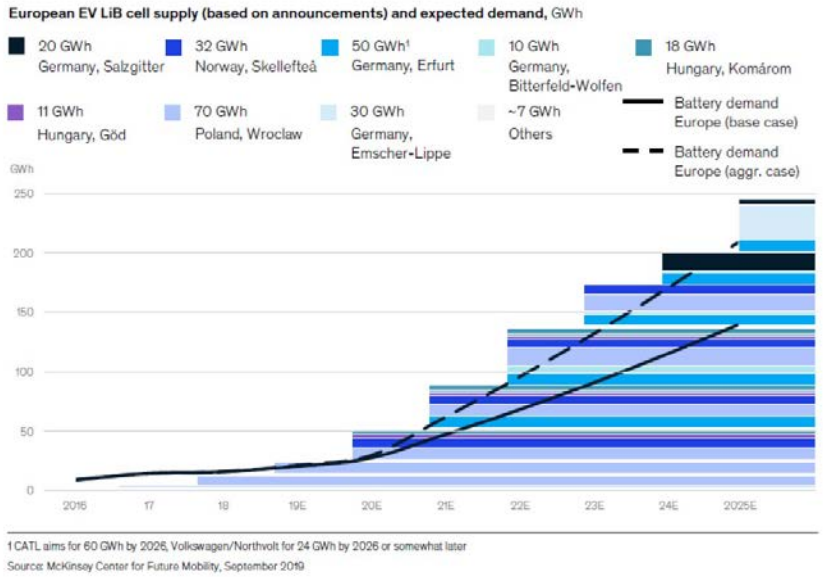




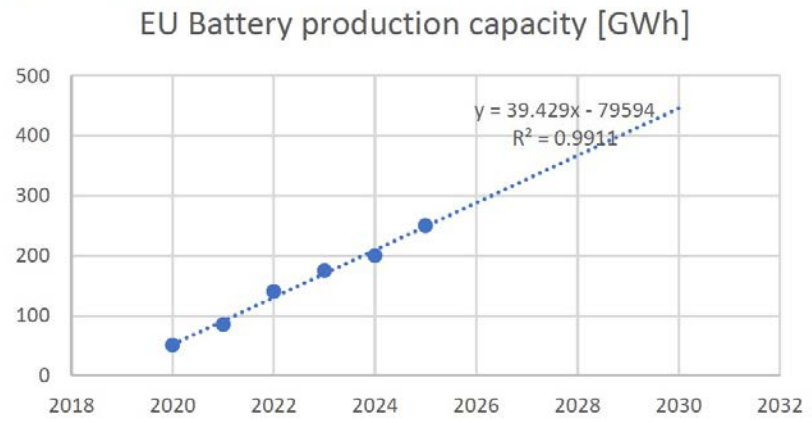
: Must-plug-in LEVs & their impact on fleet CO_2

EU27 + UK

Battery production capacity limitations



- Forecast of battery production capacity in EU based on announcements until 2025
- 250 GWh in 2025



- Extrapolated capacity increase towards 2030 and 2050
- 450 GWh in 2030
- 1200 GWh in 2050

Source: McKinsey – Reboost: A comprehensive view on the changing powertrain component market and how suppliers can succeed.

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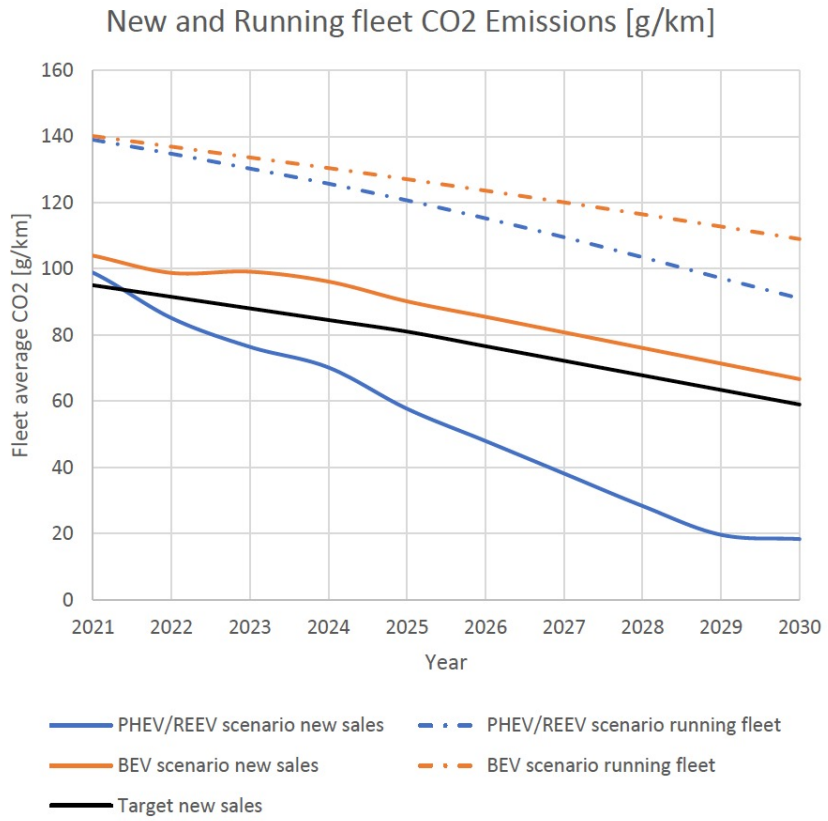
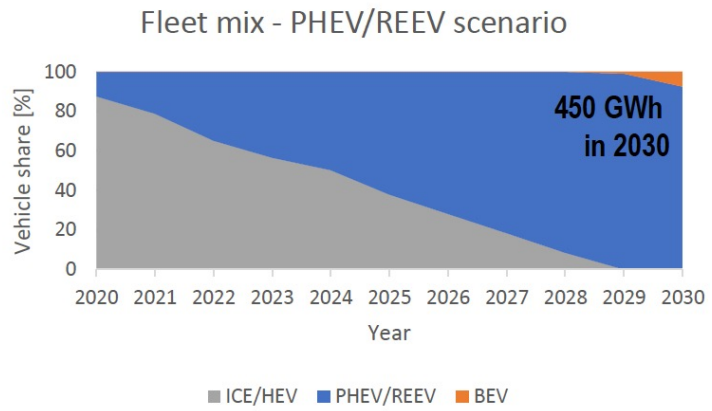
: Must-plug-in LEVs & their impact on fleet CO_2

