

the Hydrid

a hydraulic hybrid transmission



I N N A S

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Seminar für Fahrzeugtechnik - Institut für Fahrzeugtechnik und Mobile Arbeitsmaschinen
12 November 2009

this presentation

- ❖ passenger car
 - options and limitations
- ❖ hydraulics
 - advantages and disadvantages
 - new components
- ❖ the hy^{red}rid: a hydraulic hybrid
 - system architecture
 - fuel consumption and CO₂-emissions
- ❖ coming years

the fuel consumption and CO₂-emissions of passenger cars

passenger car demands:



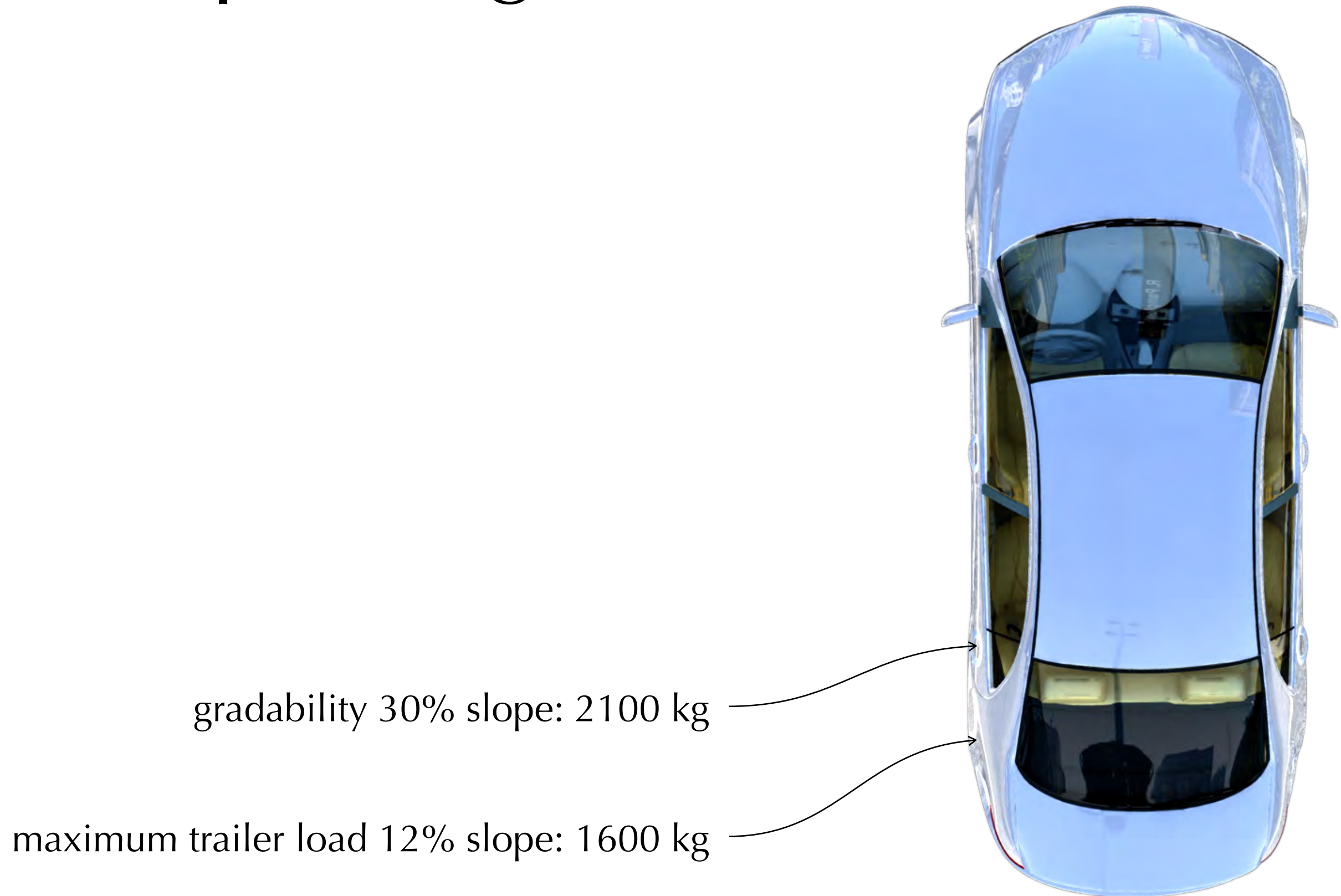
passenger car demands:



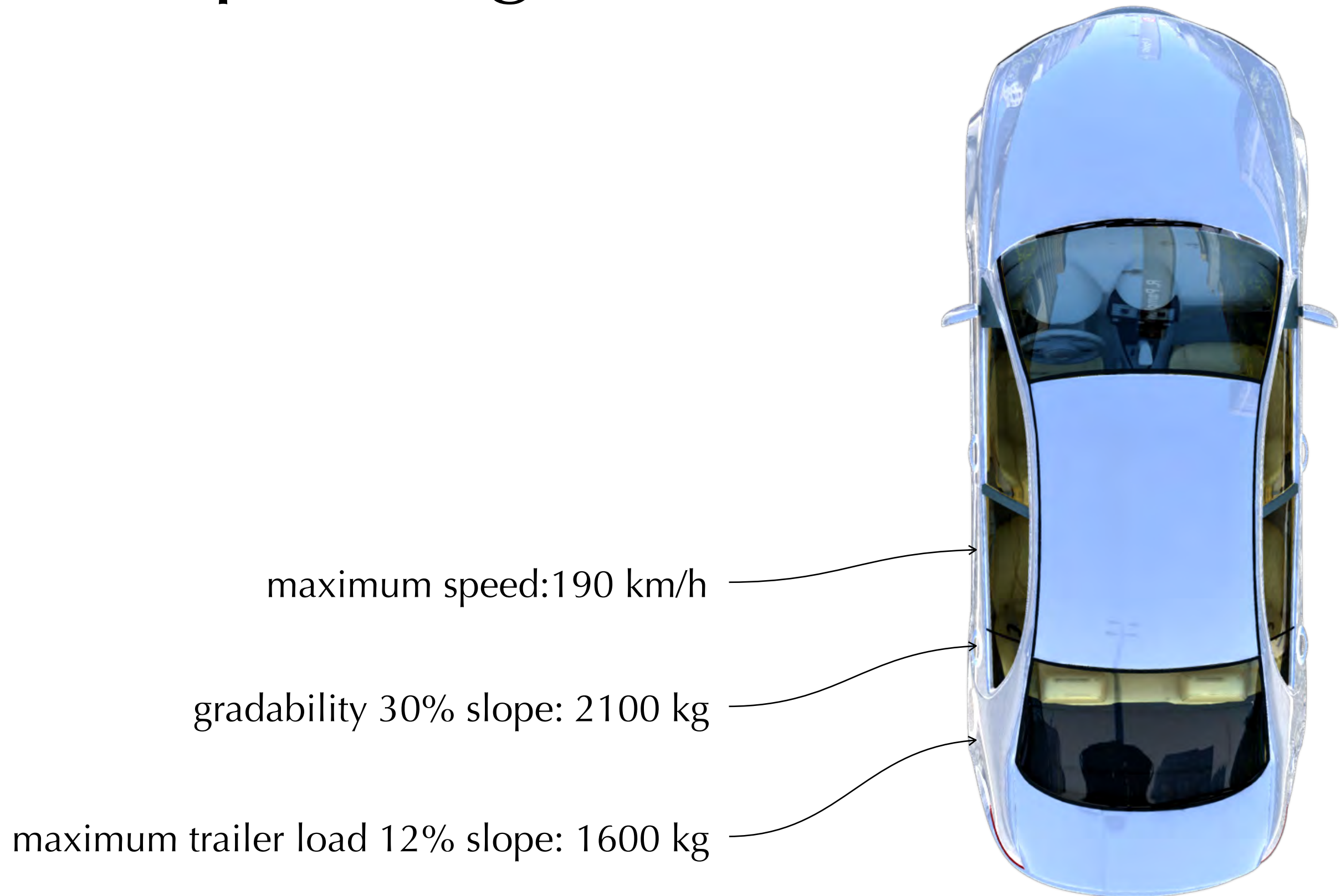
maximum trailer load 12% slope: 1600 kg



passenger car demands:



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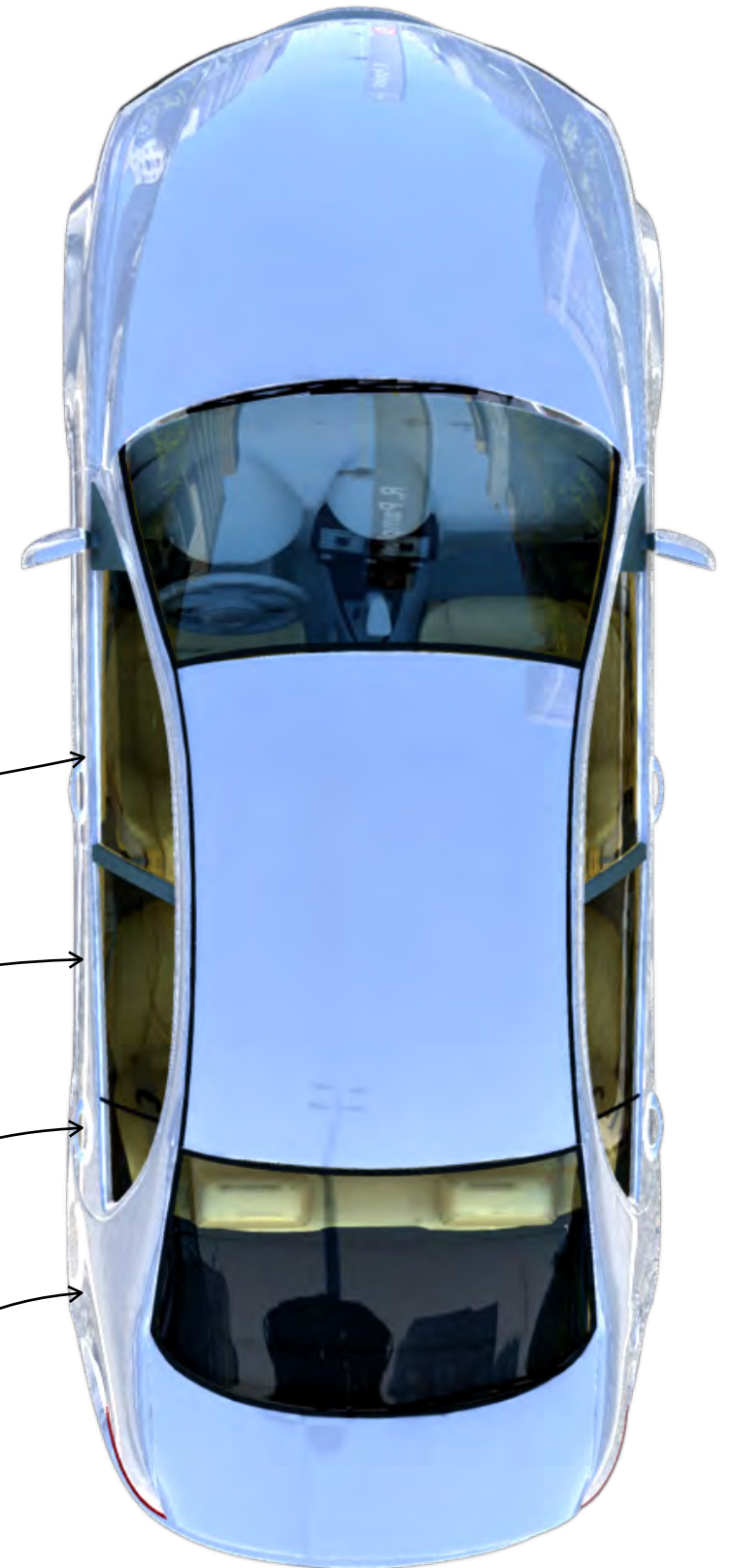
passenger car demands:

acceleration 0 - 100 km/h: 10 seconds

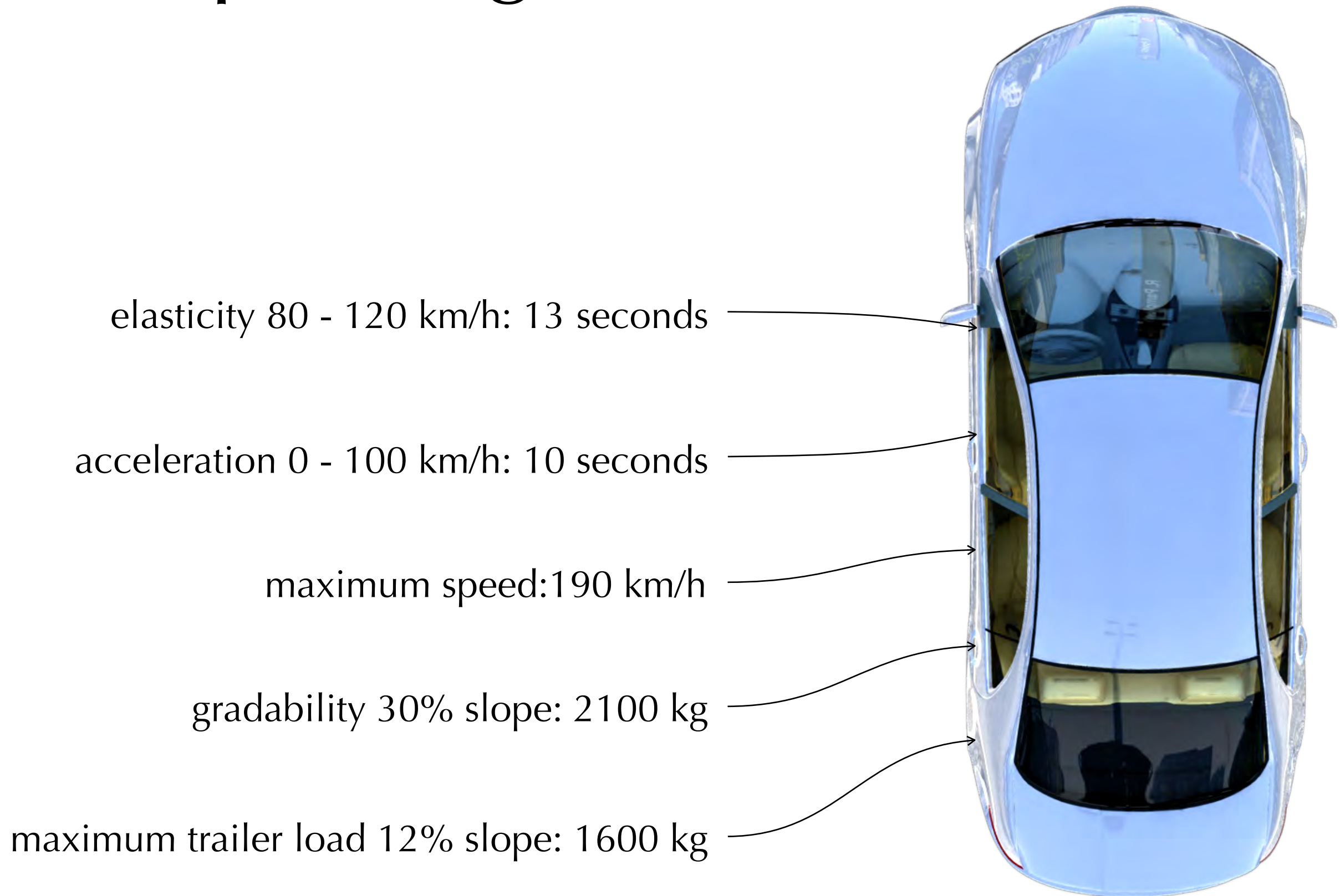
maximum speed: 190 km/h

gradability 30% slope: 2100 kg

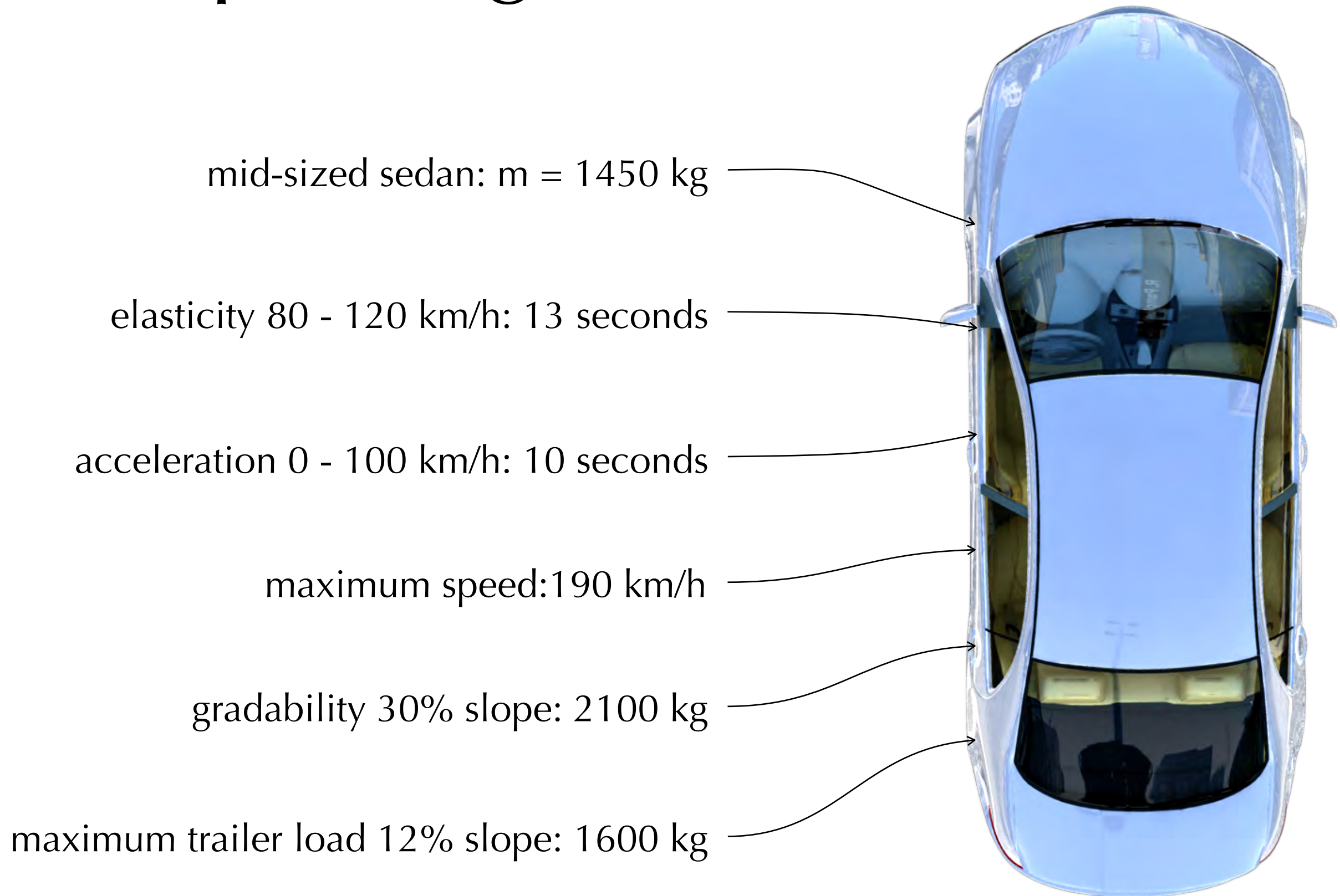
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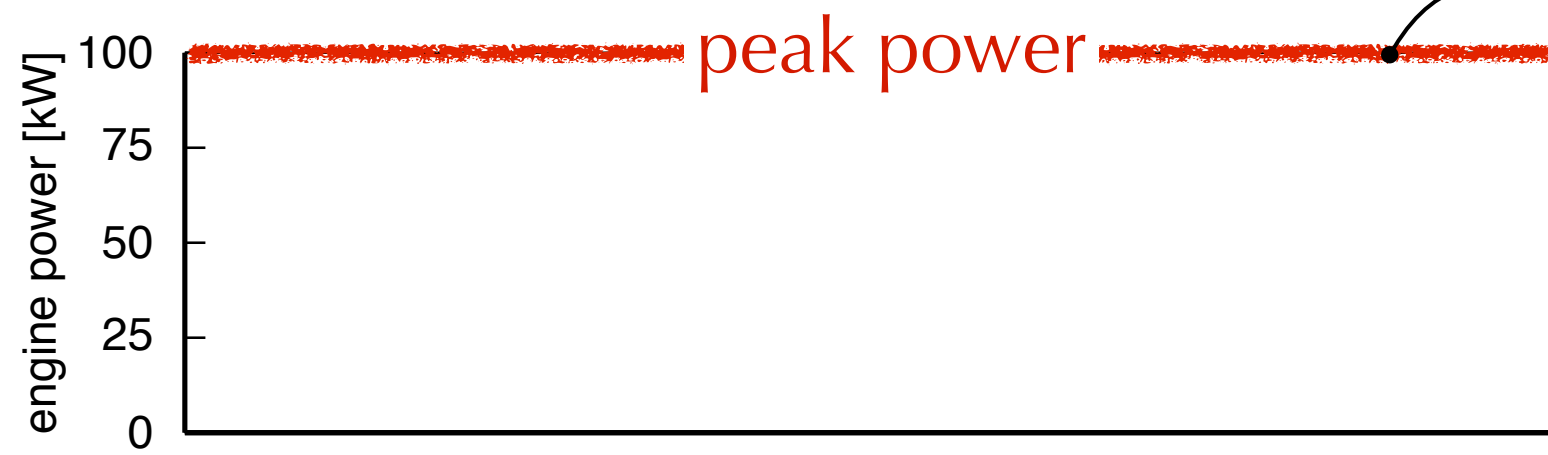


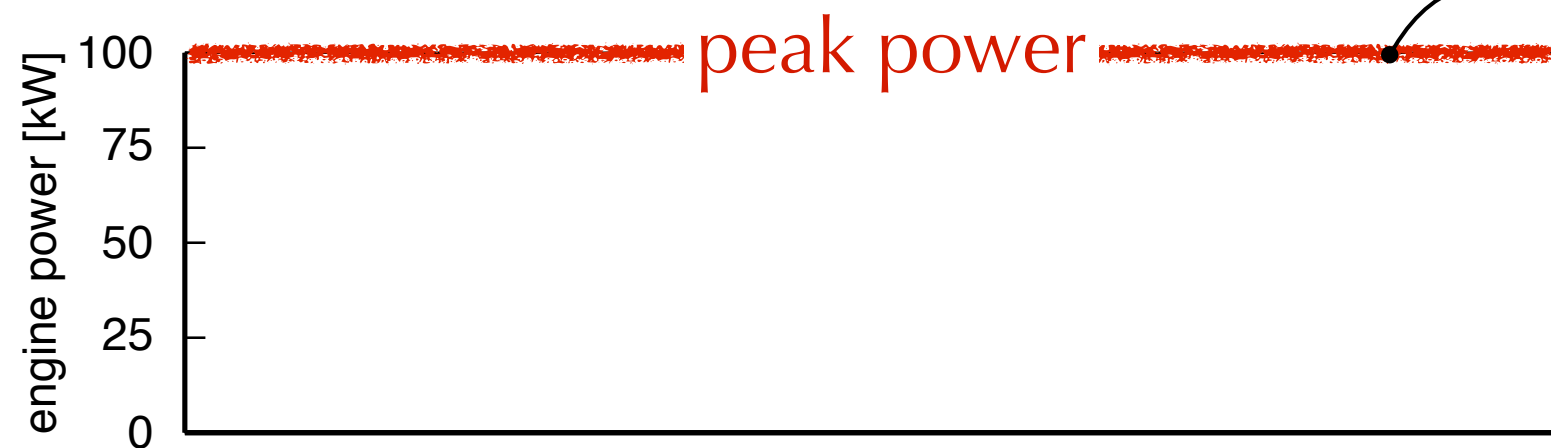
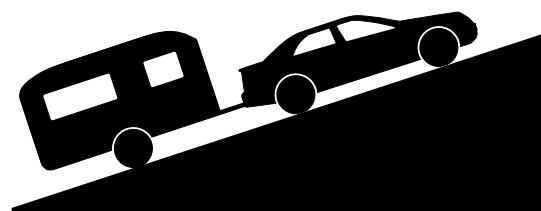
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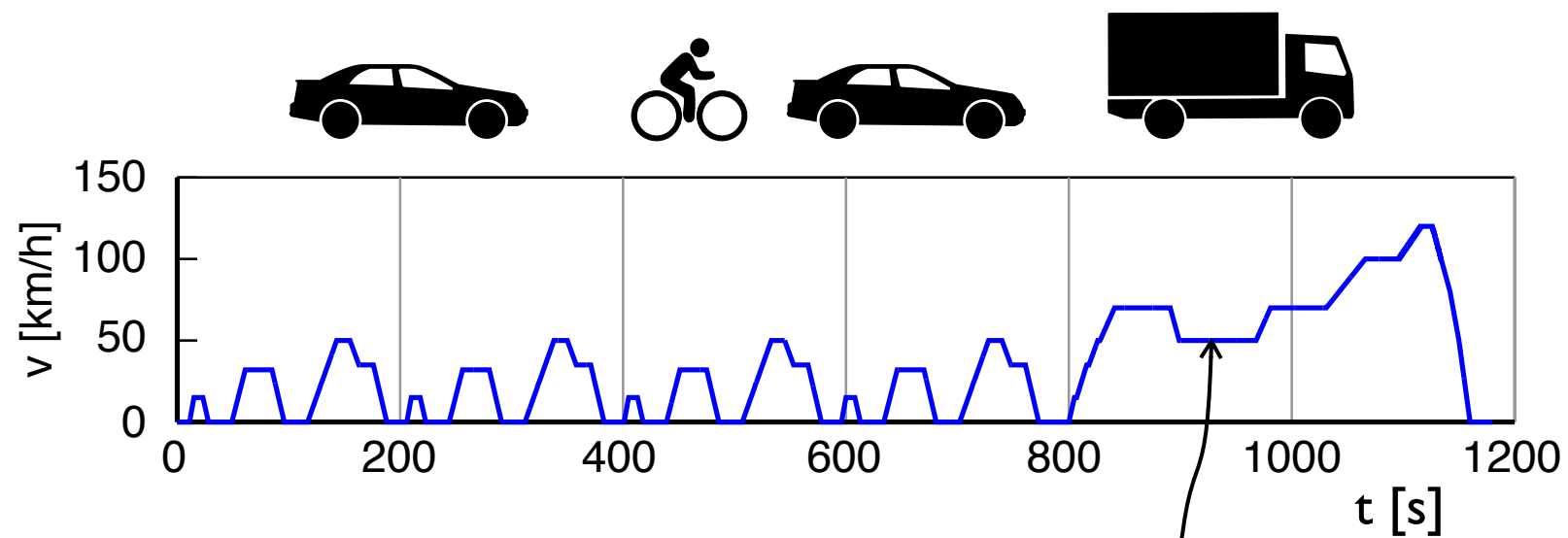
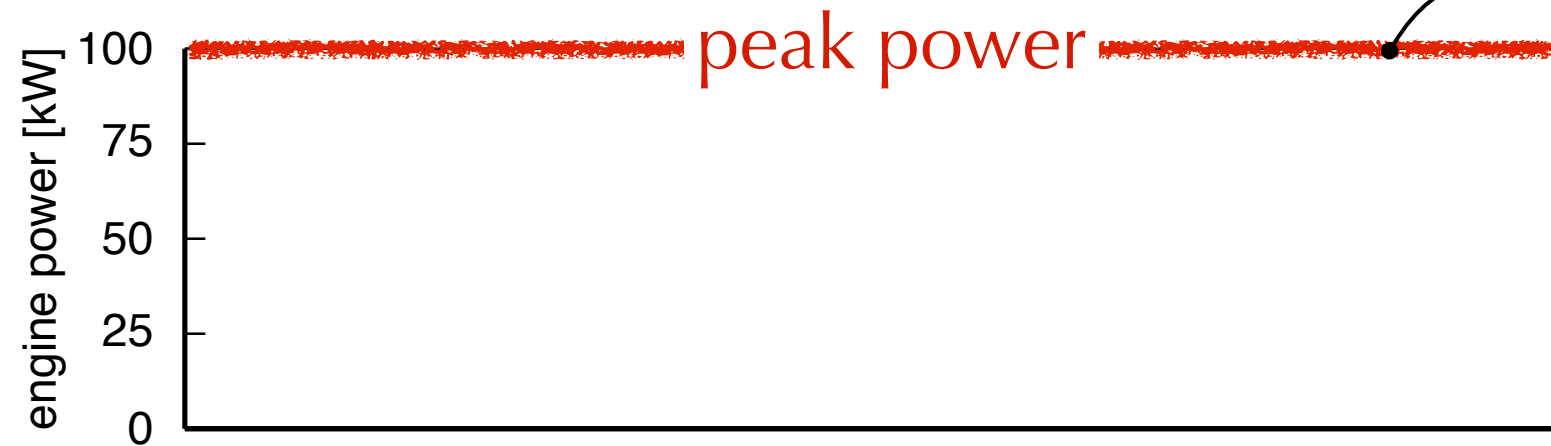
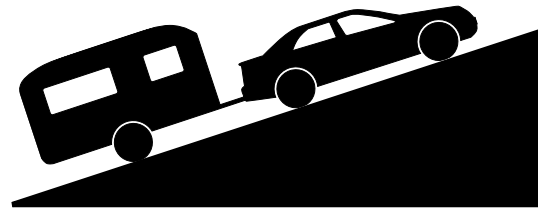


passenger car demands:



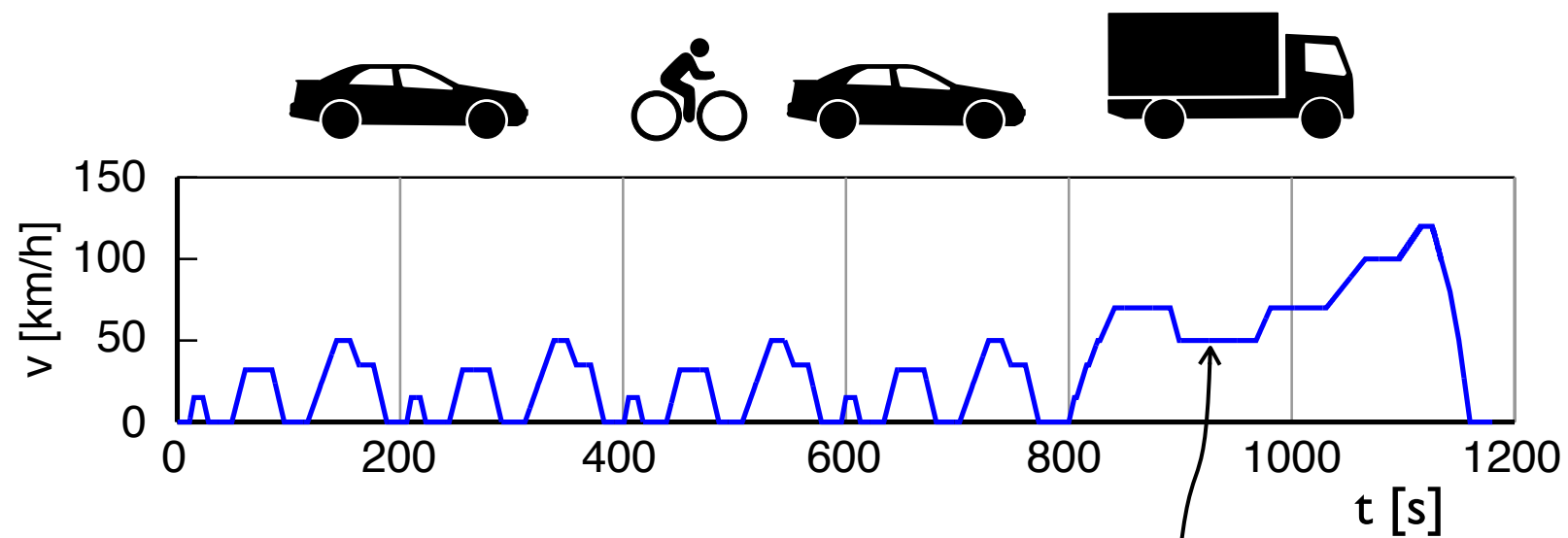
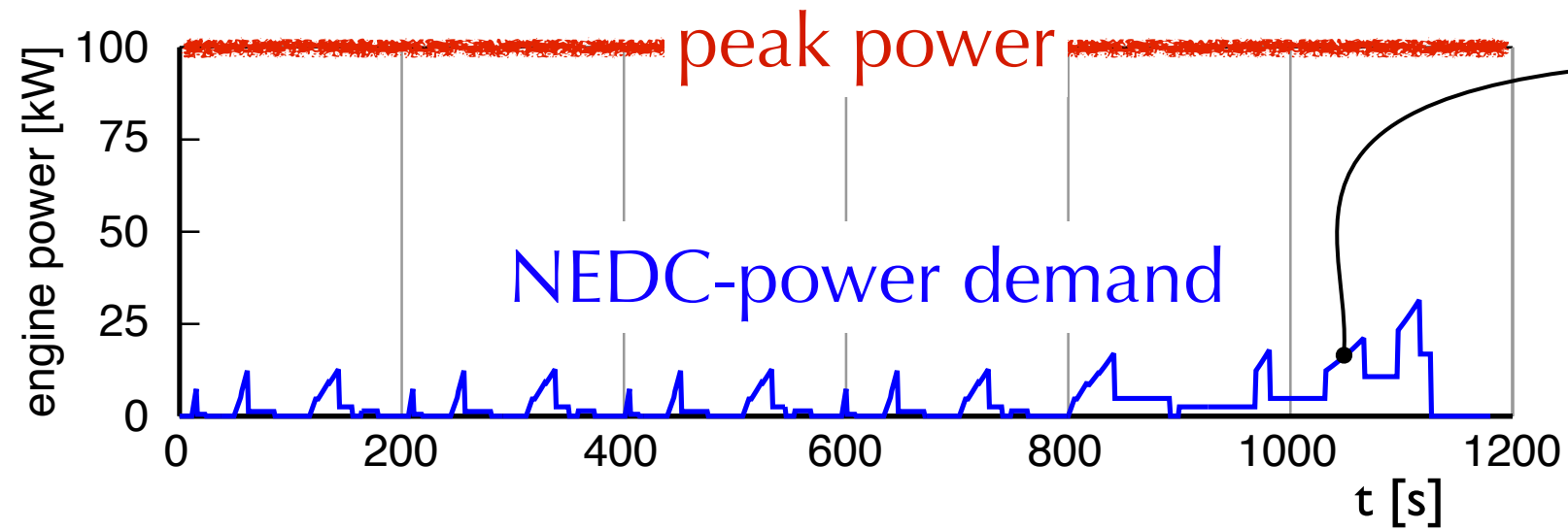
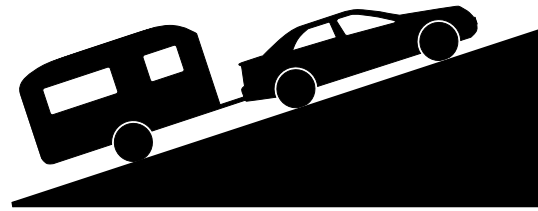






New European Driving Cycle
NEDC





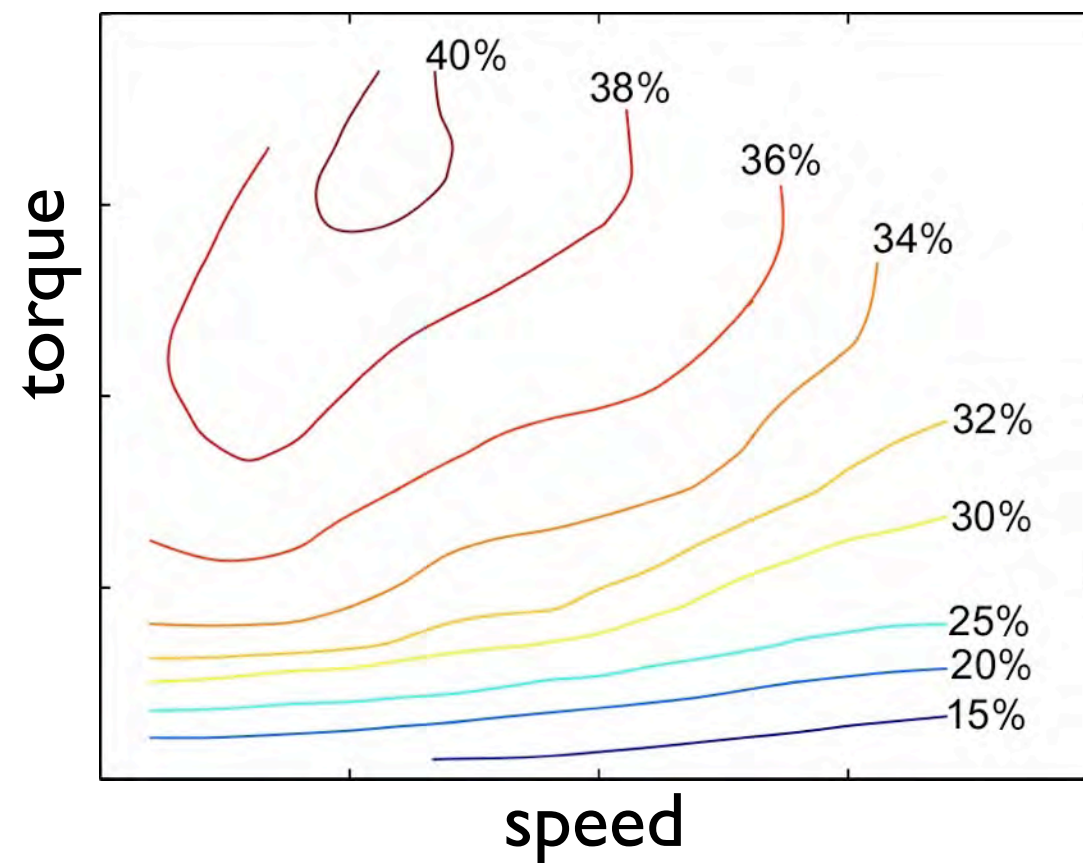
New European Driving Cycle
NEDC



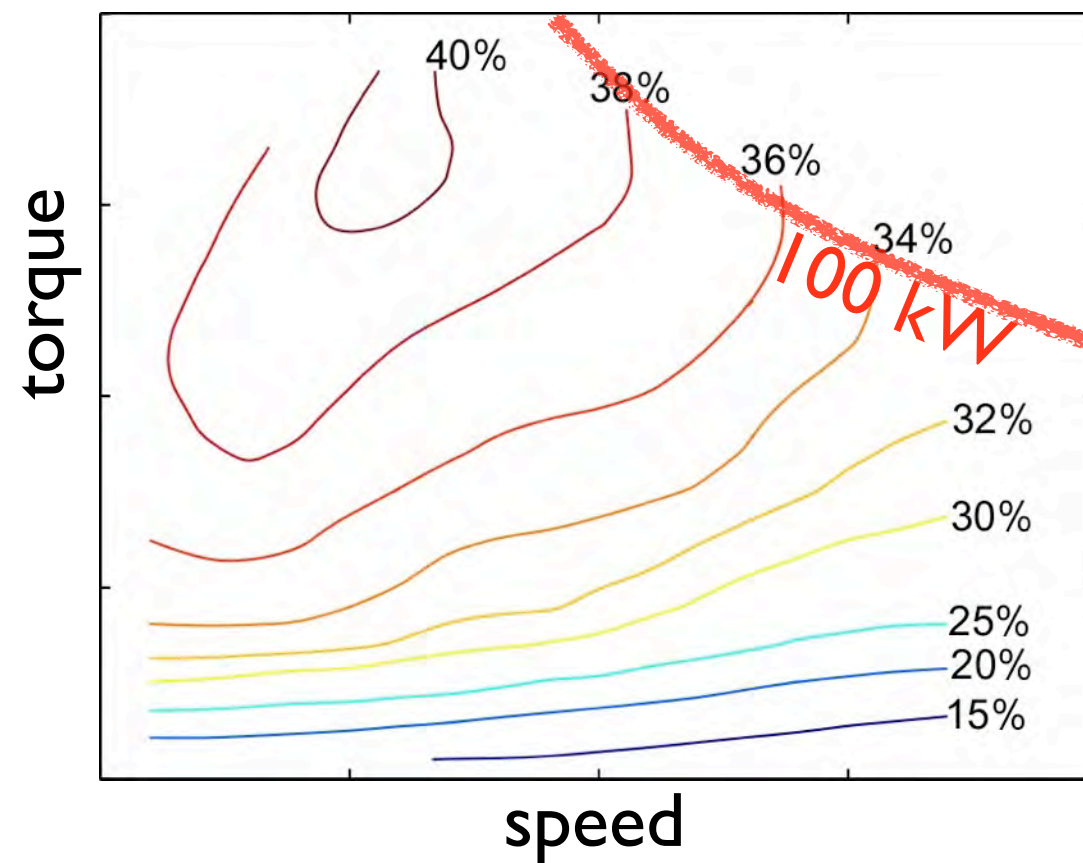
- ❖ 90% NEDC:
wheel power < 11 kW
poor engine efficiency
- ❖ 25% NEDC: standstill
idle losses
- ❖ 16% NEDC: braking
dissipation in the brakes



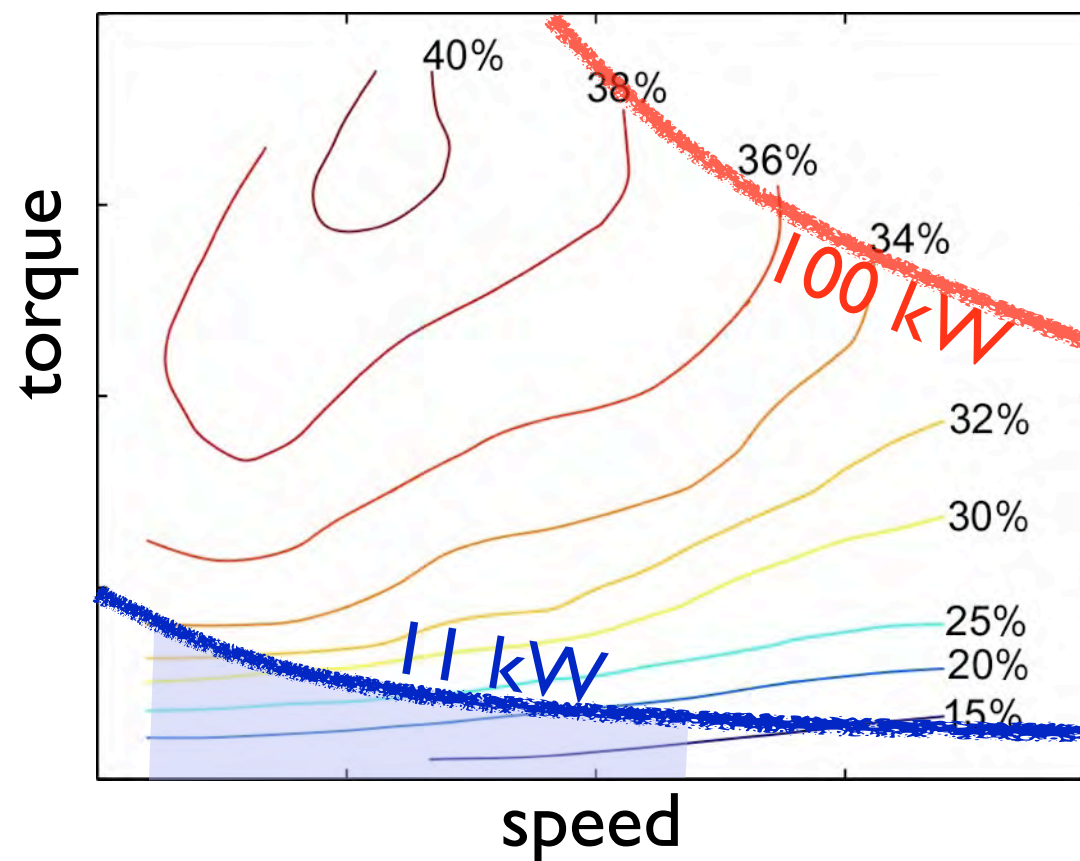
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specific fuel consumption

mid-sized European diesel sedan, NEDC

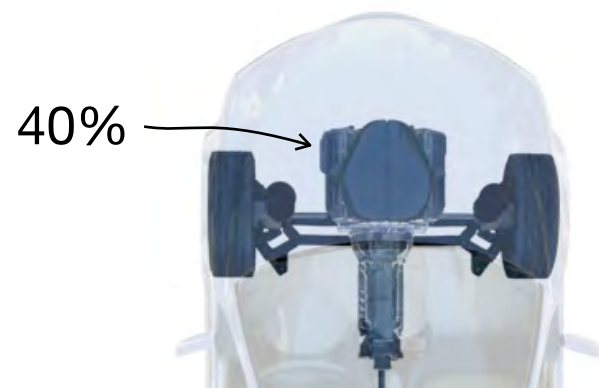
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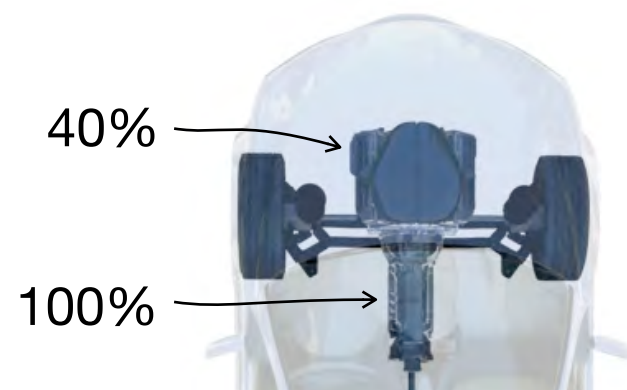
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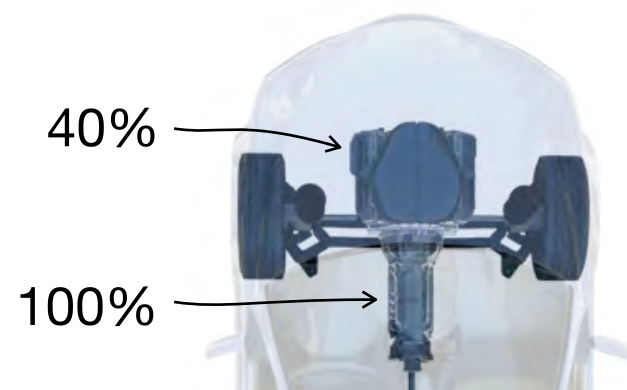


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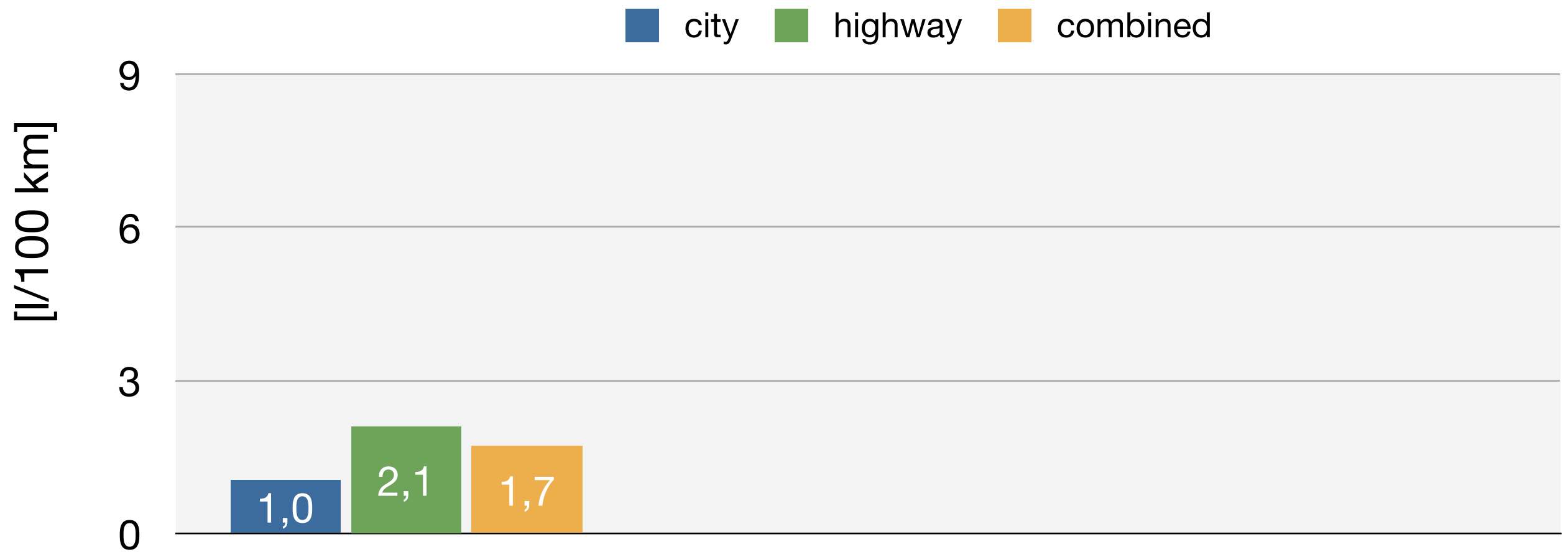