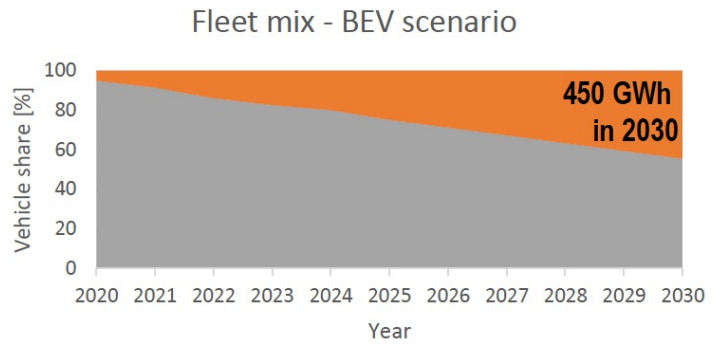
EU27 + UK

Optimal use of battery production capacity

- Steeper CO_2 reduction well below target by using all available batteries in PHEV/REEV
- CO_2 target not reached by using all available batteries in BEV





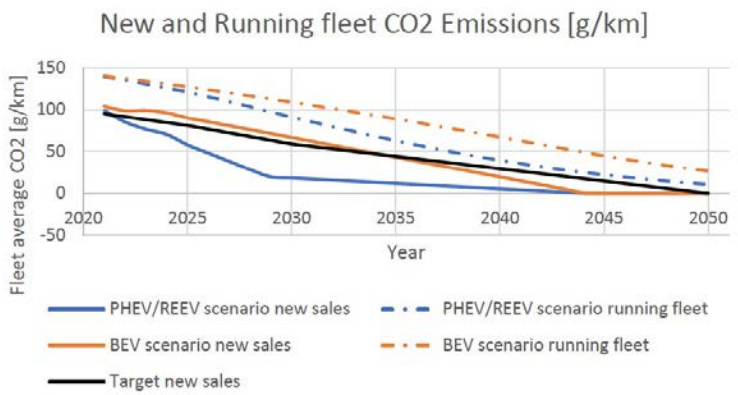


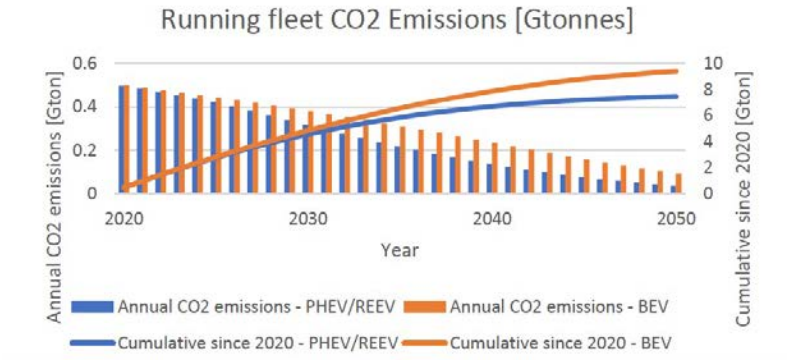
: Must-plug-in LEVs & their impact on fleet CO_2

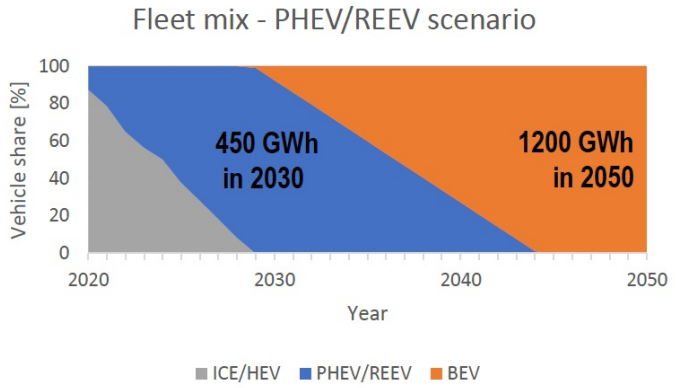
EU27 + UK

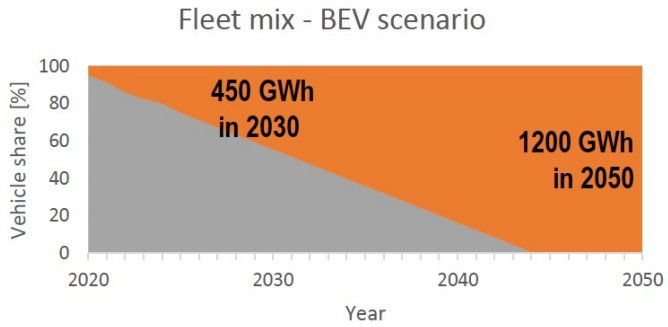
Optimal use of battery production capacity

- Only PHEV/REEV scenario enables CO_2 neutrality for entire running fleet towards 2050
- In the BEV scenario, CO_2 reduction of entire running fleet is delayed by 7 years, resulting in 2 Gt of extra CO_2 emissions





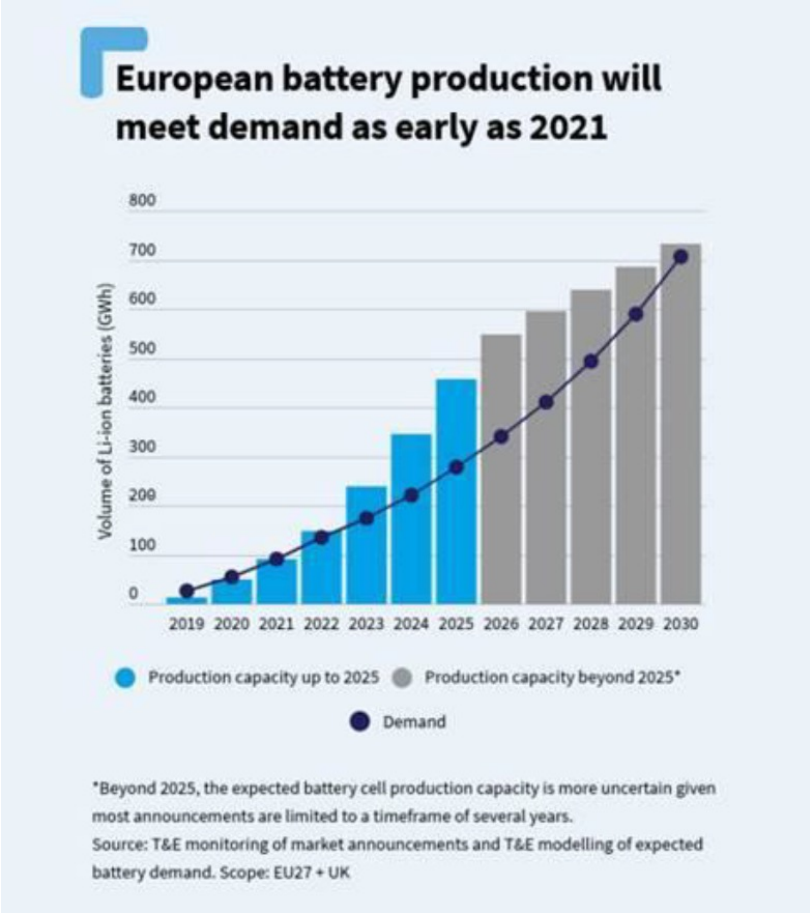


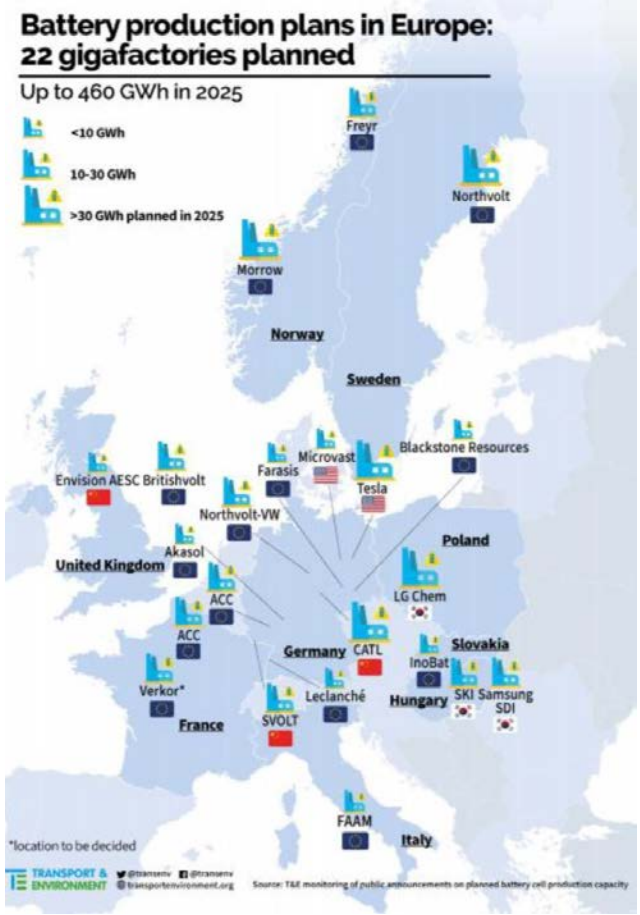


: Must-plug-in LEVs & their impact on fleet CO_2

EU27 + UK

2021 update – Battery production capacity





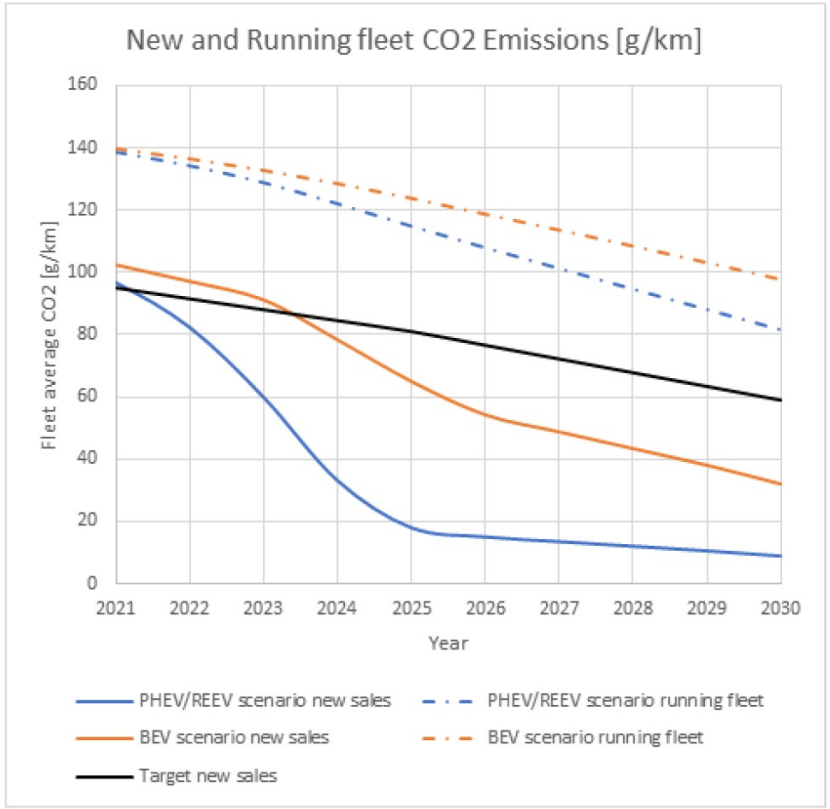
- Forecast of battery production capacity in EU based on announcements until 2025
- 450 GWh in 2025
- 700+ GWh in 2030