100% recuperation

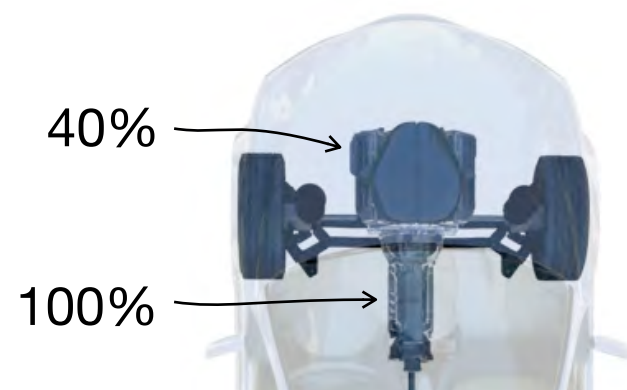


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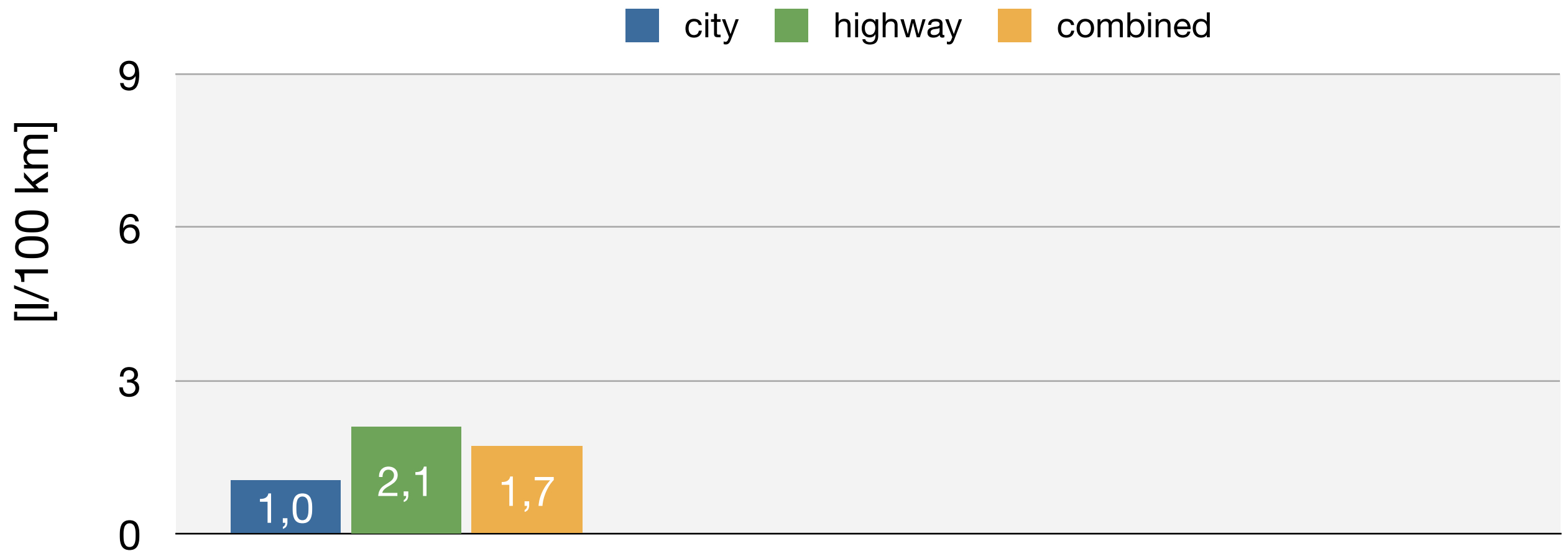


100% recuperation

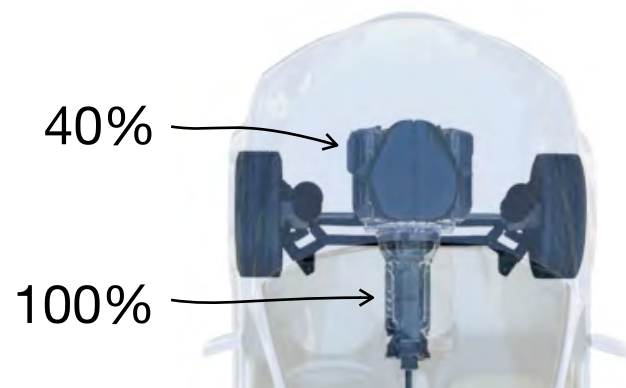


specific fuel consumption

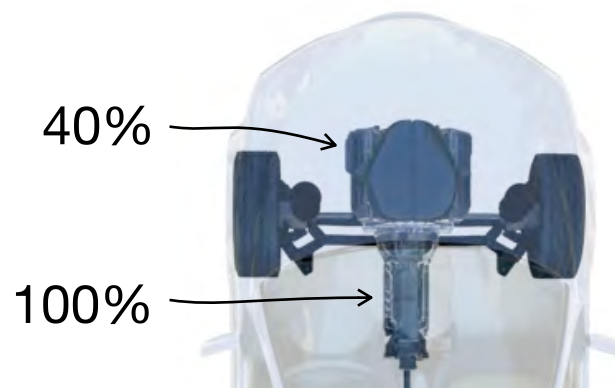
mid-sized European diesel sedan, NEDC



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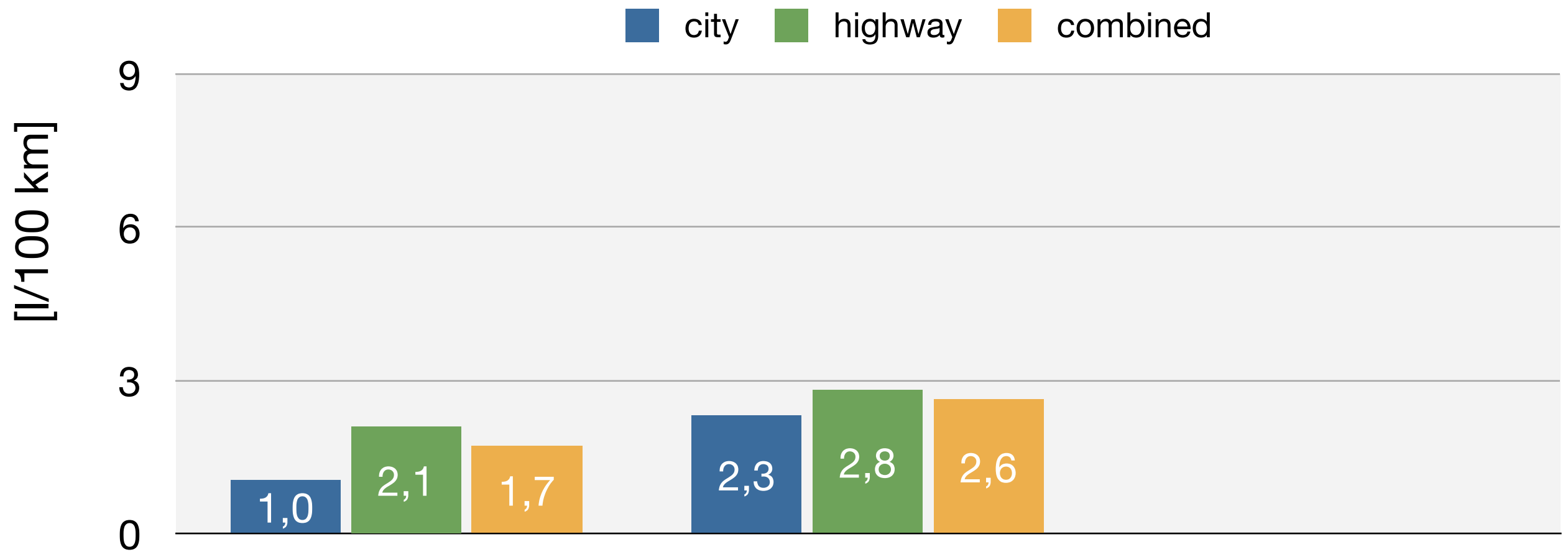


no recuperation



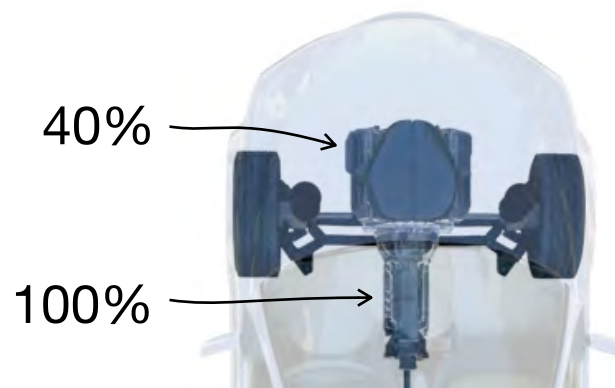
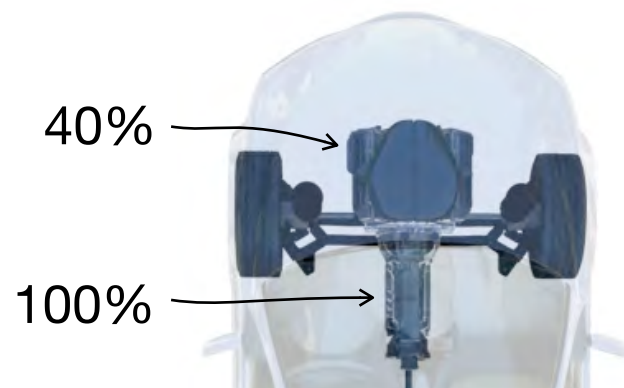
specific fuel consumption

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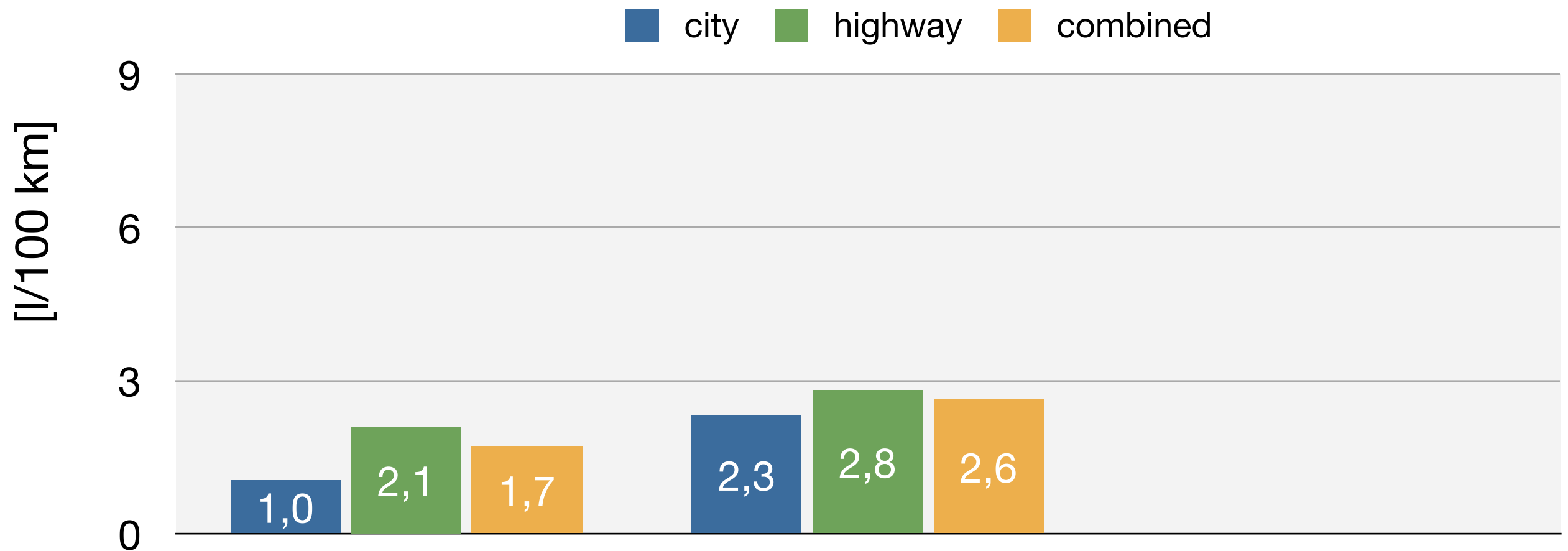
100% recuperation

no recuperation



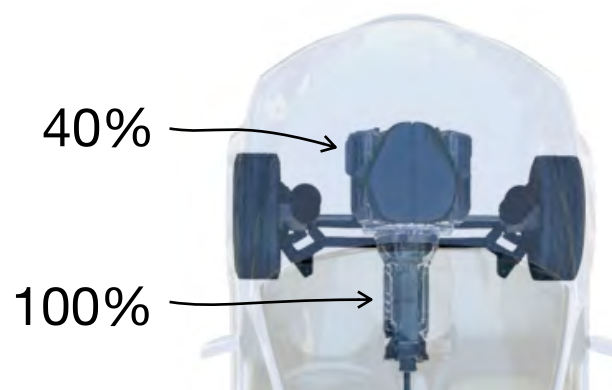
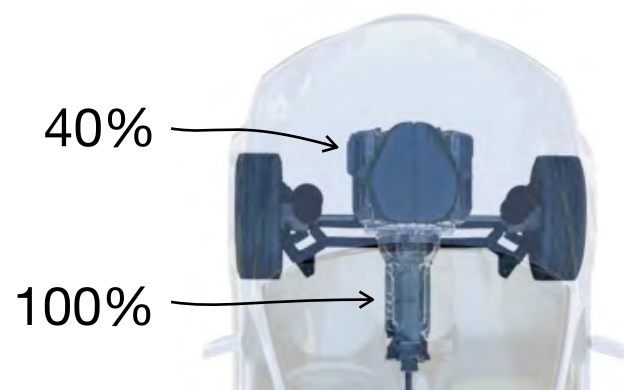
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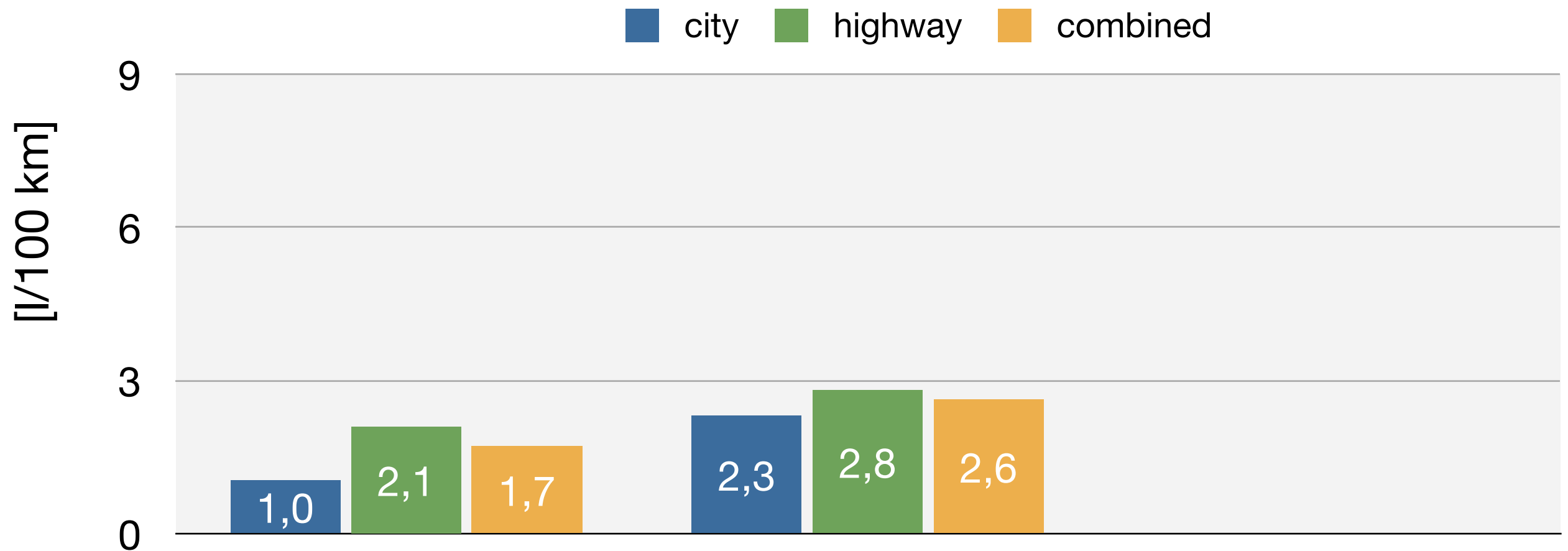
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specific fuel consumption

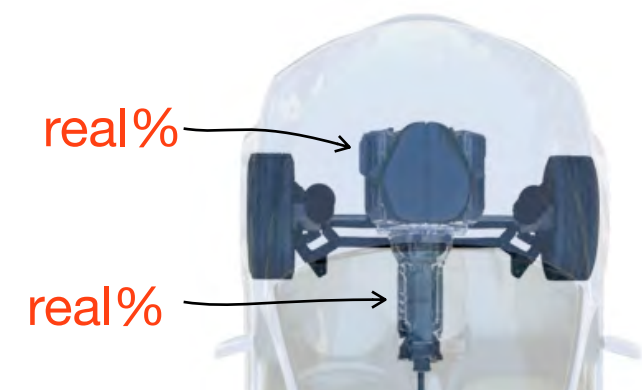
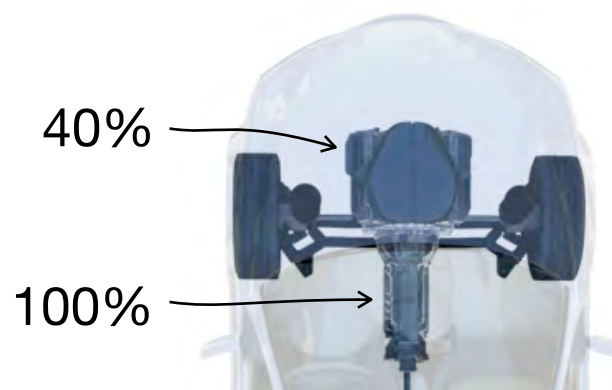
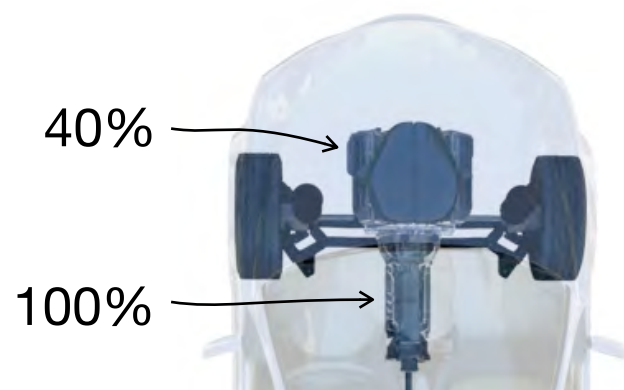
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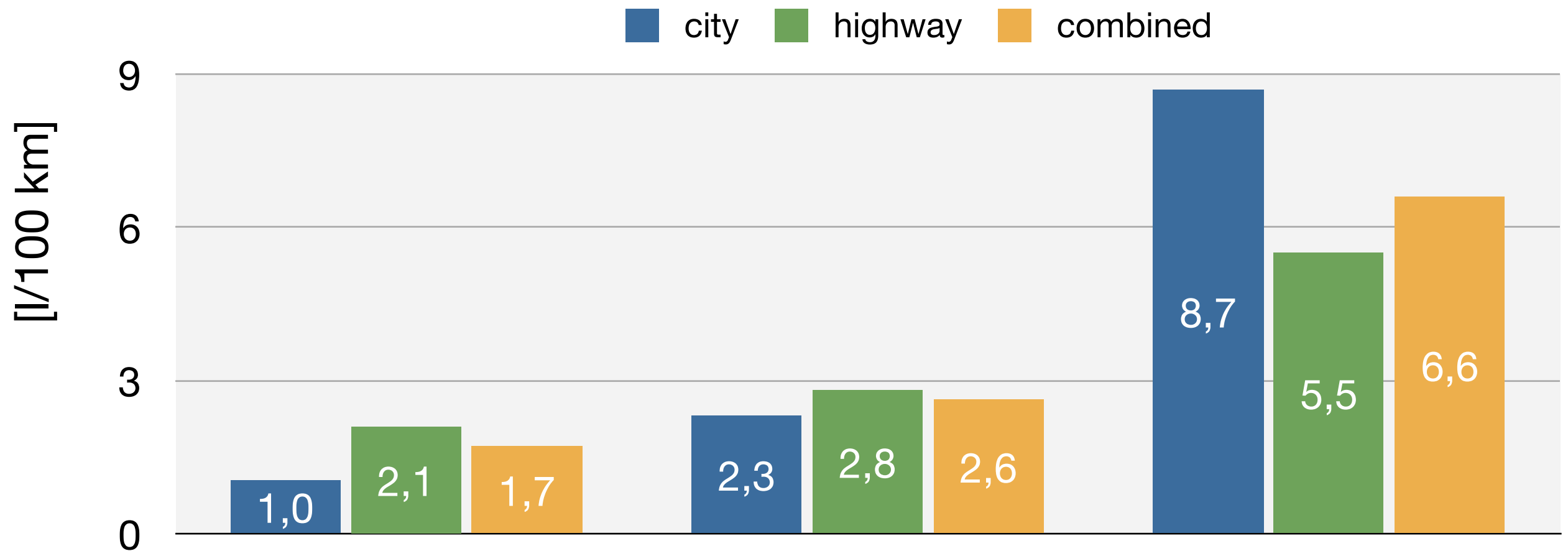
no recuperation

no recuperation

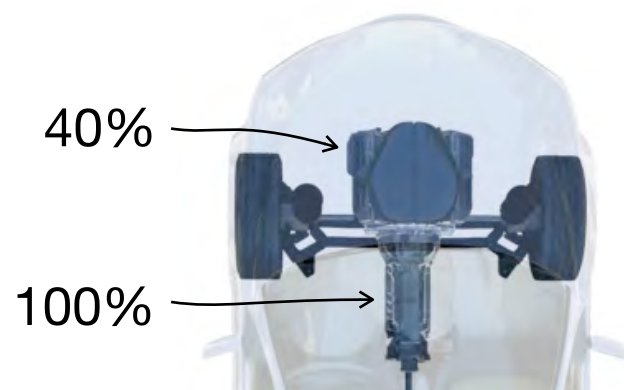


specific fuel consumption

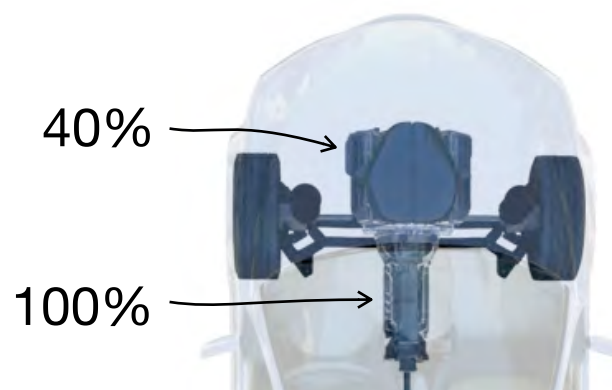
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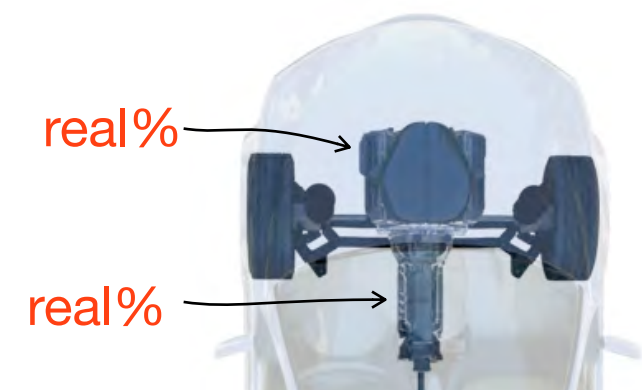
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no recuperation



no recuperation



specific CO₂ emission

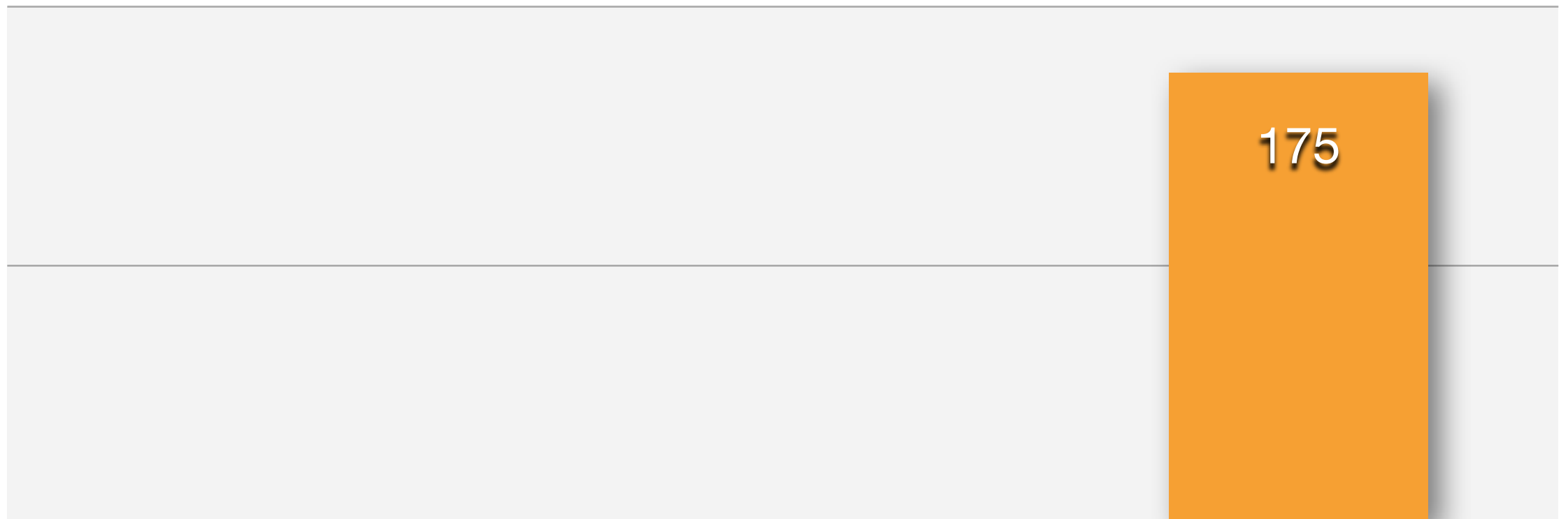
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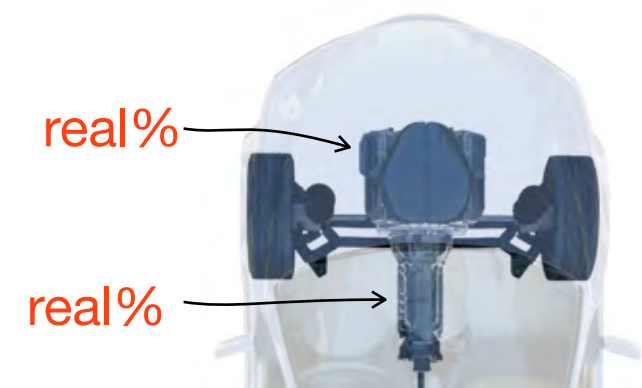
mid-sized European diesel sedan, NEDC

combined

CO₂ [g/km]



no recuperation



specific CO₂ emission

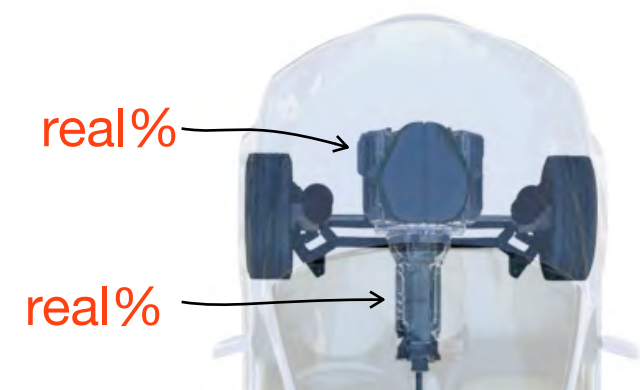
mid-sized European diesel sedan, NEDC

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CO₂ [g/km]



no recuperation

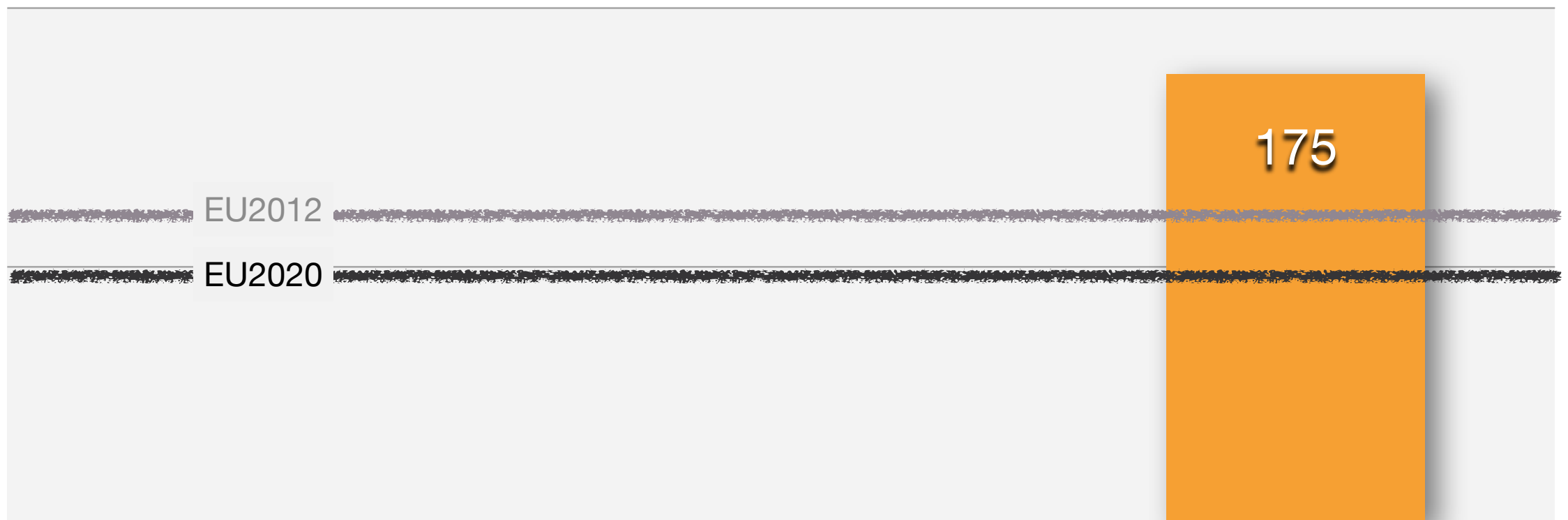


specific CO₂ emission

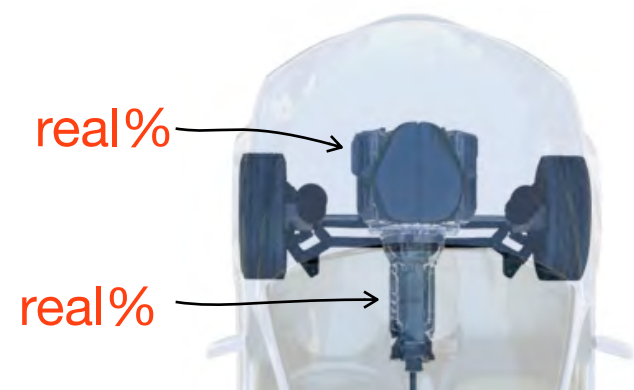
mid-sized European diesel sedan, NEDC

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CO₂ [g/km]



no recuperation

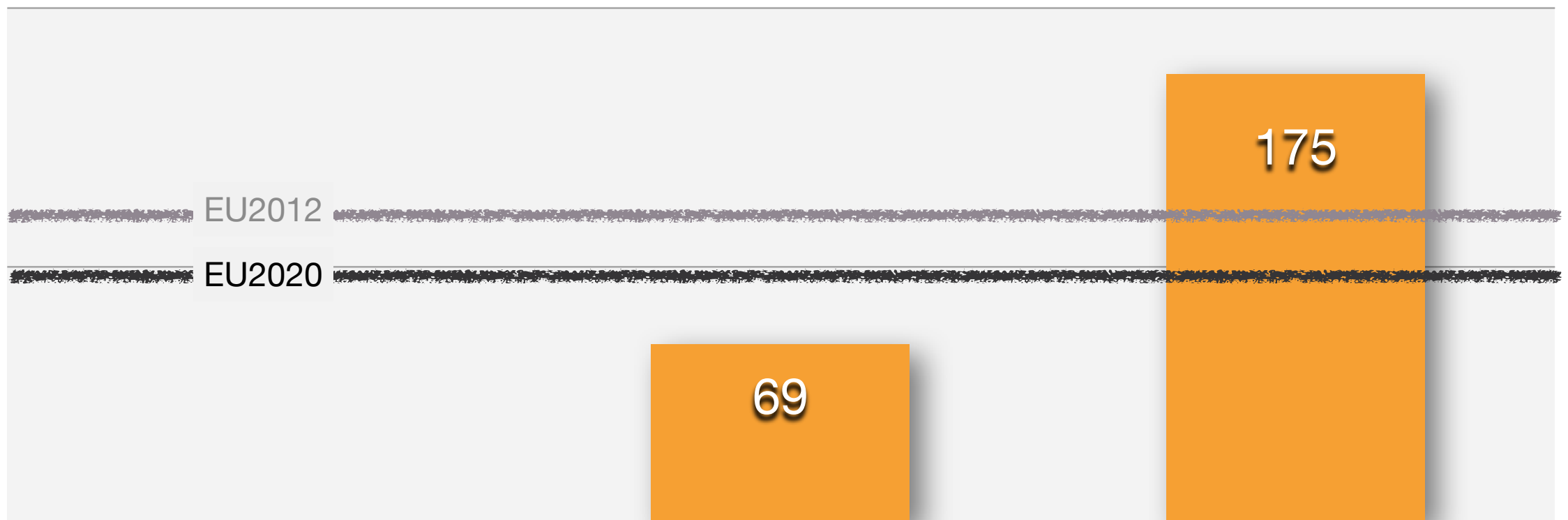


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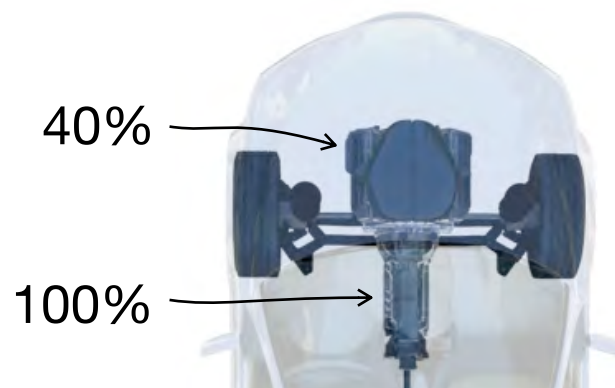
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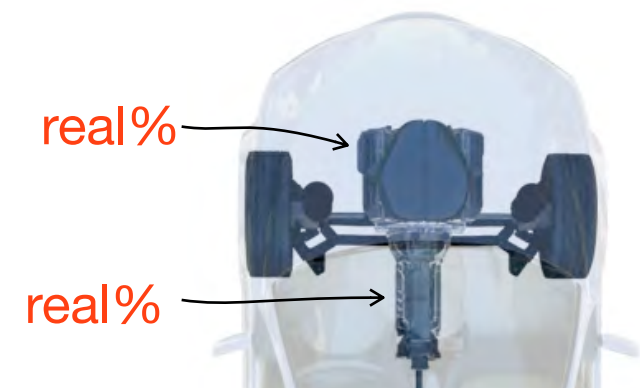
CO₂ [g/km]



no recuperation



no recuperation

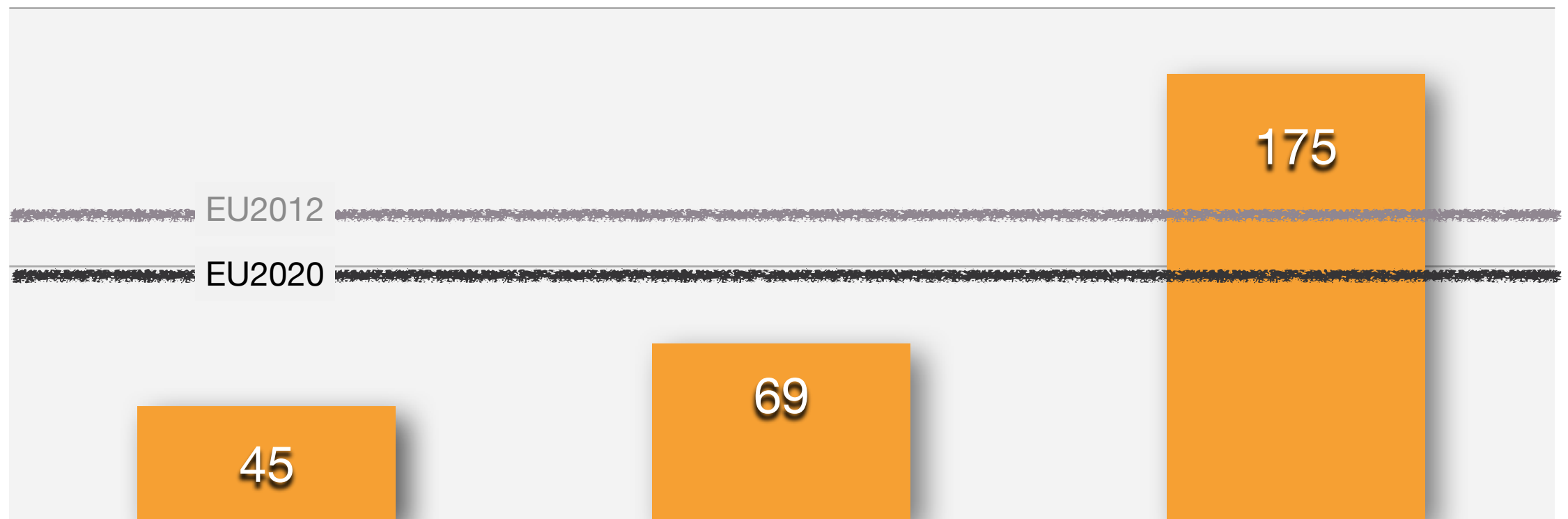


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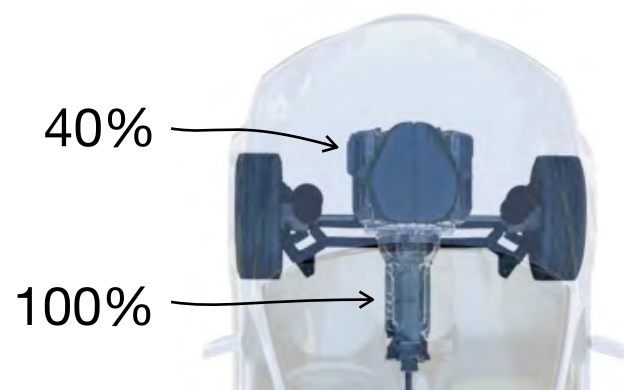
mid-sized European diesel sedan, NEDC

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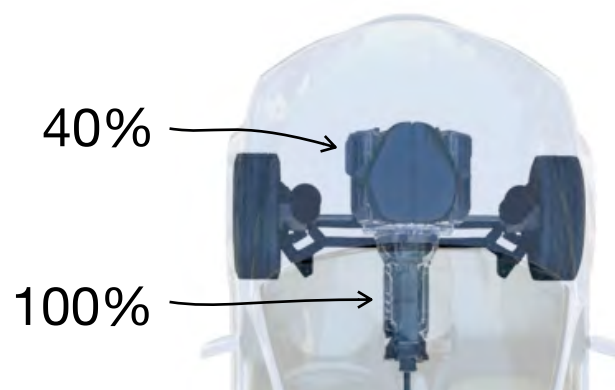
CO₂ [g/km]



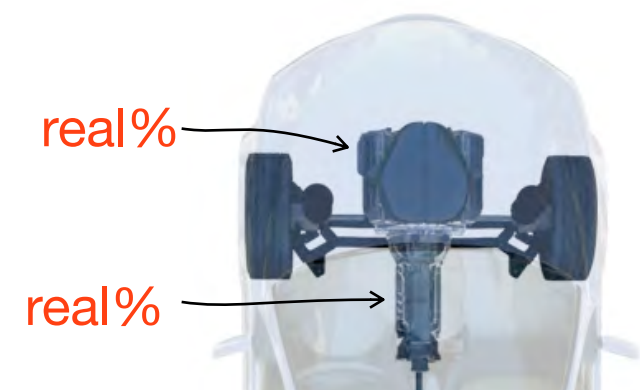
100% recuperation



no recuperation



no recuperation



conclusions



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- ❖ >50% reduction of fuel consumption and CO₂-emission is possible



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conclusions

- ❖ >50% reduction of fuel consumption and CO₂-emission is possible
- ❖ disconnect the engine from the wheels
- ❖ engine load between 50% and 100%
- ❖ NEDC: brake energy recuperation offers only a small advantage
- ❖ for real world driving conditions recuperation is much more important

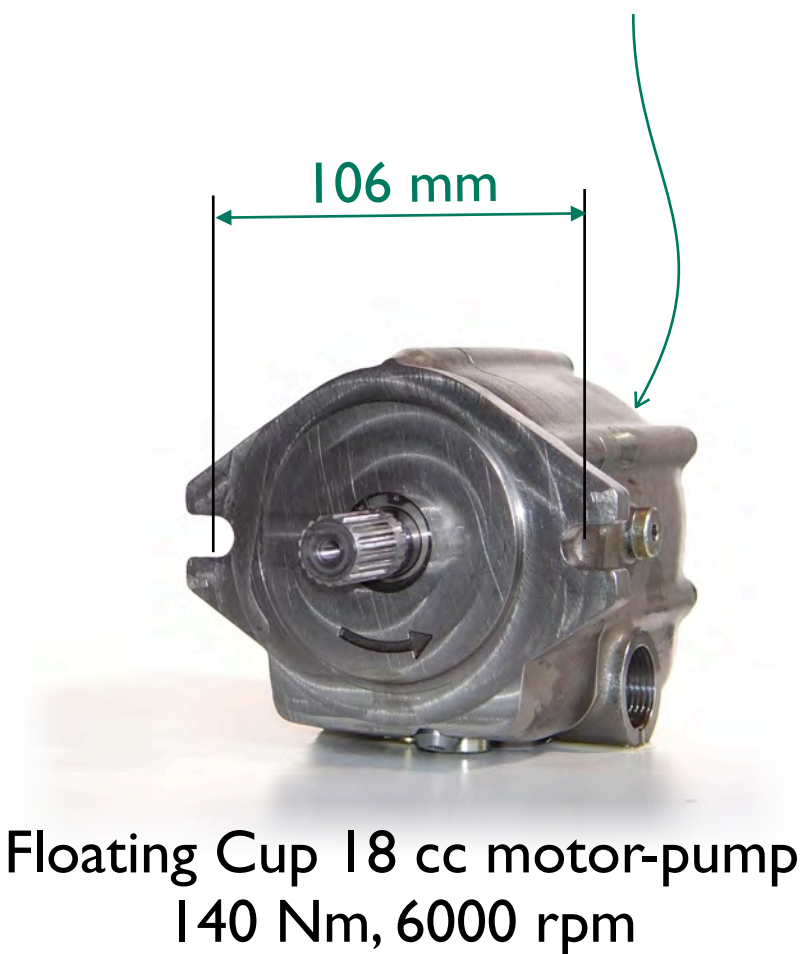


Hydraulics: advantages & disadvantages

Hydraulic advantages

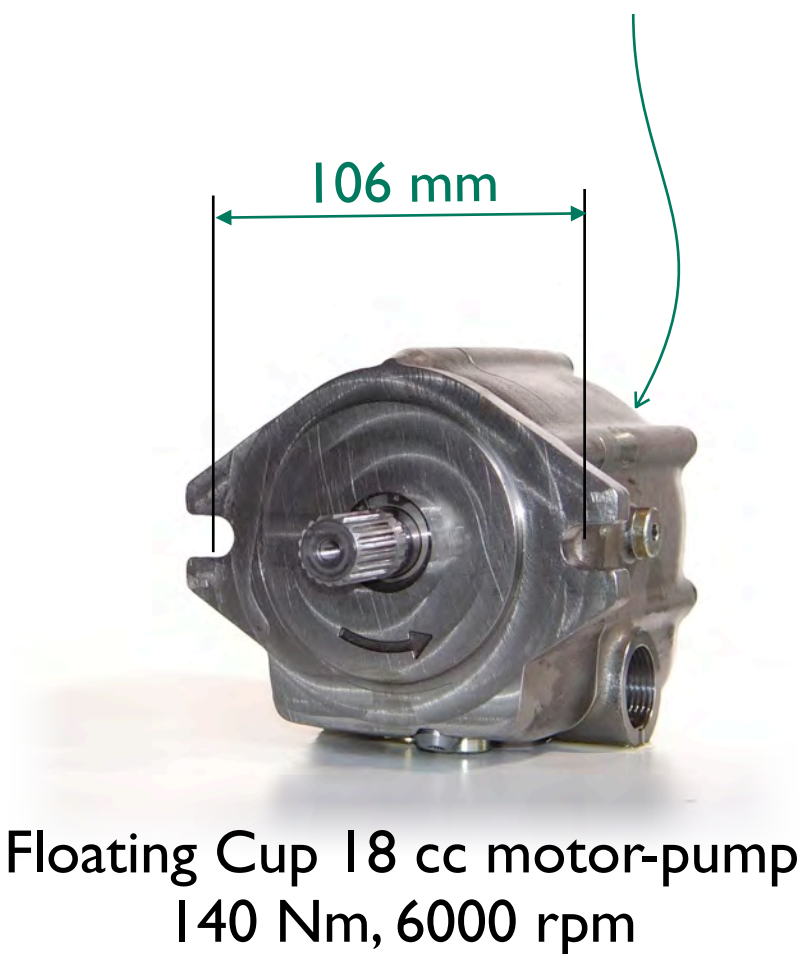
- ❖ robust
- ❖ flexible
- ❖ oil is also cooling medium
- ❖ compact

5,9 kg 90 kW



Hydraulic advantages

5,9 kg 90 kW

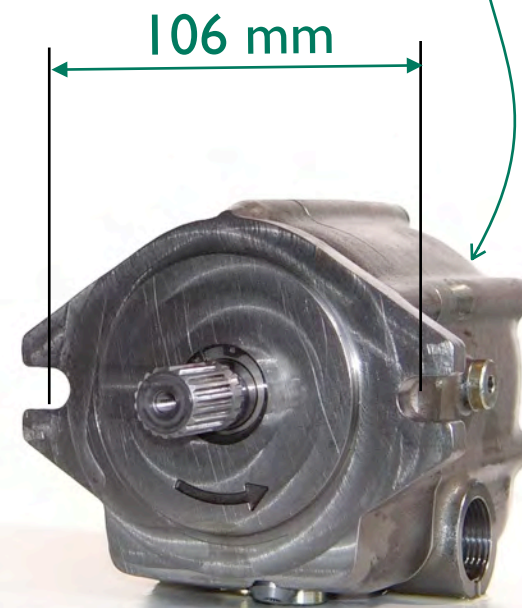


Hydraulic advantages



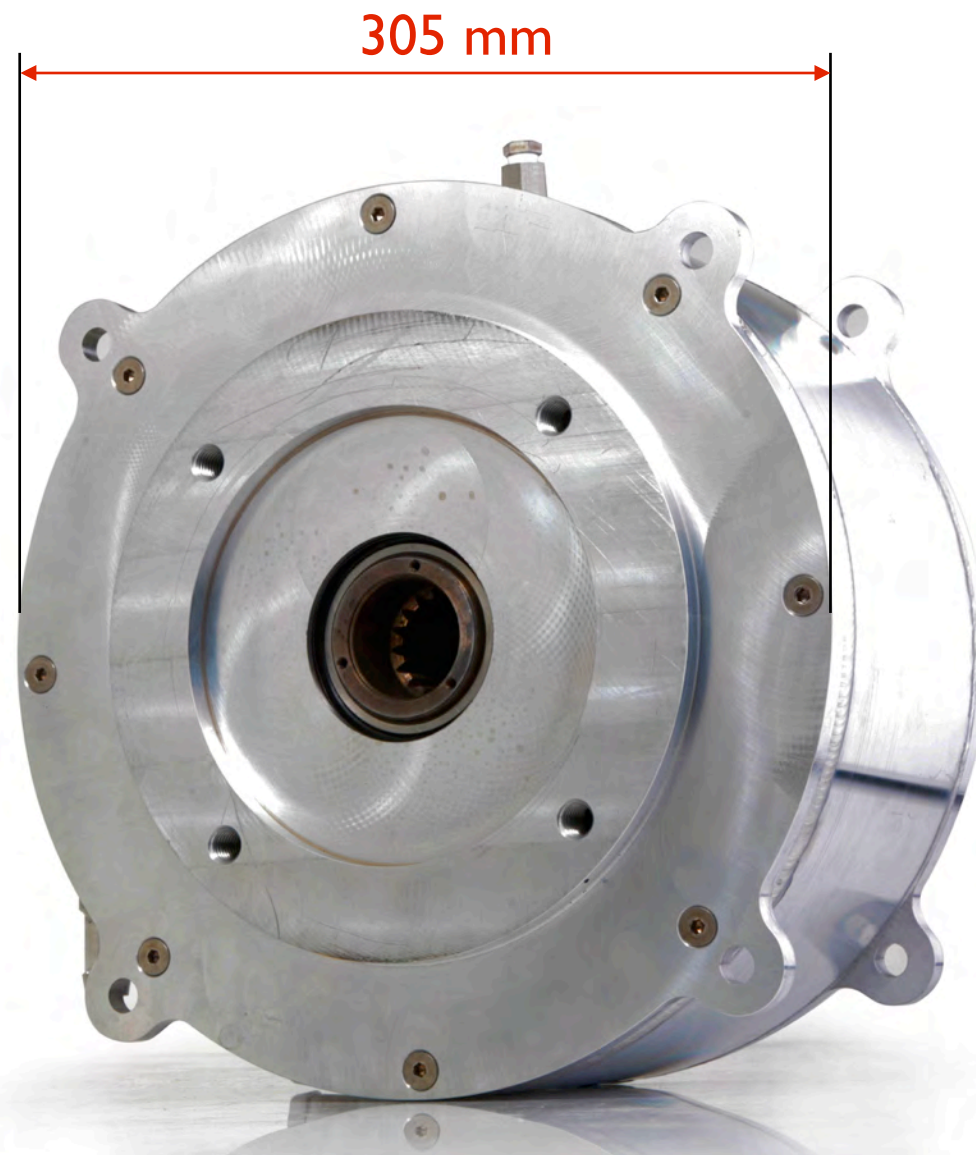
Symetron P-42 Motor-Generator
100 Nm, 6000 rpm

5,9 kg 90 kW



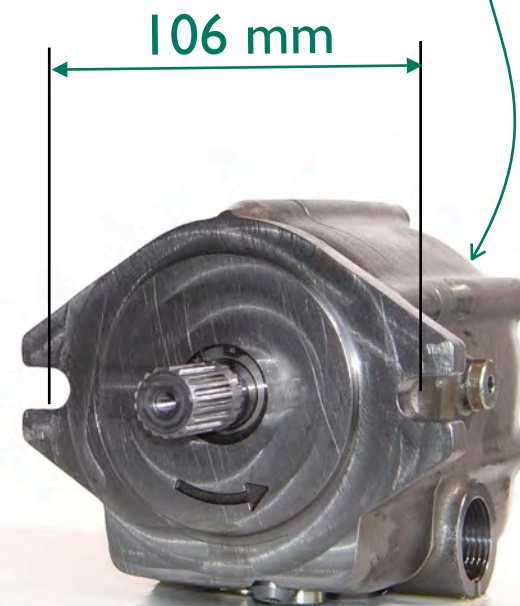
Floating Cup 18 cc motor-pump
140 Nm, 6000 rpm