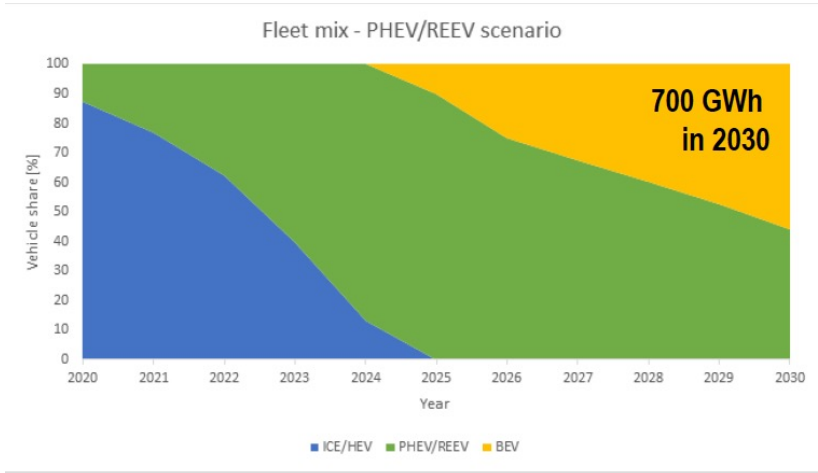
: Must-plug-in LEVs & their impact on fleet CO_2

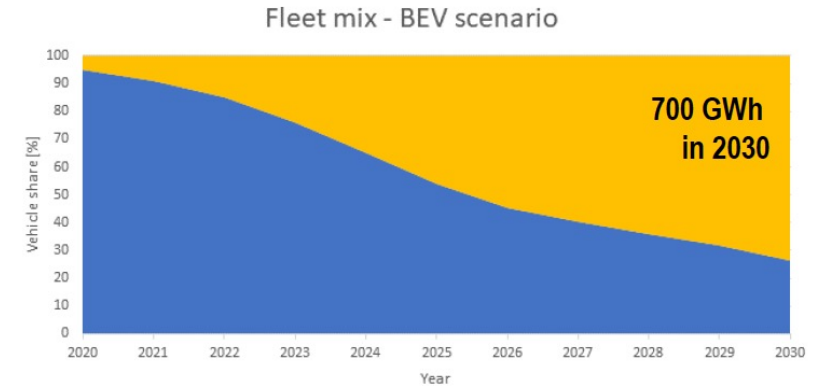
EU27 + UK

2021 update - Battery production capacity

- Steeper CO_2 reduction well below target by using all available batteries in PHEV/REEV
- CO_2 target not reached by using all available batteries in BEV







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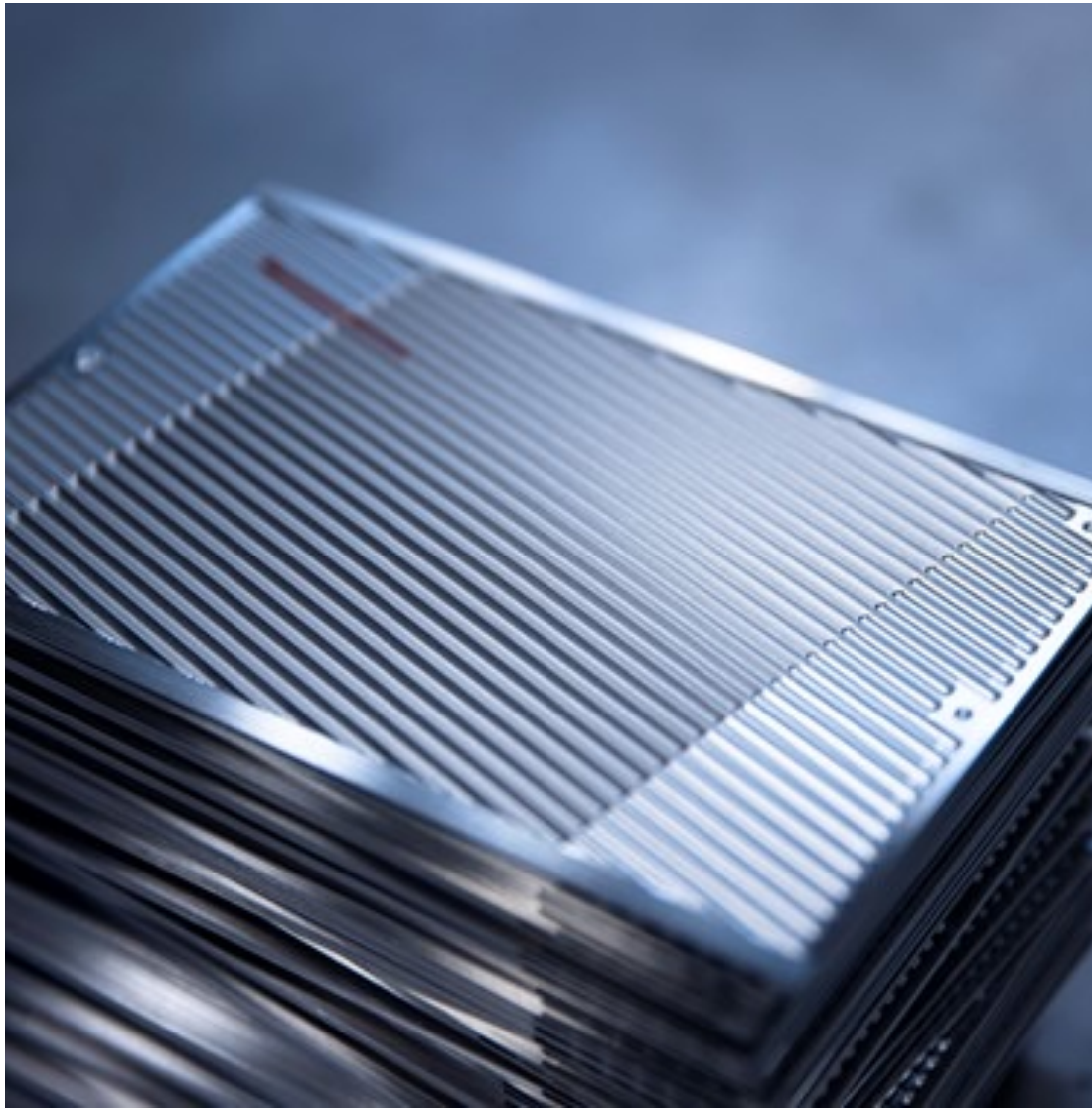


bosal : group

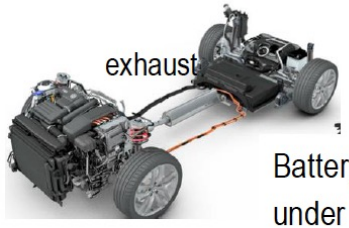
: Must-plug-in PHEV vs. REEV

Must-plug-in LEV: PHEV or REEV?

Choice depends on integration within baseline vehicle platform

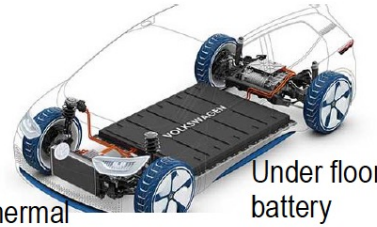
ICE platform

PHEV



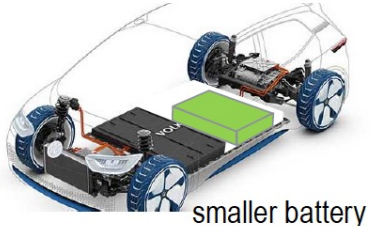
Battery
under rear seat
Or in tunnel

BEV platform



REEV

Range Extender
e.g. Micro gas turbine



No space for ICE & exhaust

bosal : group

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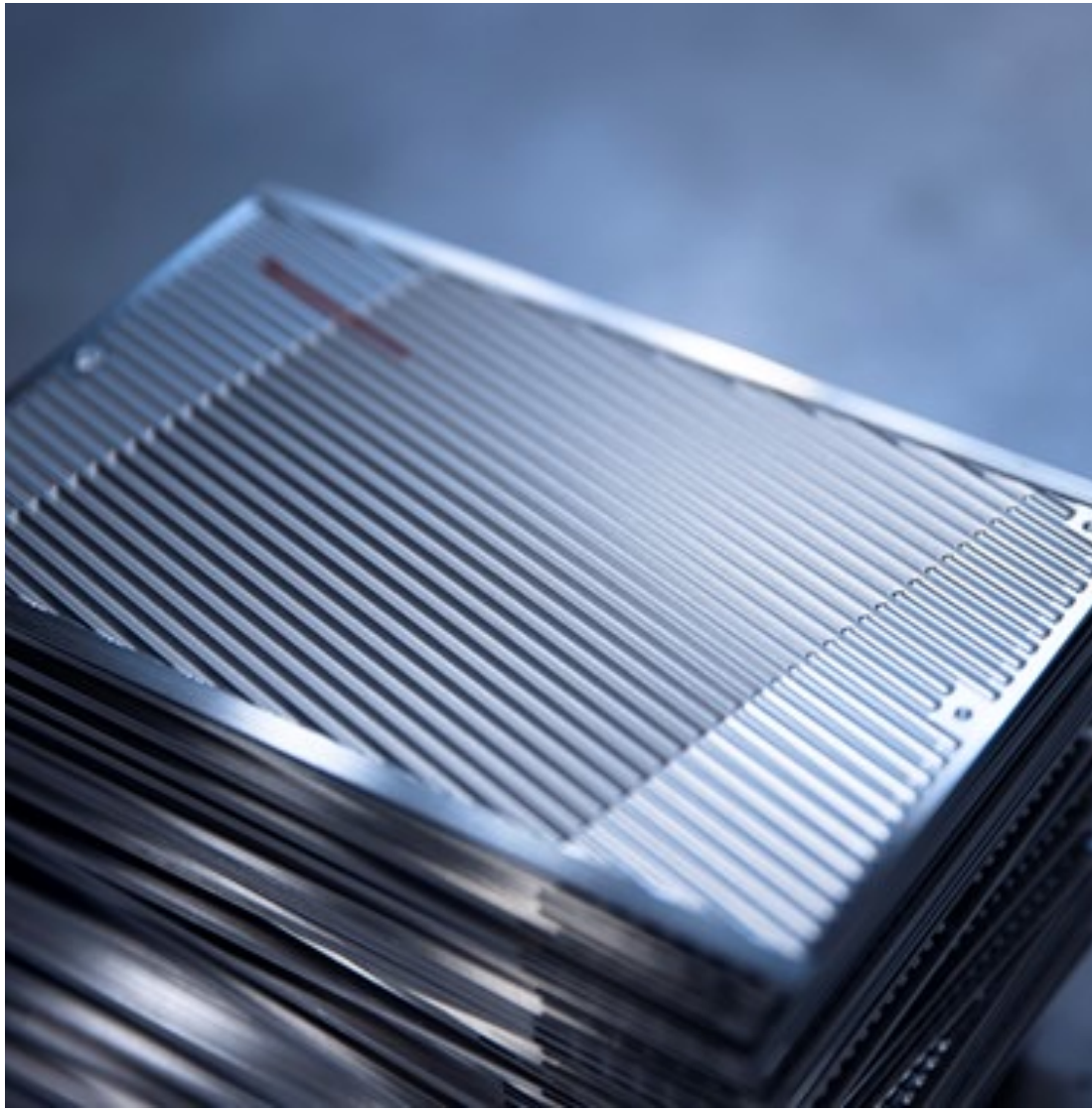