Hydraulic advantages



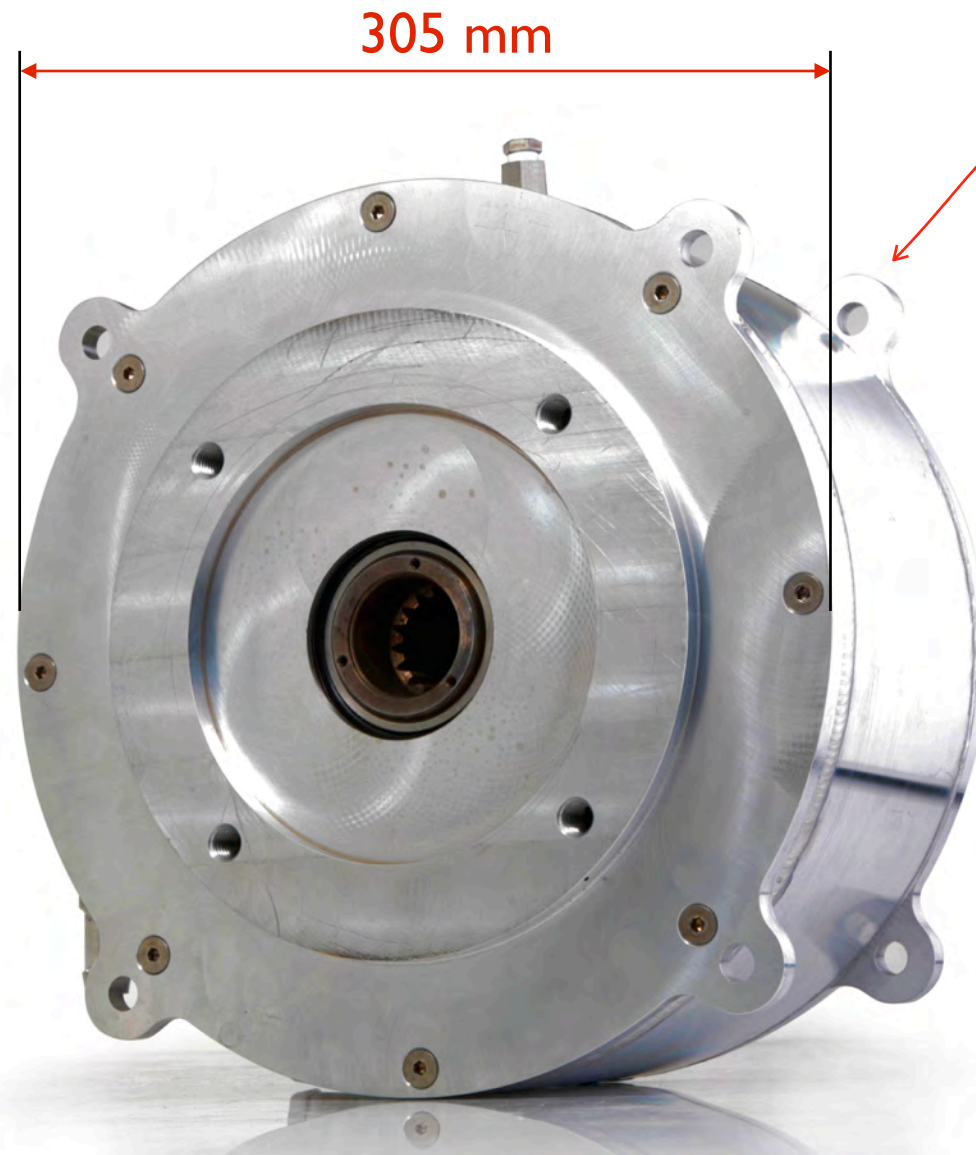
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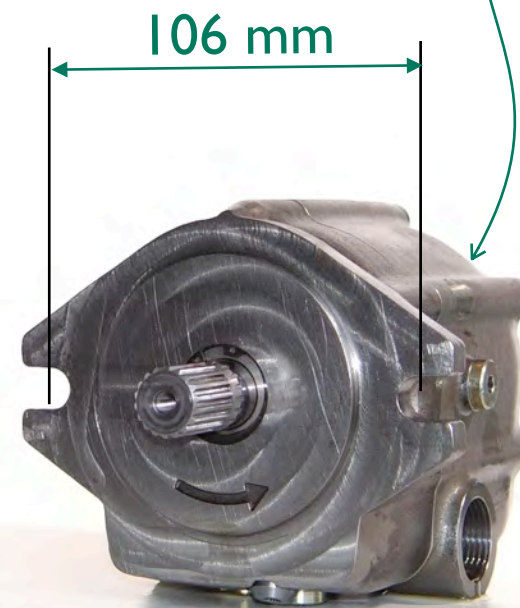
Hydraulic advantages



Symetron P-42 Motor-Generator
100 Nm, 6000 rpm

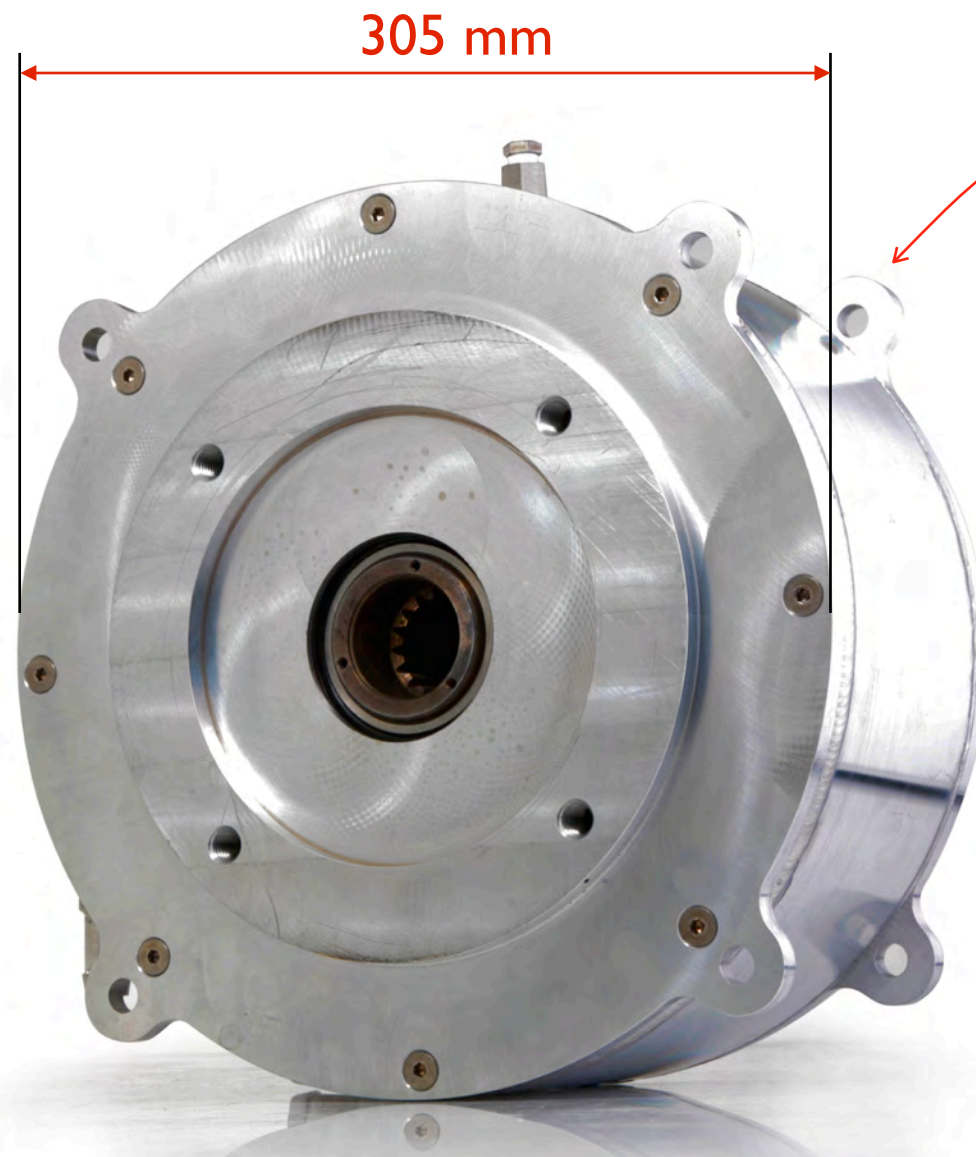
41,5 kg 21 kW

5,9 kg 90 kW



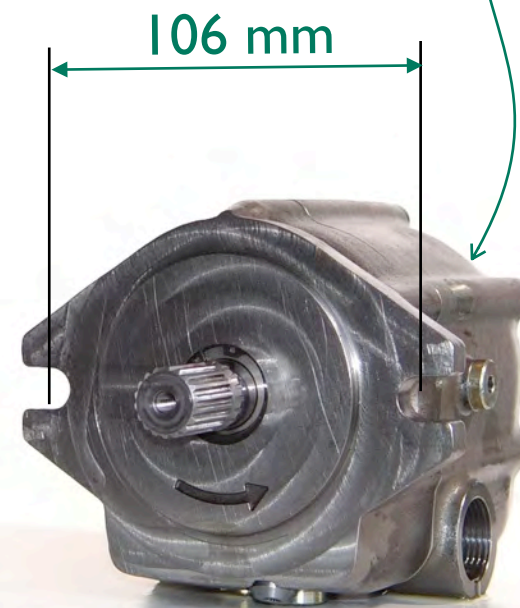
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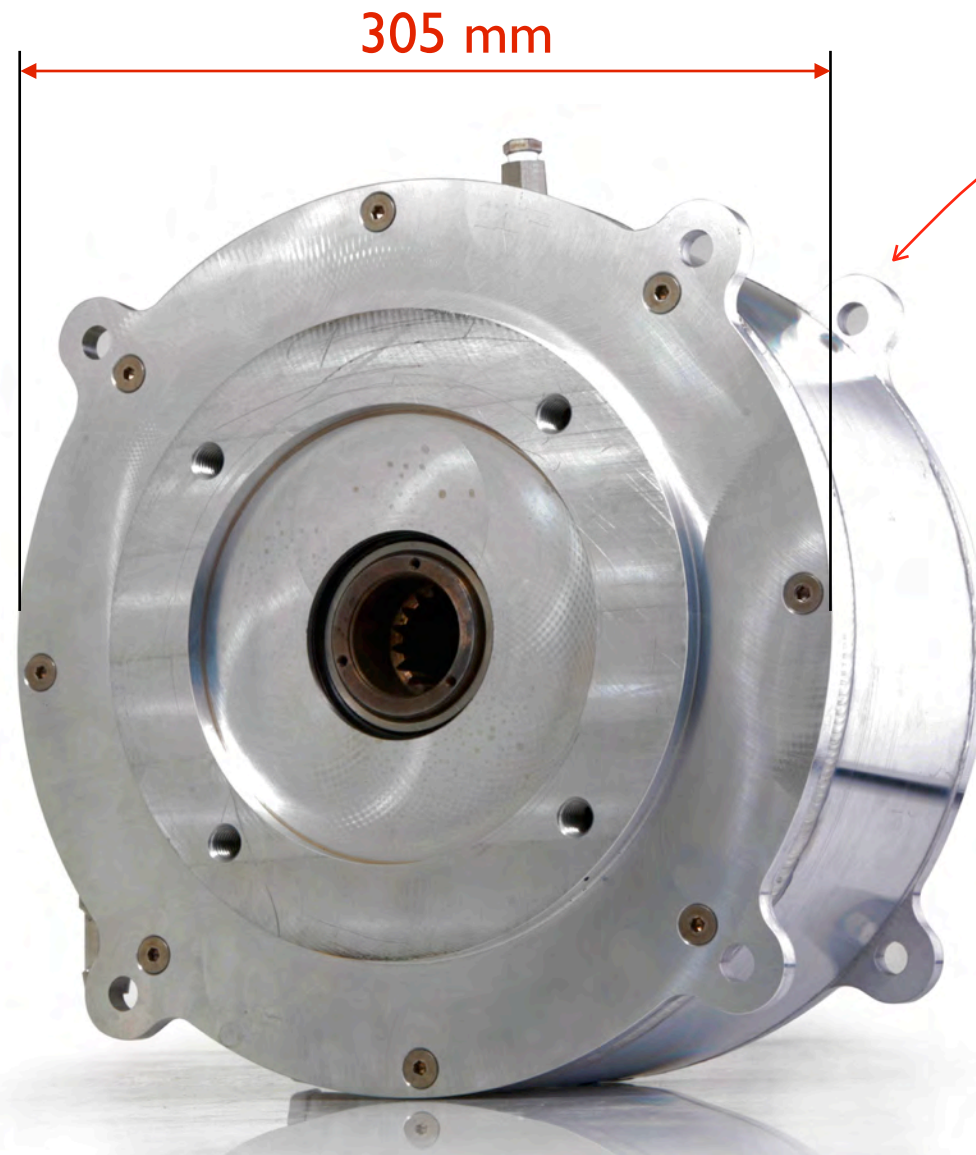
Symetron P-42 Motor-Generator
100 Nm, 6000 rpm

2,0 kg/kW
0,066 kg/kW



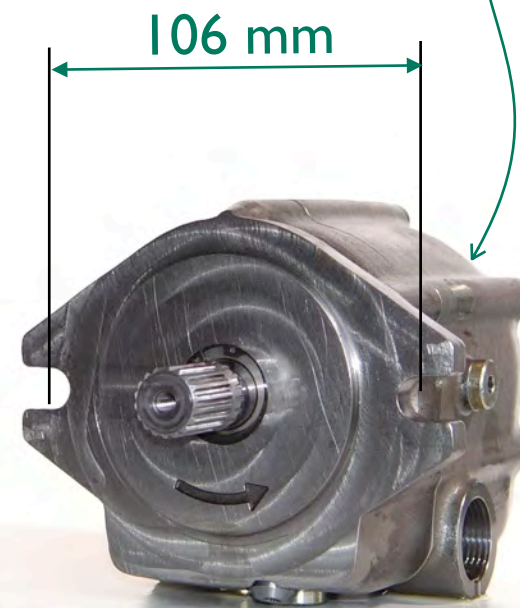
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Hydraulic advantages



Symetron P-42 Motor-Generator
100 Nm, 6000 rpm

$$\frac{2,0 \text{ kg/kW}}{0,066 \text{ kg/kW}} = 30$$



Floating Cup 18 cc motor-pump
140 Nm, 6000 rpm

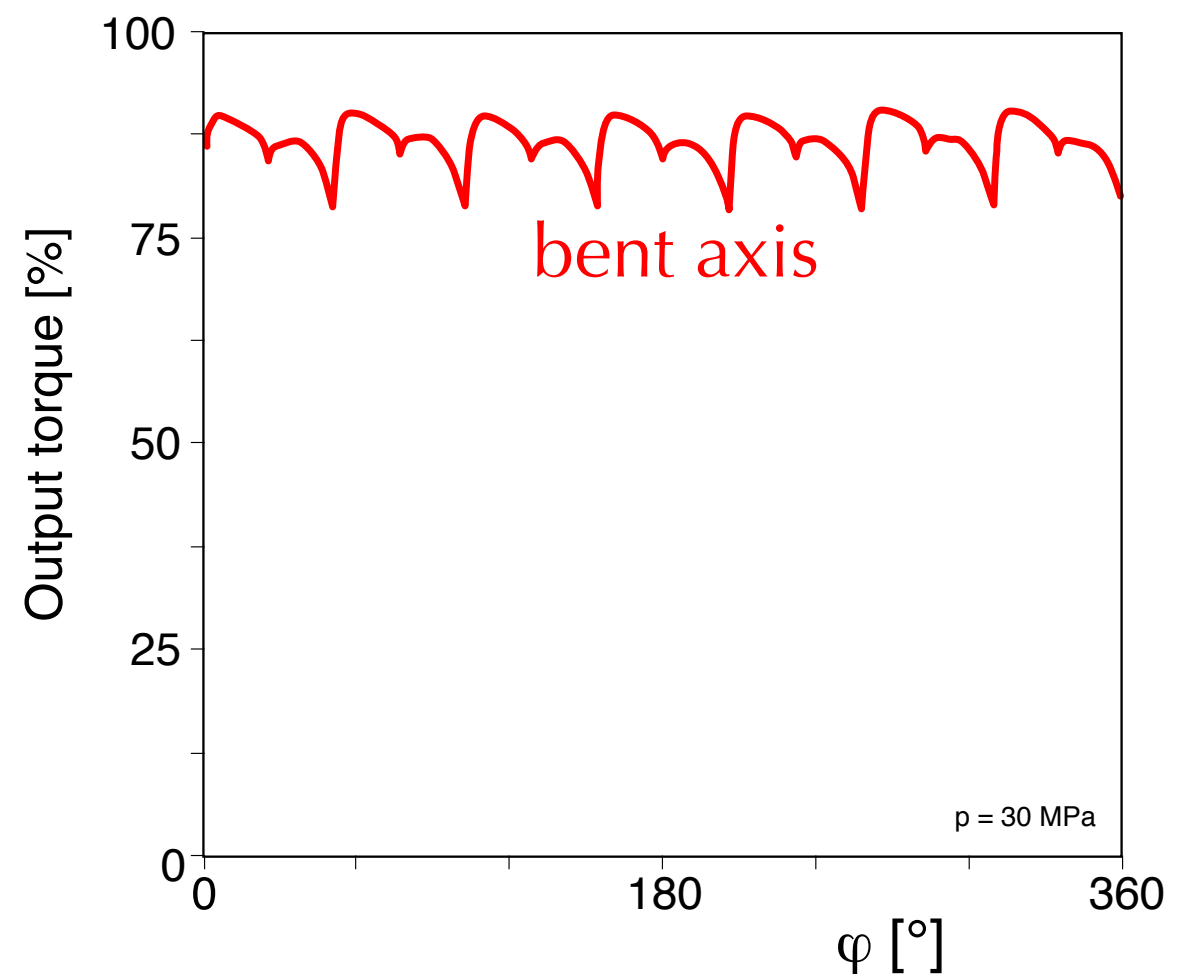
hydraulic disadvantages

hydraulic disadvantages

- ❖ noise
- ❖ torque variations

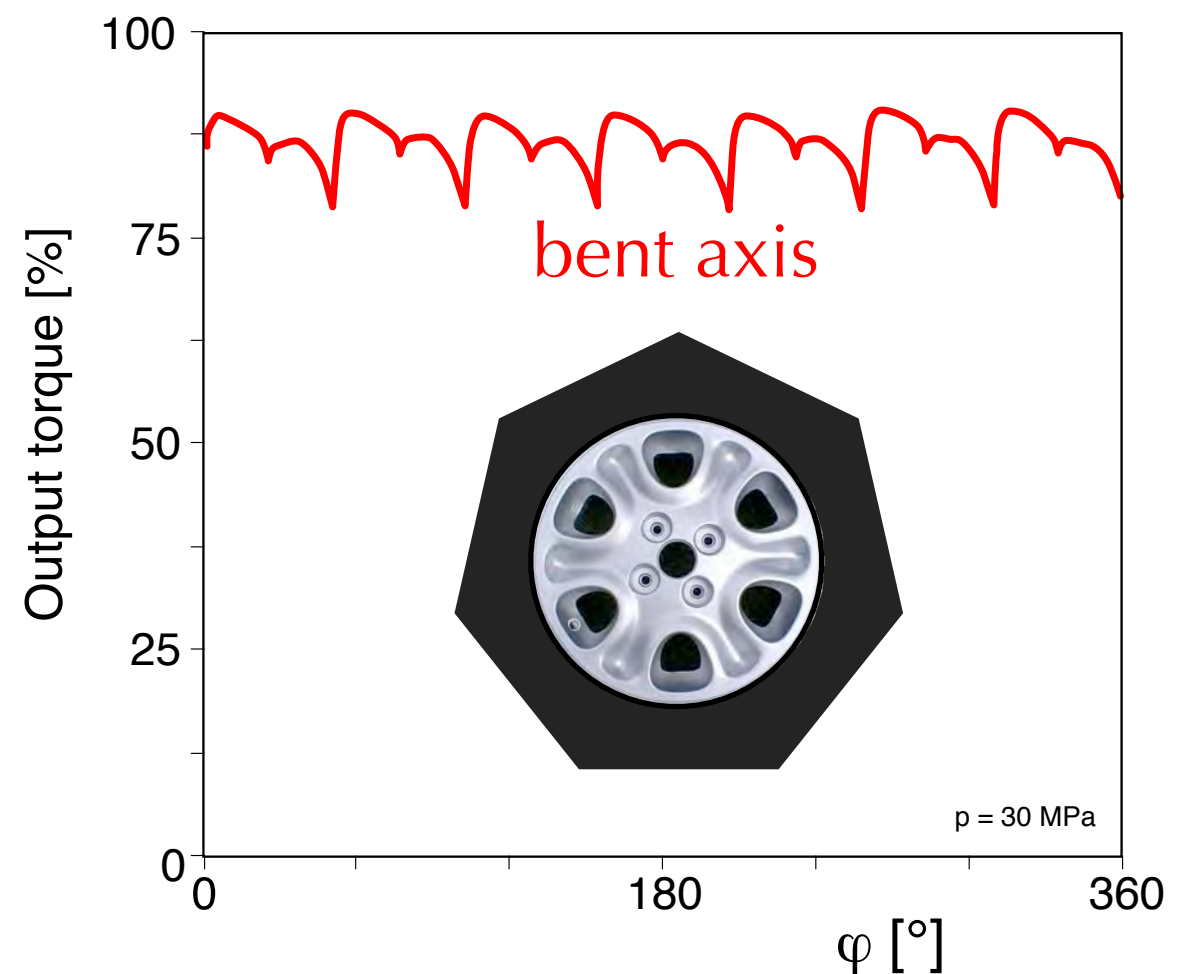
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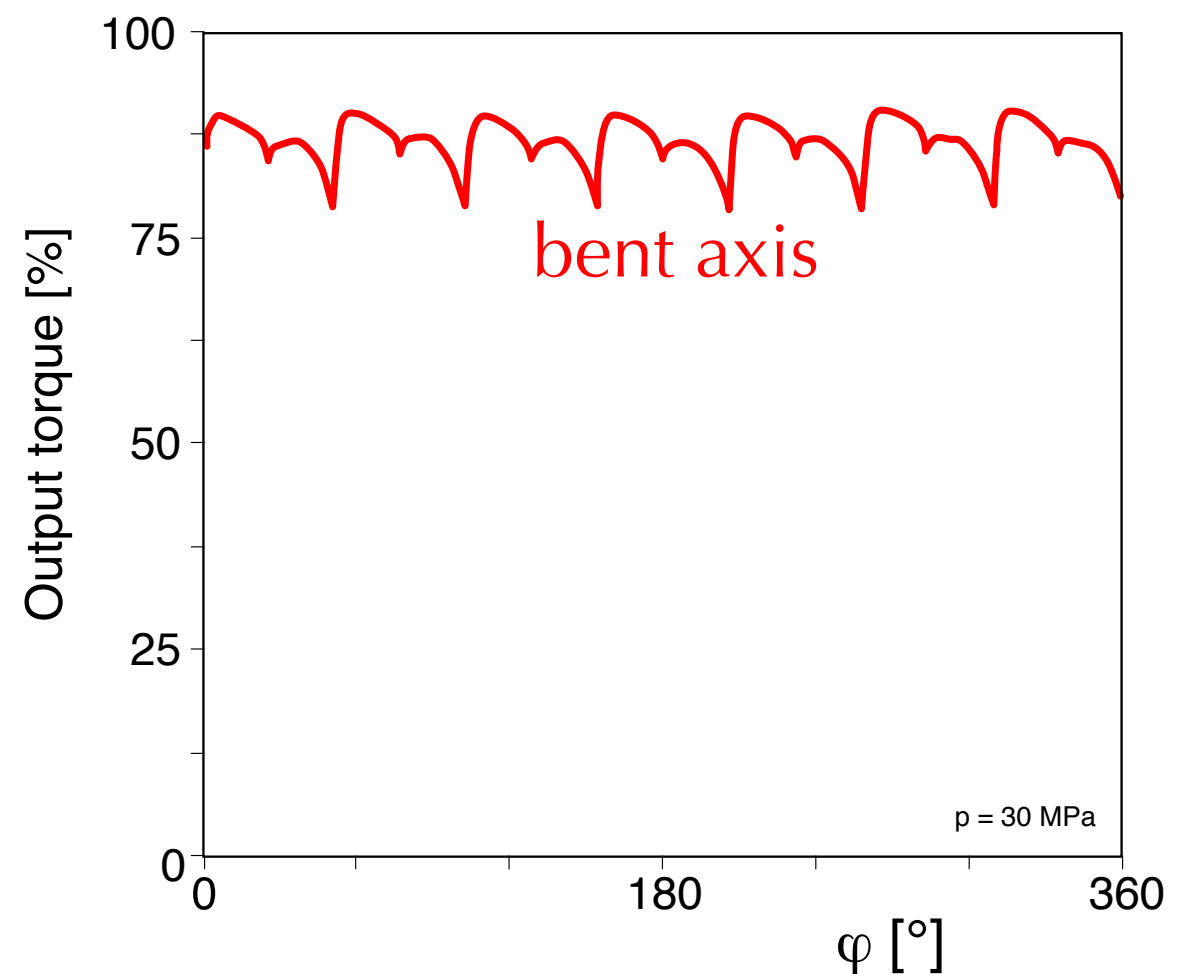
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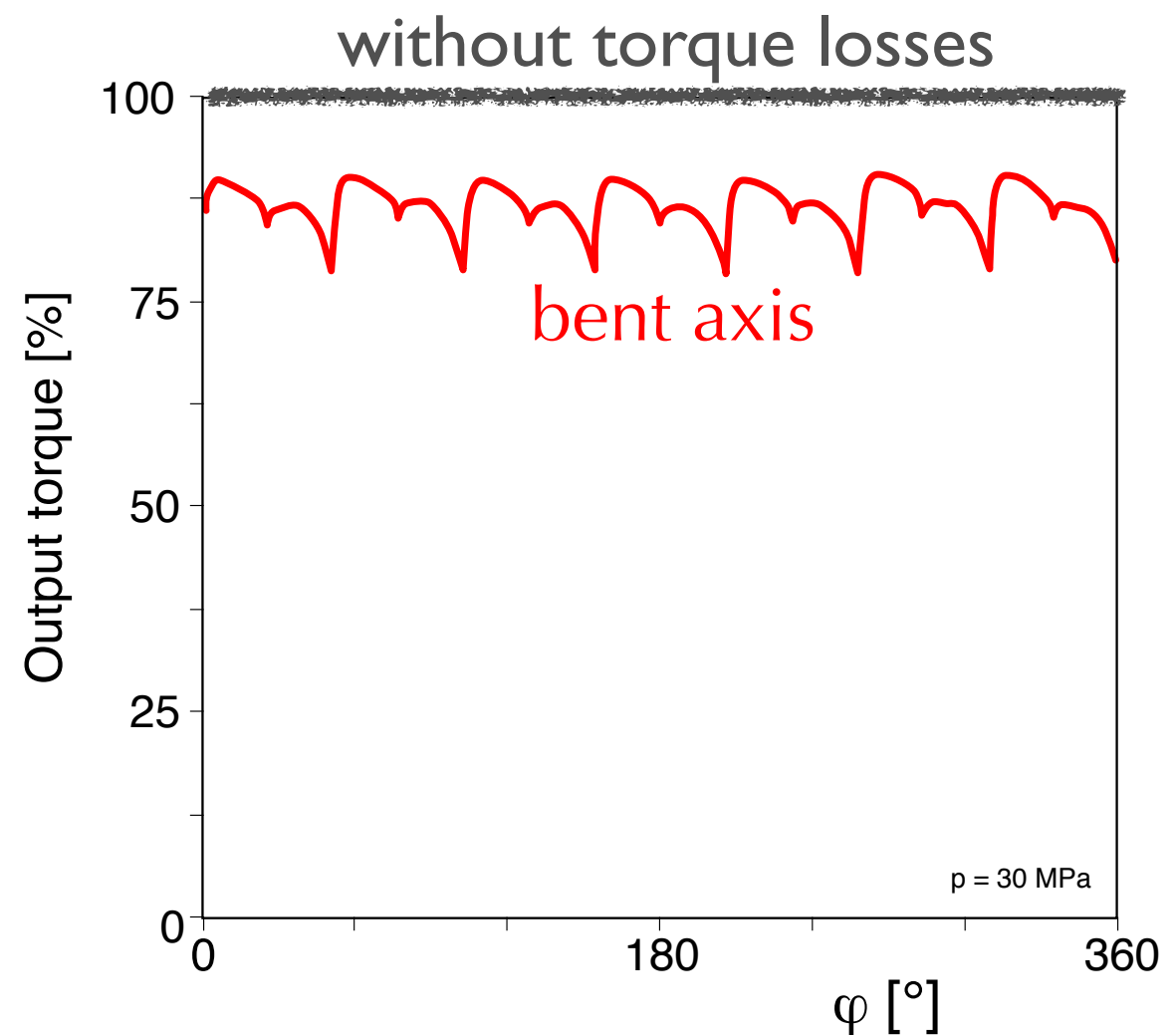
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- ❖ torque variations
- ❖ reduced startup torque



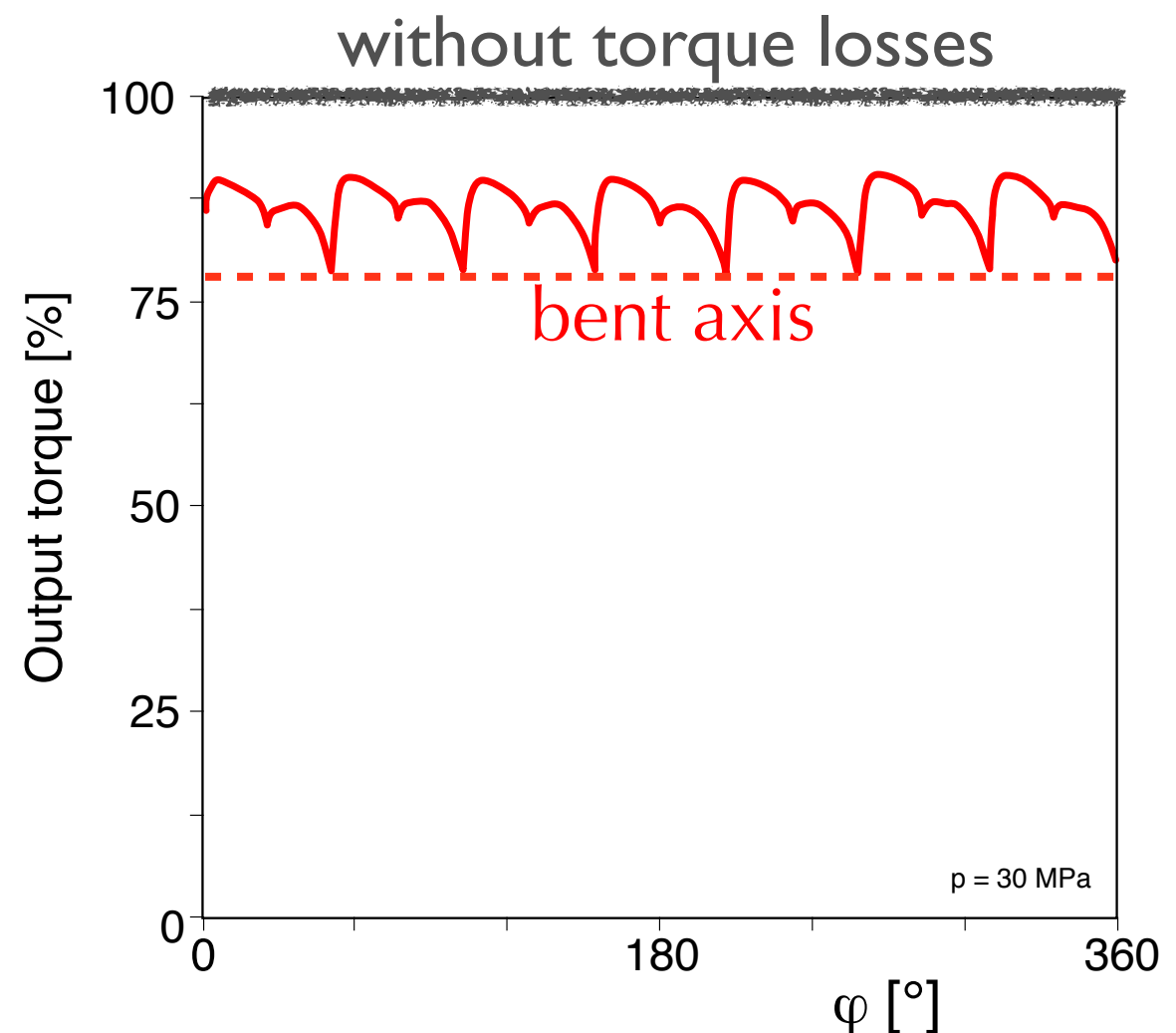
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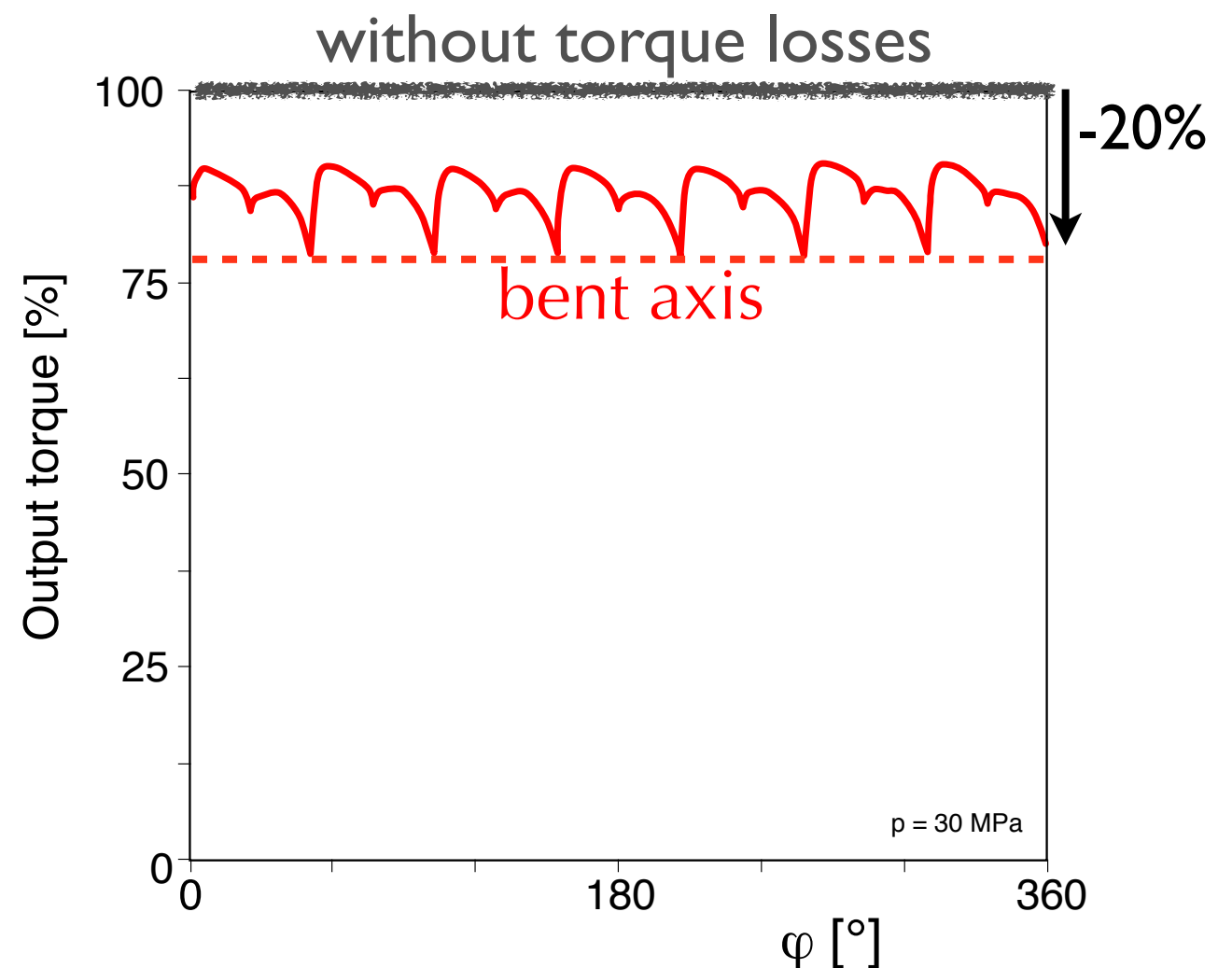
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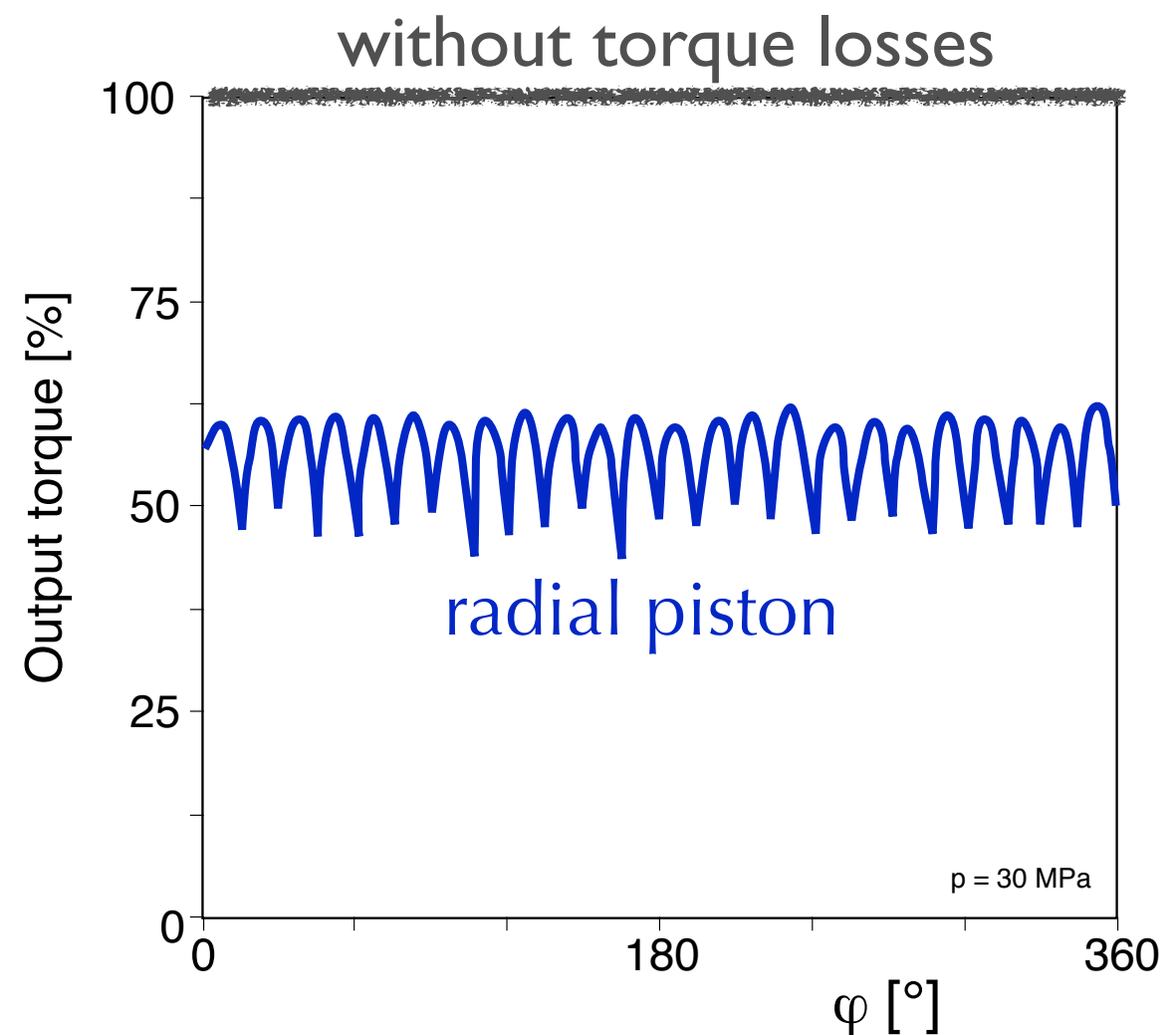
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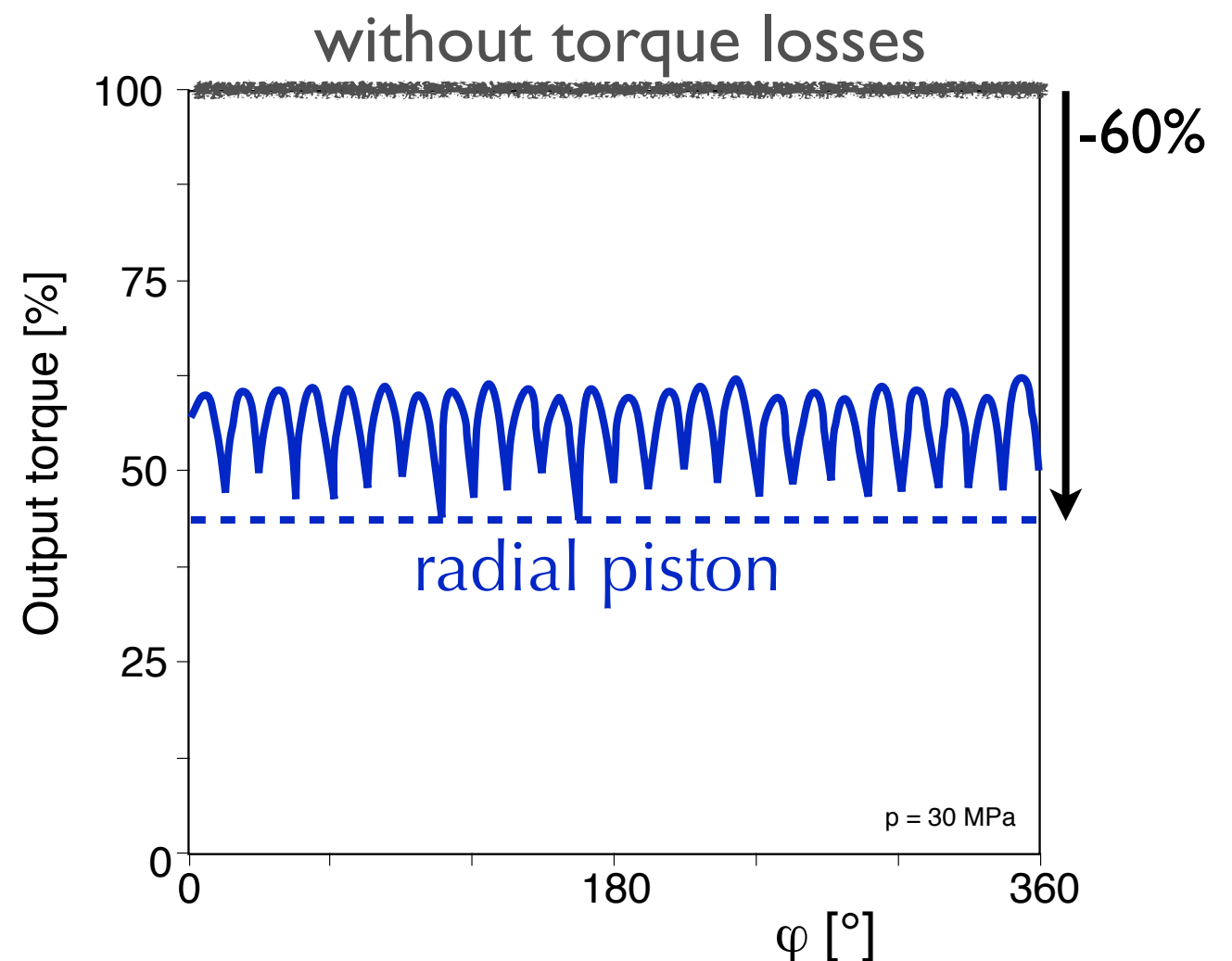
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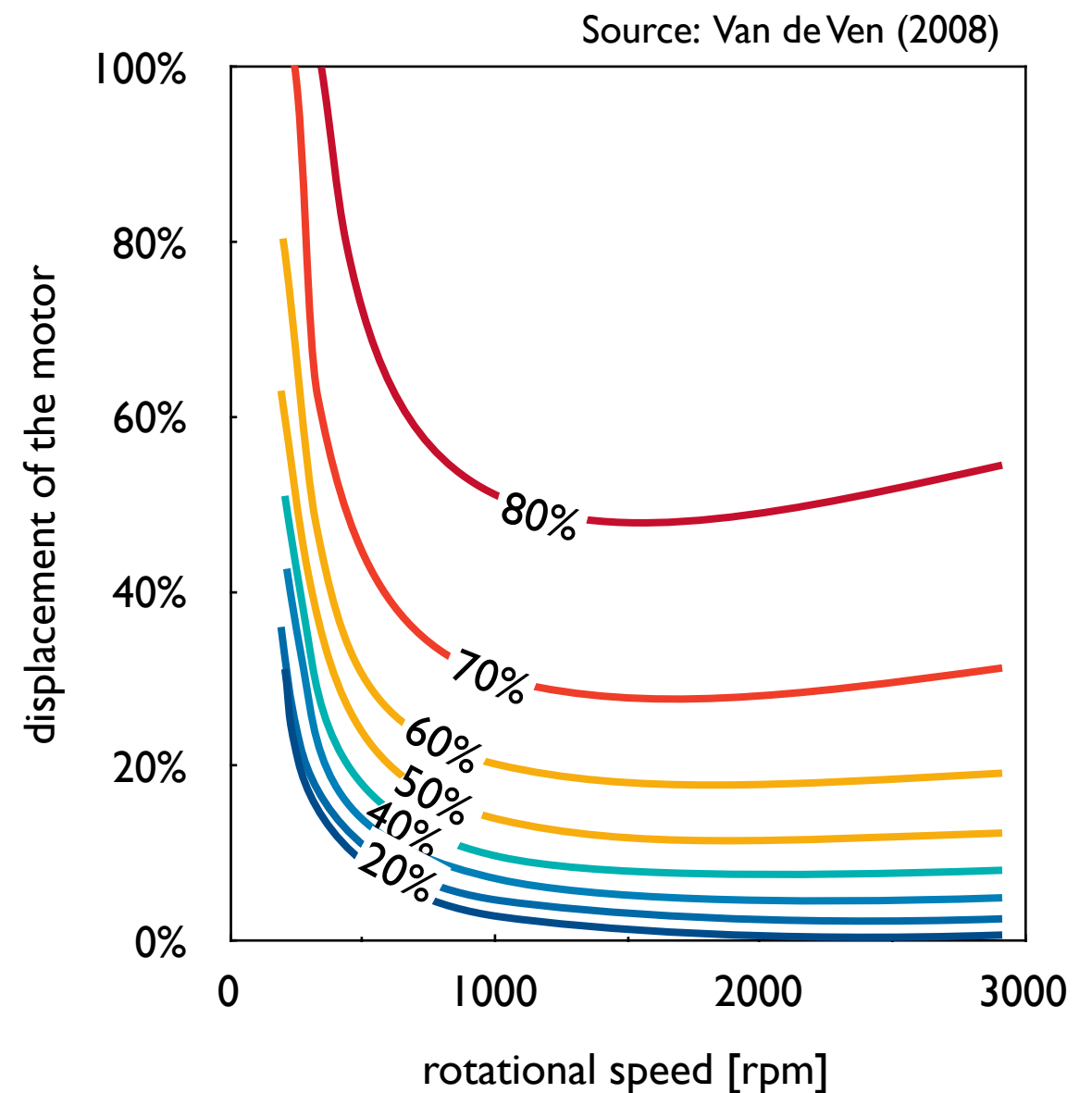
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hydraulic disadvantages

- ❖ noise
- ❖ torque variations
- ❖ reduced startup torque
- ❖ poor efficiency



hydraulic transmissions:

positive

negative

robust

too noisy

flexible

too harsh

good cooling

poor efficiency

compact

too expensive

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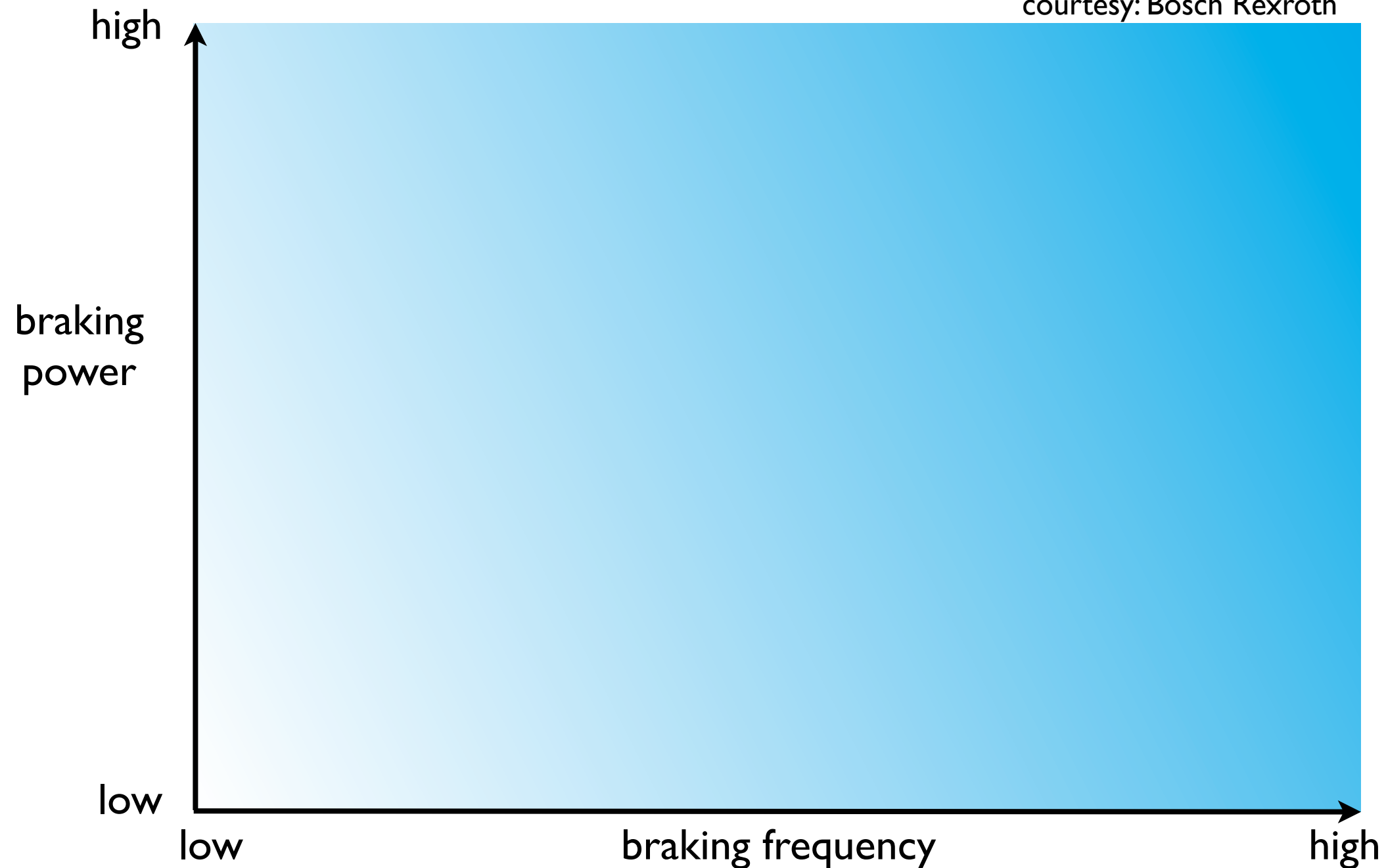
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energy storage?