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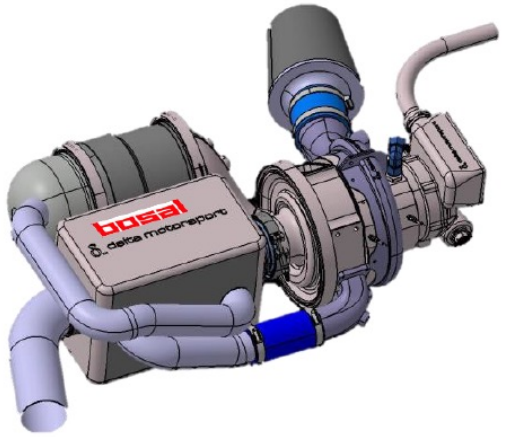
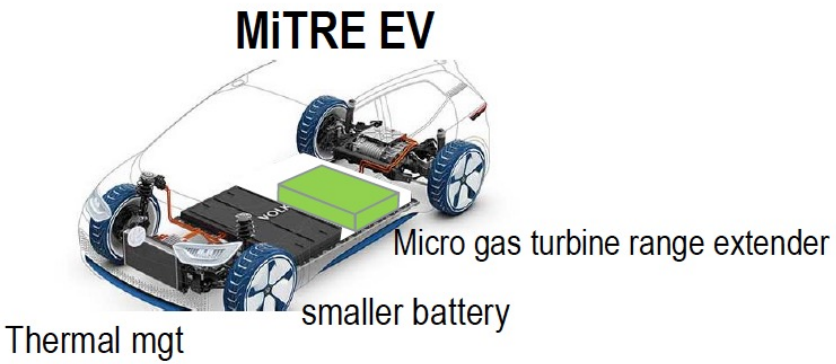
: Micro Gas Turbine REEV

Micro Gas Turbine Range Extender (MiTRE)



- 35 kW 400V-700V Catalytic Generator
- Can be adapted to different fuels in transition to CO2 neutral fuels
- Near-zero emissions (Euro7) without aftertreatment
- Silent & Light weight (approx. 50 kg)
- Compact: 80 ltr. Bounding box (<40 kWh battery space)
- 30% efficiency thanks to BOSAL recuperator
- Smaller cooling circuit (8 kW) than for ICE
- No oil cooling / lubrication
- Low cost & low maintenance



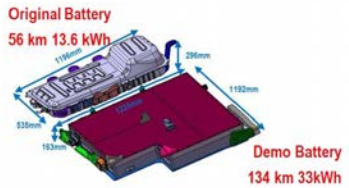
delta

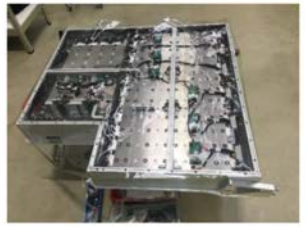
bosal : group

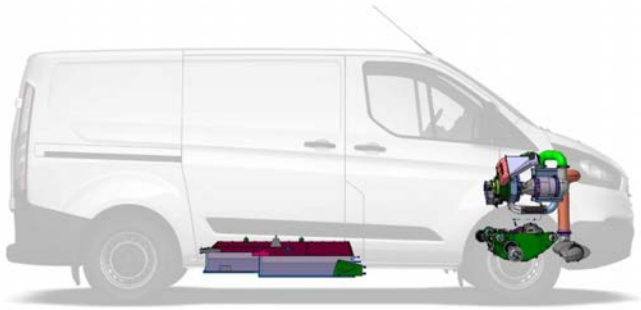
: Micro Gas Turbine REEV

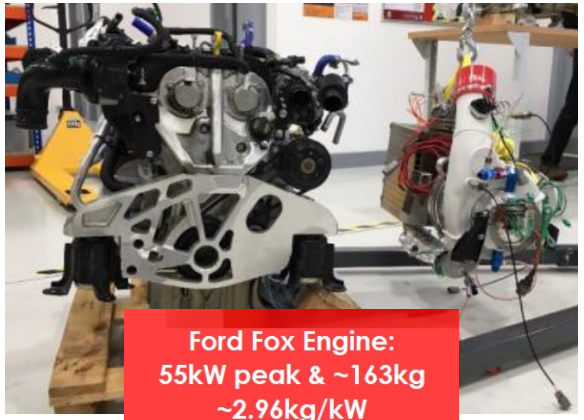
Micro Gas Turbine Range Extender demonstrator

Conversion of Ford Transit PHEV to MiTRE









Ford Fox Engine:
55kW peak & ~163kg
~2.96kg/kW
~0.34kW/kg

Catalytic Generator:
35kW cont. & ~50kg
~1.43kg/kW
~0.7kW/kg

Example London Fleet Trials Emissions	Ford Transit PHEV	MiTRE demo
Pure EV Range (km)	56	134
Pure EV Driving (%)	35	84
Total Mileage (km)	240,000	240,000
Pure EV Mileage (km)	85,000	201,600
CO_2 Emissions (g/km)	70	40
Total CO_2 Emissions (t)	10.85	1.54
Weight (kg)	Ref	Ref - 60 kg