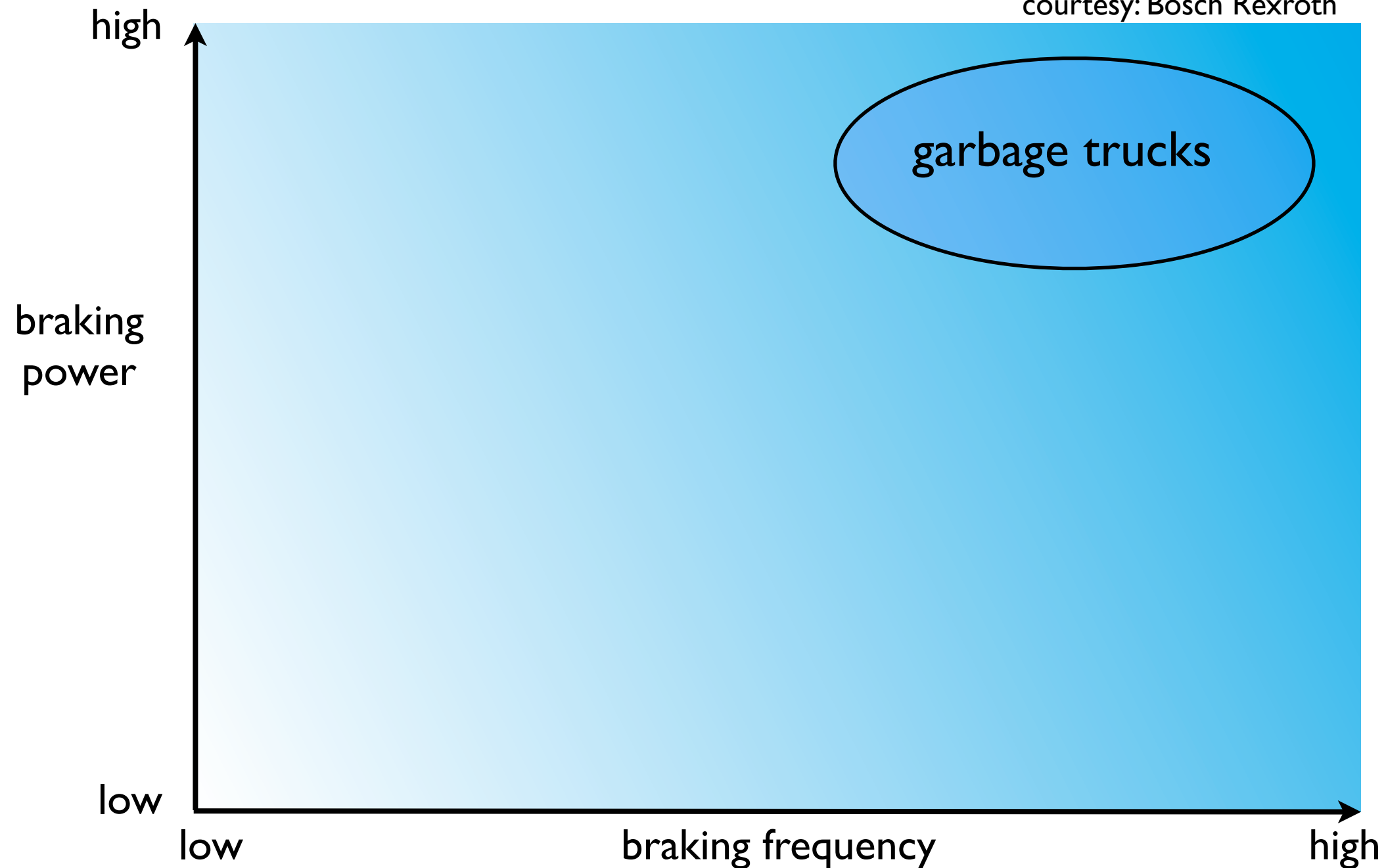
heavy duty hydraulic hybrids

courtesy: Bosch Rexroth



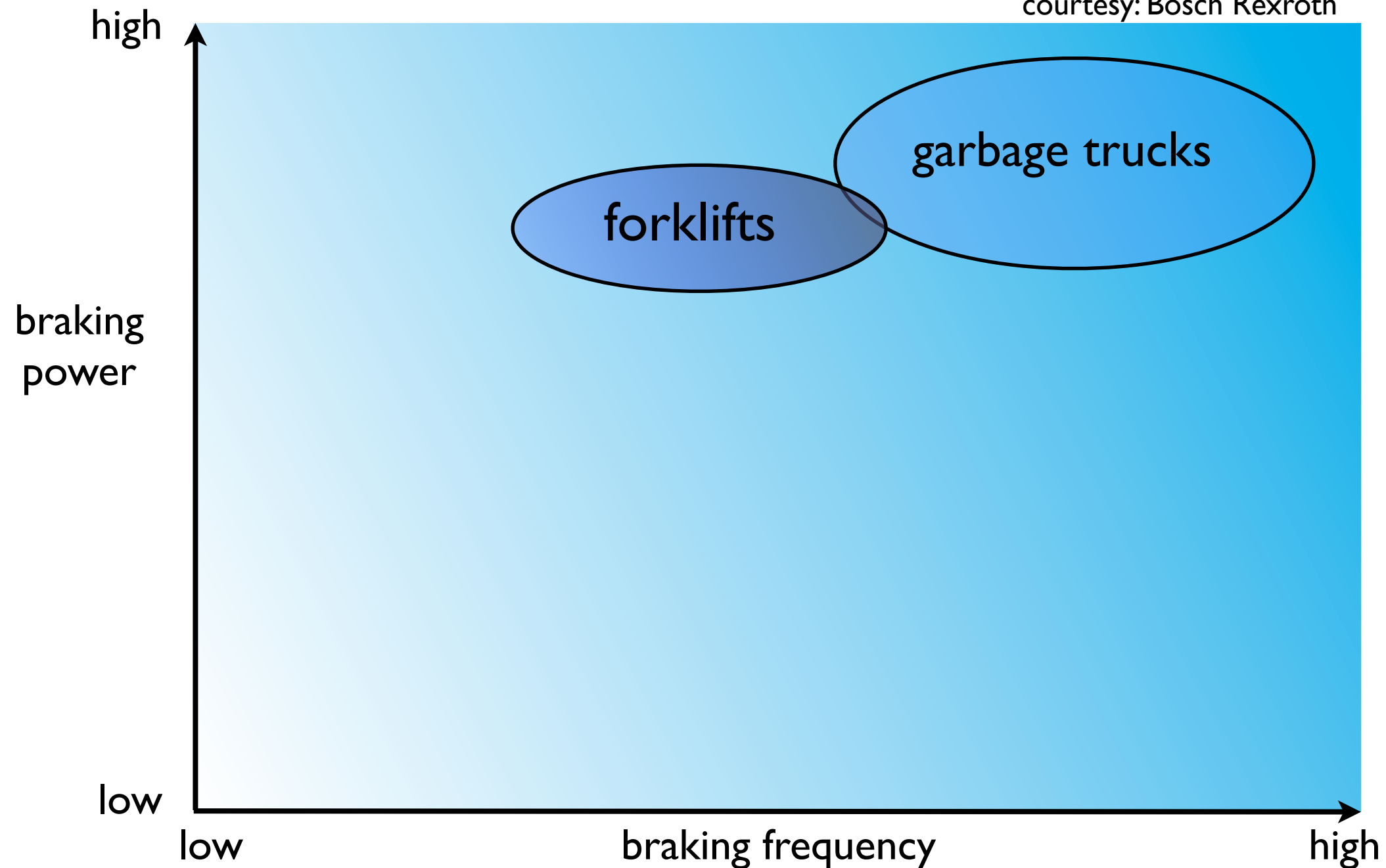
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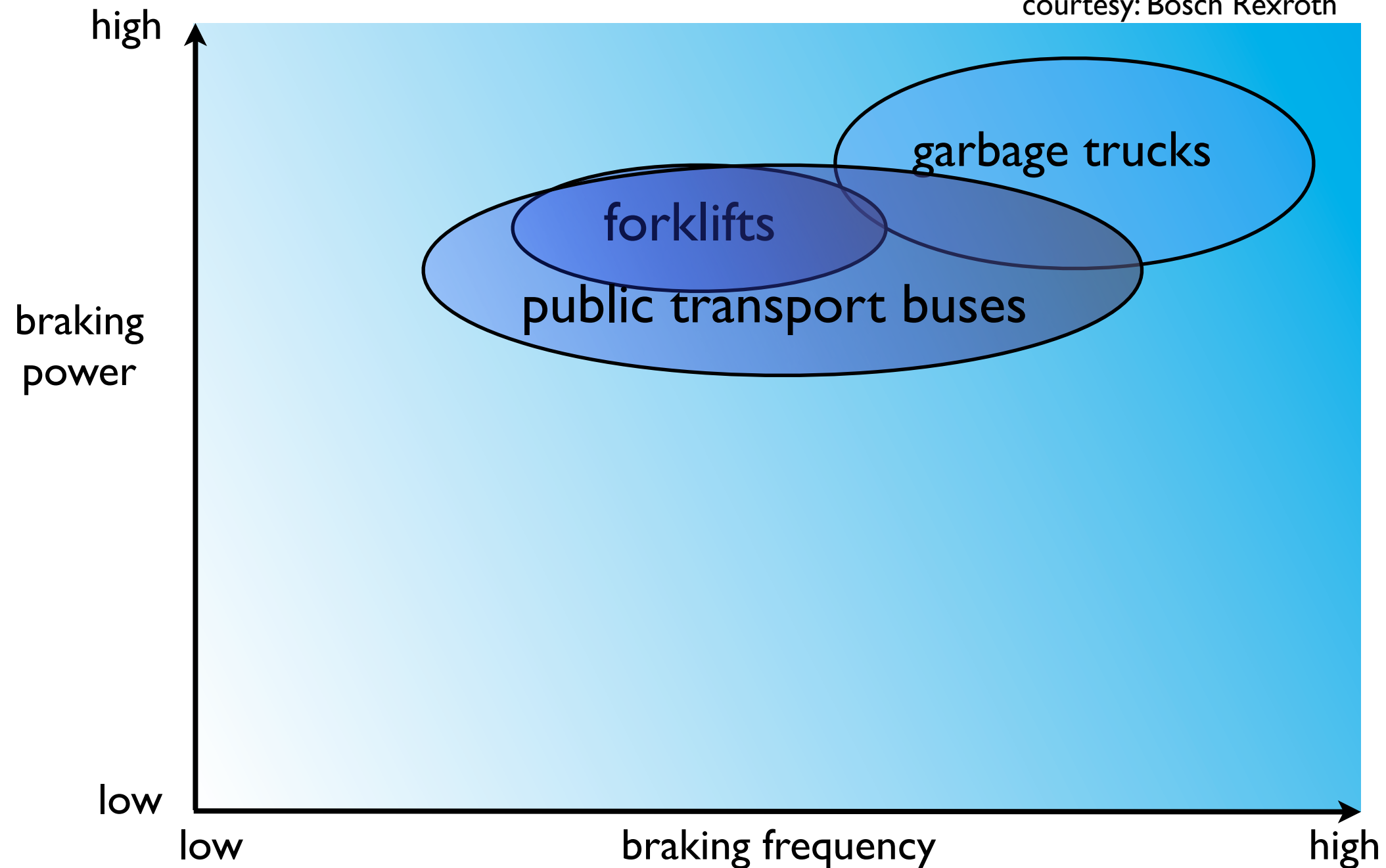
heavy duty hydraulic hybrids

courtesy: Bosch Rexroth



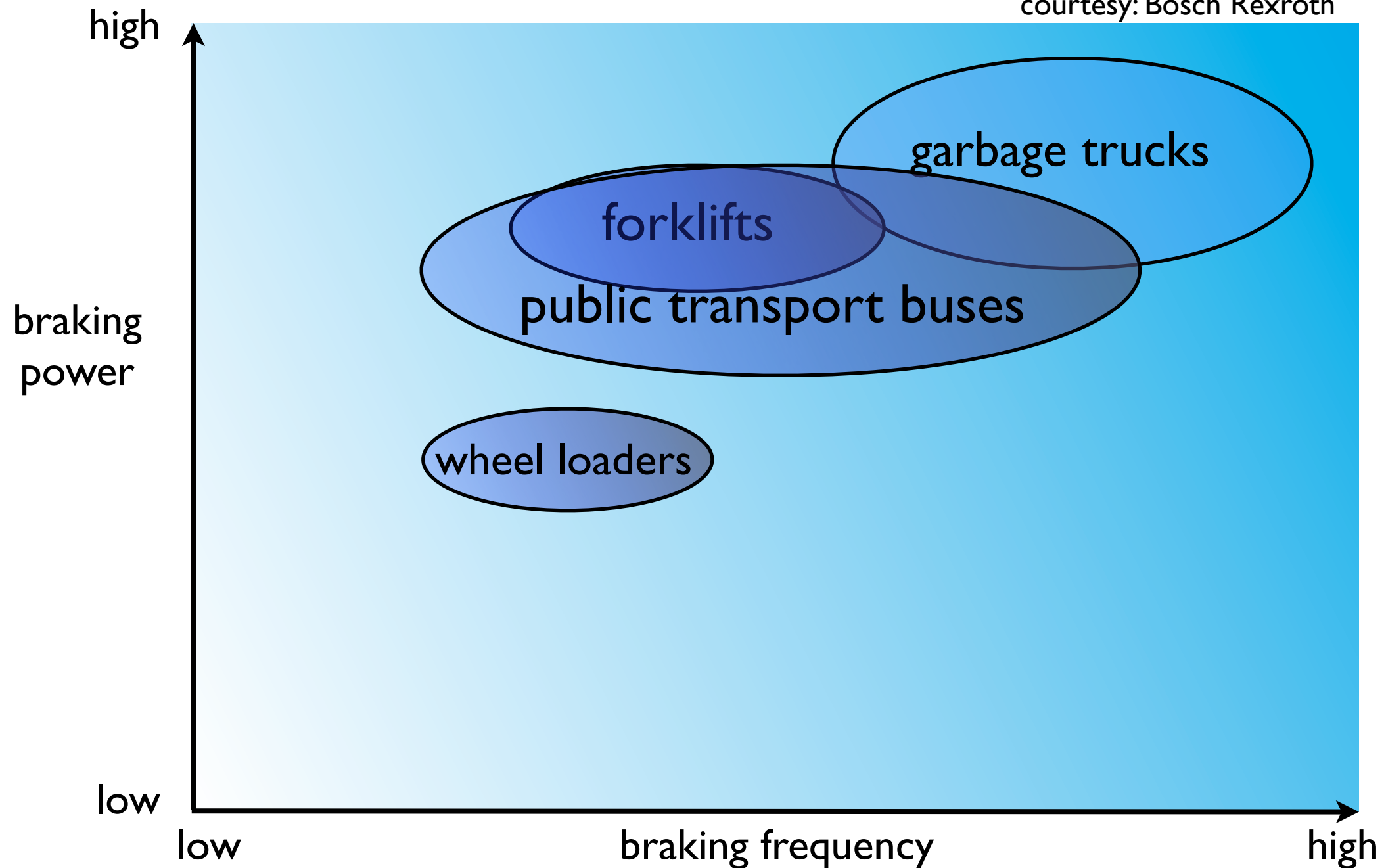
heavy duty hydraulic hybrids

courtesy: Bosch Rexroth



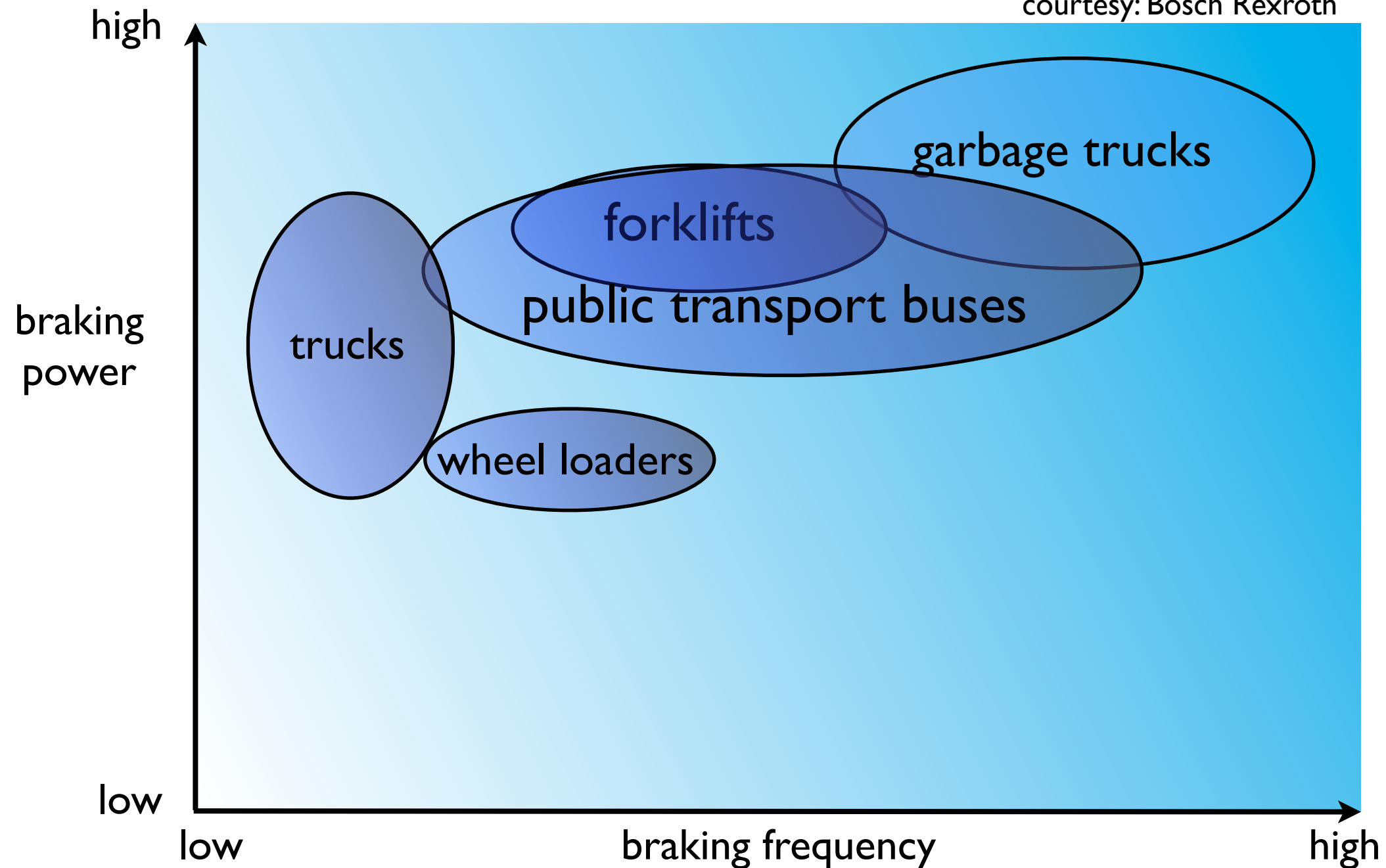
heavy duty hydraulic hybrids

courtesy: Bosch Rexroth



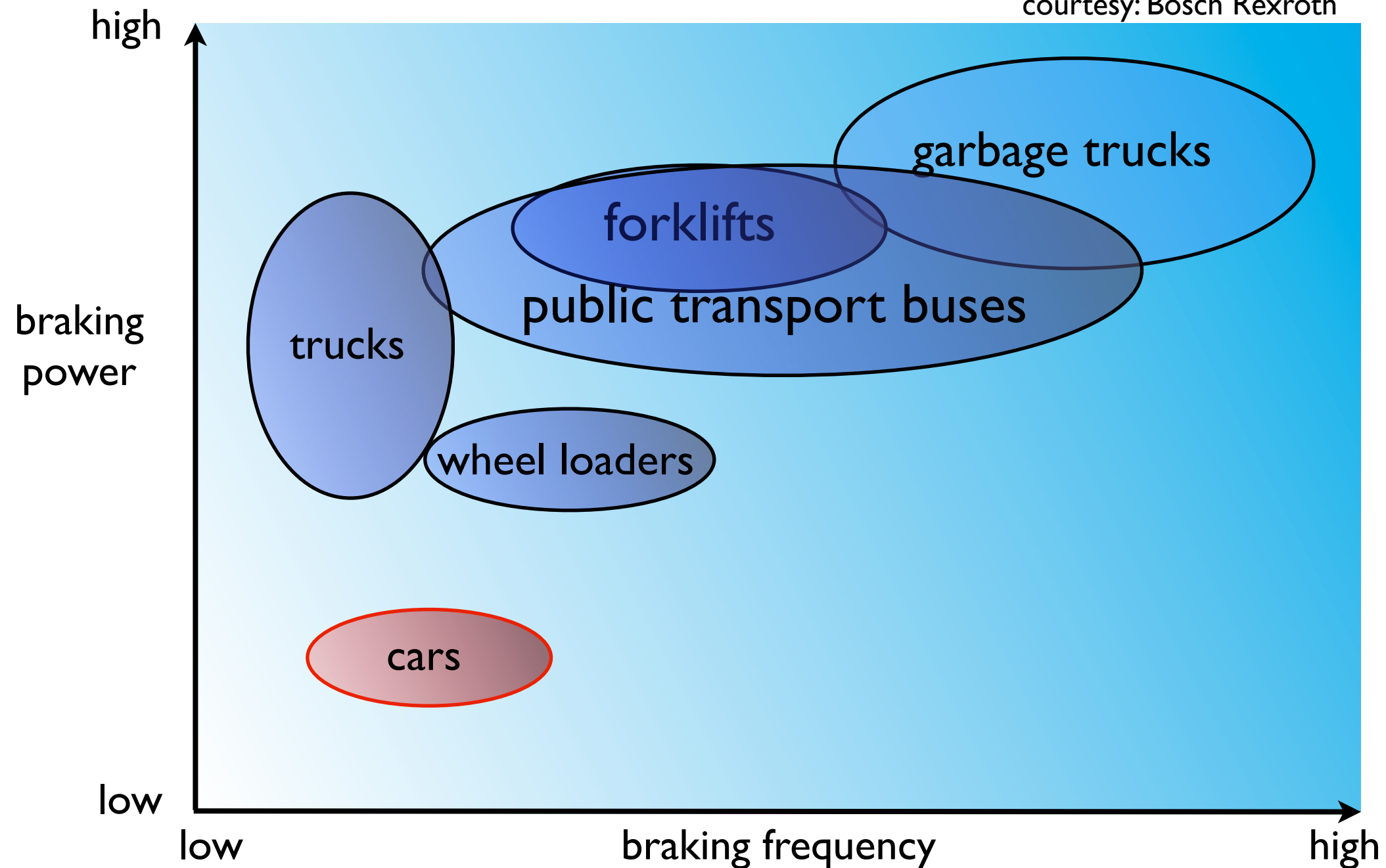
heavy duty hydraulic hybrids

courtesy: Bosch Rexroth



heavy duty hydraulic hybrids

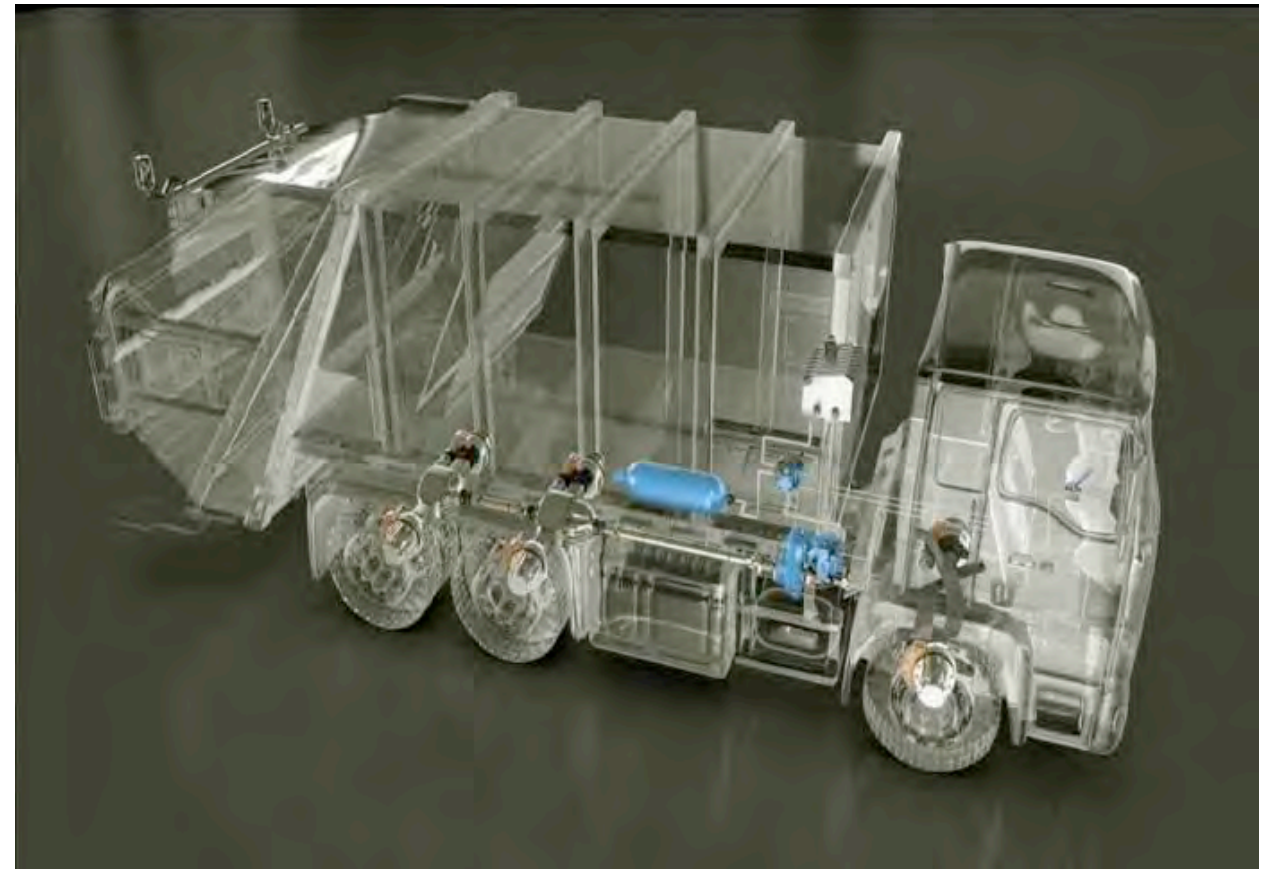
courtesy: Bosch Rexroth



heavy duty hydraulic hybrid



courtesy: Bosch Rexroth



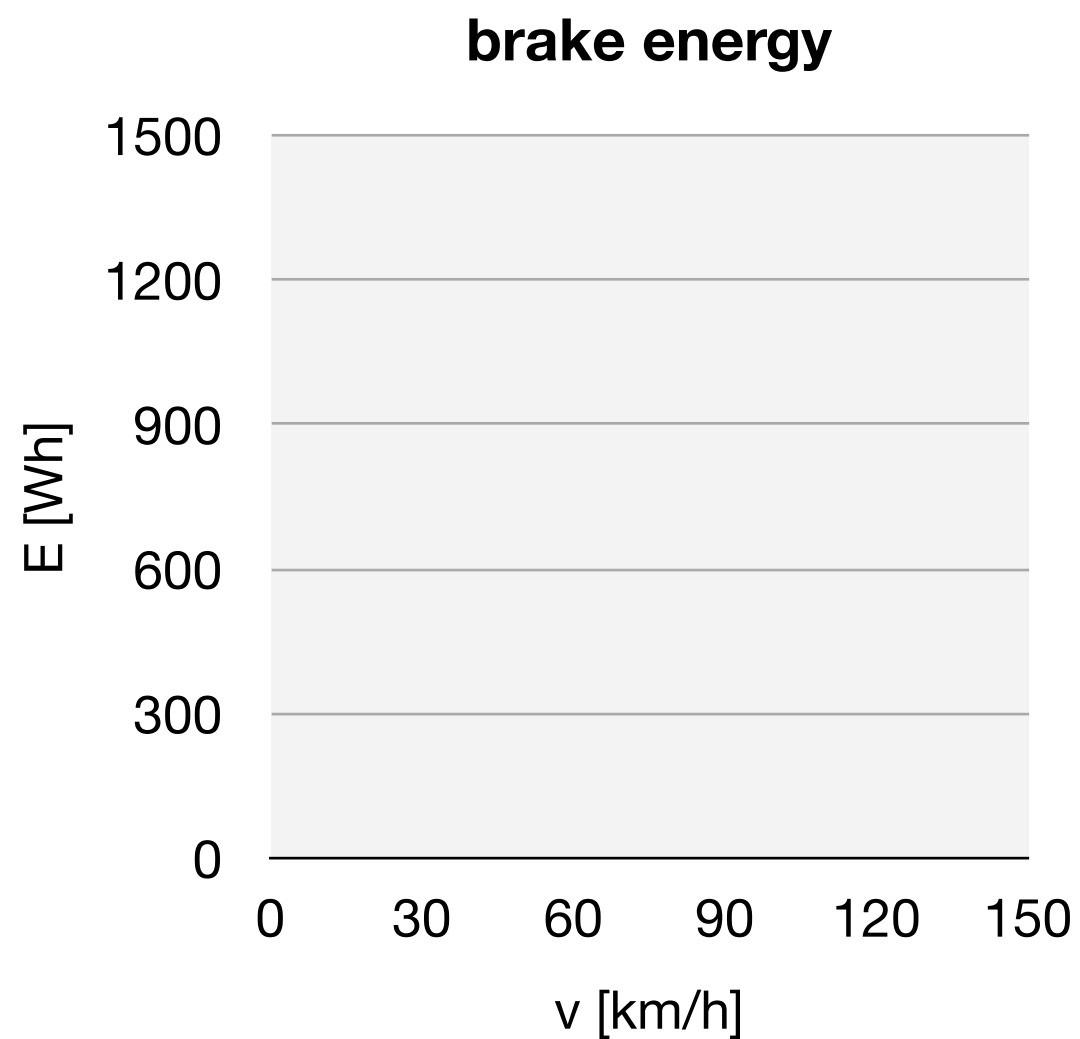
courtesy: Bosch Rexroth

battery demands

vehicle mass = 1600 kg

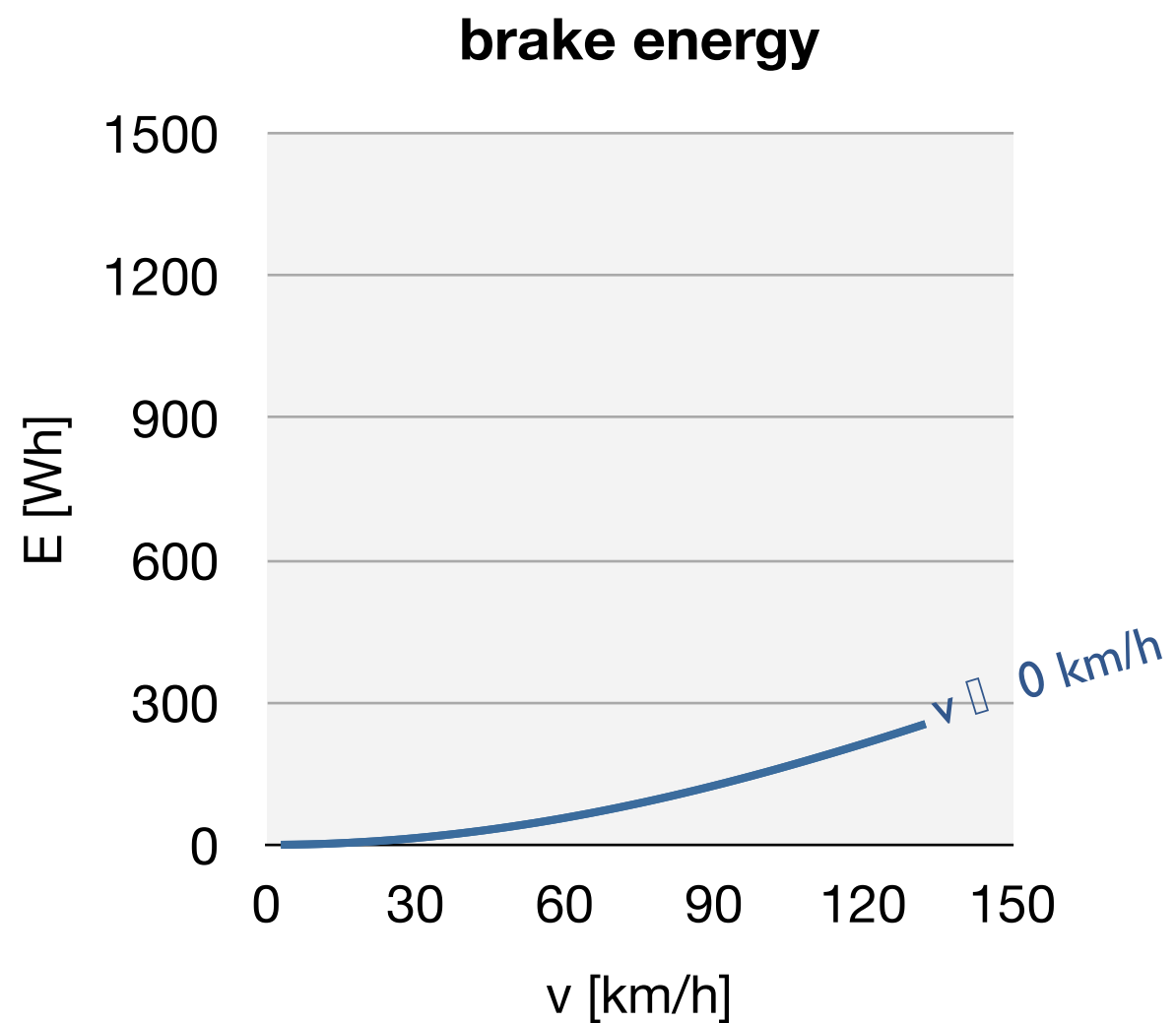
battery demands

vehicle mass = 1600 kg



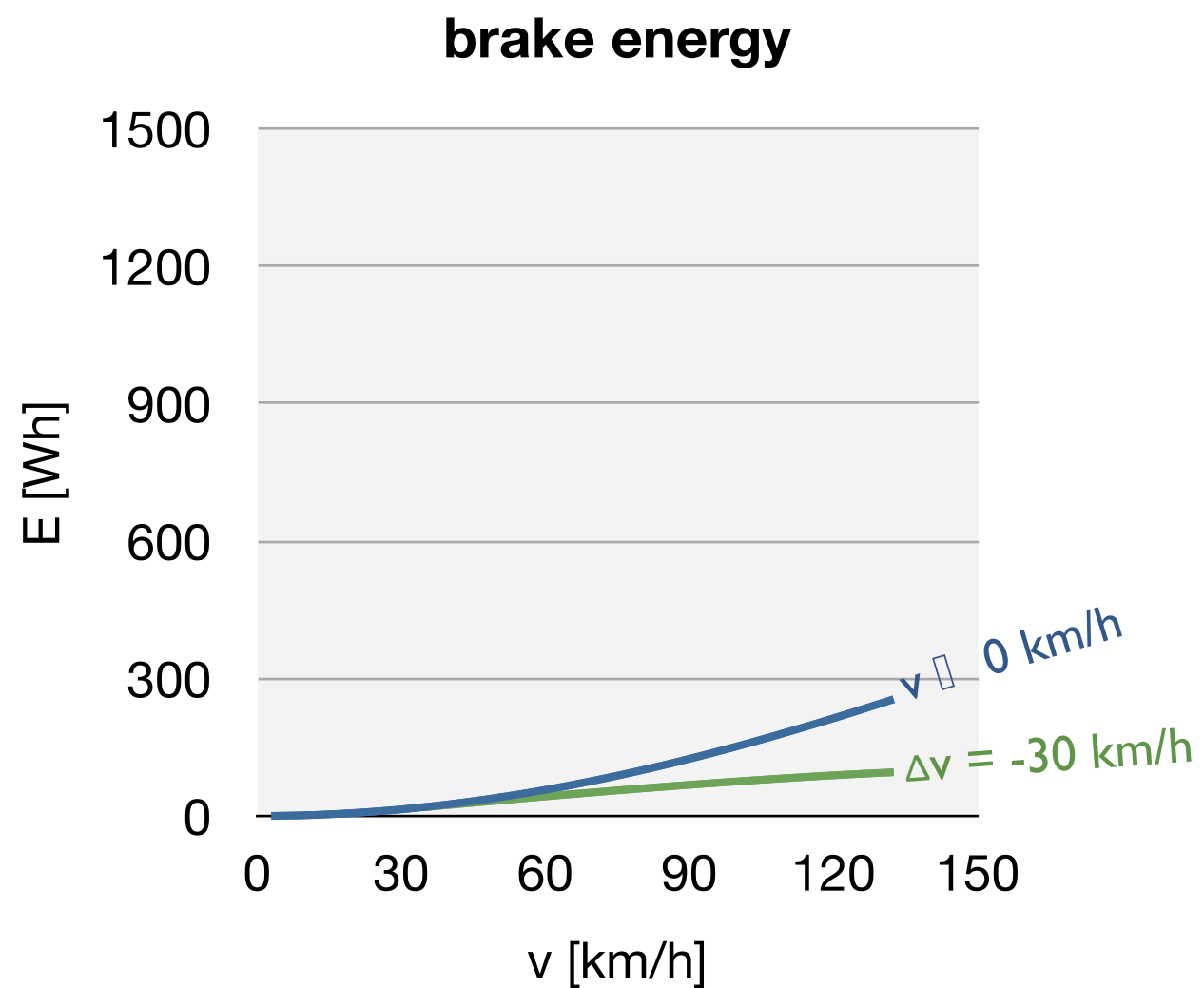
battery demands

vehicle mass = 1600 kg



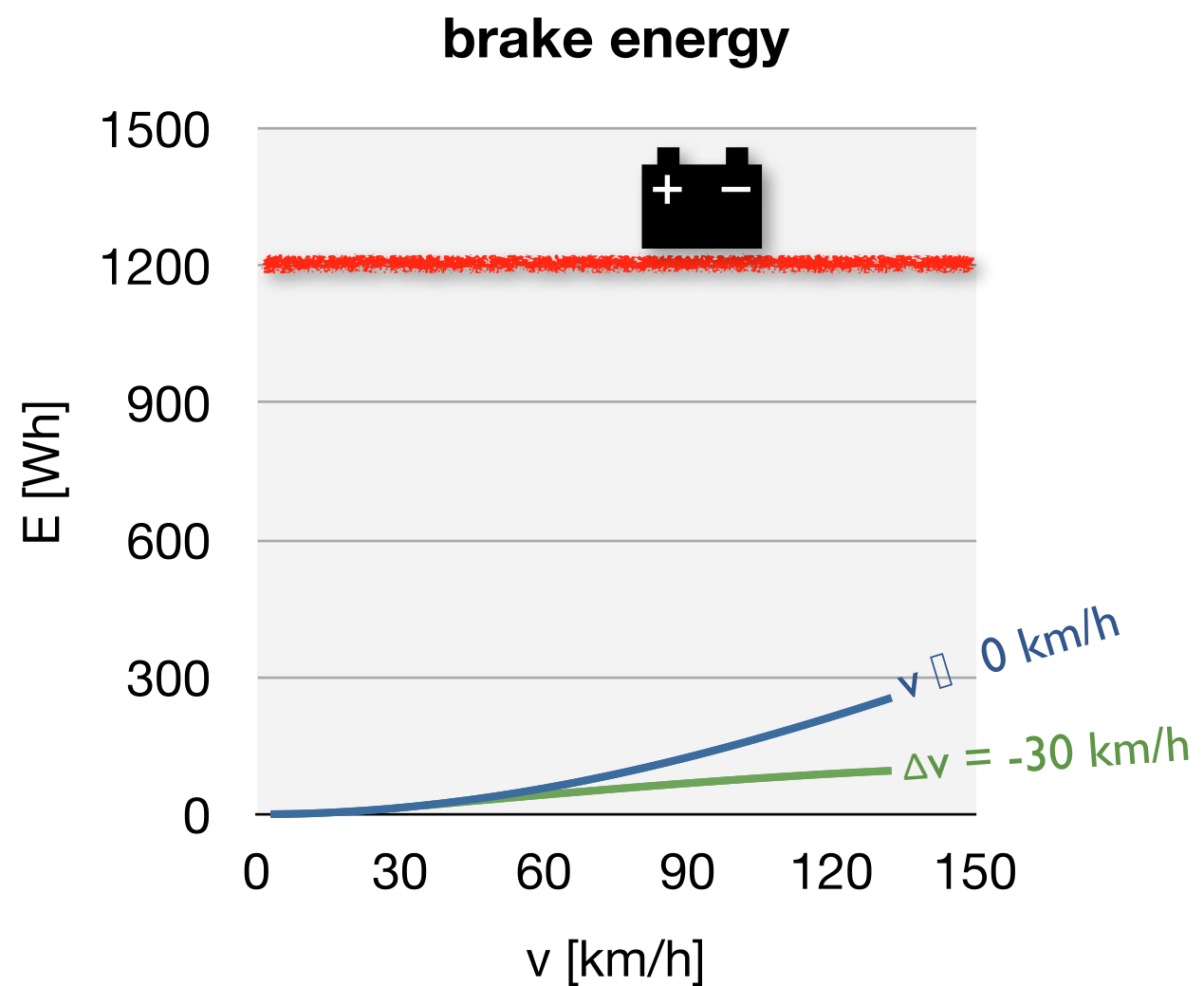
battery demands

vehicle mass = 1600 kg



battery demands

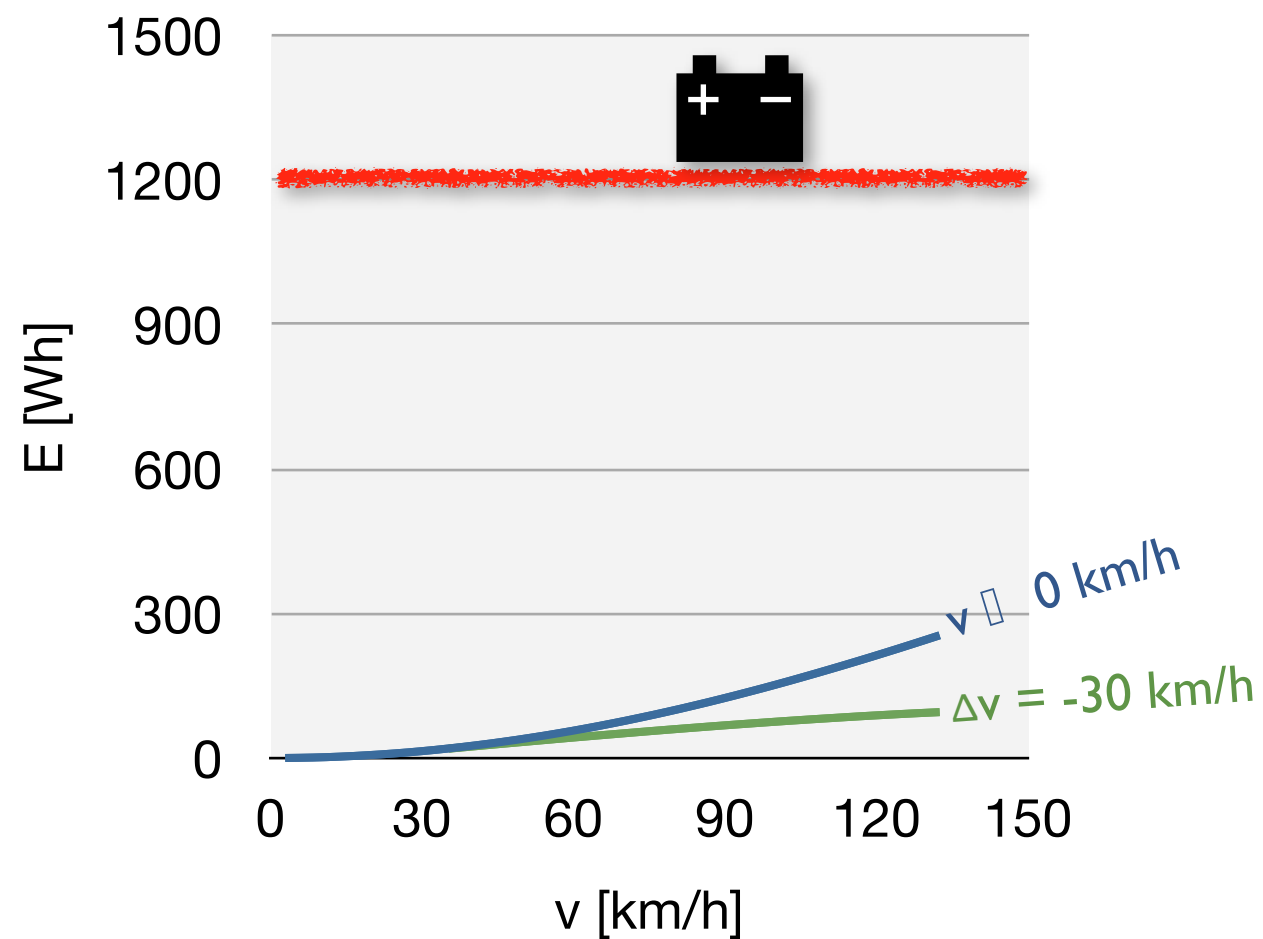
vehicle mass = 1600 kg



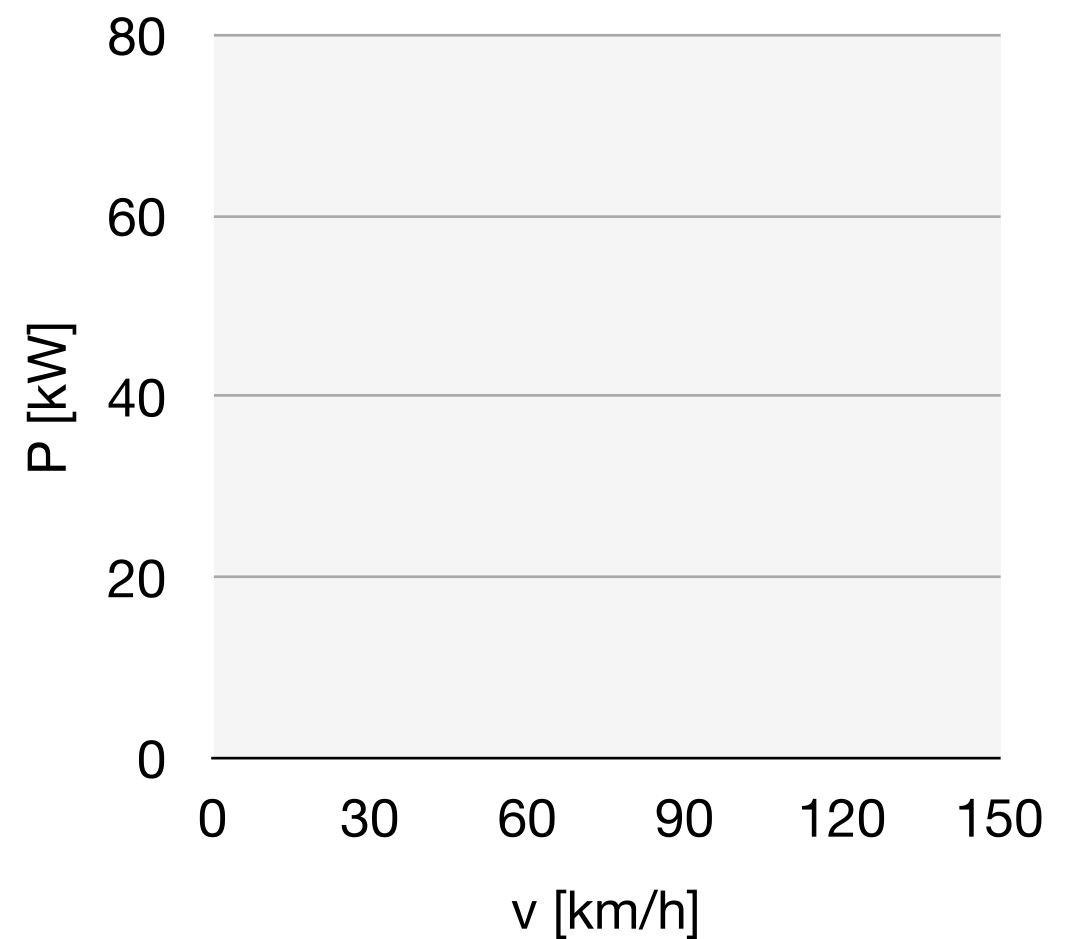
battery demands

vehicle mass = 1600 kg

brake energy



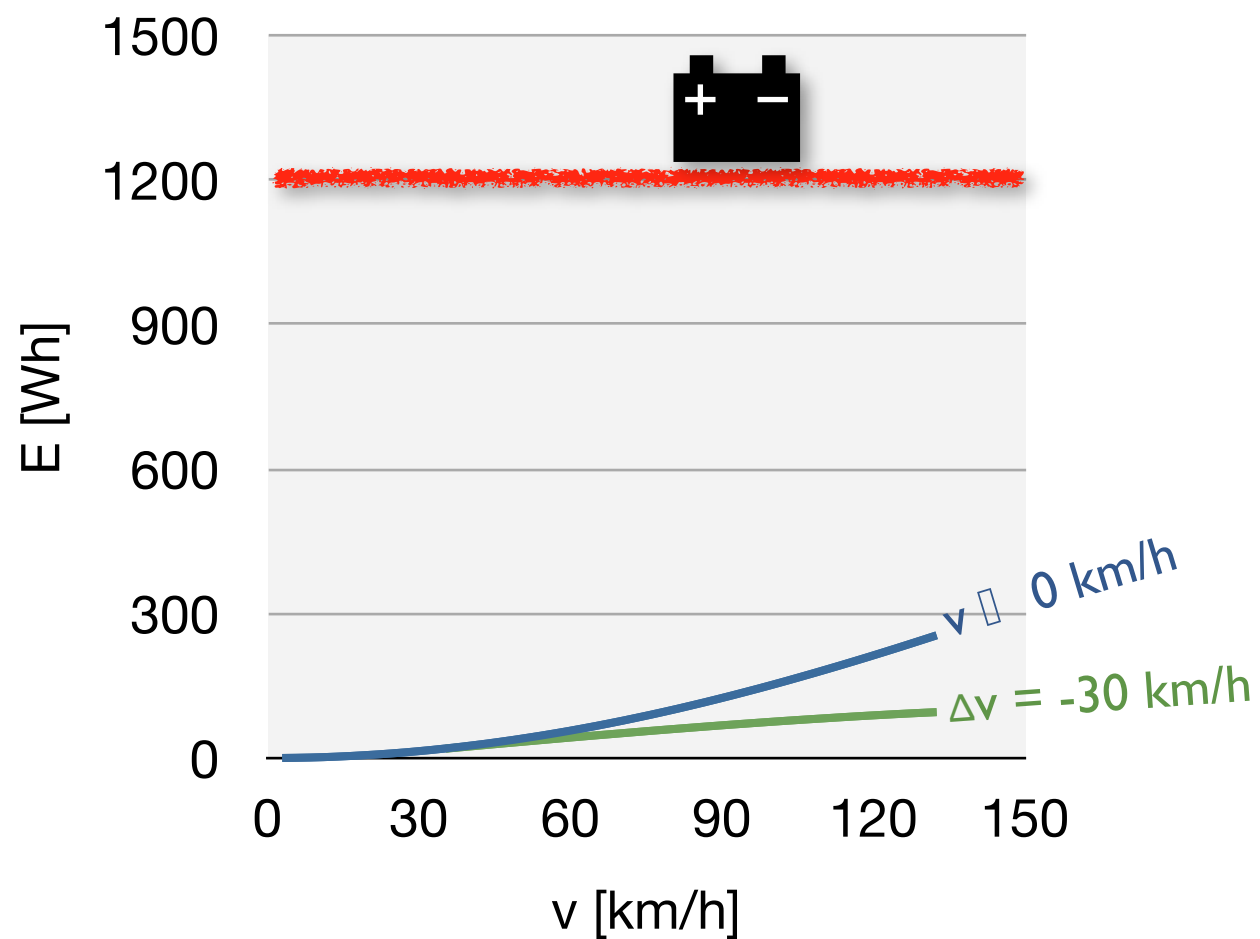
brake power



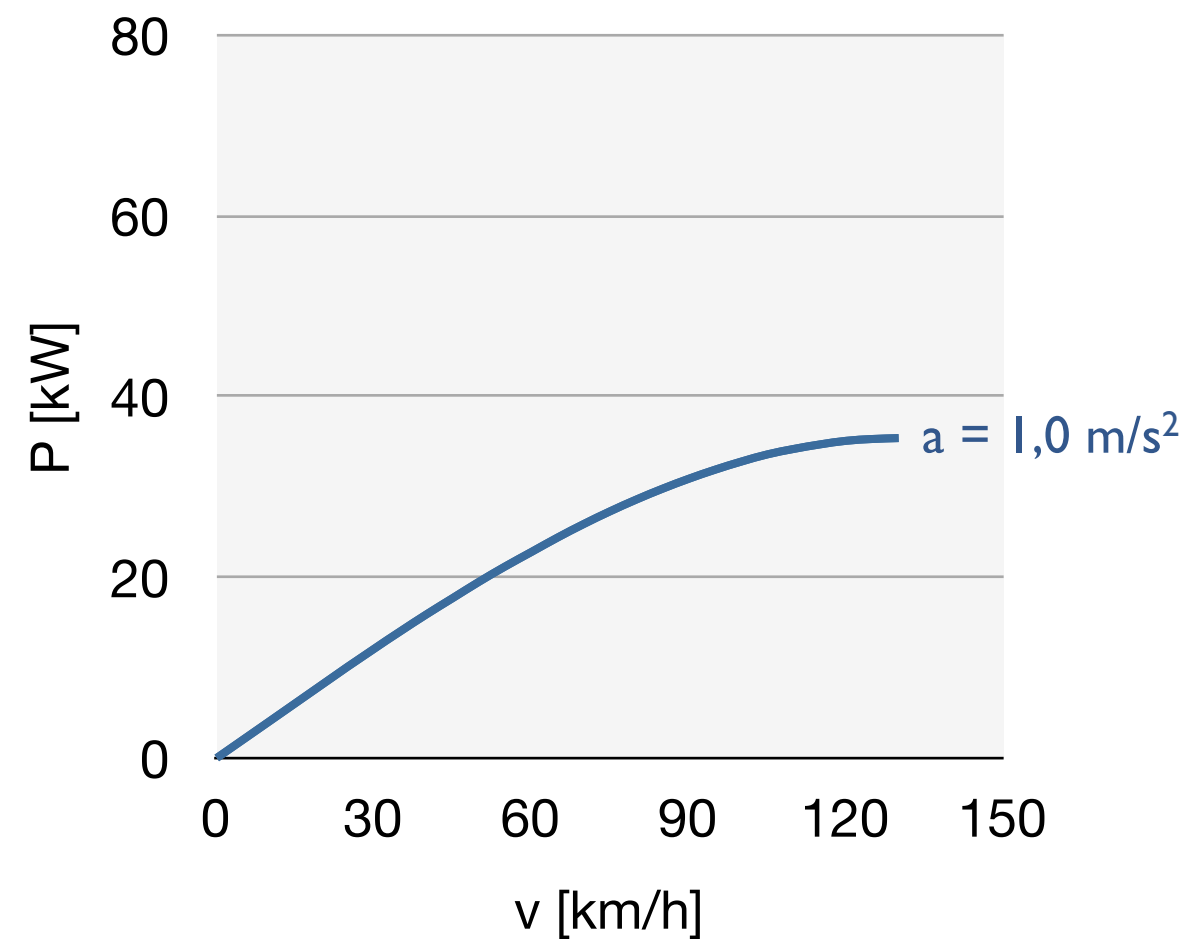
battery demands

vehicle mass = 1600 kg

brake energy



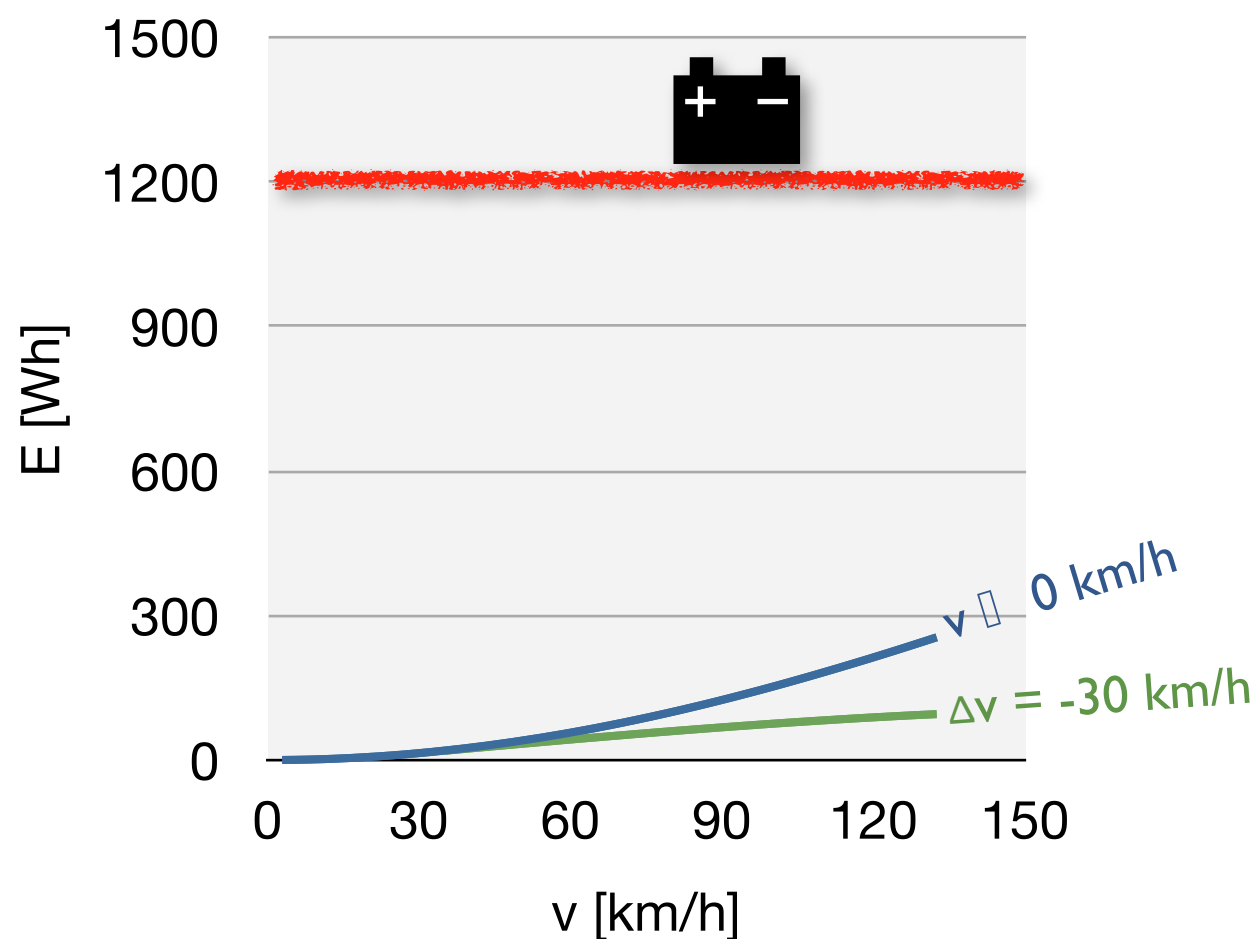
brake power



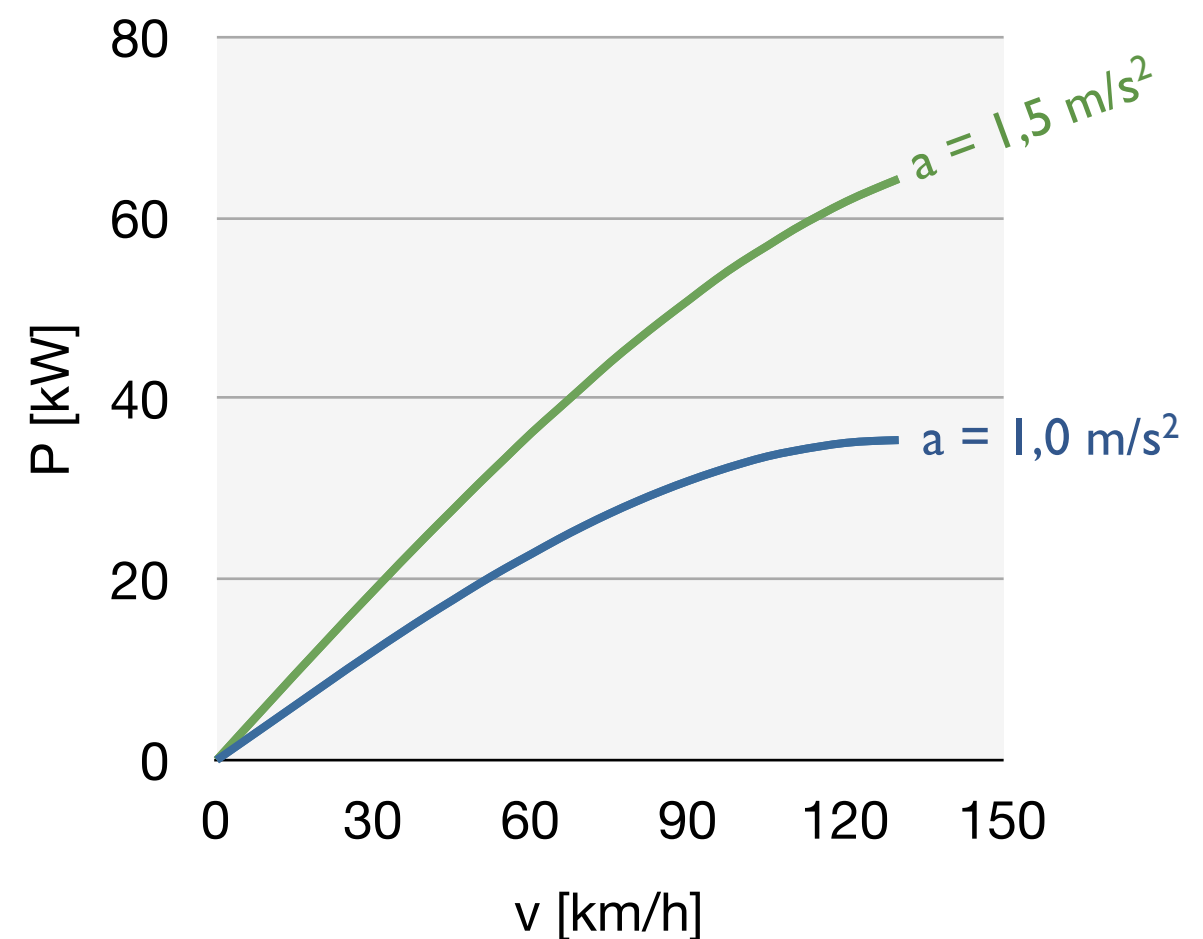
battery demands

vehicle mass = 1600 kg

brake energy



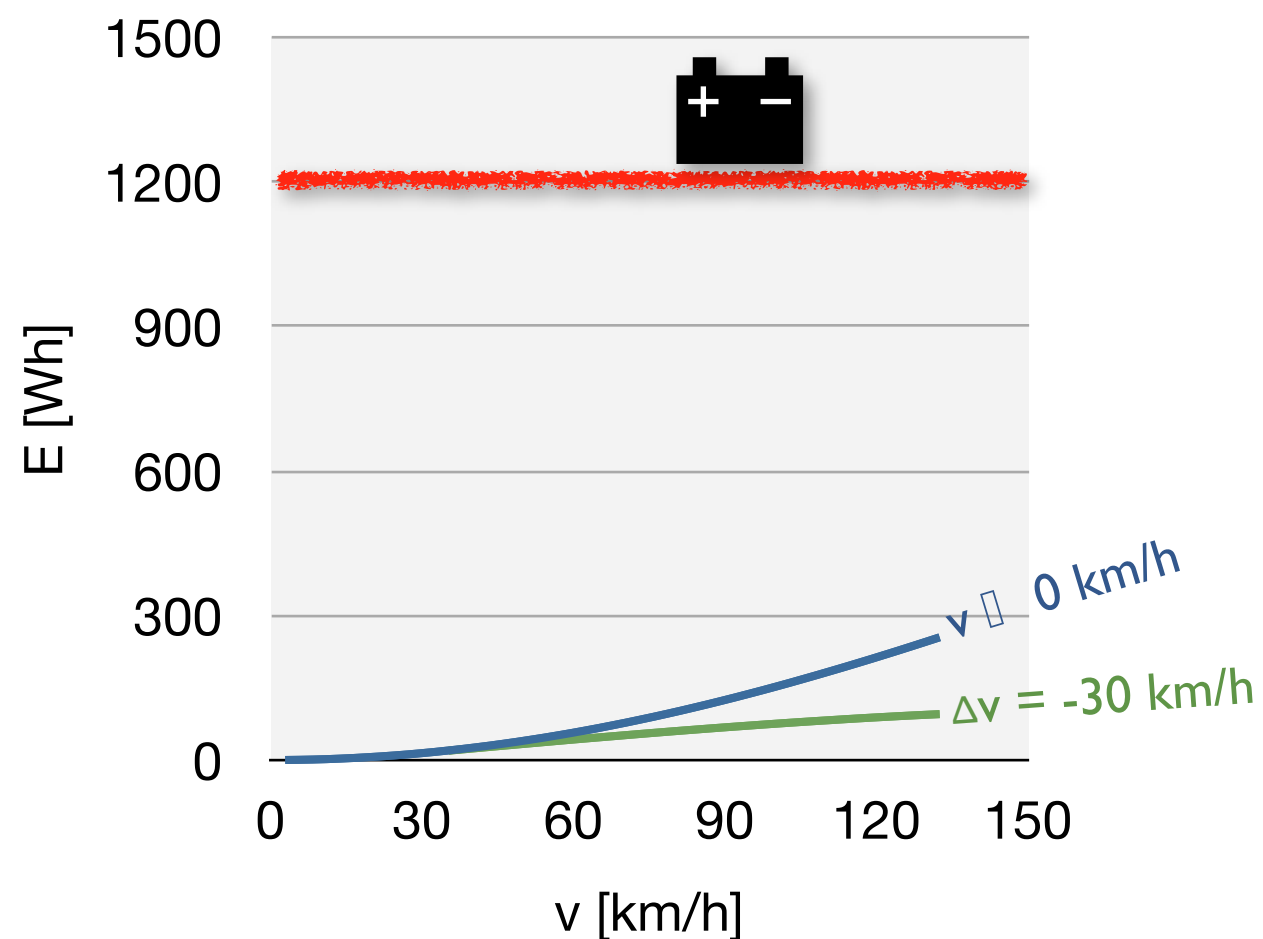
brake power



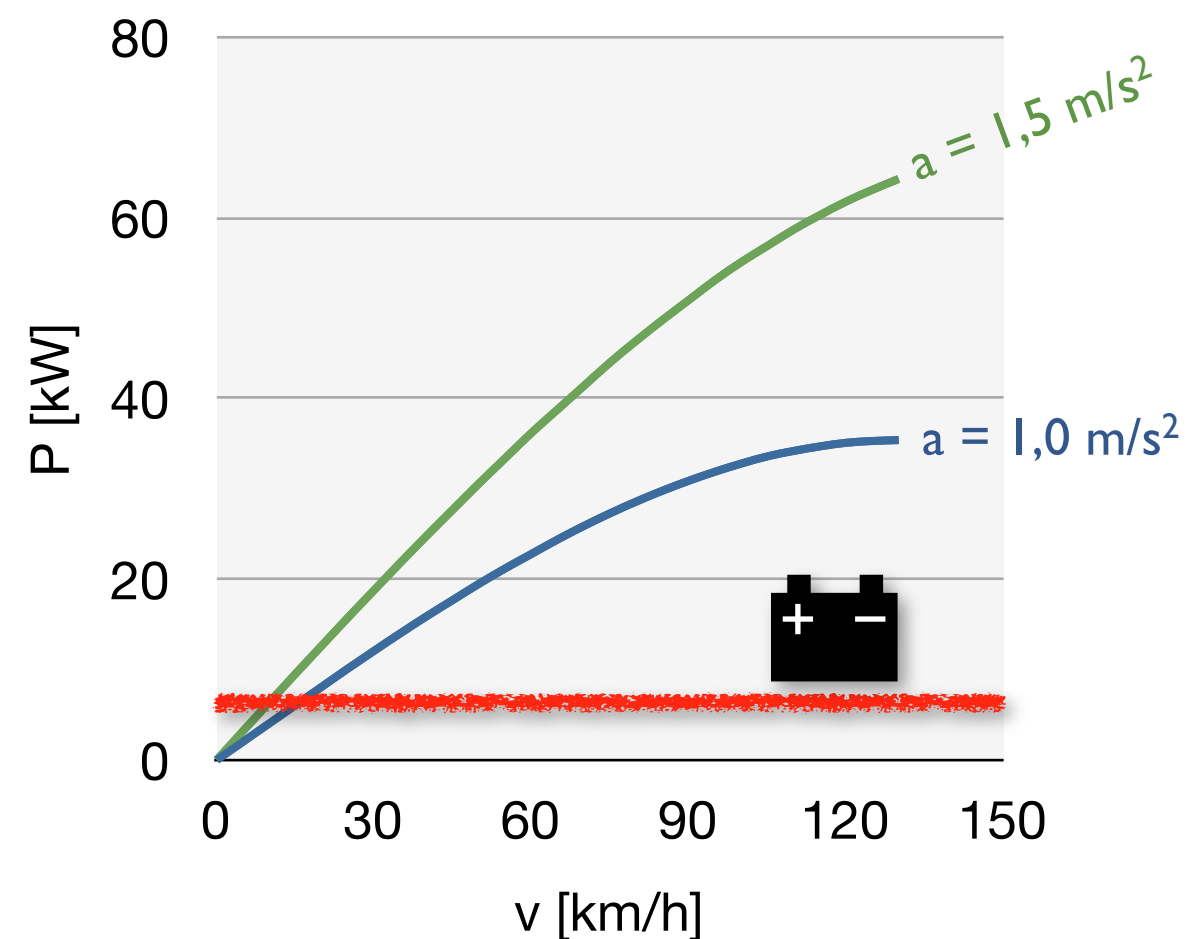
battery demands

vehicle mass = 1600 kg

brake energy



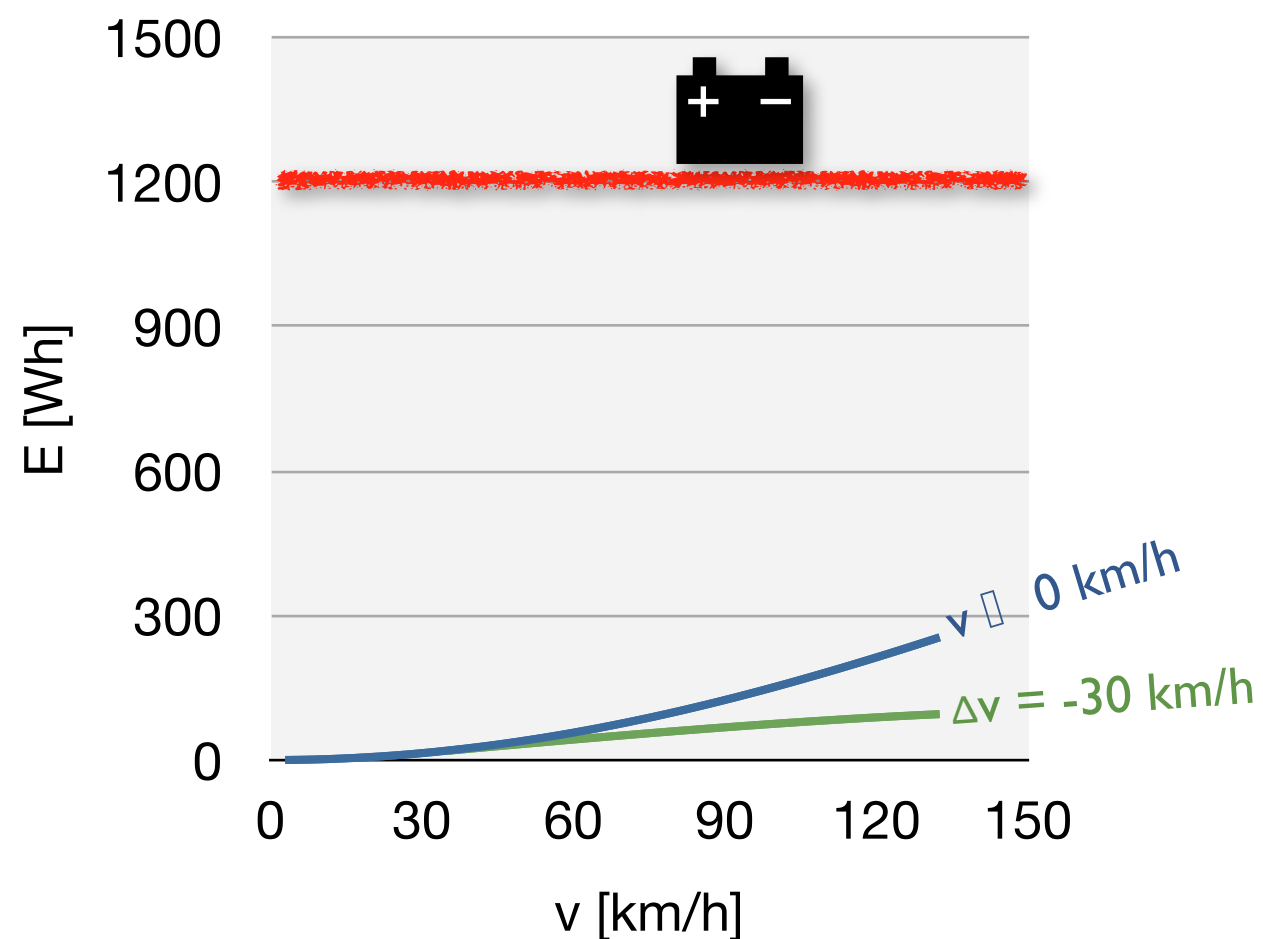
brake power



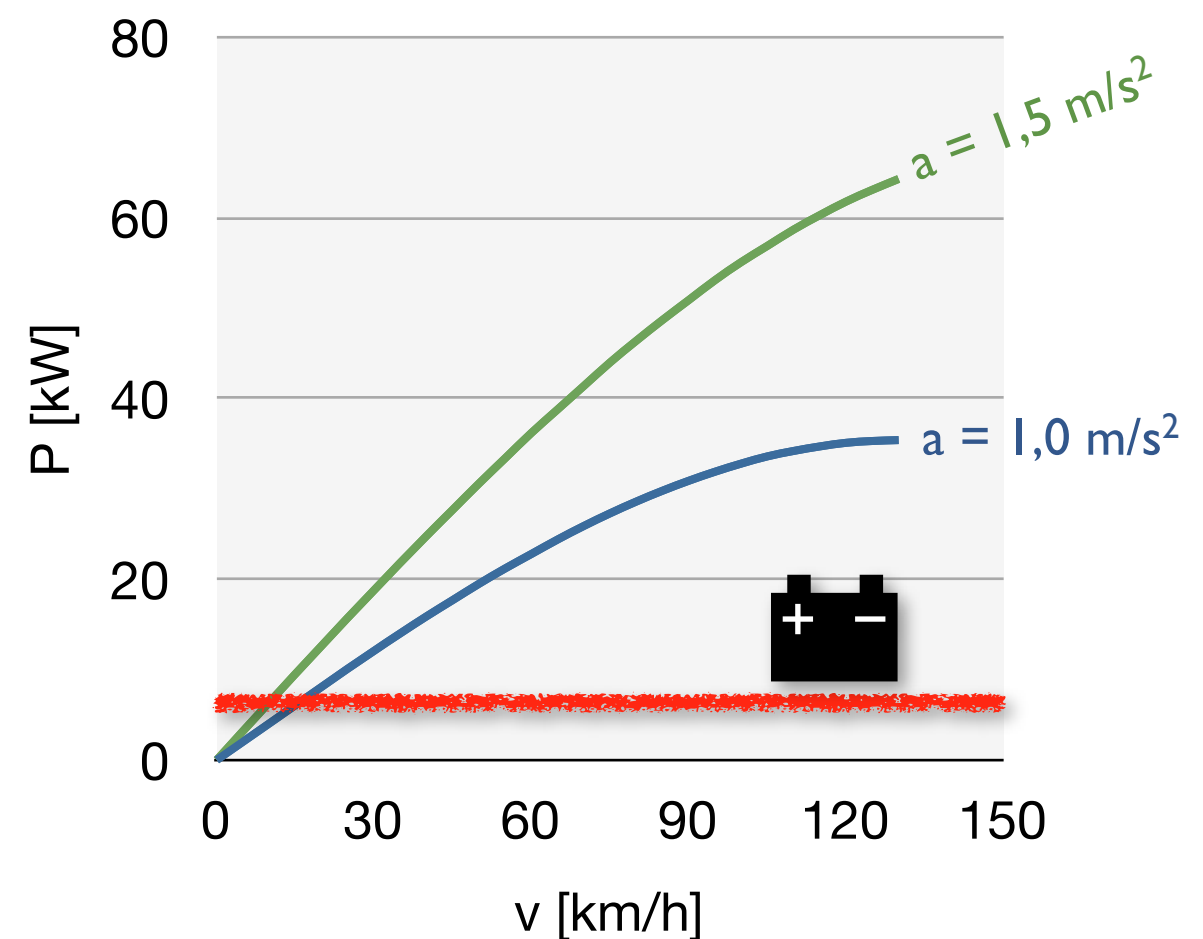
battery demands

vehicle mass = 1600 kg

brake energy



brake power

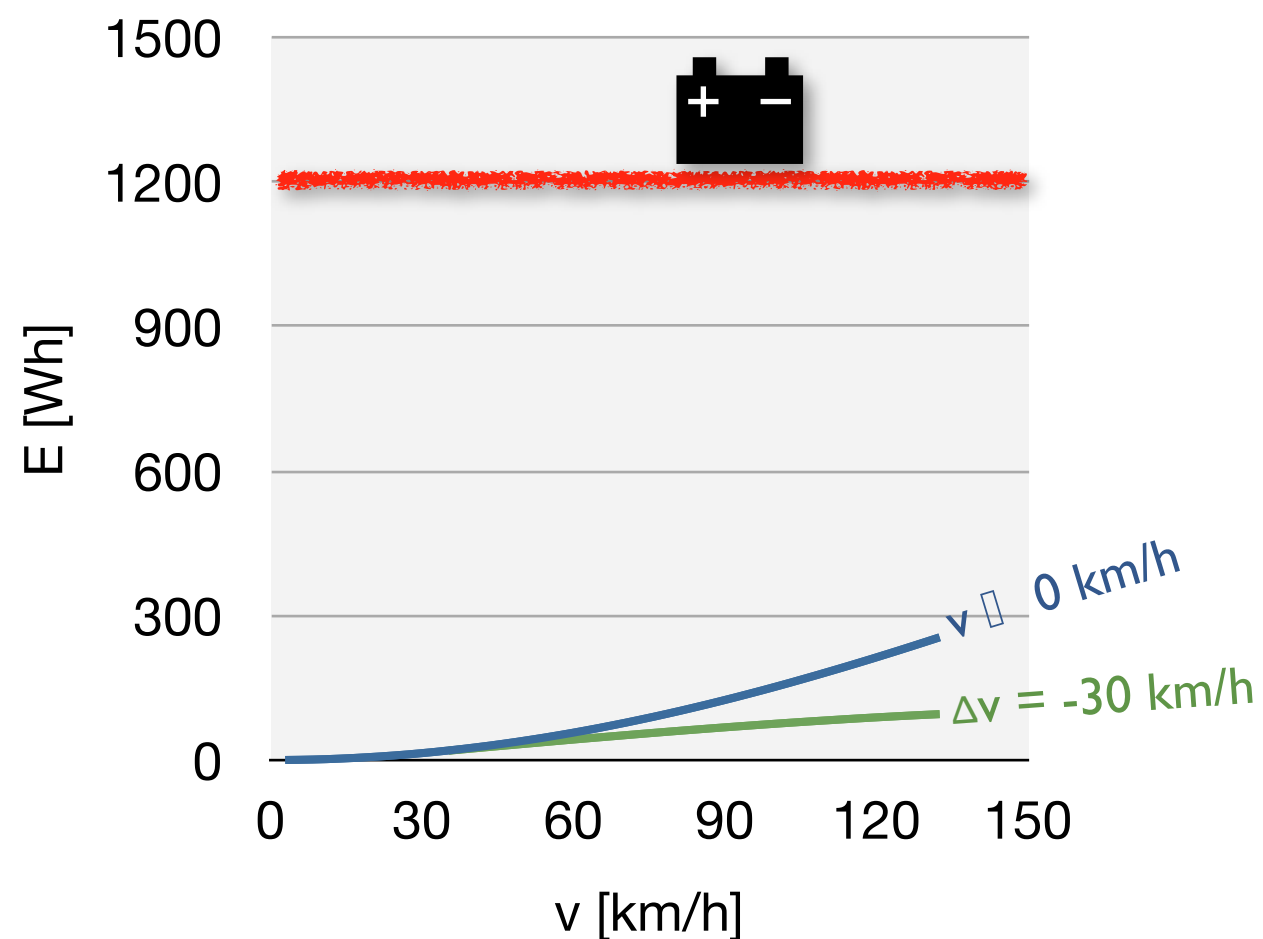


low energy demand

battery demands

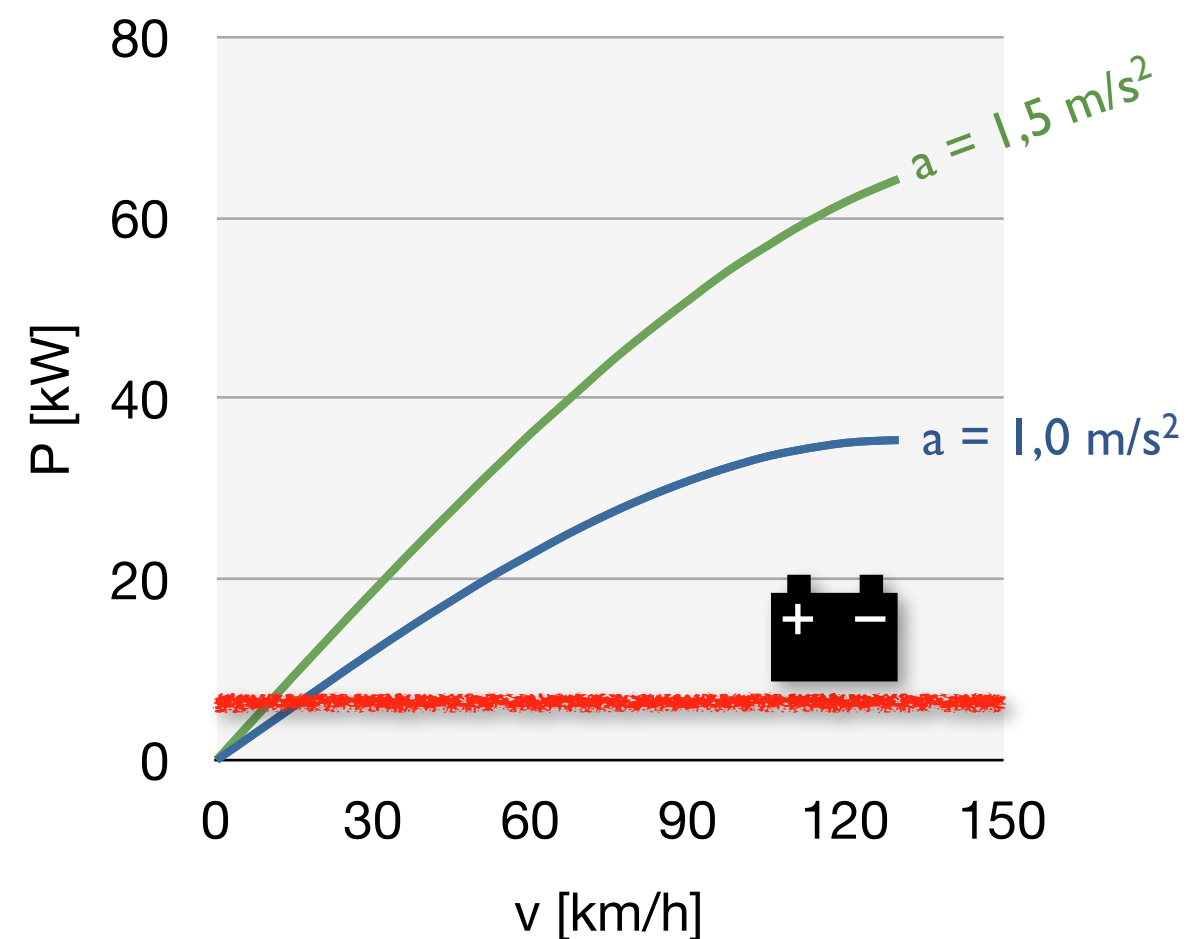
vehicle mass = 1600 kg

brake energy



low energy demand

brake power



high power demand

hydraulic transmissions:

positive

negative

robust

too noisy

flexible

too harsh

good cooling

poor efficiency

compact

too expensive

energy storage?

hydraulic transmissions:

positive

negative

robust

too noisy

flexible

too harsh

good cooling

poor efficiency

compact

too expensive

energy storage

hydraulic transmissions:

positive

negative

robust

~~too noisy~~

flexible

~~too harsh~~

good cooling

~~poor efficiency~~

compact

~~too expensive~~

energy storage

hydraulic transmissions:

positive

negative

robust

~~too noisy~~

flexible

~~too harsh~~

good cooling

~~poor efficiency~~

compact

~~too expensive~~

energy storage

hydraulic transmissions:

positive

negative

robust

flexible

good cooling

compact

energy storage

~~too noisy~~

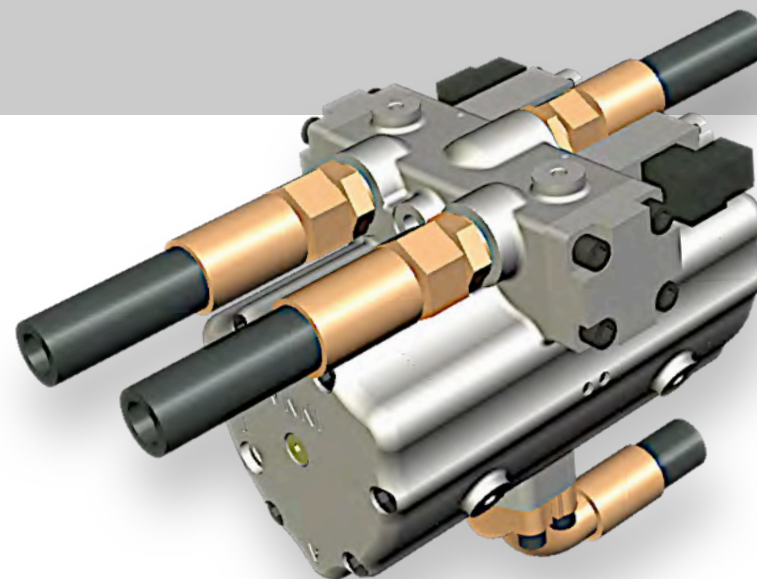
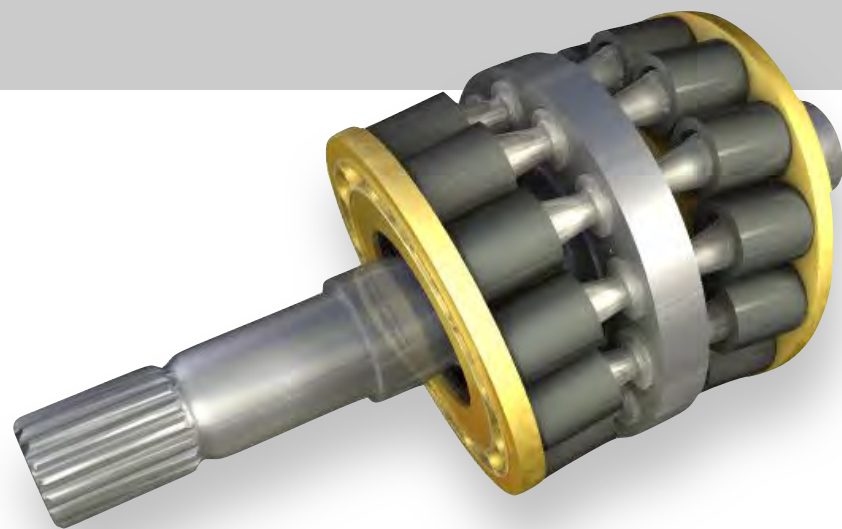
~~too harsh~~