delta

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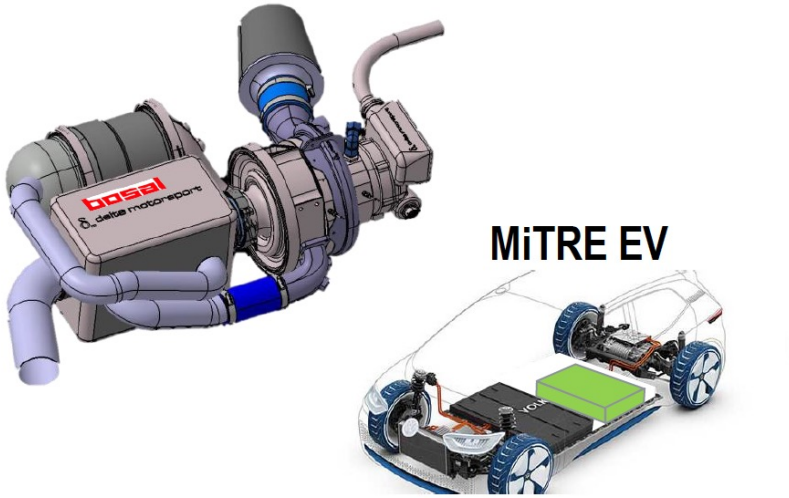
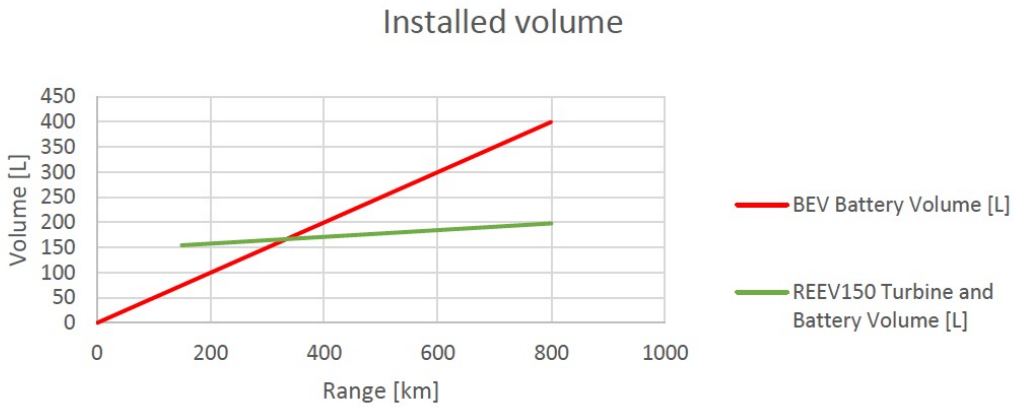
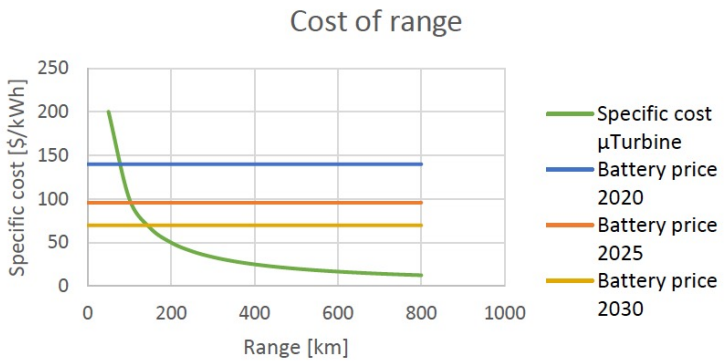
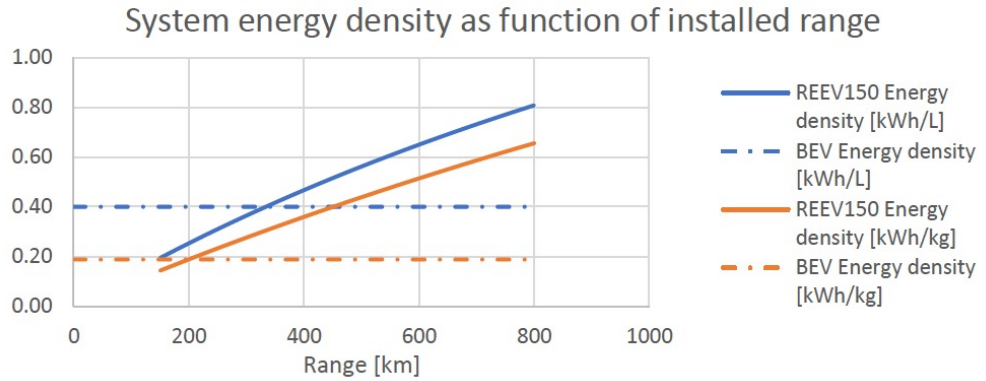
: Micro Gas Turbine REEV

Micro Gas Turbine Range Extender (MiTRE)









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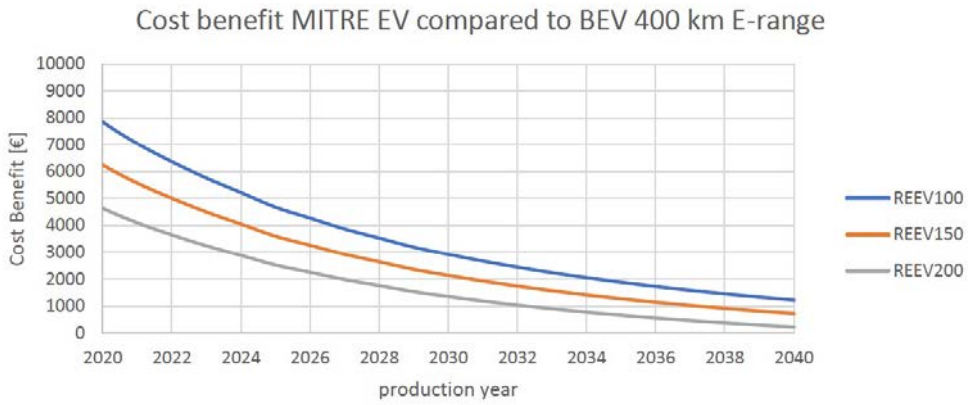
: Micro Gas Turbine REEV

Investment cost and TCO comparison

Both investment and TCO are better for REEV than for large range BEV



- Significant investment cost benefit for REEV with 100-200 km electric range compared to BEV with 400 km electric range
- Benefit decrease due to decreasing battery cost by 2040
- TCO for REEV and BEV with smaller electric range comparable to gasoline & diesel
- BEV 400 km and H_2 fuel cell have a higher TCO

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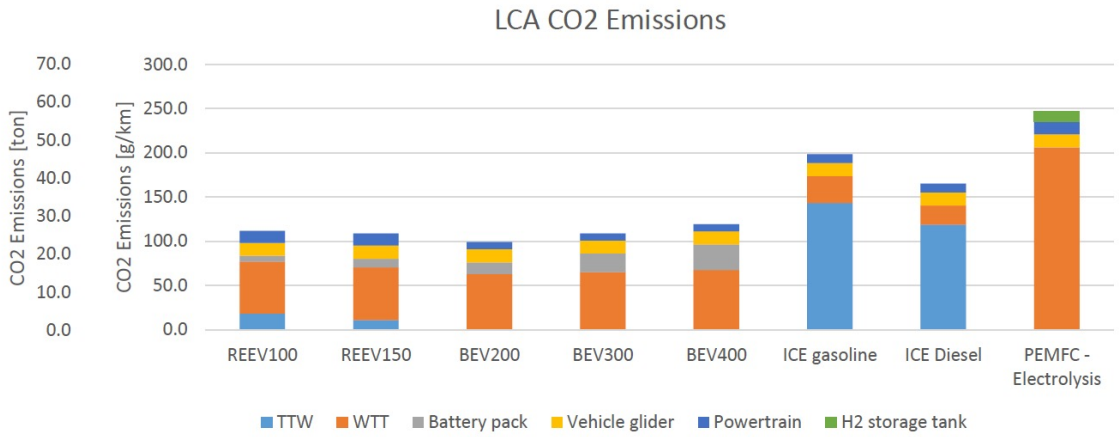
: Micro Gas Turbine REEV

Life cycle CO_2 emissions (g/km & ton)



Vehicle	Electric range	Battery capacity
	[km]	[kWh]
REEV100 - Diesel	100	24
REEV240 - Diesel	240	57
REEV100 - CNG	100	24
REEV240 - CNG	240	57
BEV200	200	49
BEV300	300	76
BEV400	400	105
ICE gasoline	0	0
ICE Diesel	0	0

- Life cycle CO_2 is lowest for BEV with small electric range (200 km)
- Range Extended EVs better than BEV with large electric range
- Life cycle CO_2 for REEV drops further when using biofuel / synthetic fuel

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Outline

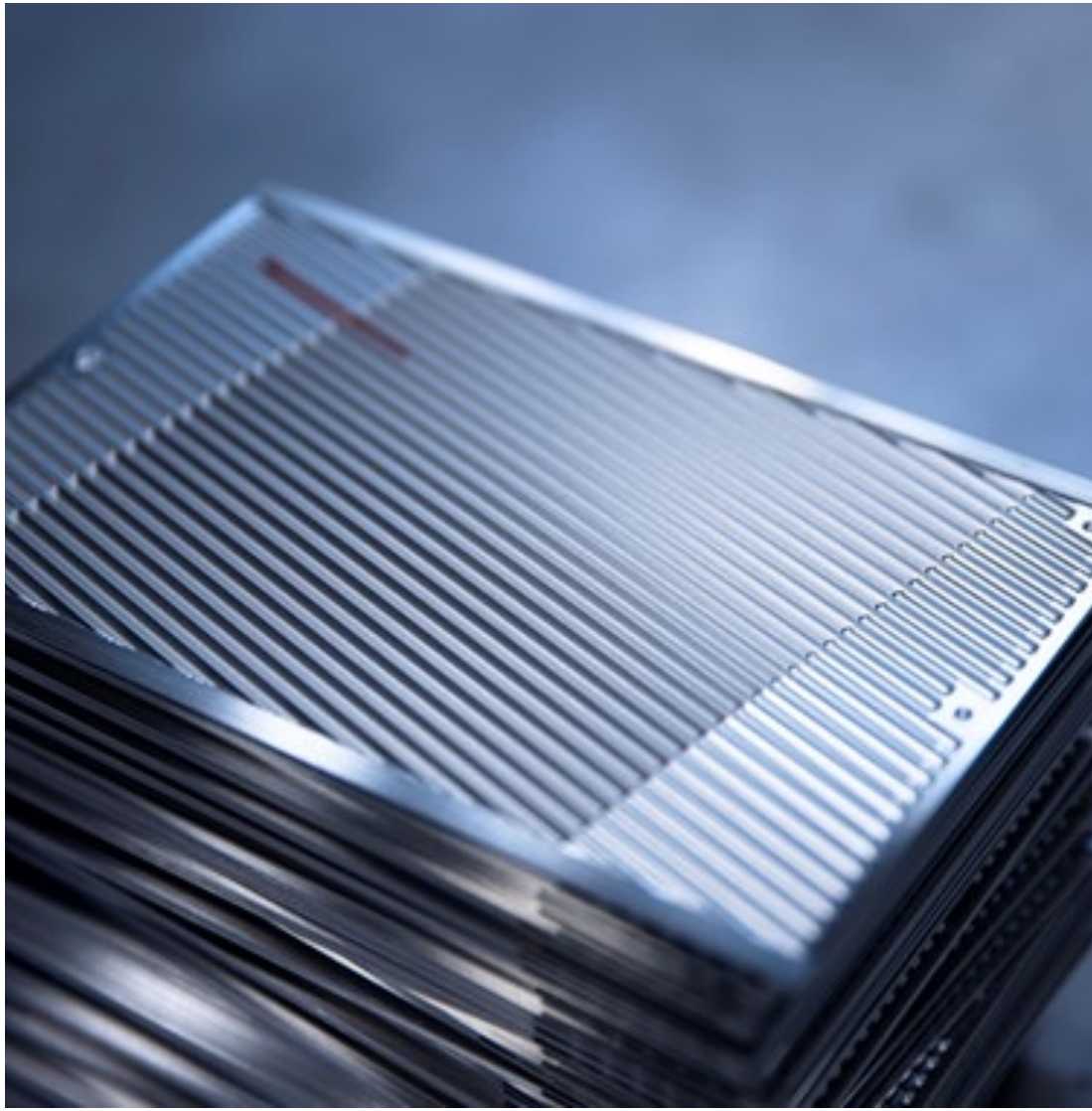
: CO_2 objectives, contributions & policies

: Must-plug-in LEV & their impact on fleet CO_2

: Must-plug-in PHEV vs. REEV

: Micro gas turbine REEV

: Conclusions



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: Conclusions

: **Must-plug-in PHEV and REEV are optimal trade-off to:**

- Reduce Tank-to-Wheel CO2 emissions for both new & entire running fleet more rapidly towards 2030-2050.
- Ensure CO2 neutrality of entire running fleet by 2050
- Minimize life cycle CO2 emissions (Well-to-Thank & Thank-to-Wheel)
- Minimize investment cost and TCO for faster consumer acceptance
- Secure trip freedom outside of cities for faster consumer acceptance (Eliminate range anxiety)
- Improve clean air rapidly / Reduction of pollutants of total fleet
- Enable pure electric driving in cities
- Enable focus of charging infrastructure investments to cities, benefitting from existing infrastructure outside the cities
- Make transition to CO2 neutral energy (biofuel / synthetic fuel / hydrogen)

: **BEVs with a range of >200 km should be discouraged**

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Thank you.