~~poor efficiency~~

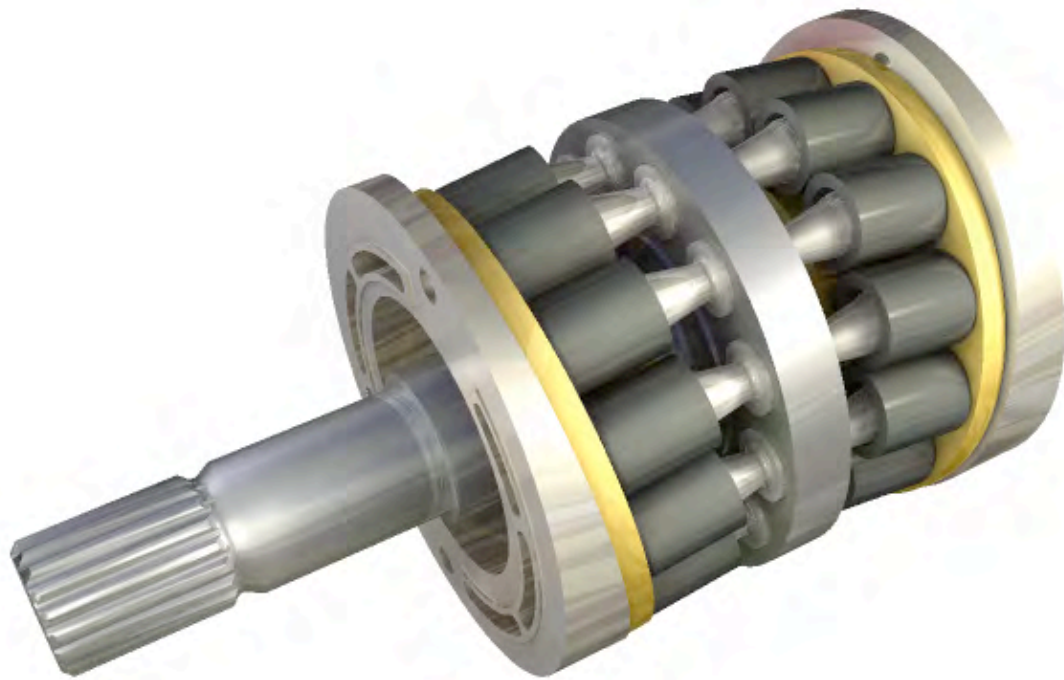
~~too expensive~~

new hydraulic machines

new hydraulic components

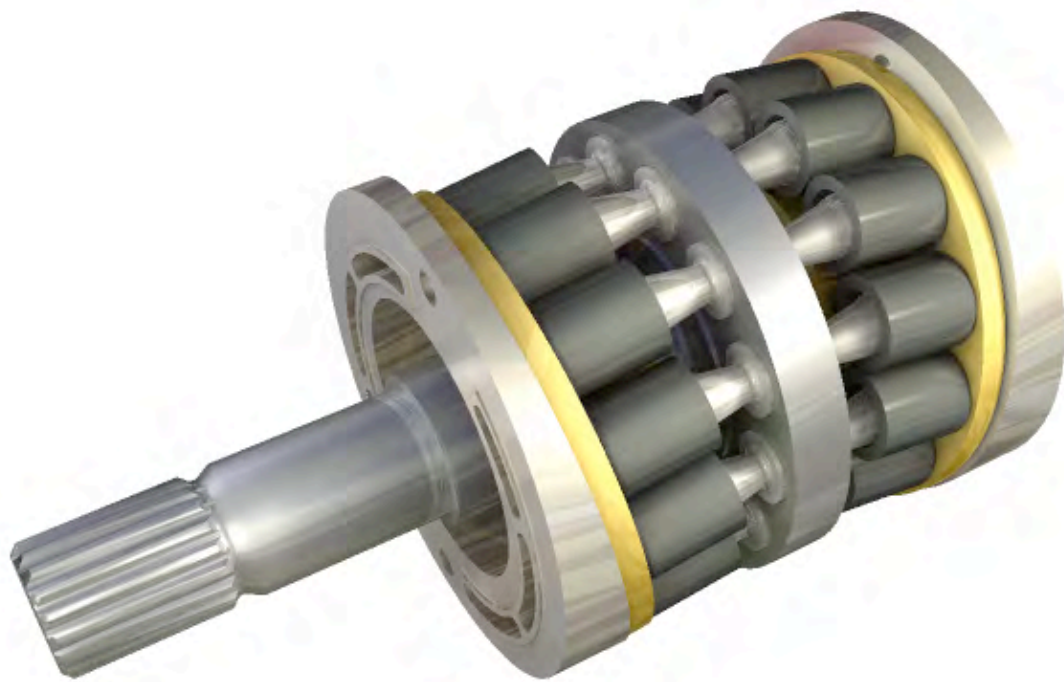


floating cup principle



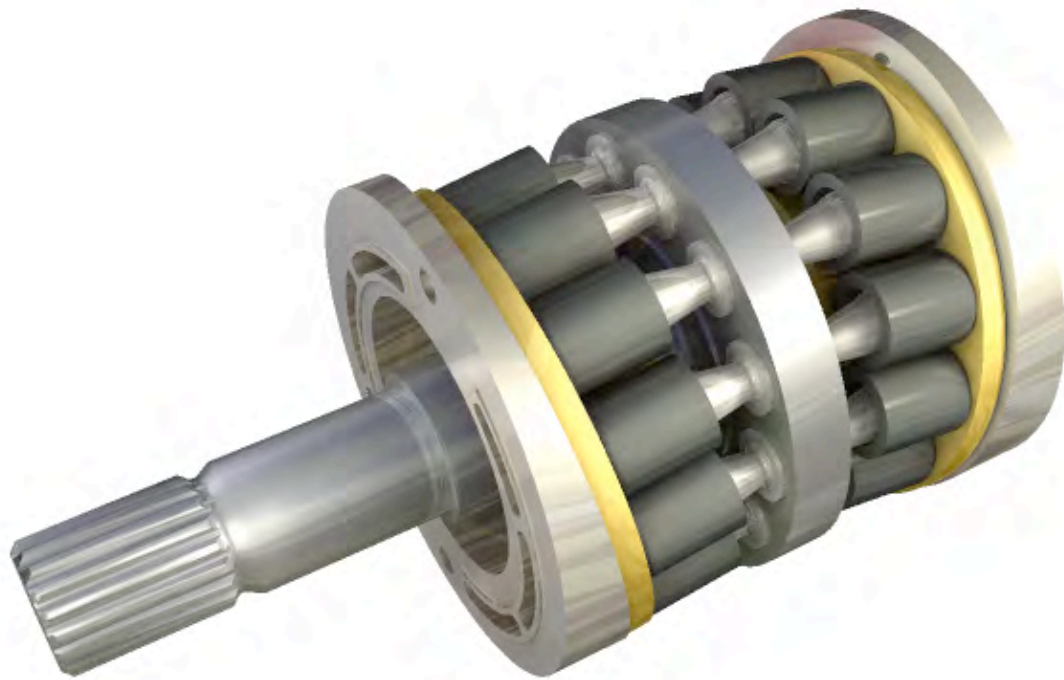
floating cup principle

❖ axial piston



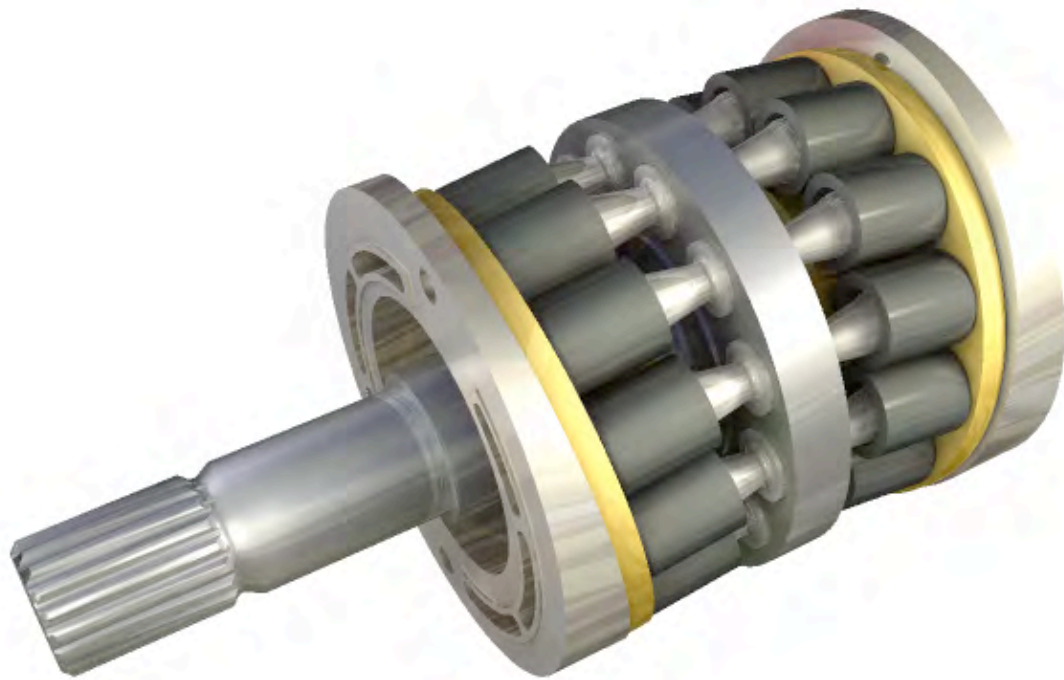
floating cup principle

- ❖ axial piston
- ❖ multi piston

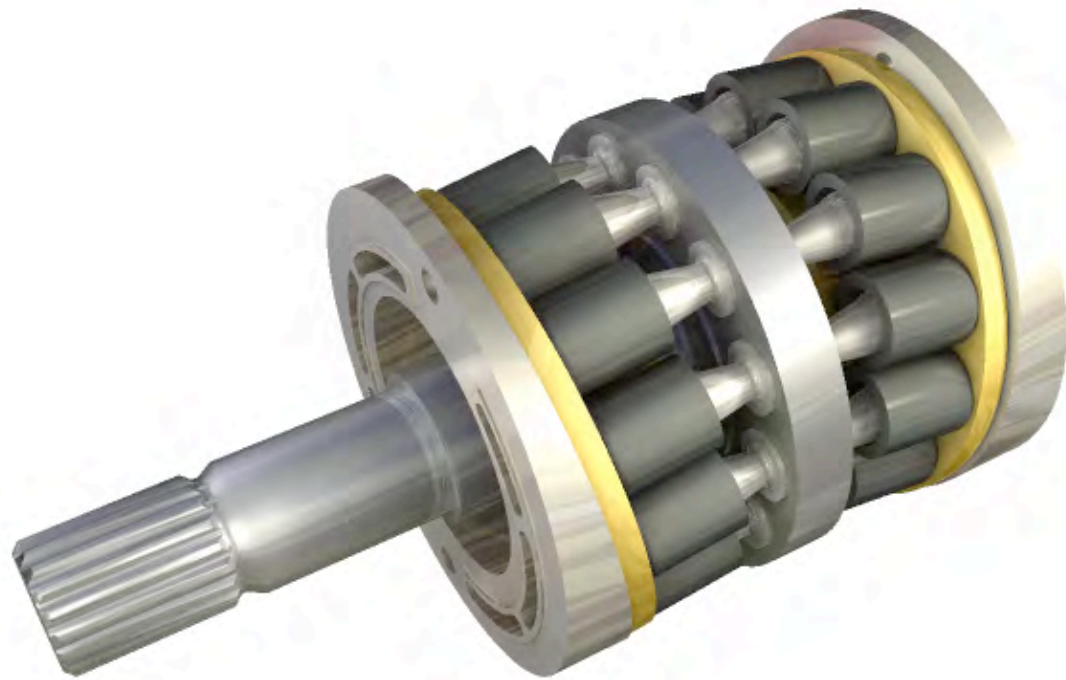


floating cup principle

- ❖ axial piston
- ❖ multi piston
- ❖ balanced

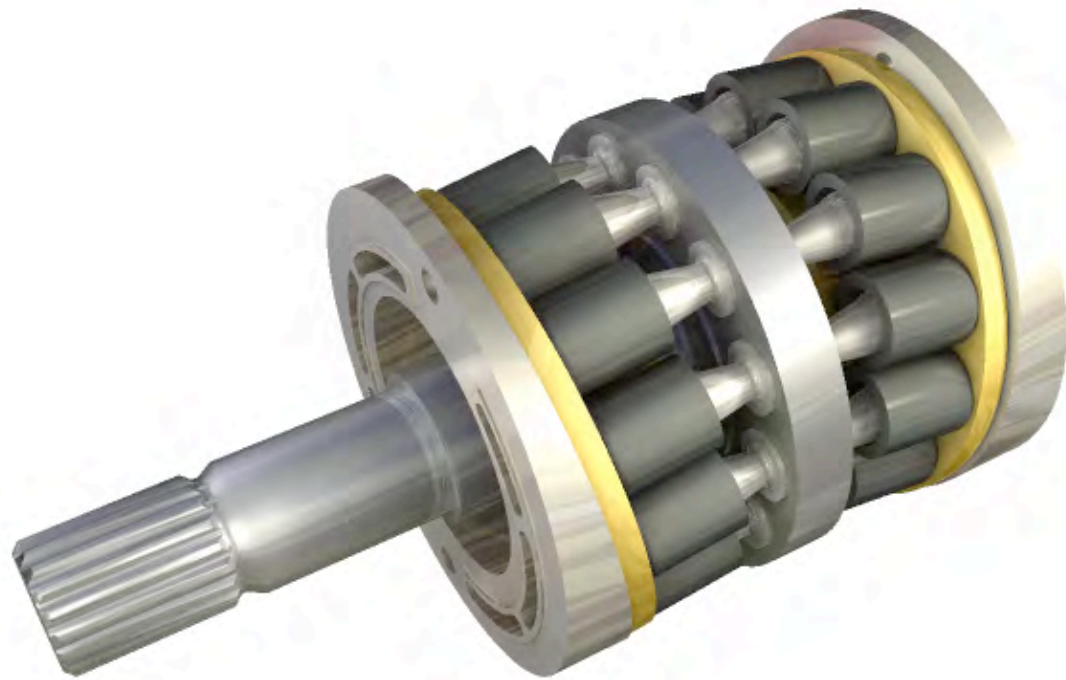


floating cup principle



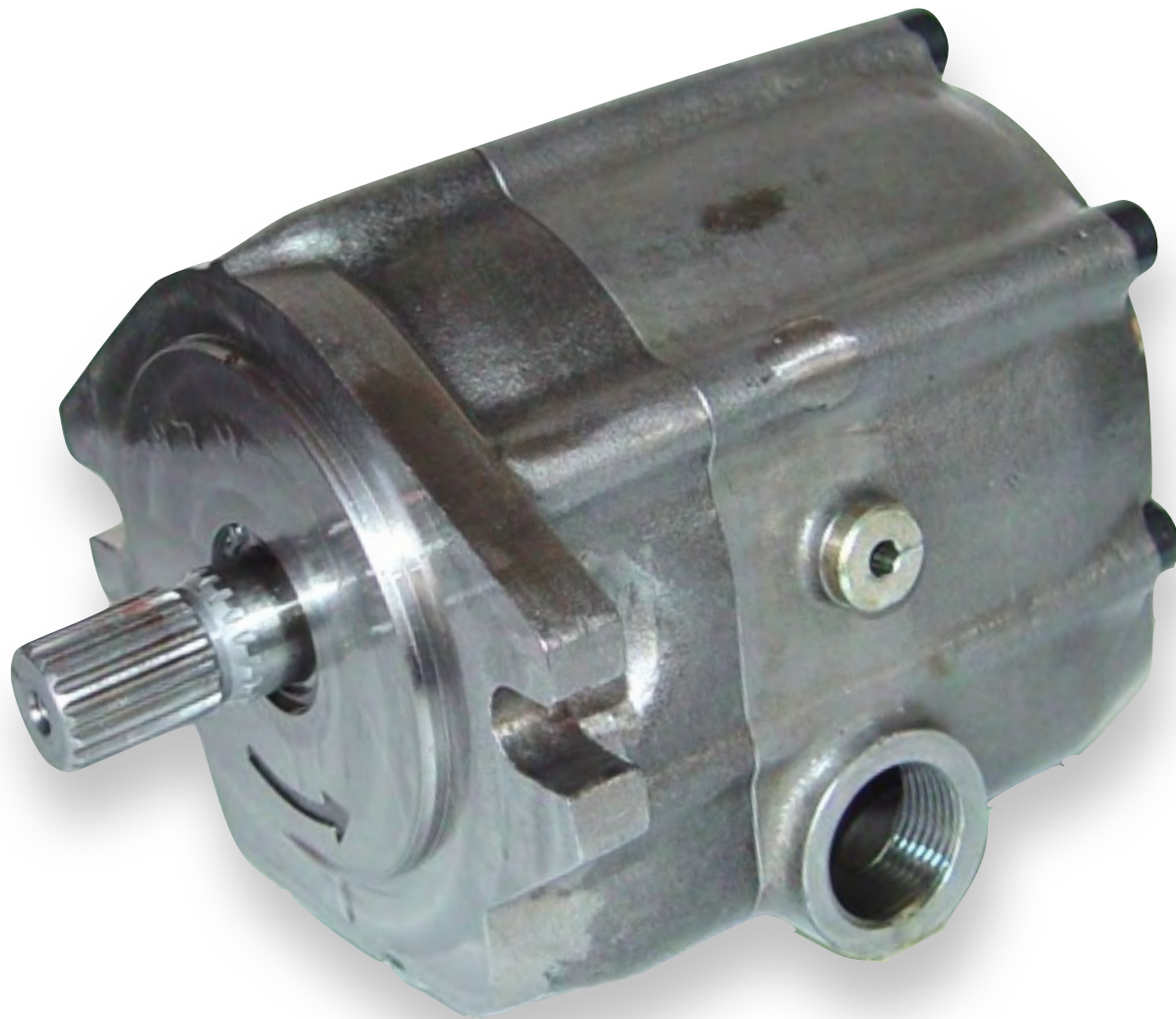
- ❖ axial piston
- ❖ multi piston
- ❖ balanced
- ❖ direct conversion

floating cup principle



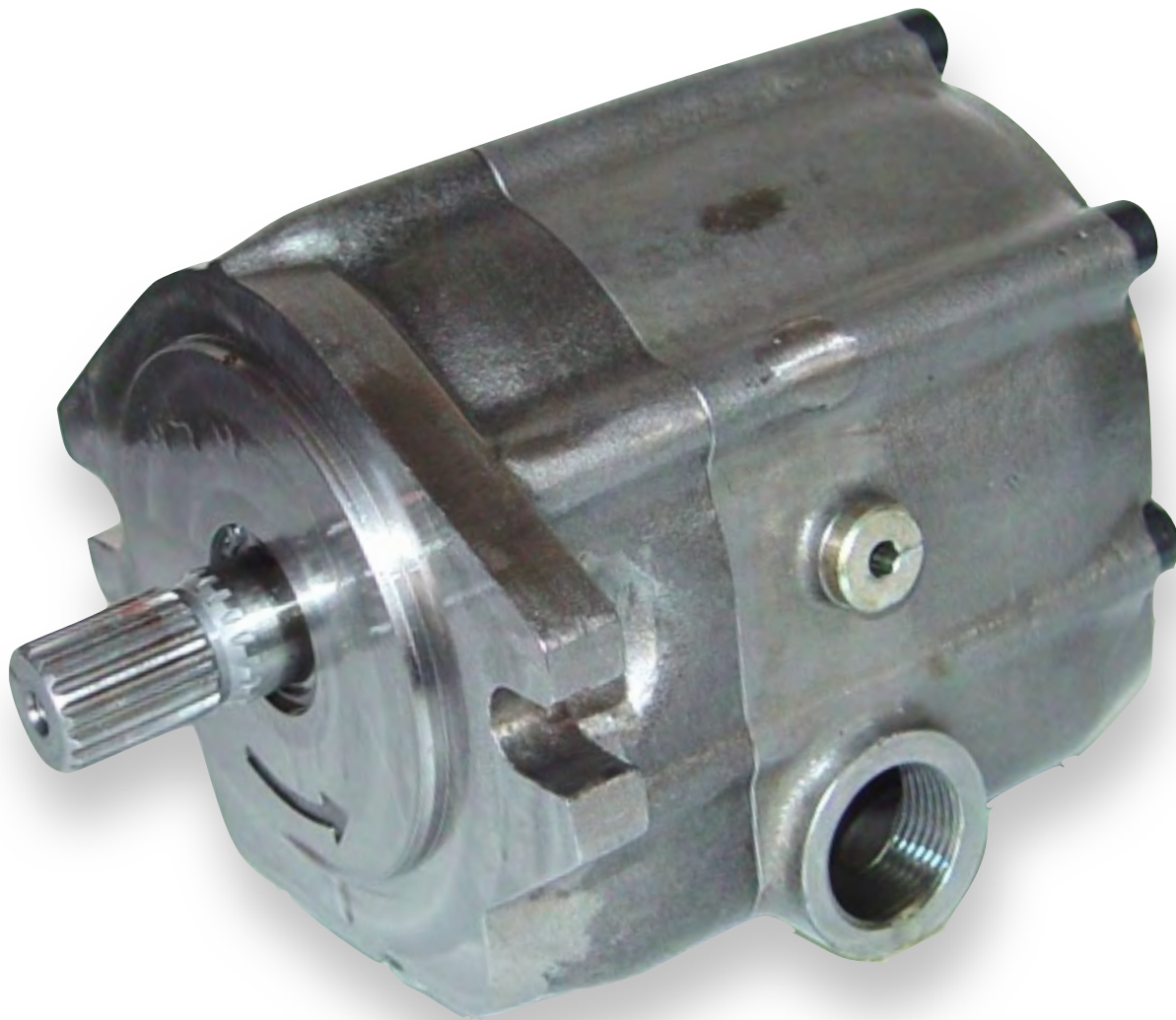
- ❖ axial piston
- ❖ multi piston
- ❖ balanced
- ❖ direct conversion
- ❖ automotive production

floating cup principle



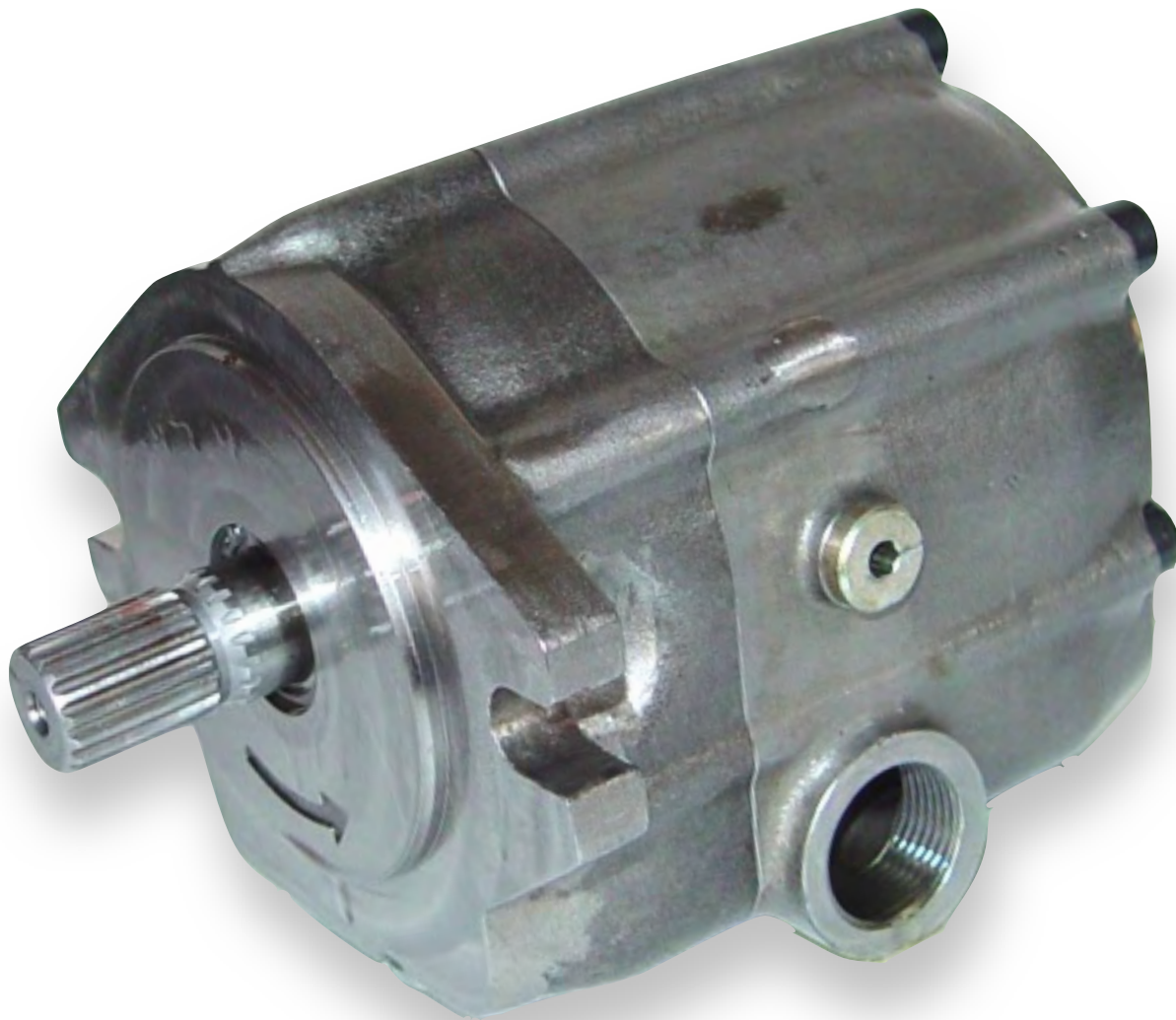
floating cup principle

❖ compact

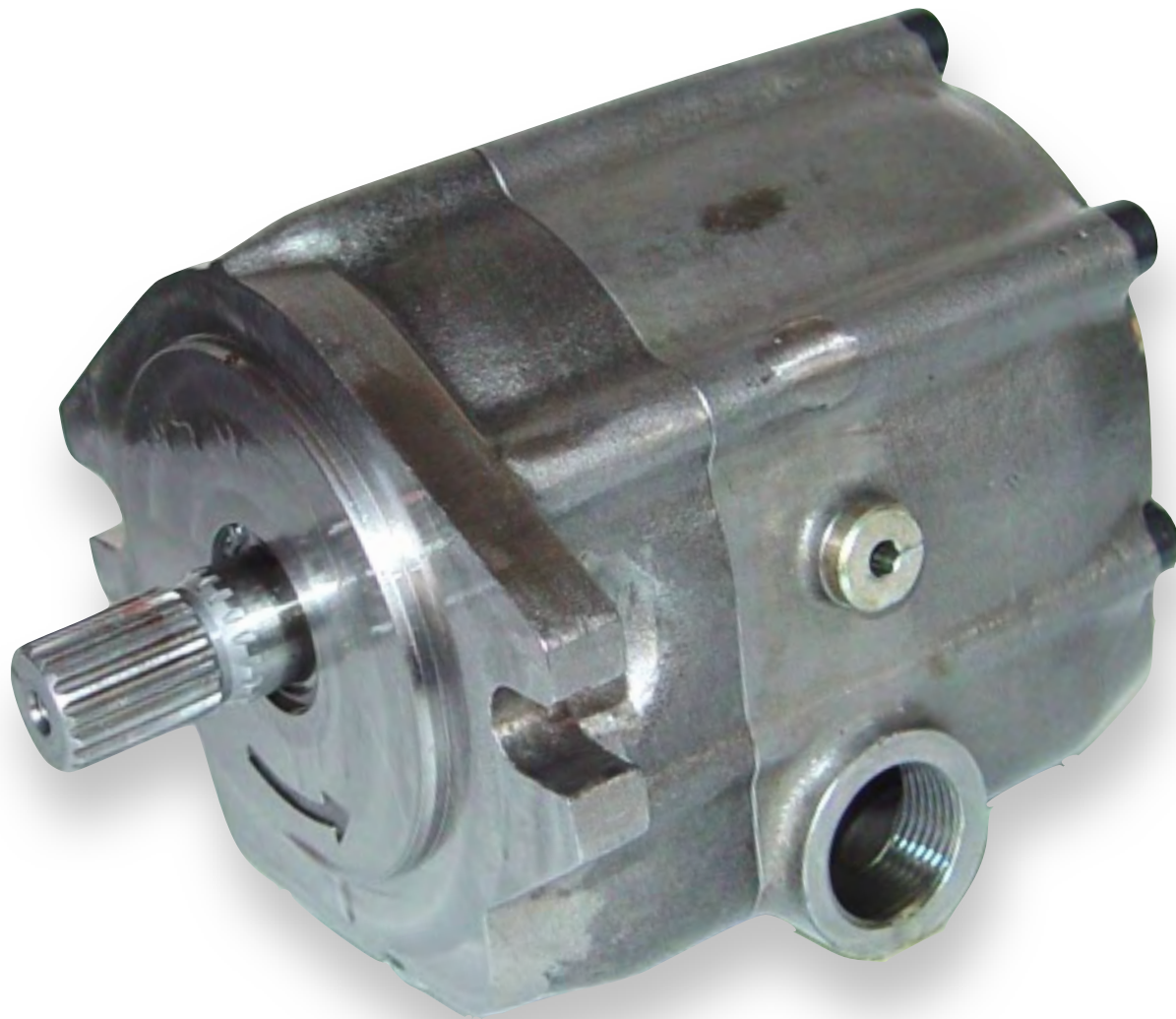


floating cup principle

- ❖ compact
- ❖ low torque ripple

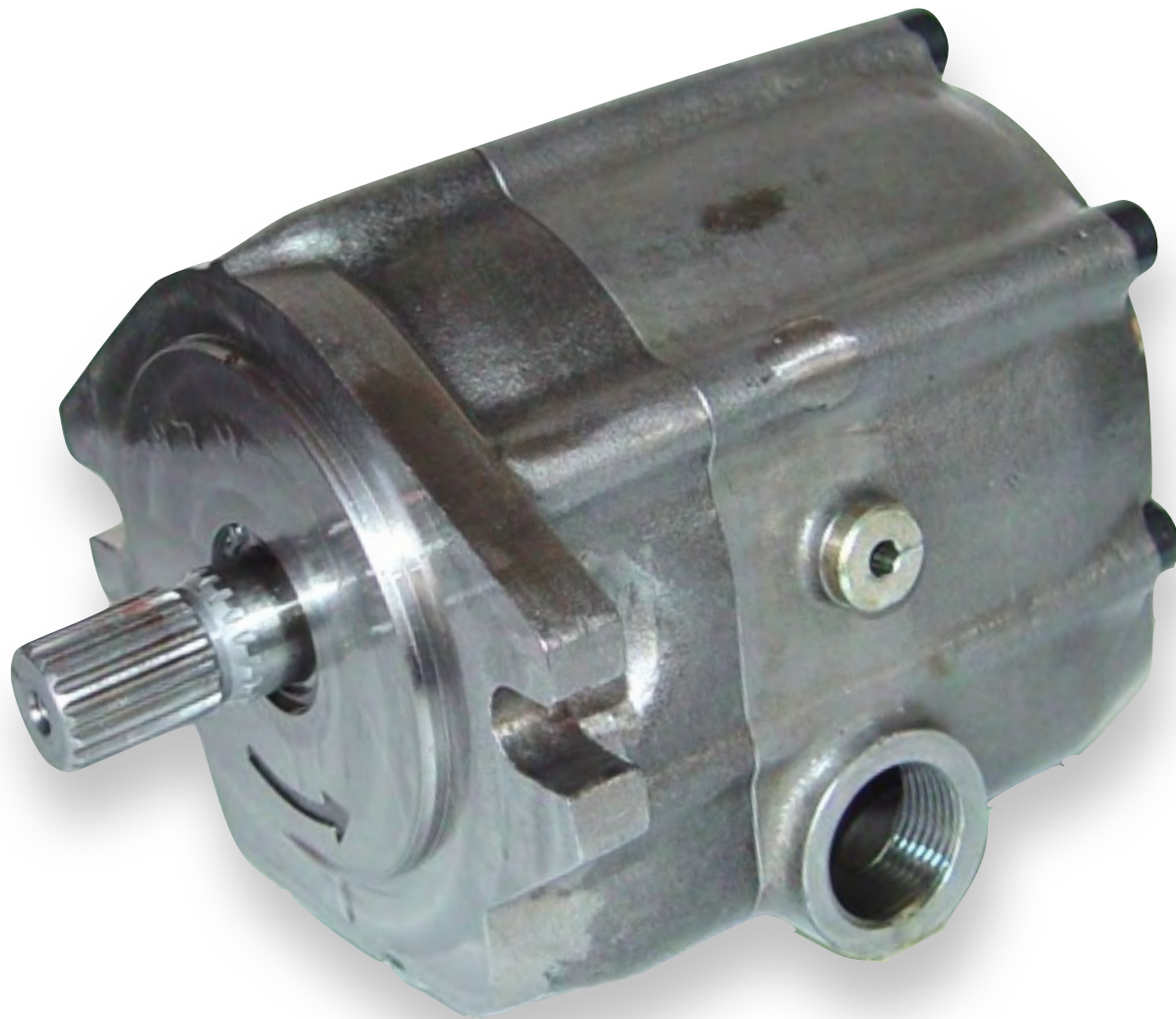


floating cup principle



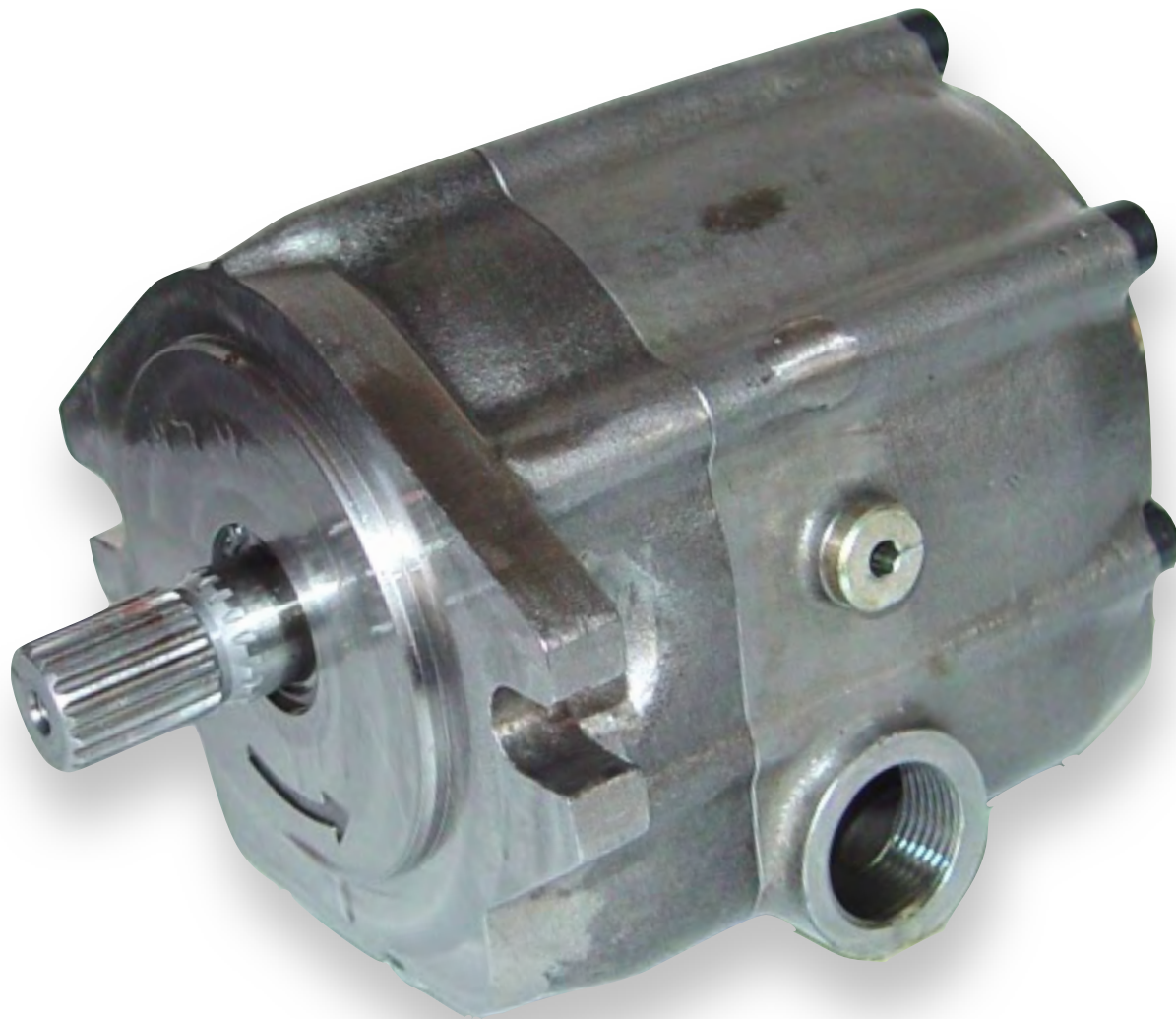
- ❖ compact
- ❖ low torque ripple
- ❖ high starting torque

floating cup principle



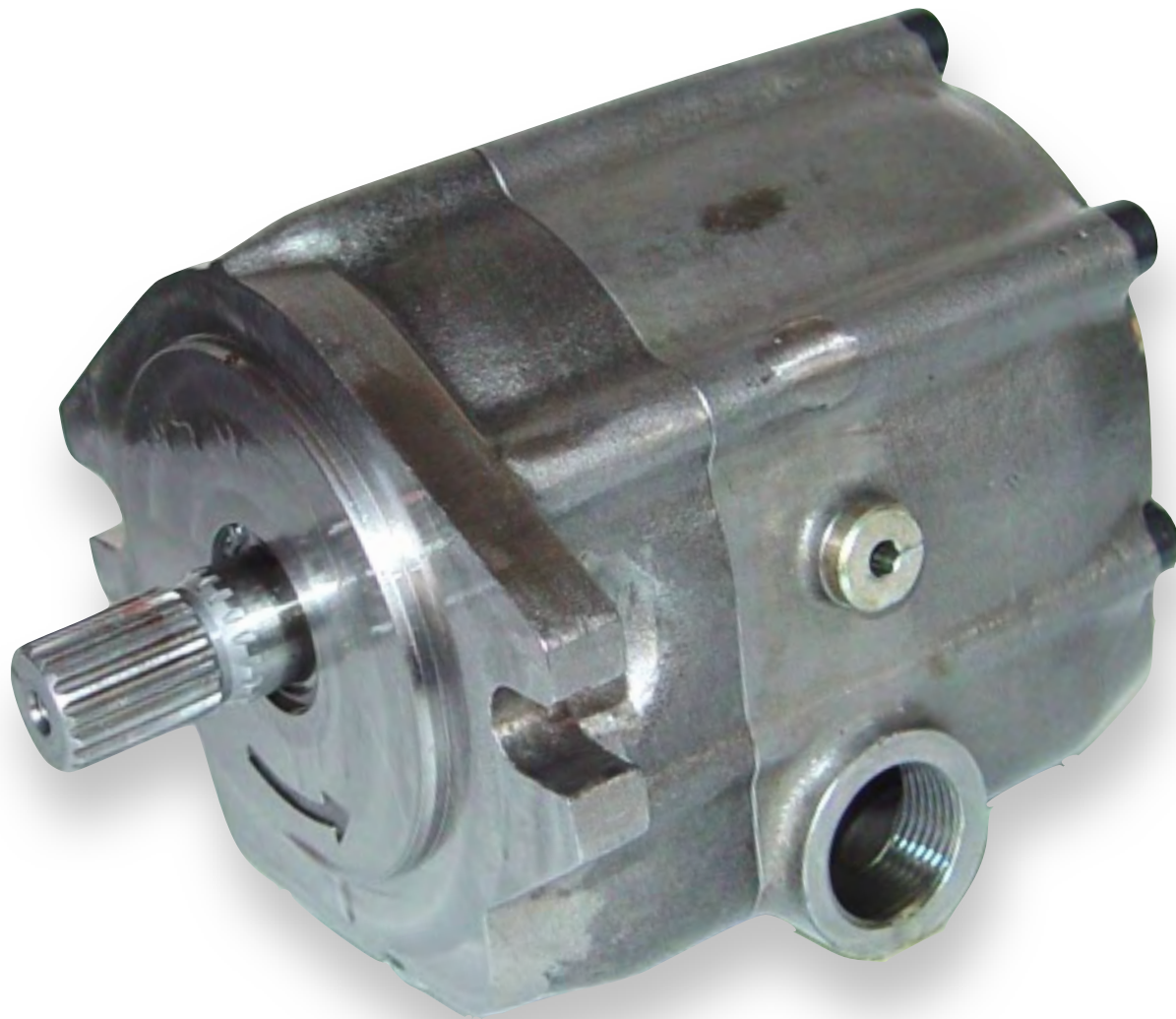
- ❖ compact
- ❖ low torque ripple
- ❖ high starting torque
- ❖ low noise

floating cup principle



- ❖ compact
- ❖ low torque ripple
- ❖ high starting torque
- ❖ low noise
- ❖ efficient

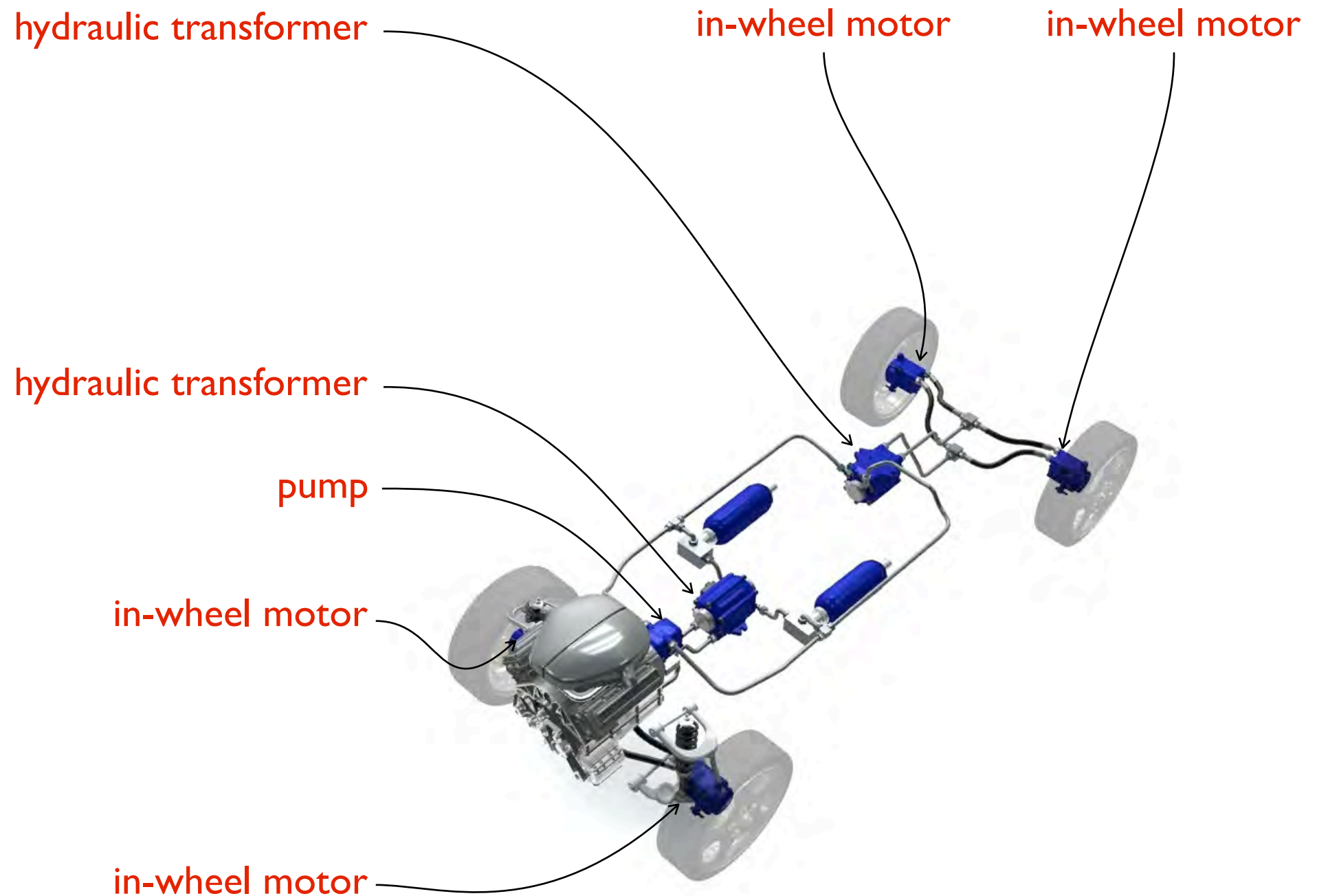
floating cup principle



- ❖ compact
- ❖ low torque ripple
- ❖ high starting torque
- ❖ low noise
- ❖ efficient
- ❖ low cost

the Hydrid

new components & technologies:



the Hydrid

objectives



objectives

- ❖ reduce the fuel consumption and the CO₂-emissions by more than 50%



objectives

- ❖ reduce the fuel consumption and the CO₂-emissions by more than 50%
- ❖ without increasing the weight and the manufacturing cost



objectives

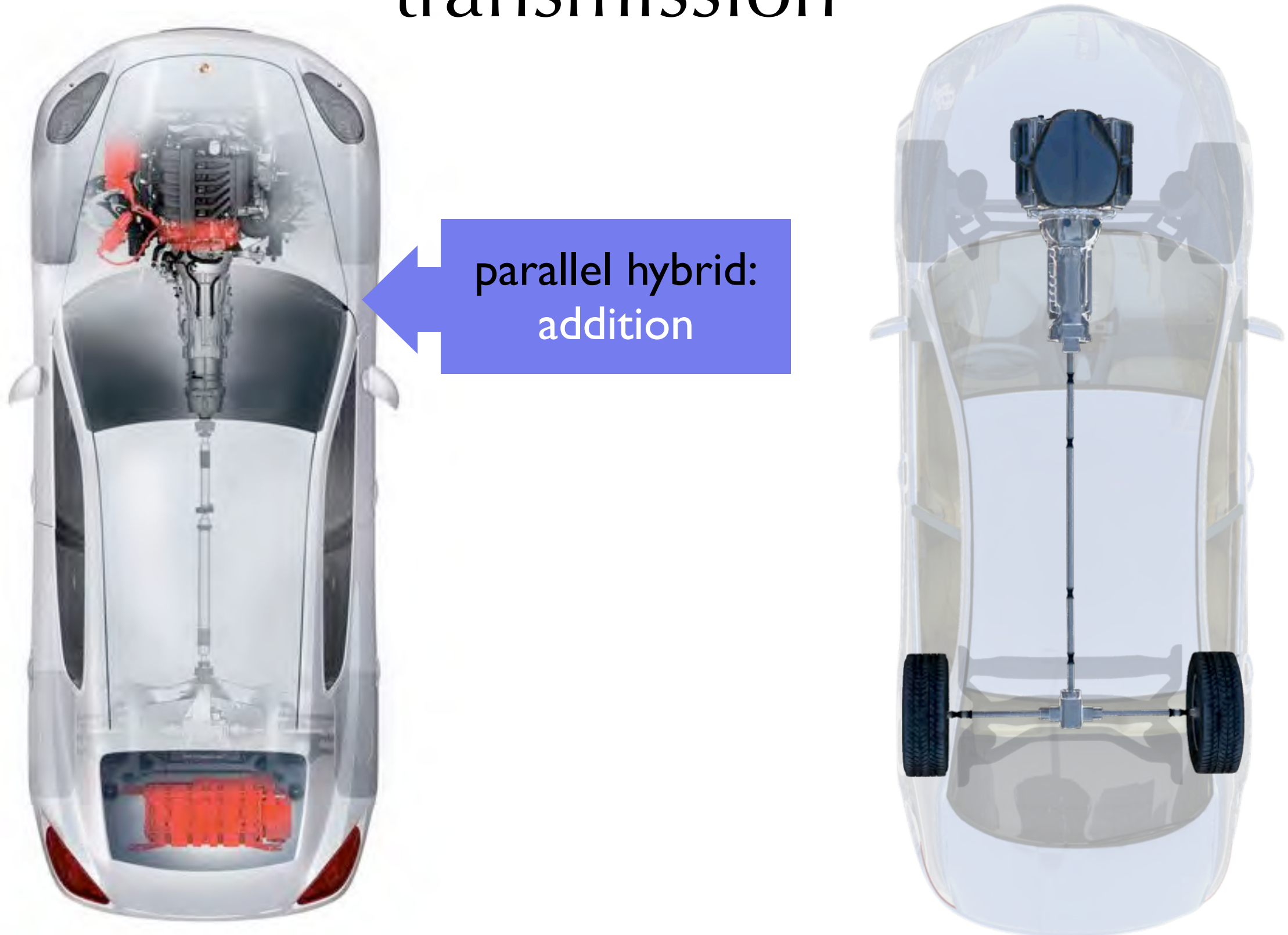
- ❖ reduce the fuel consumption and the CO₂-emissions by more than 50%
- ❖ without increasing the weight and the manufacturing cost
- ❖ without compromising the vehicle performance



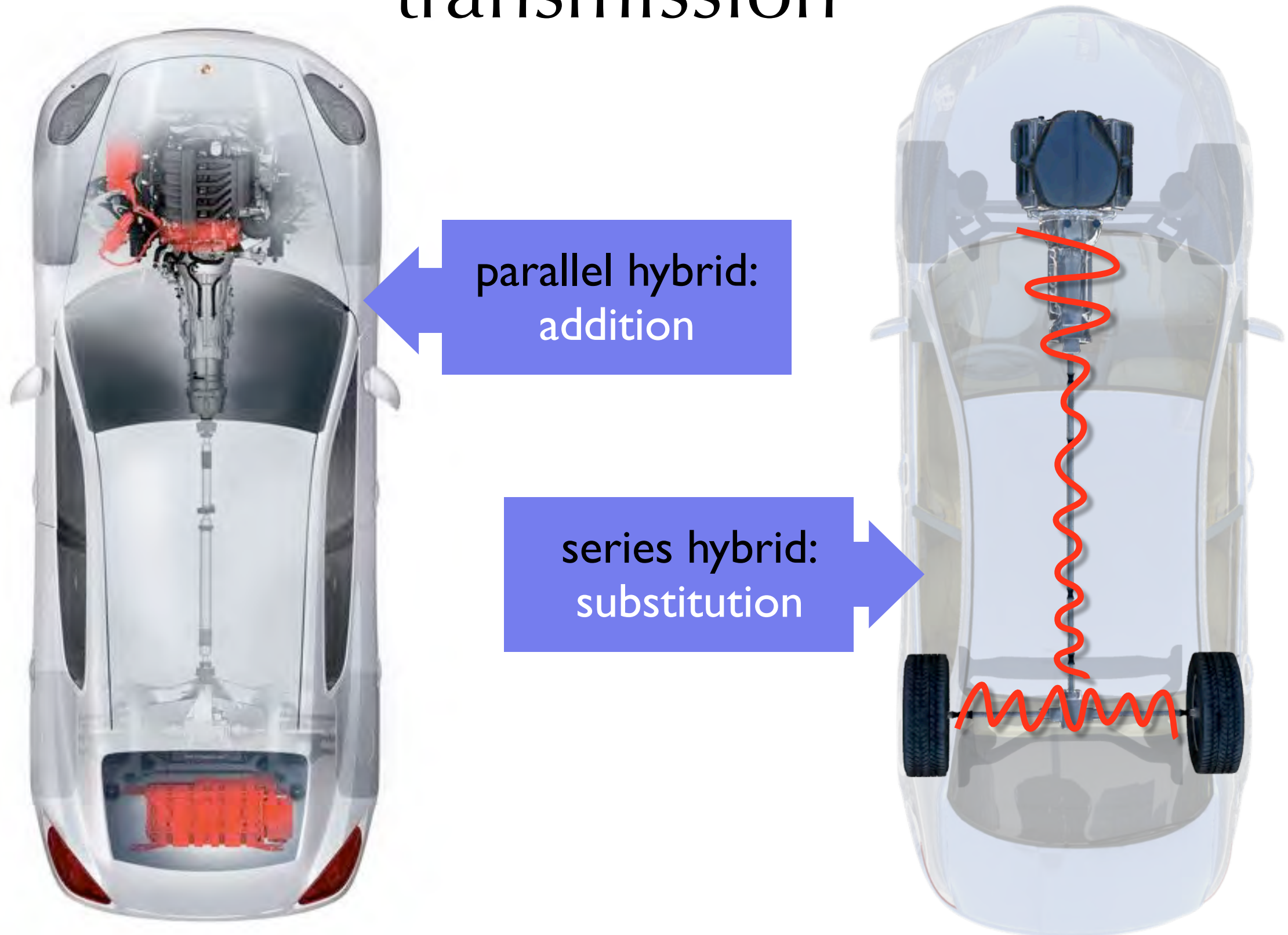
substituting the mechanical transmission



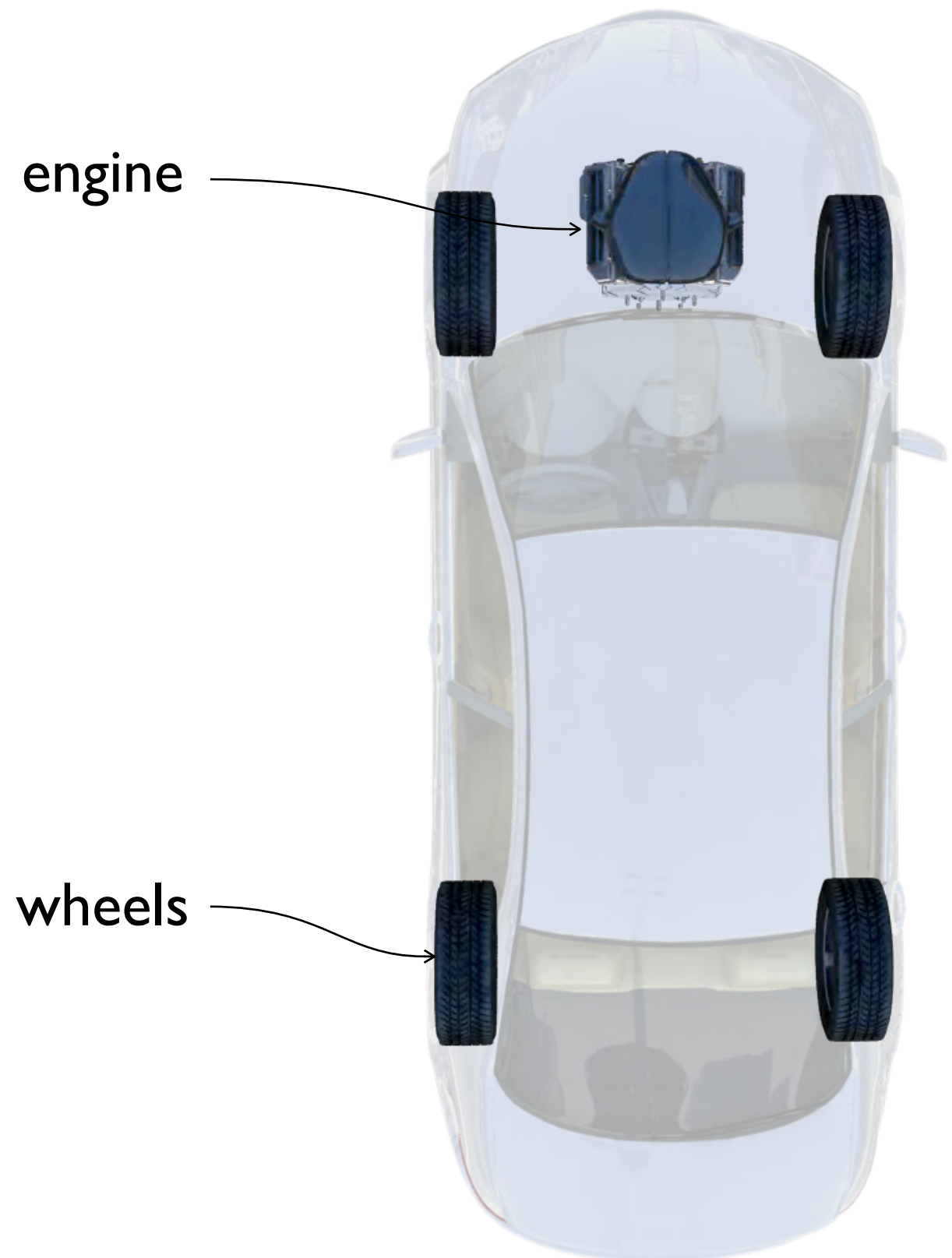
substituting the mechanical transmission



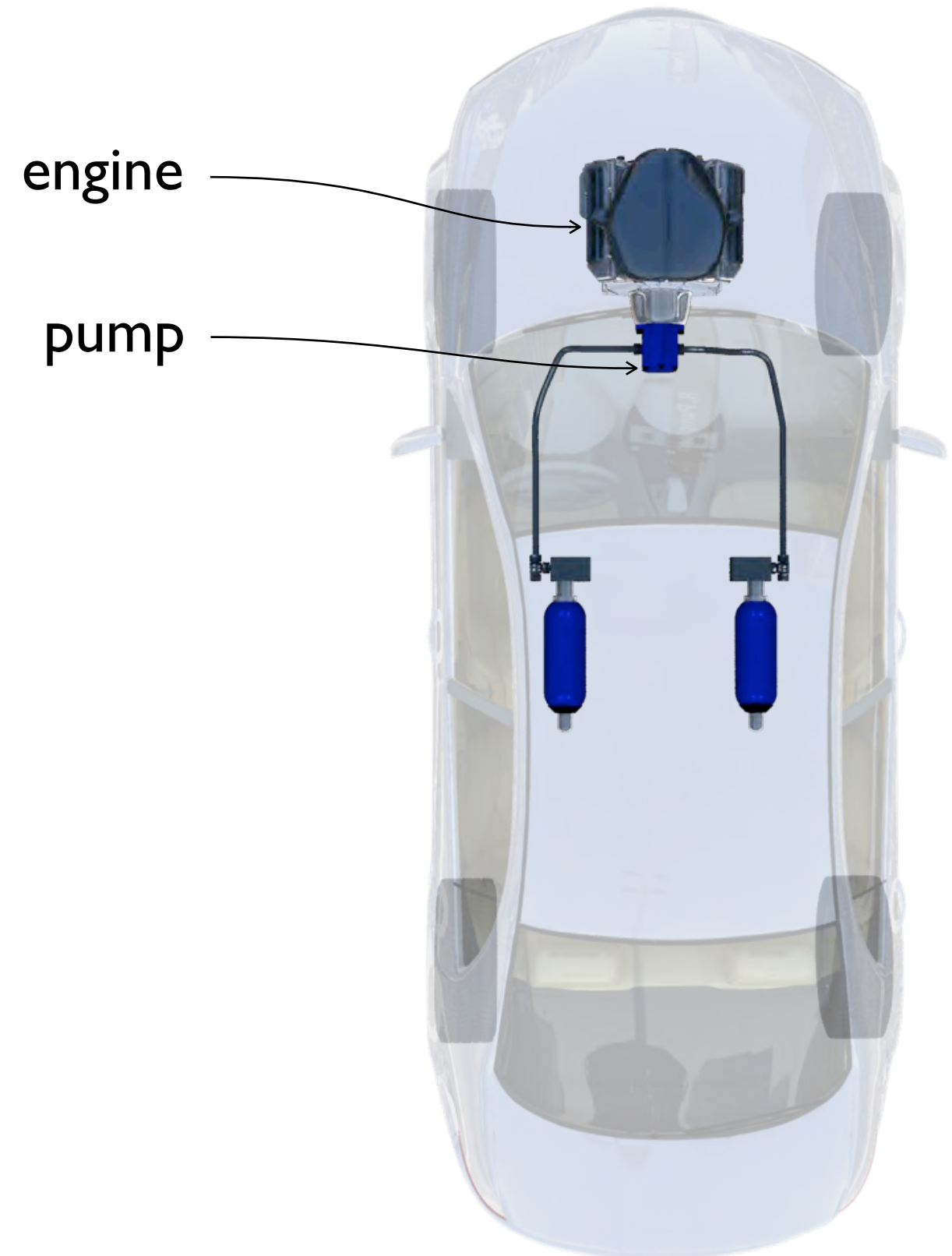
substituting the mechanical transmission



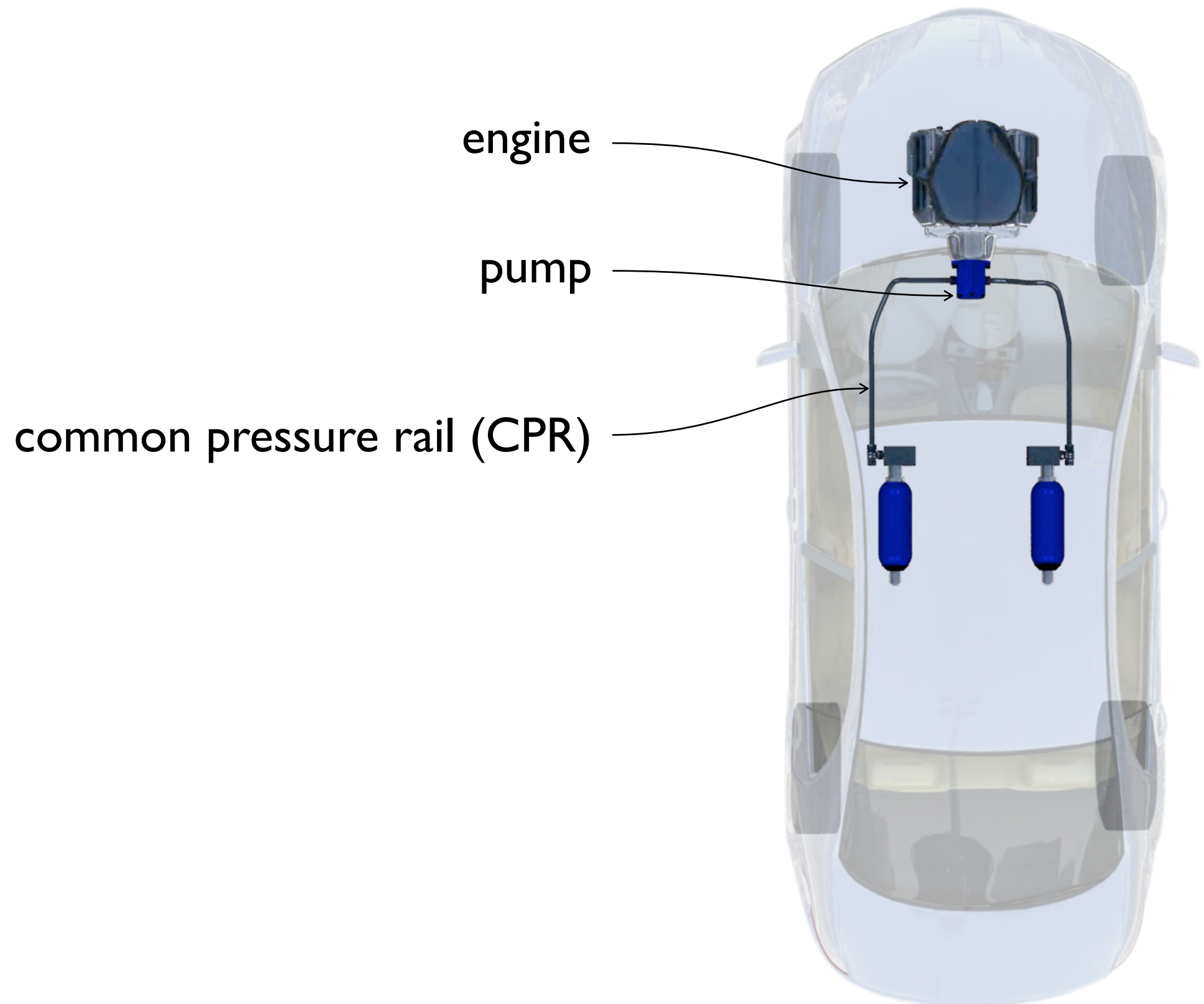
what remains



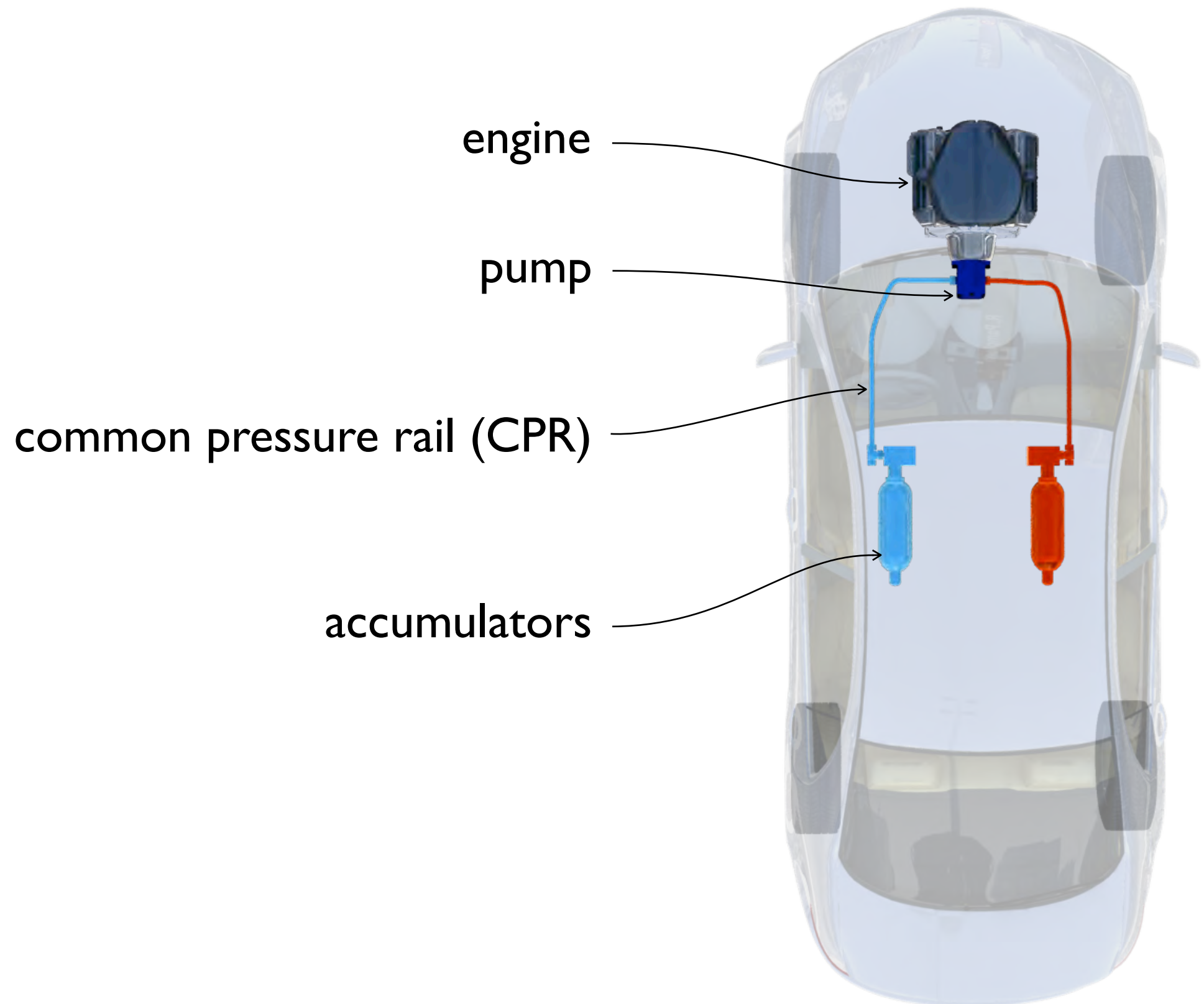
engine-pump = power plant



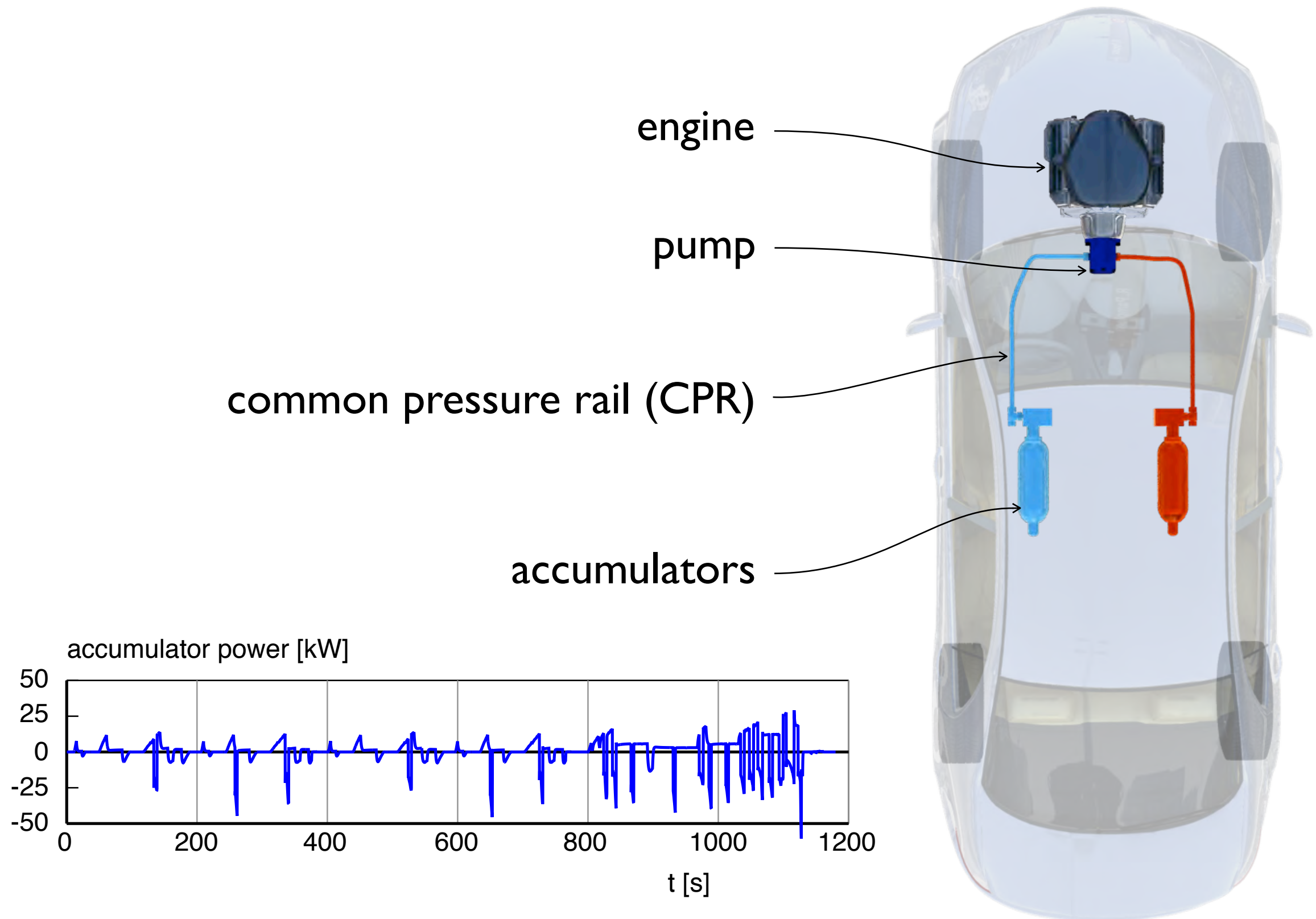
engine-pump = power plant



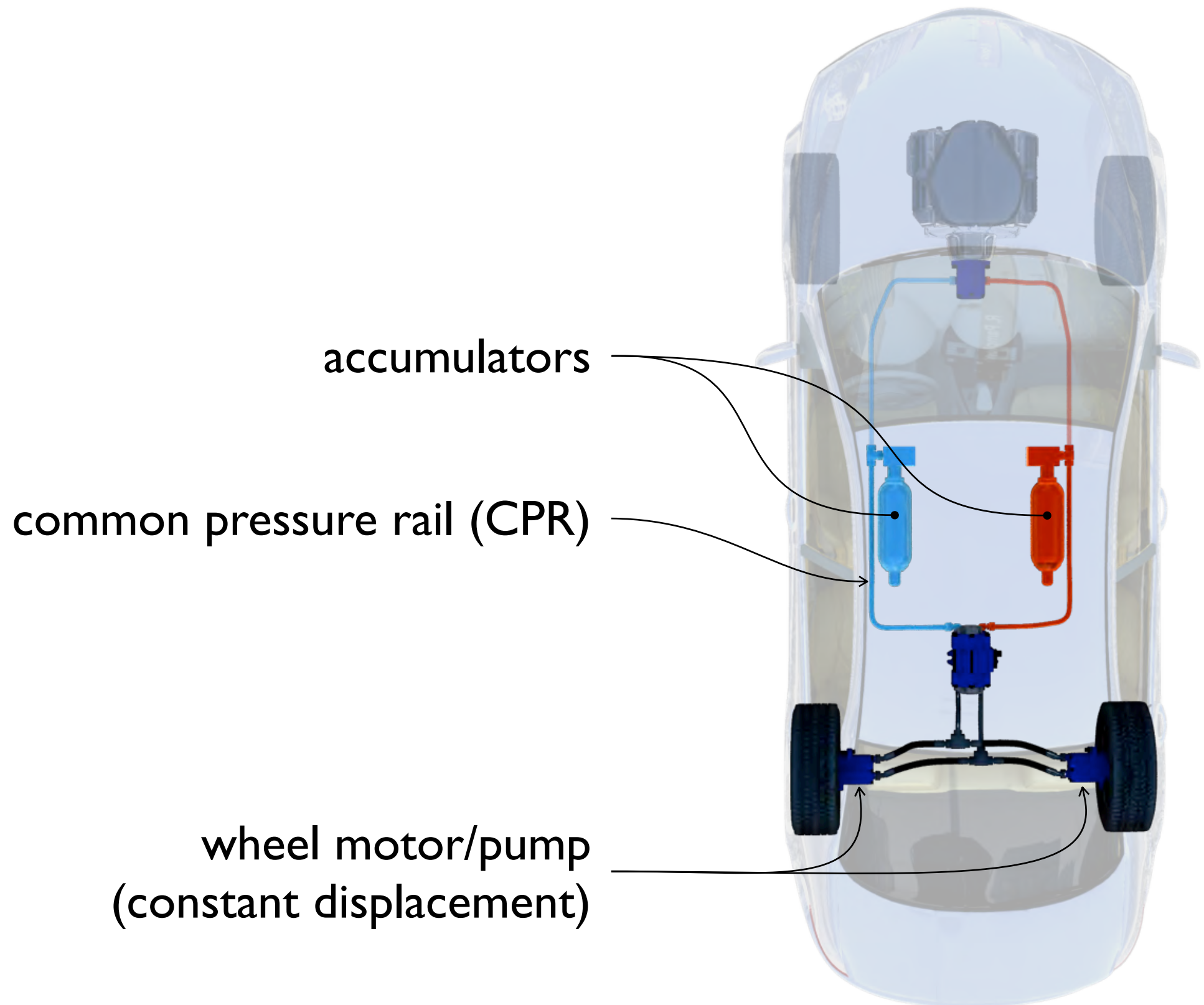
engine-pump = power plant



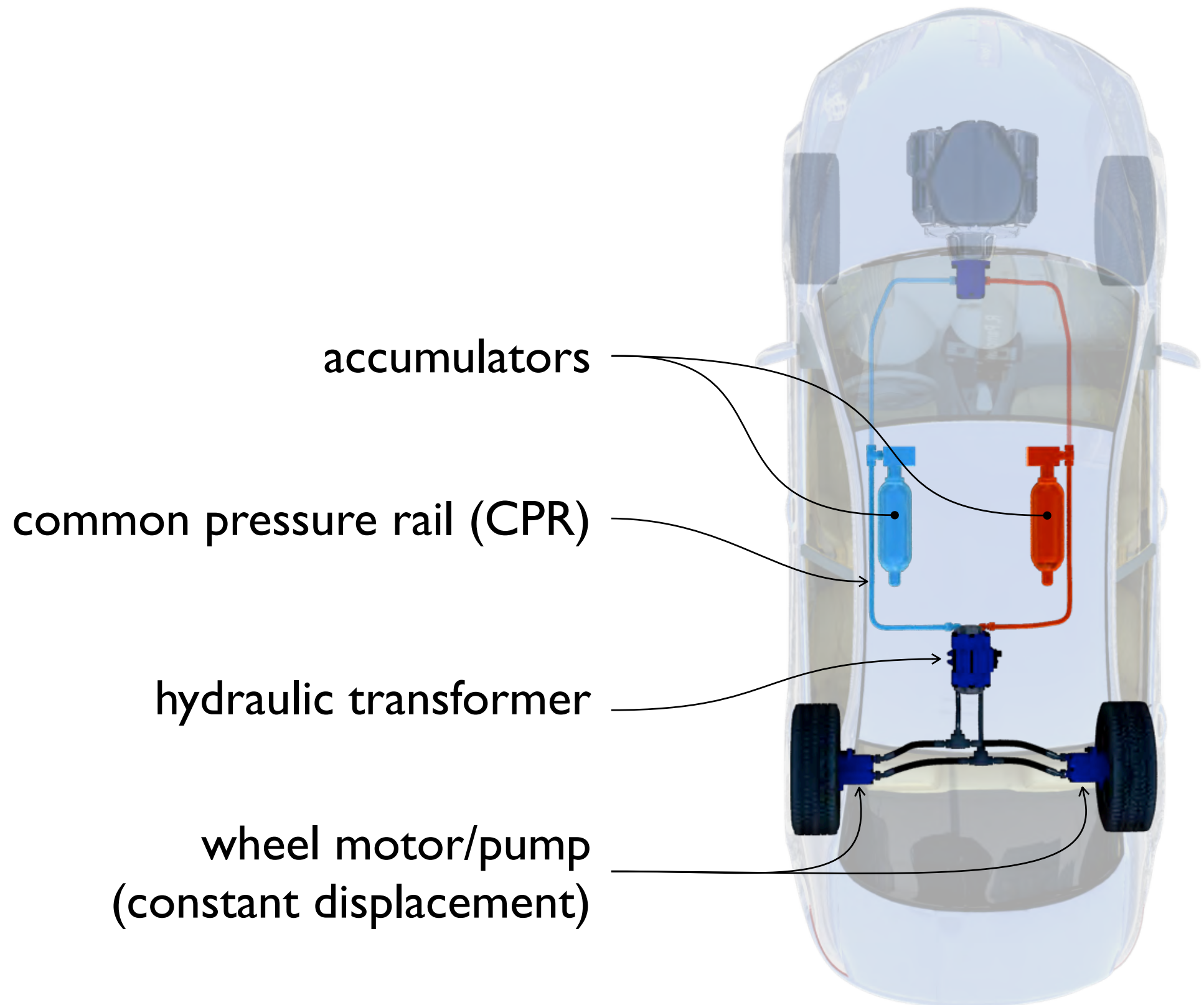
engine-pump = power plant



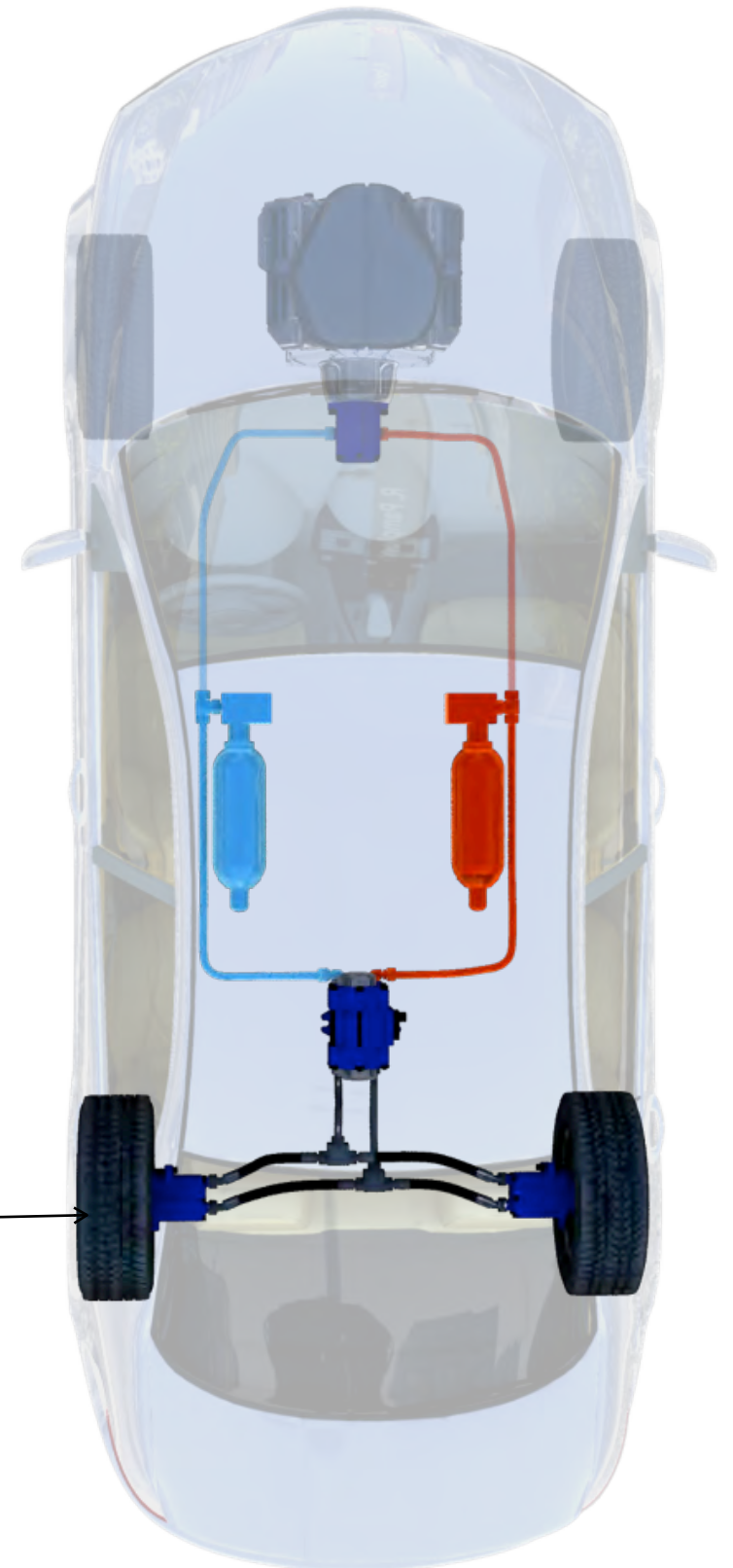
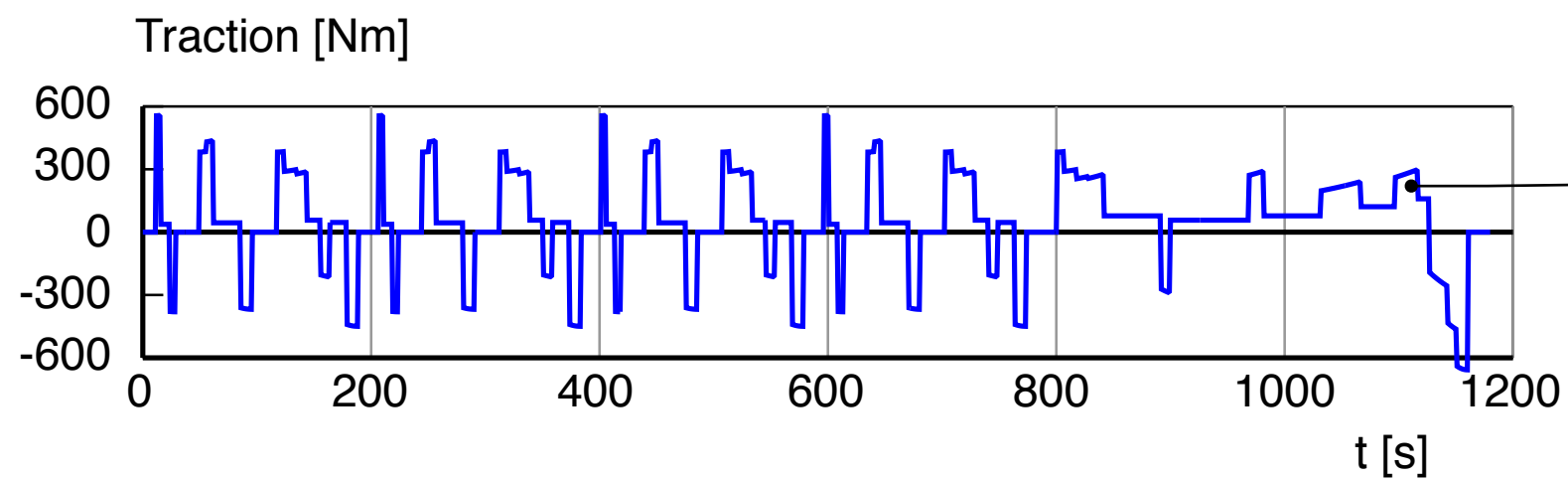
traction control



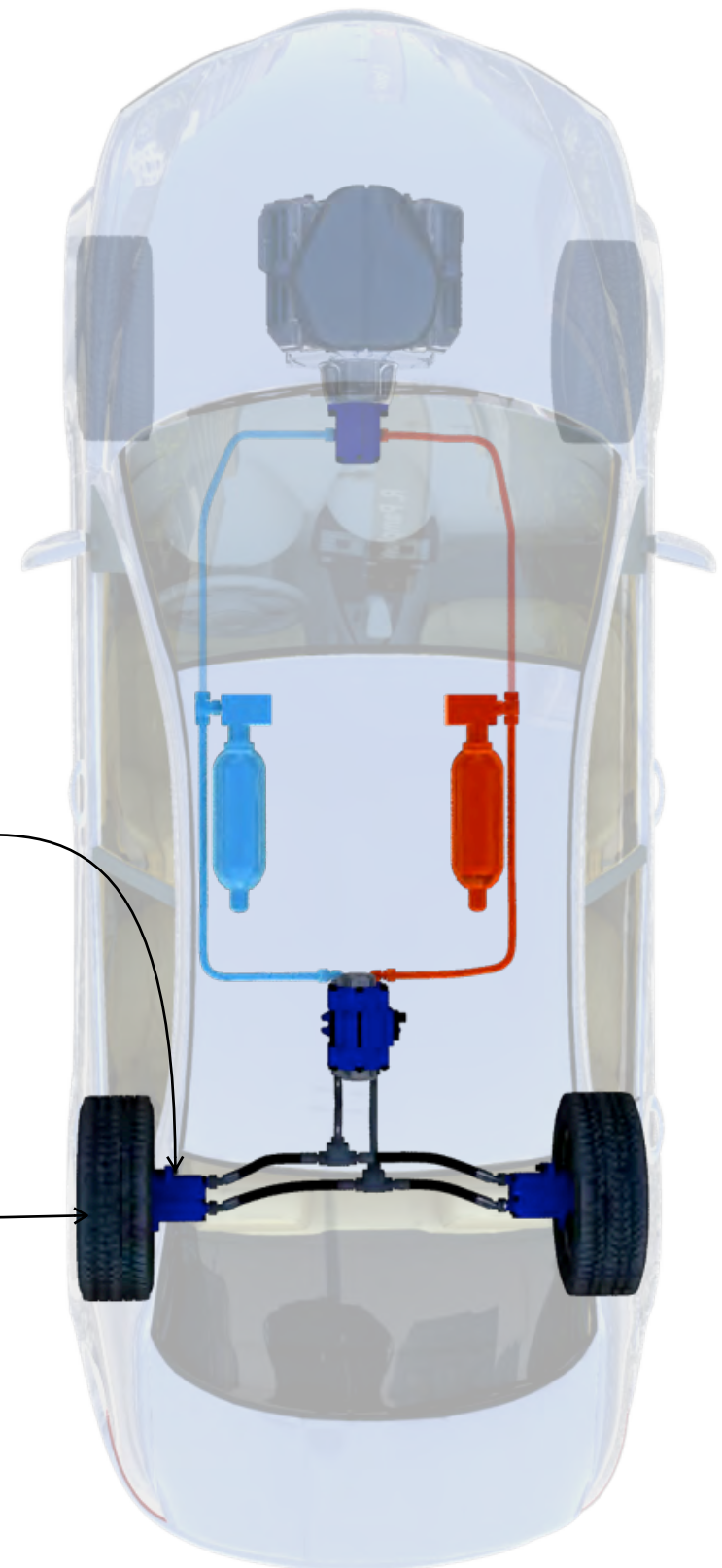
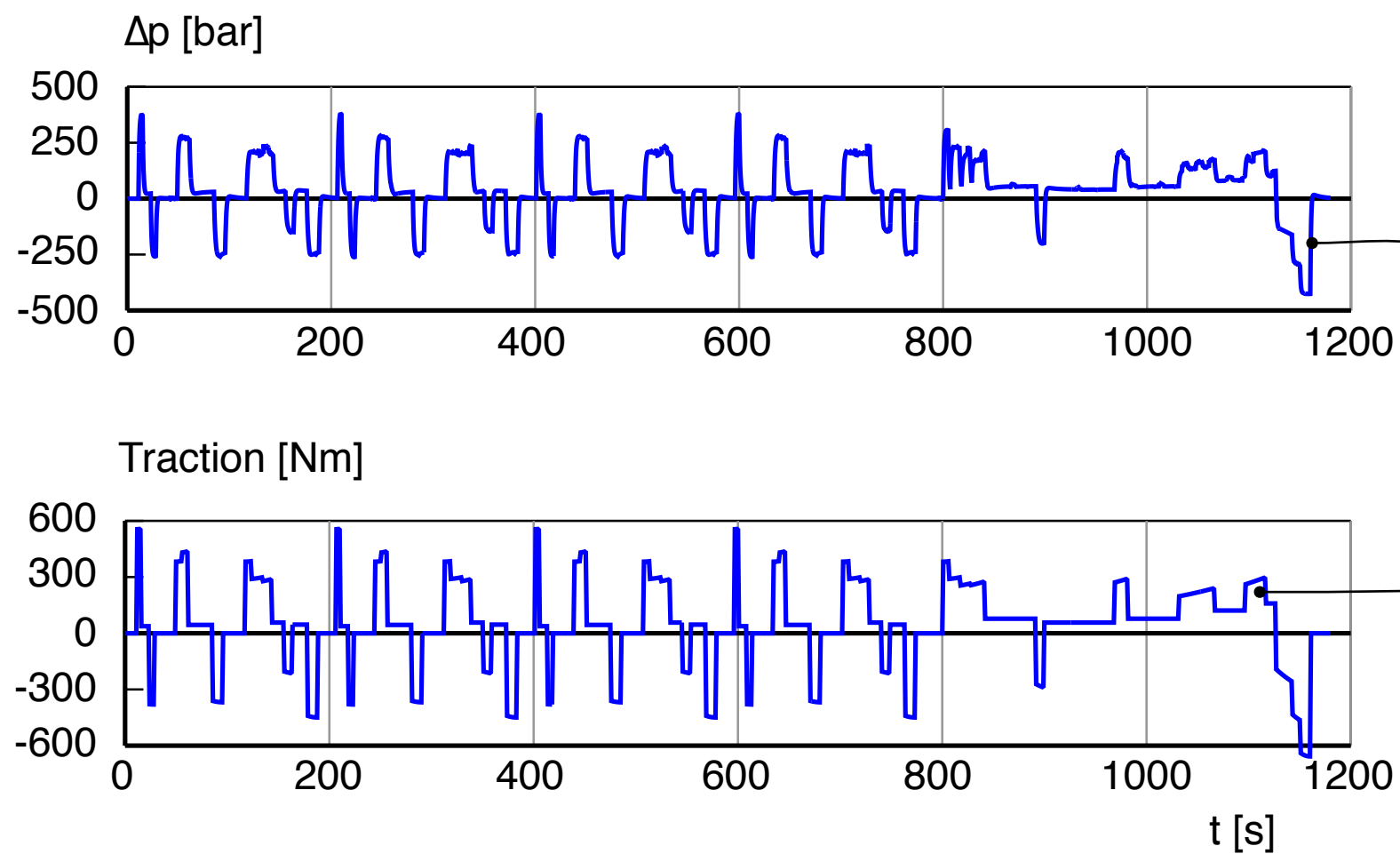
traction control



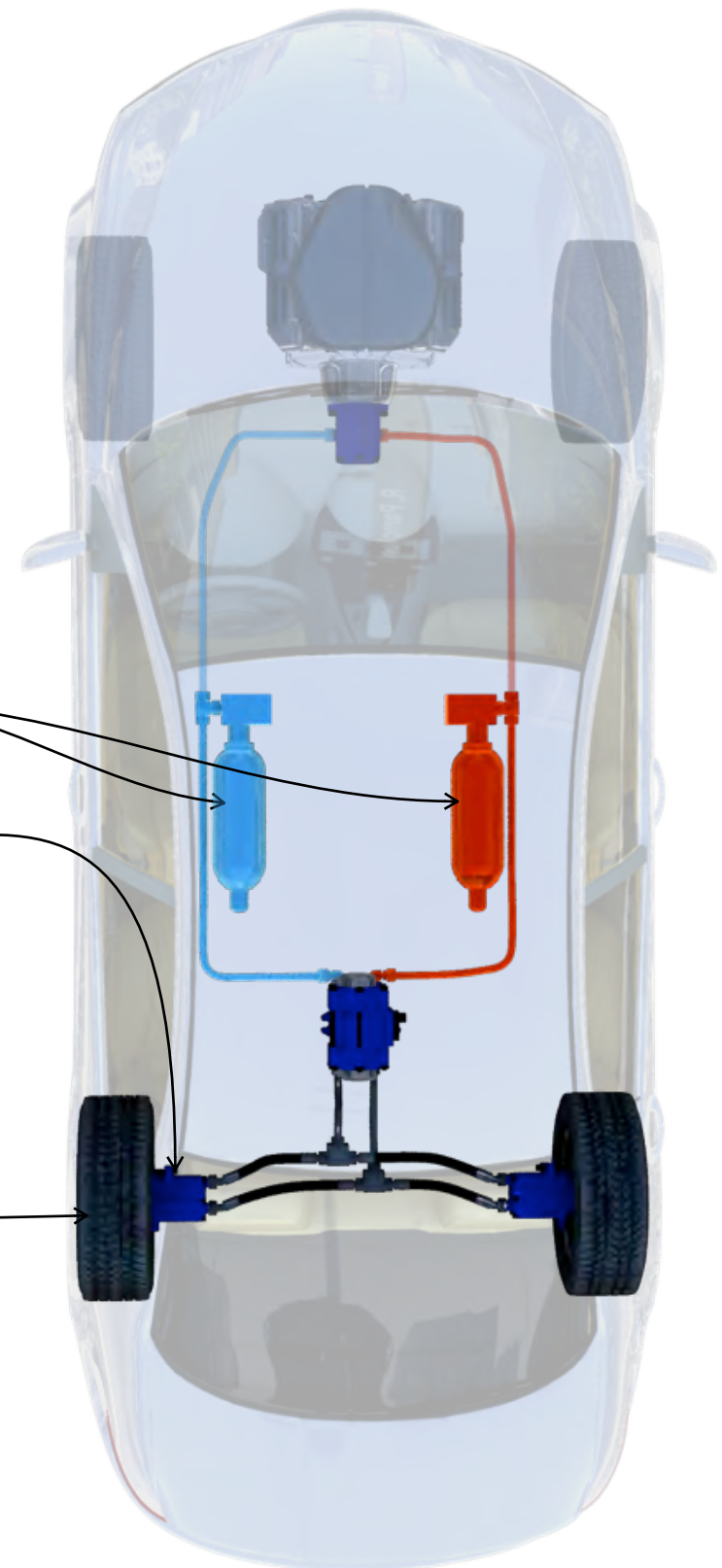
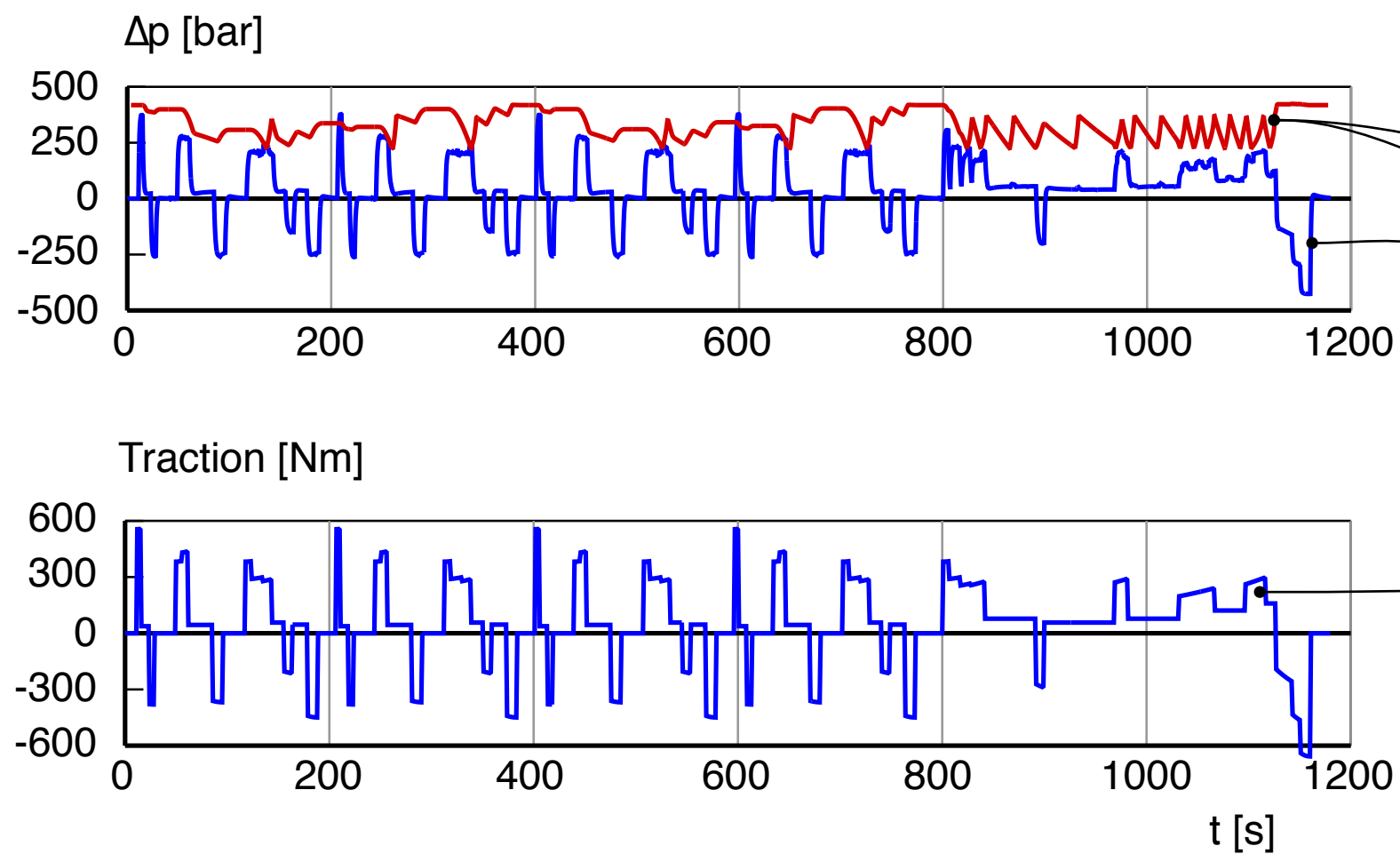
traction control



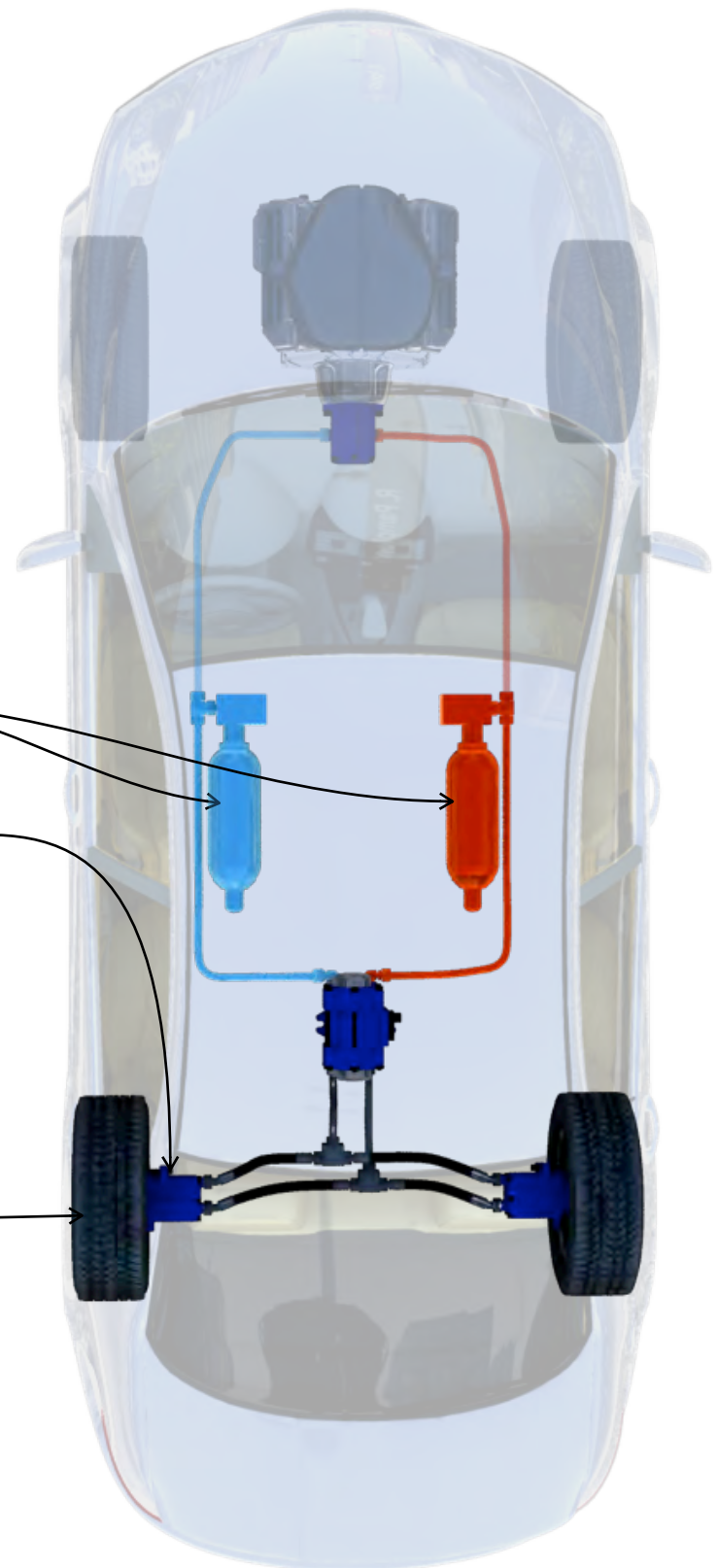
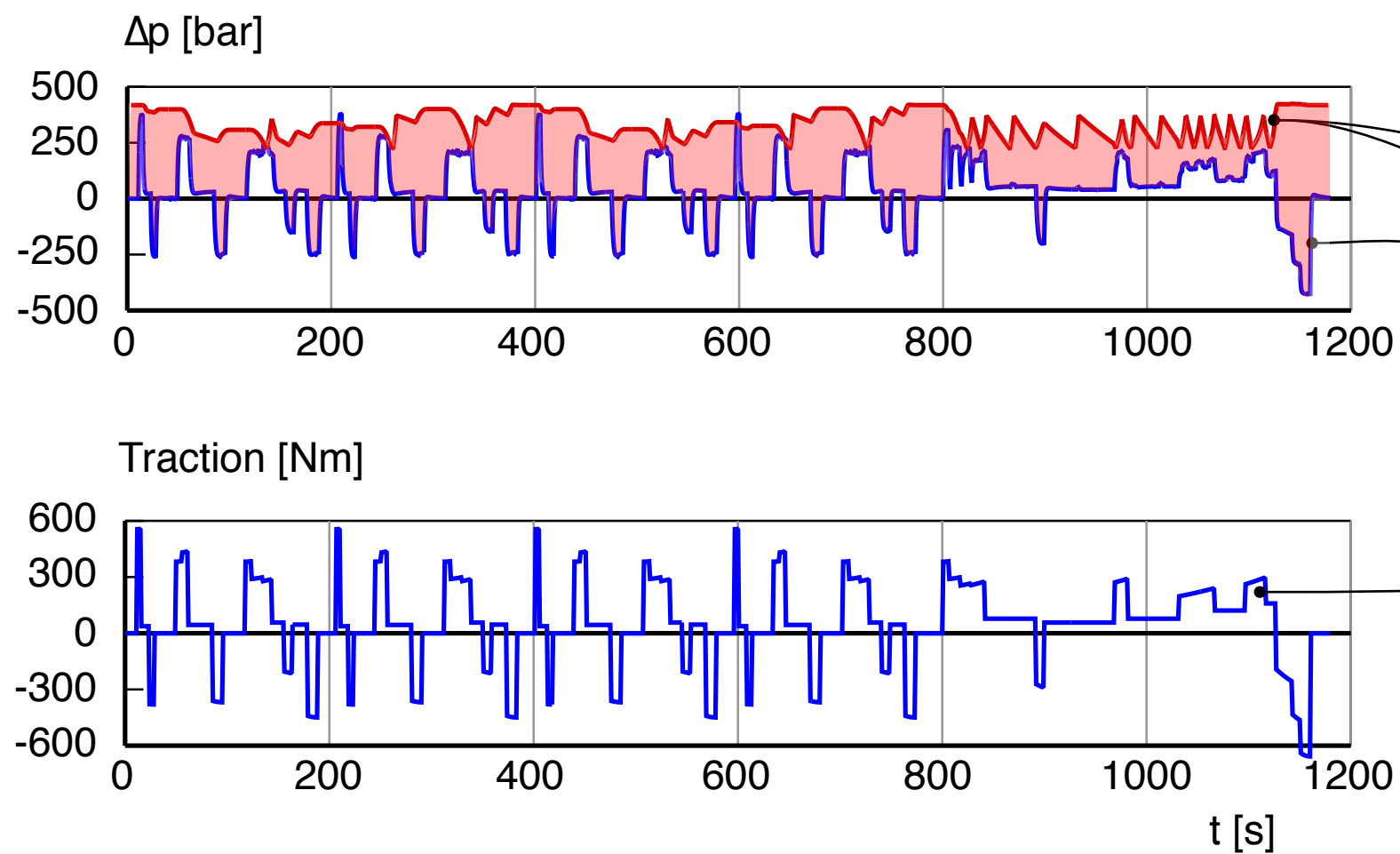
traction control



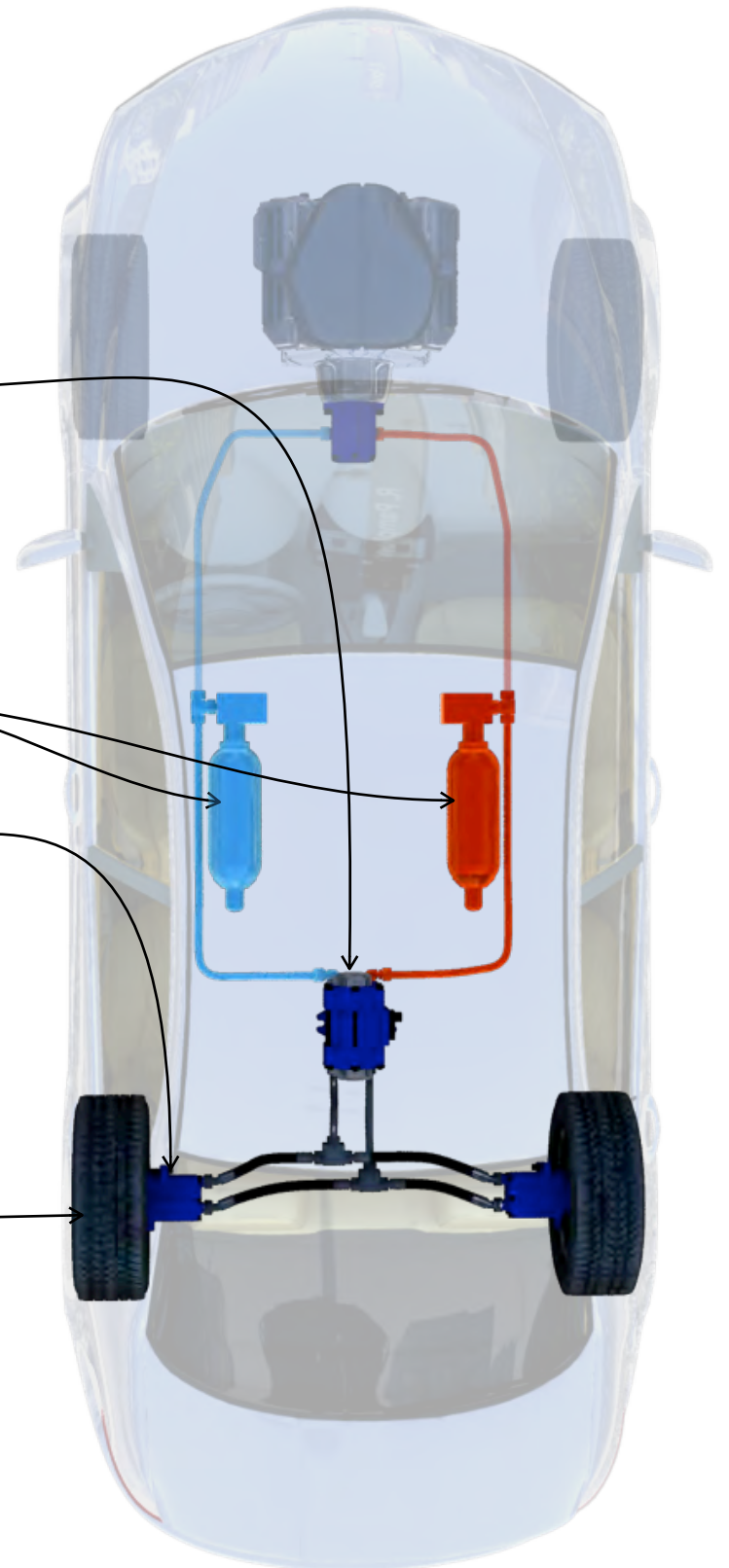
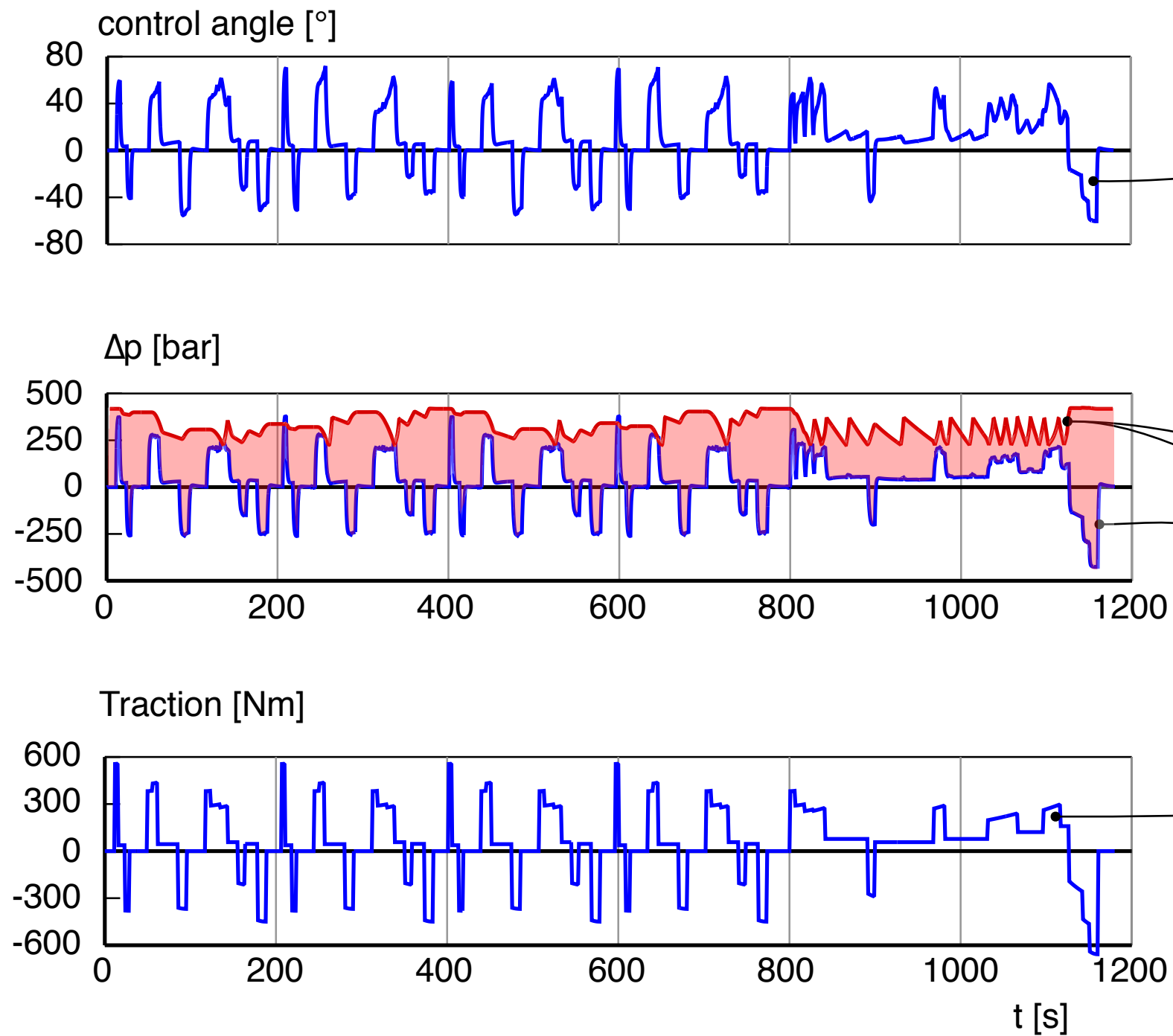
traction control



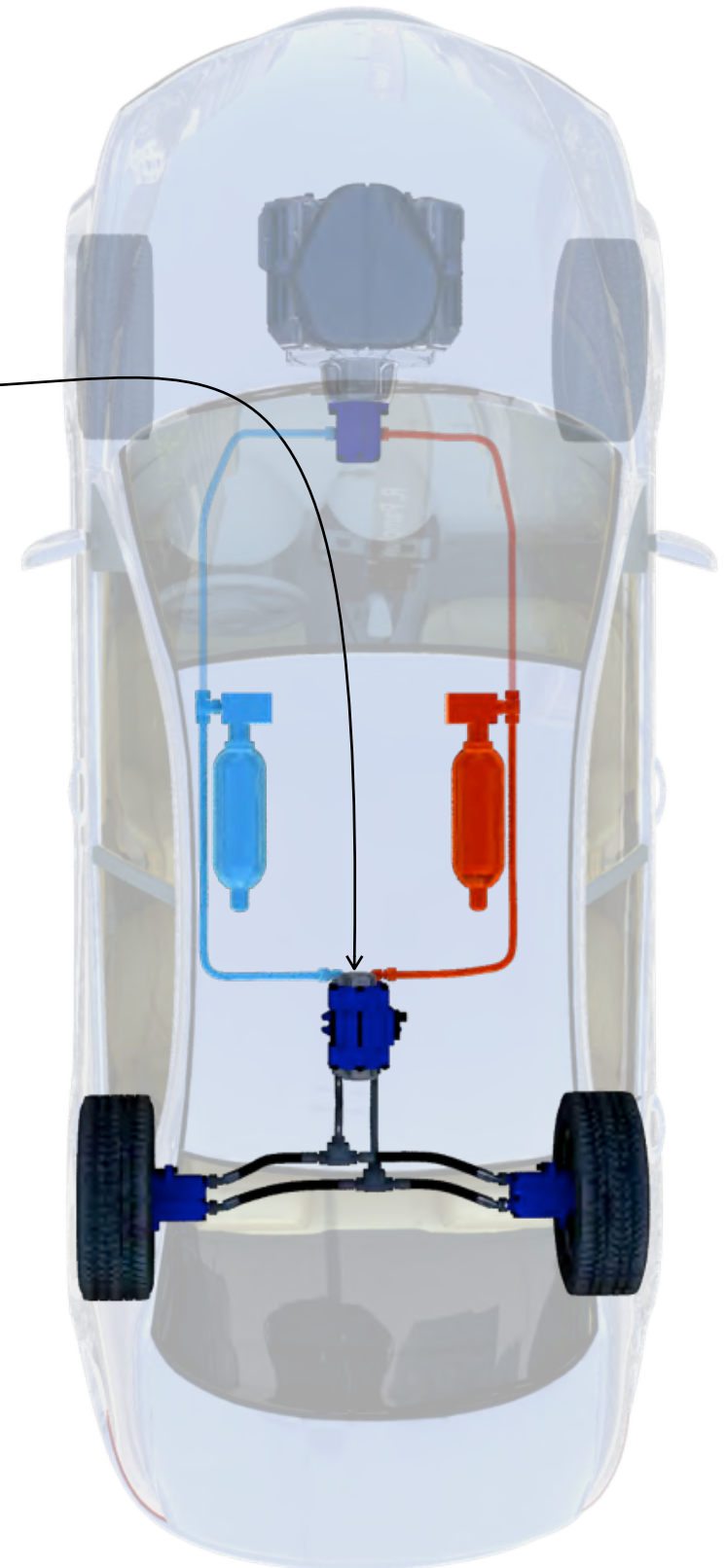
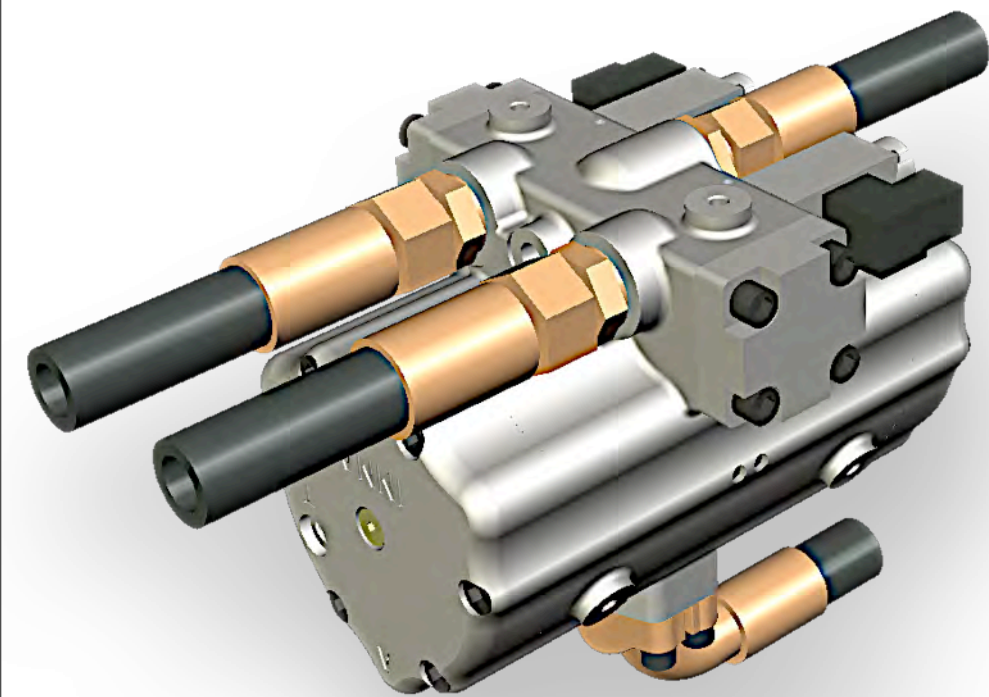
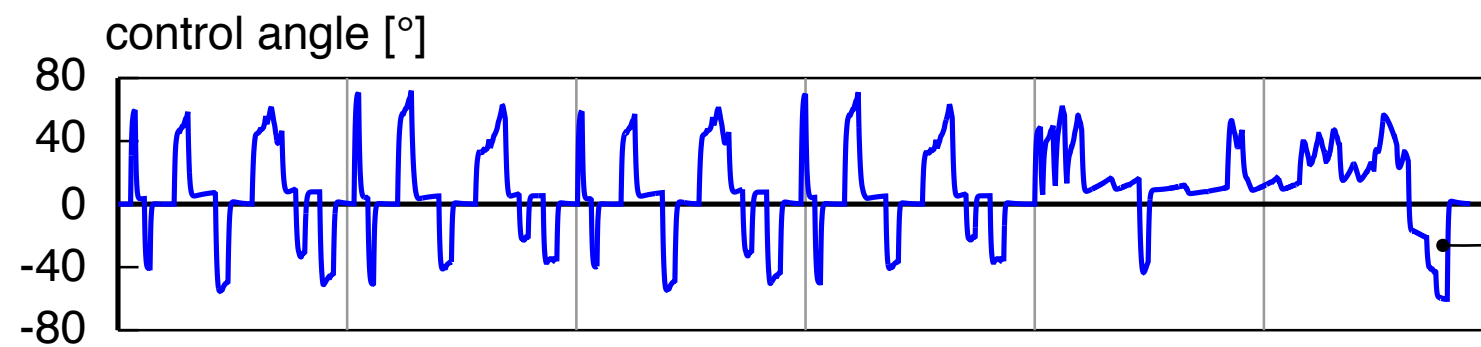
traction control



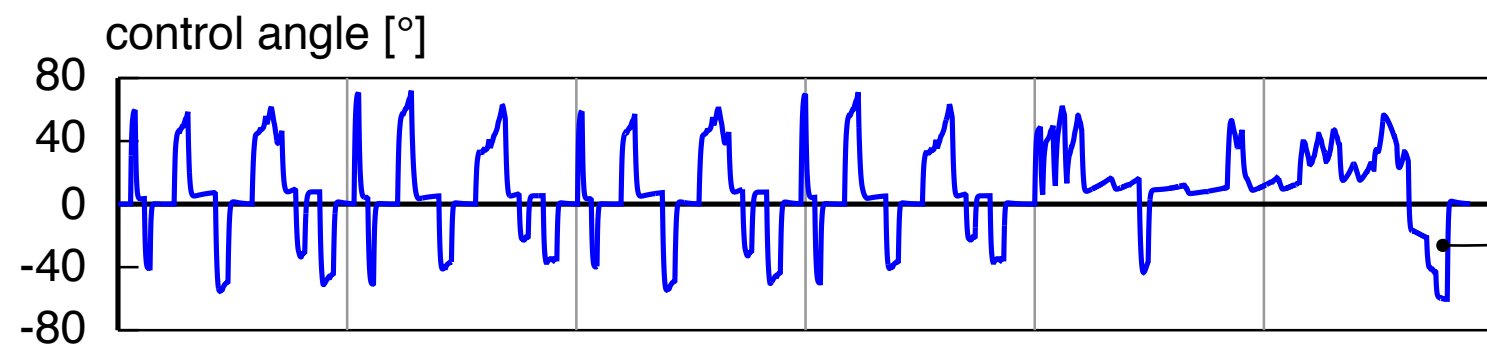
traction control



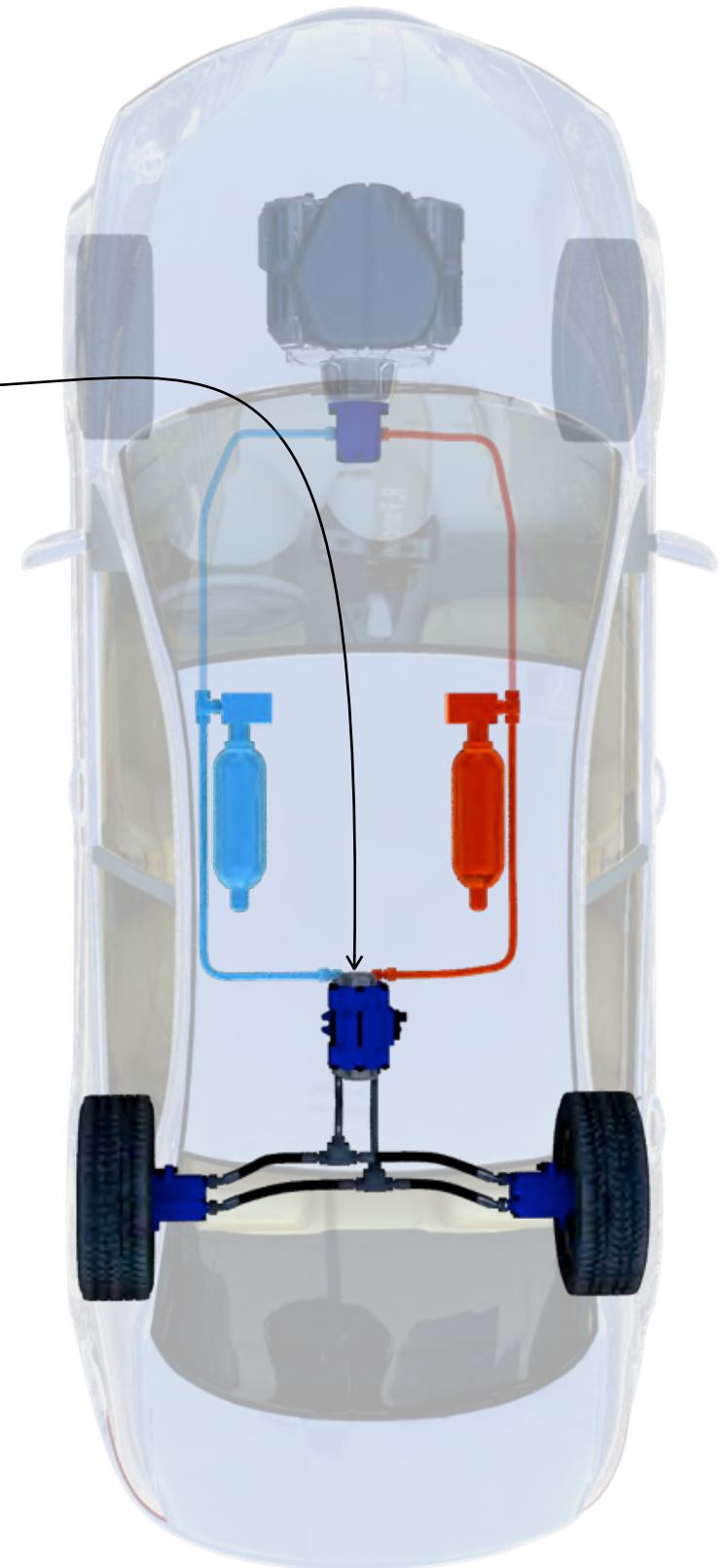
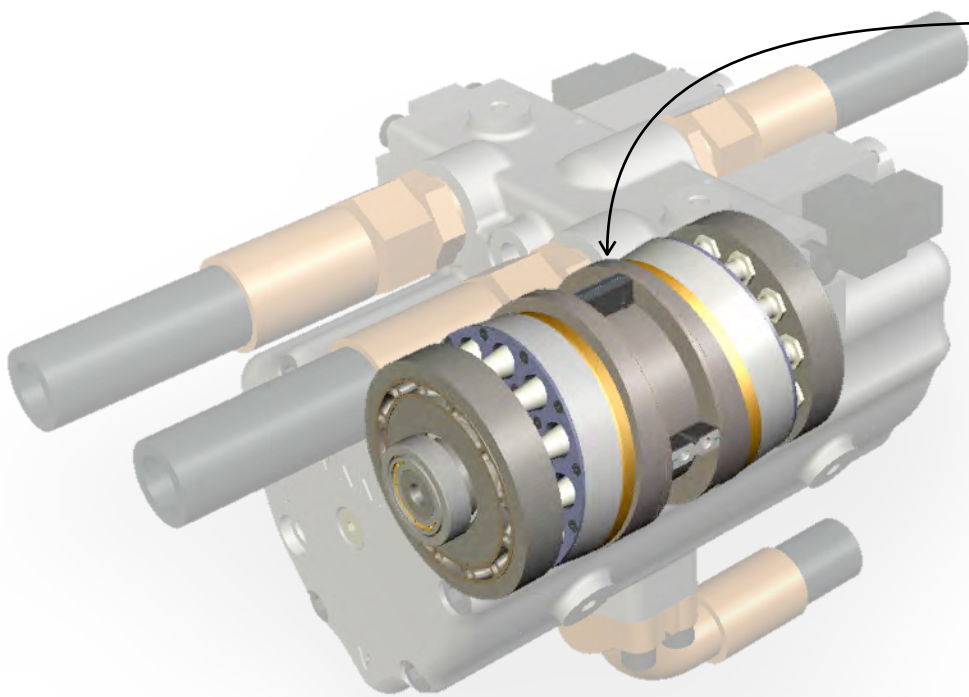
traction control



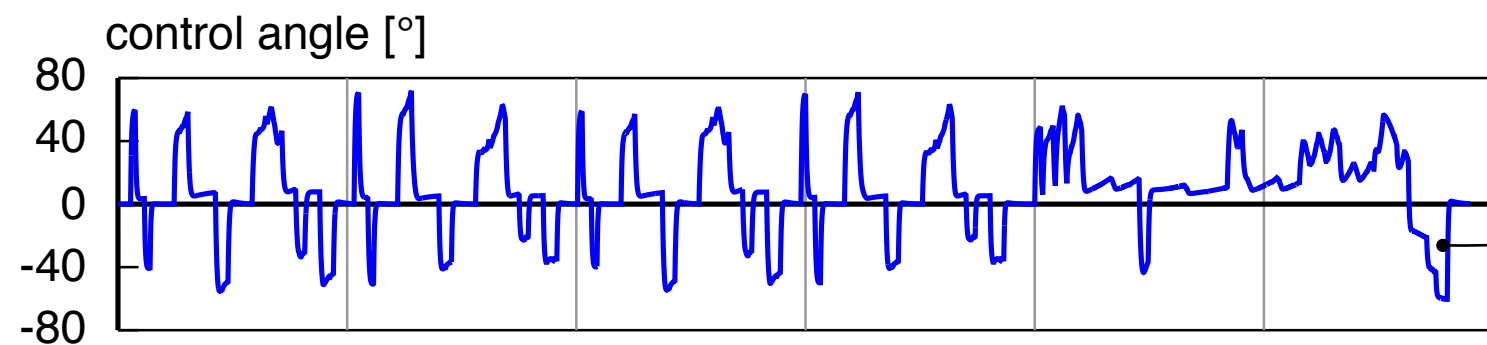
traction control



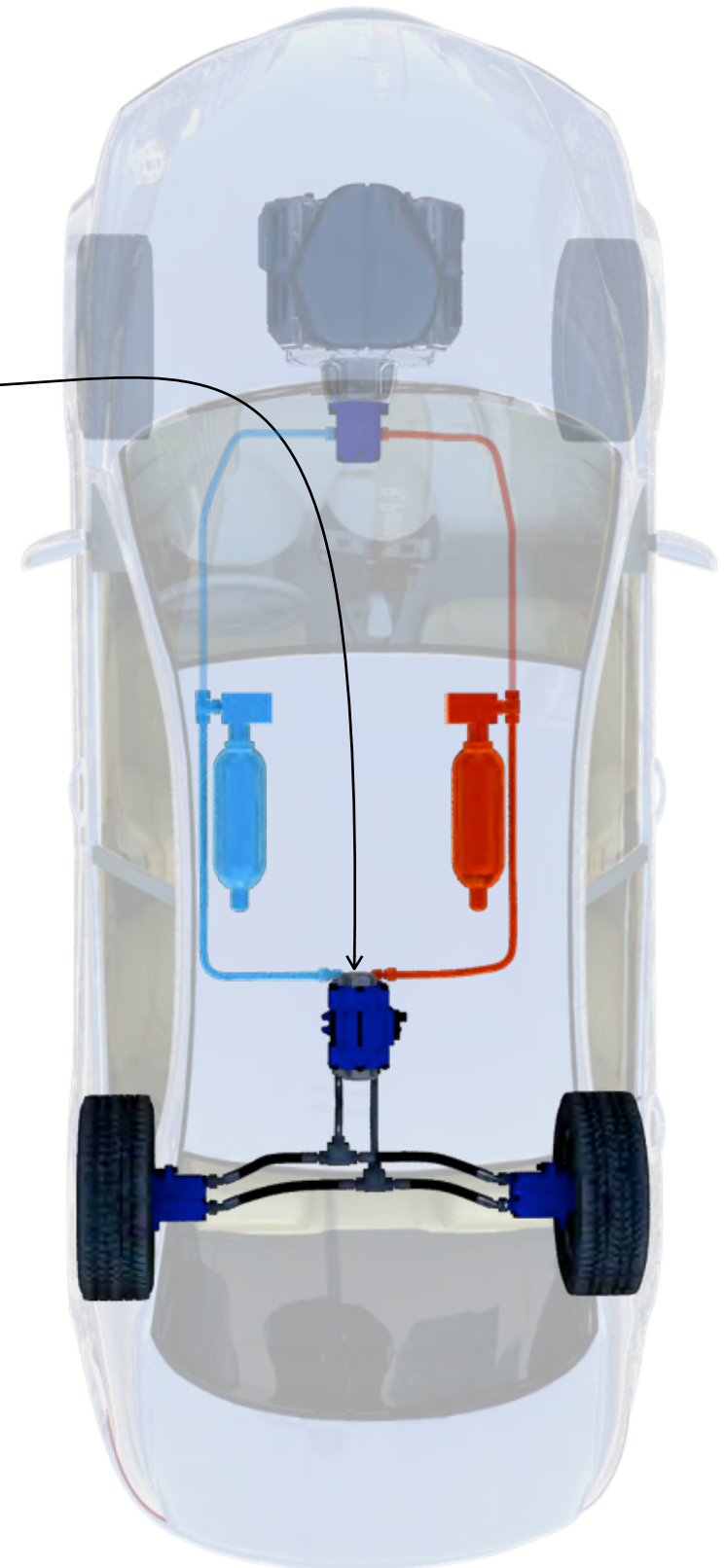
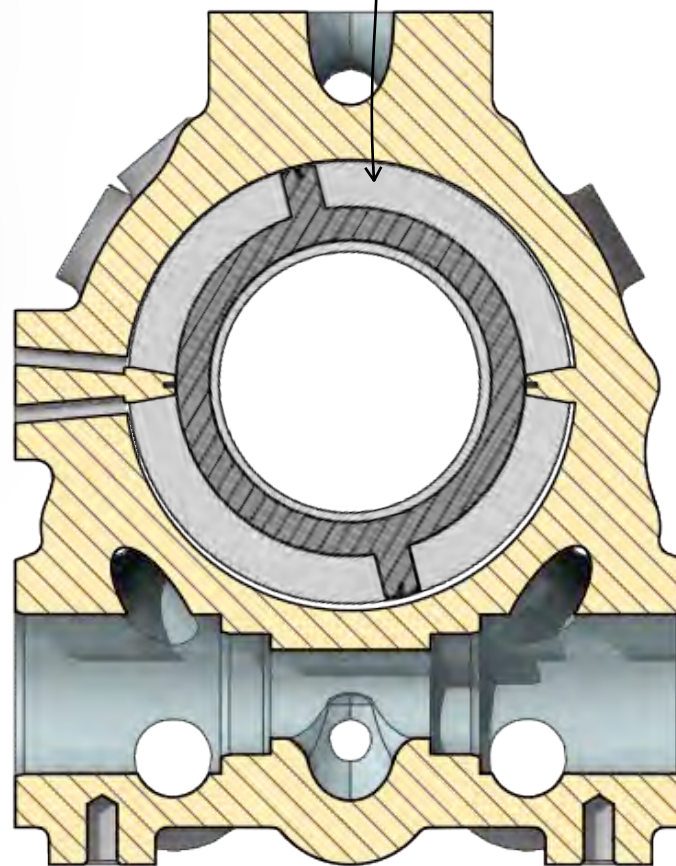
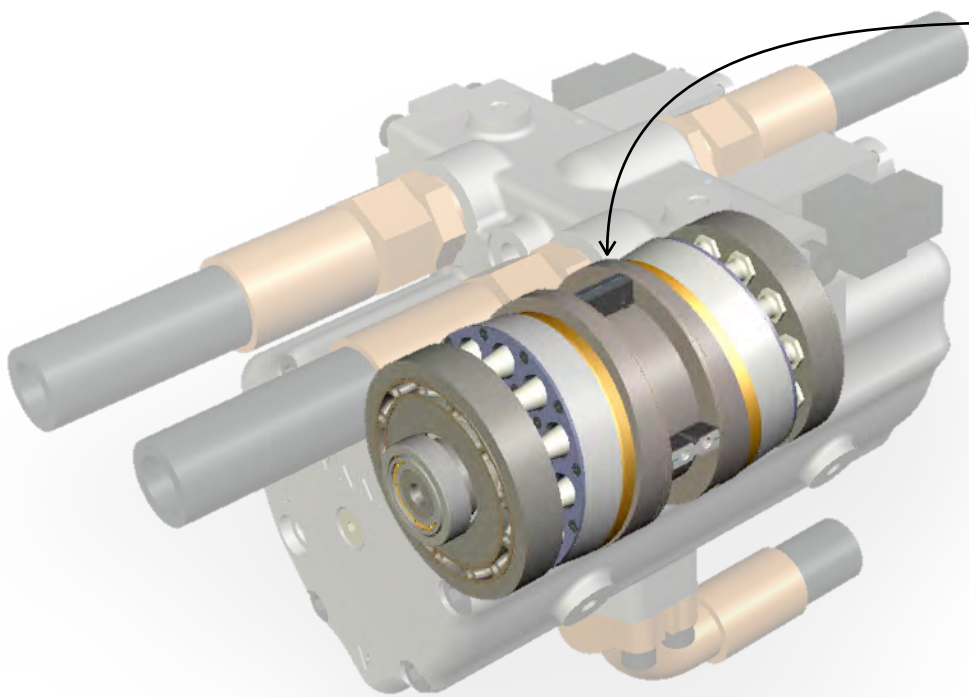
rotating swash block



traction control

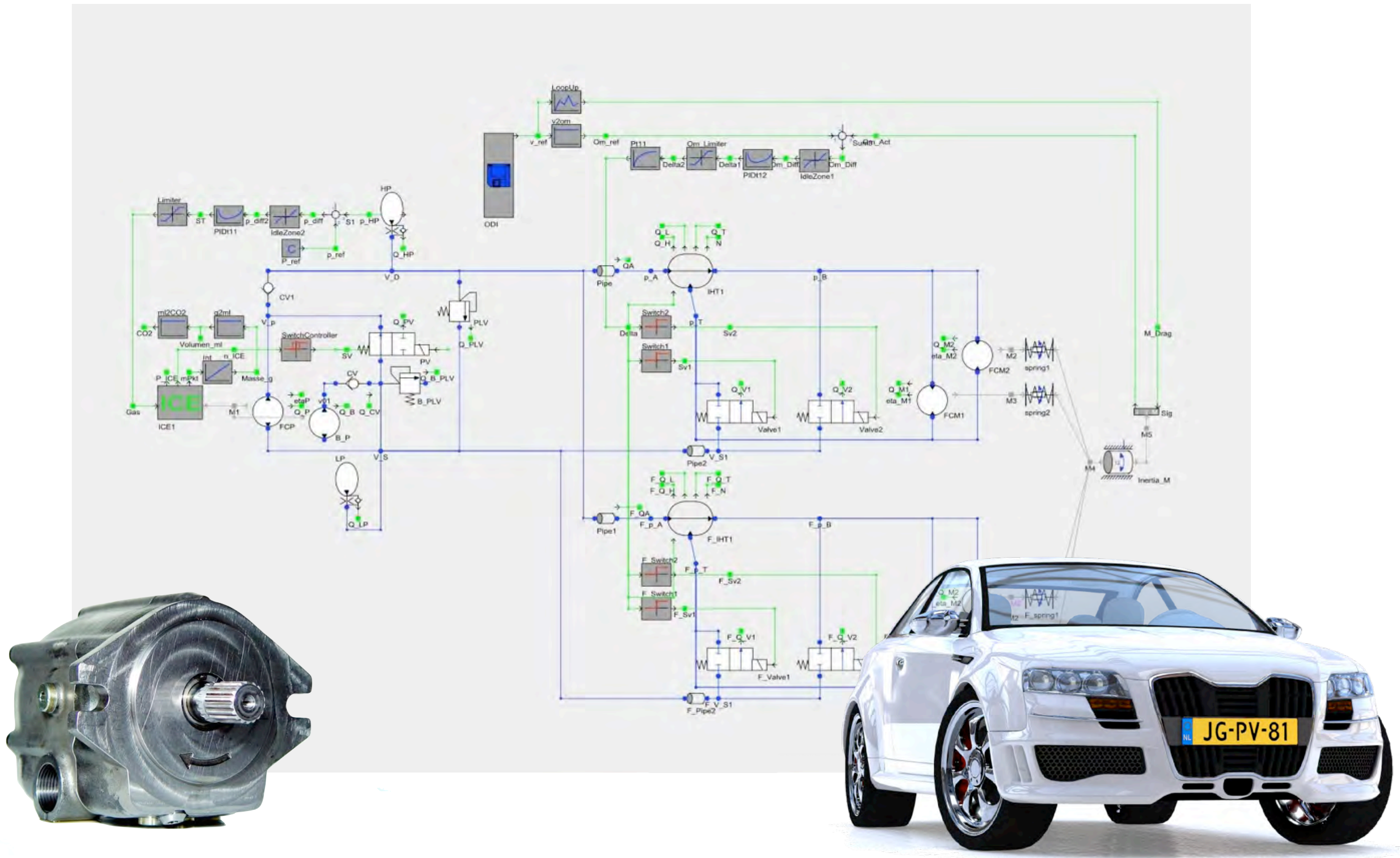


rotating swash block



Fuel consumption, CO₂-emissions and acceleration performance

IFAS-study



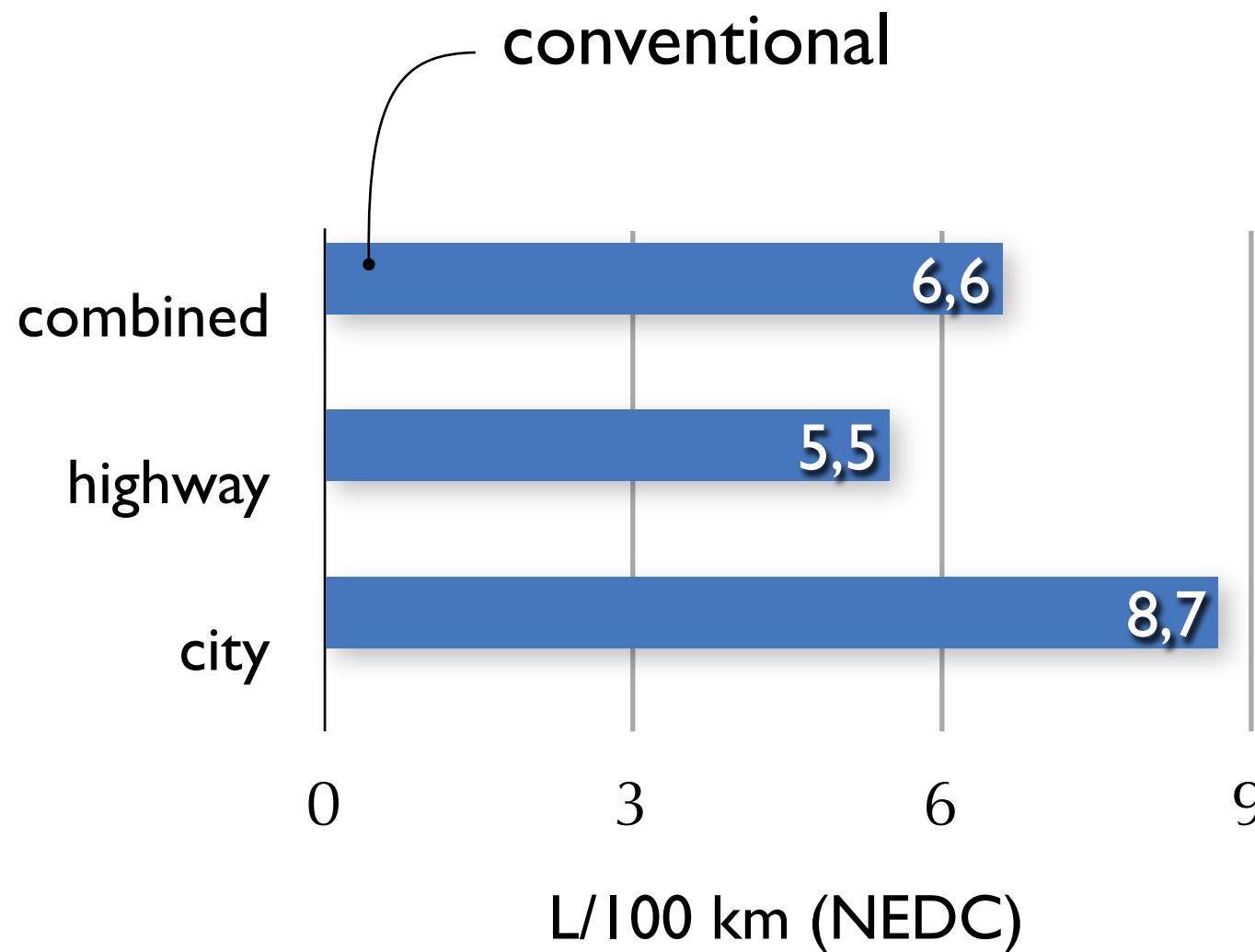
the Hydrid

fuel consumption



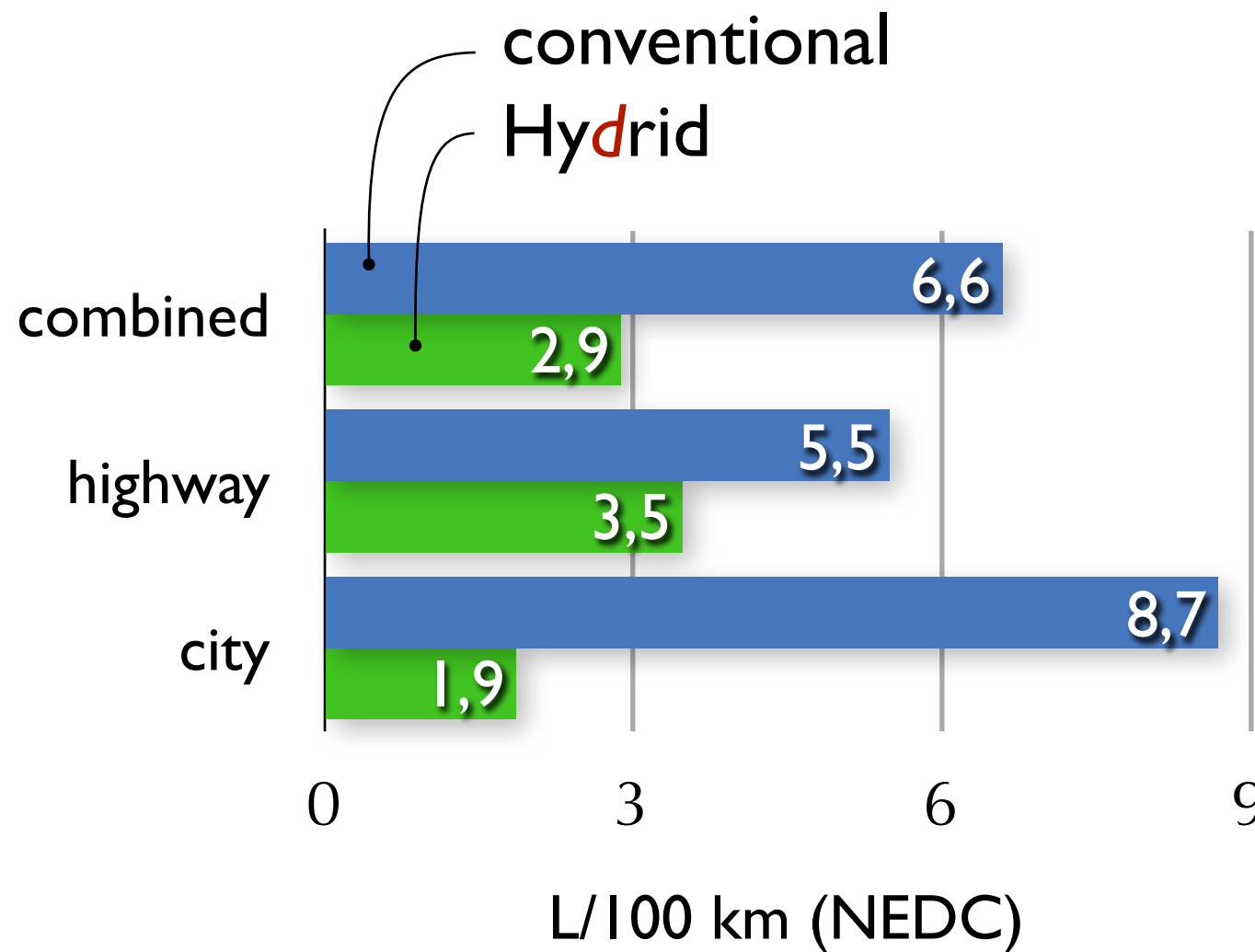
the Hydr**i**d

fuel consumption



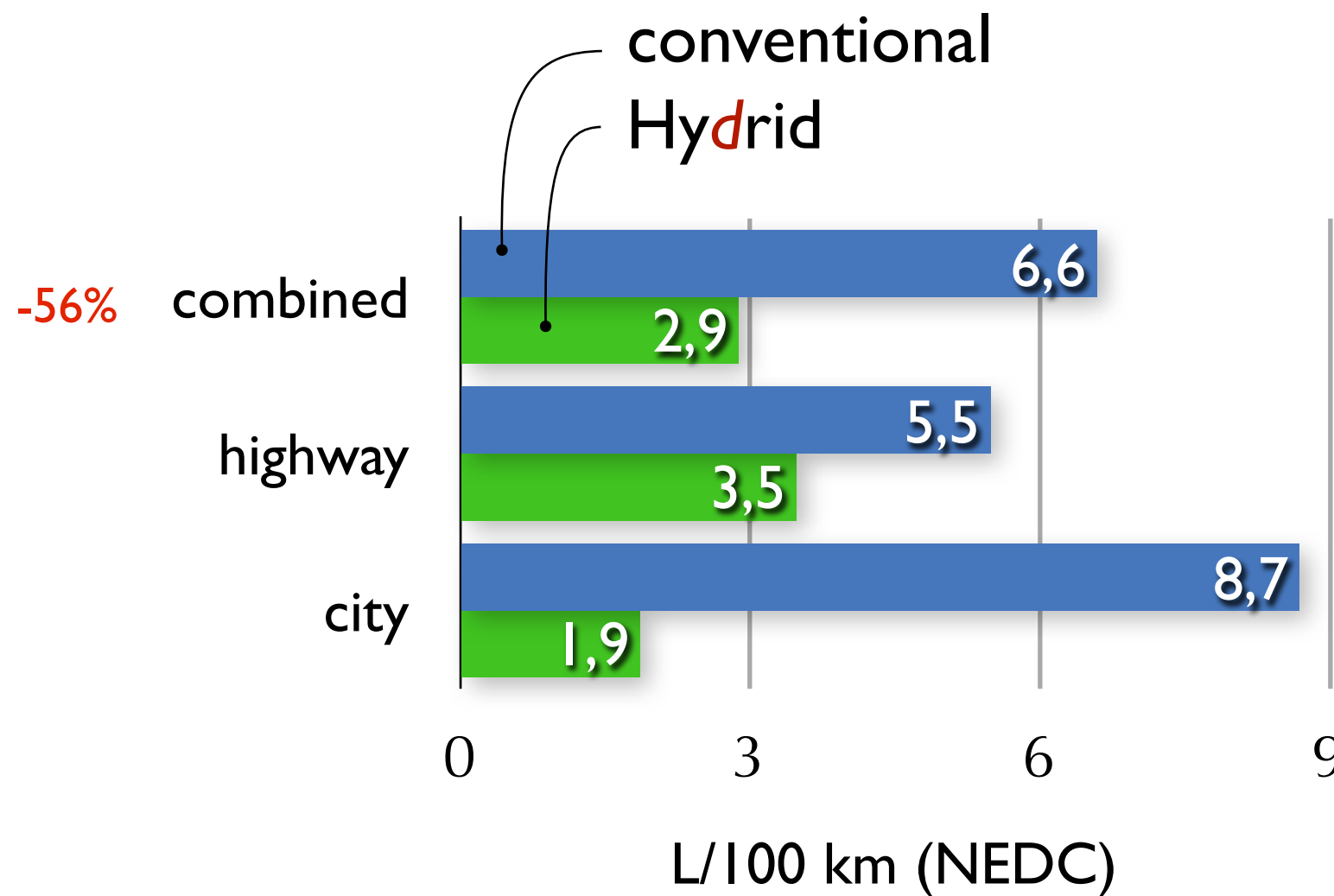
the Hydr**i**d

fuel consumption



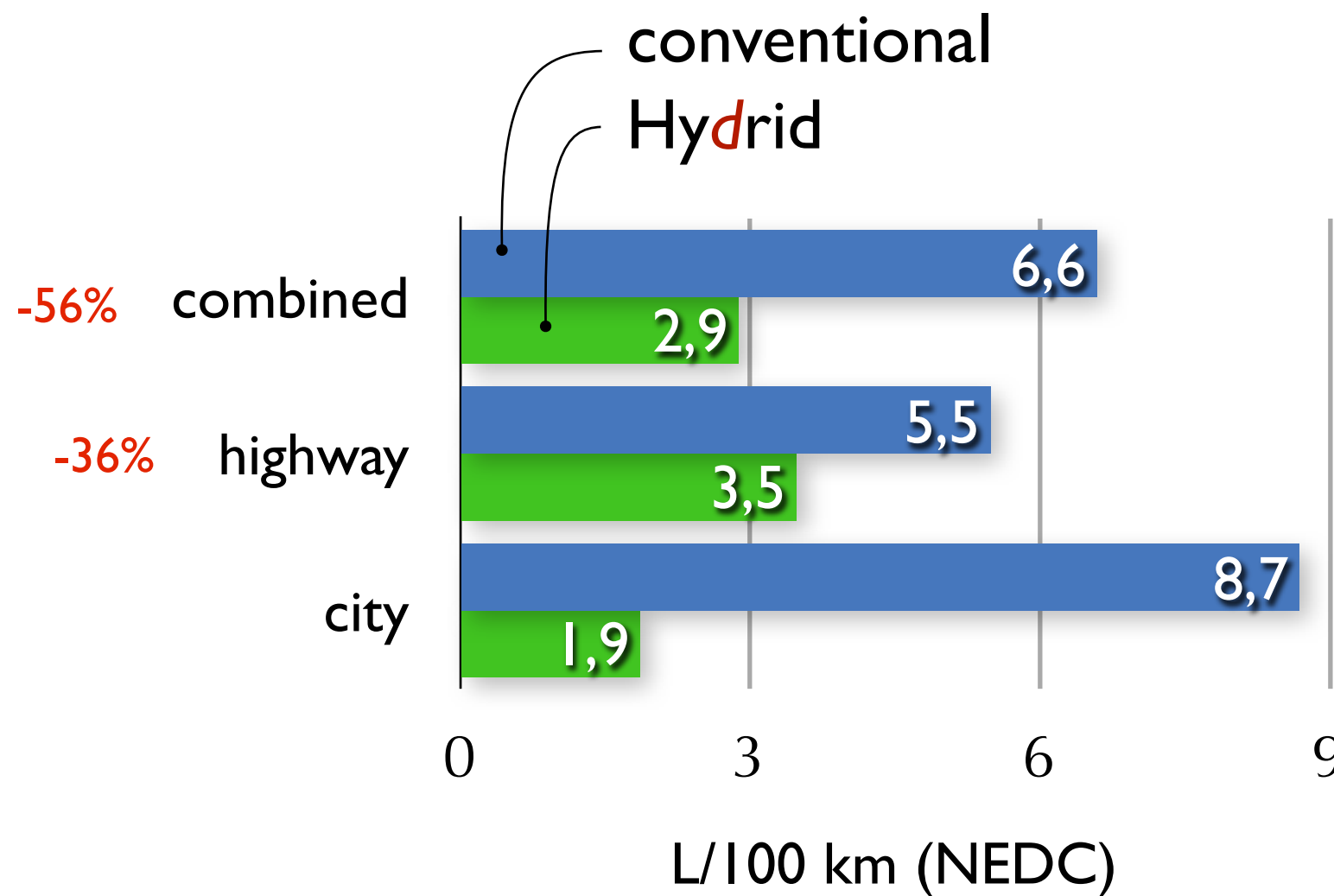
the Hydr**i**d

fuel consumption



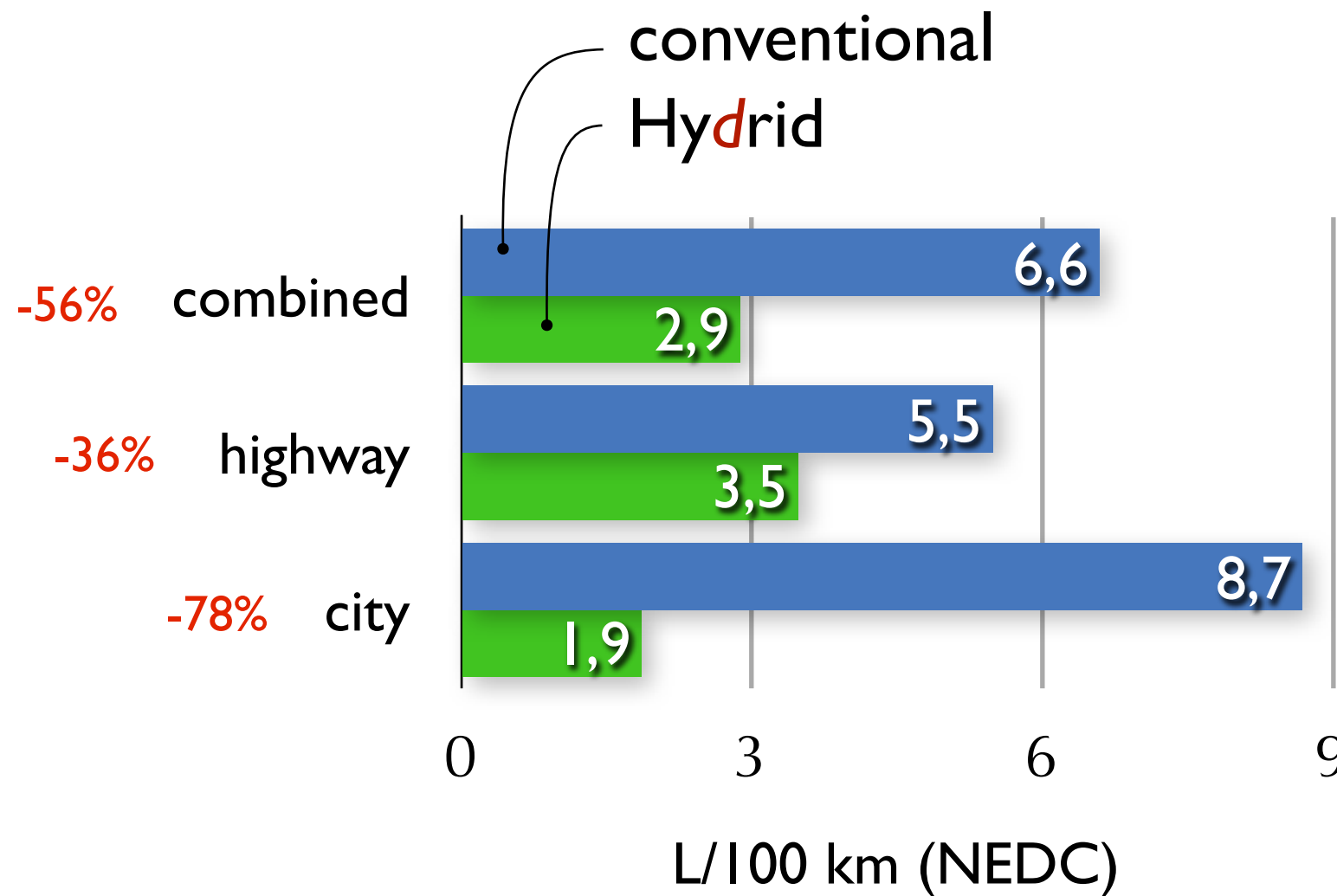
the Hydr**i**d

fuel consumption



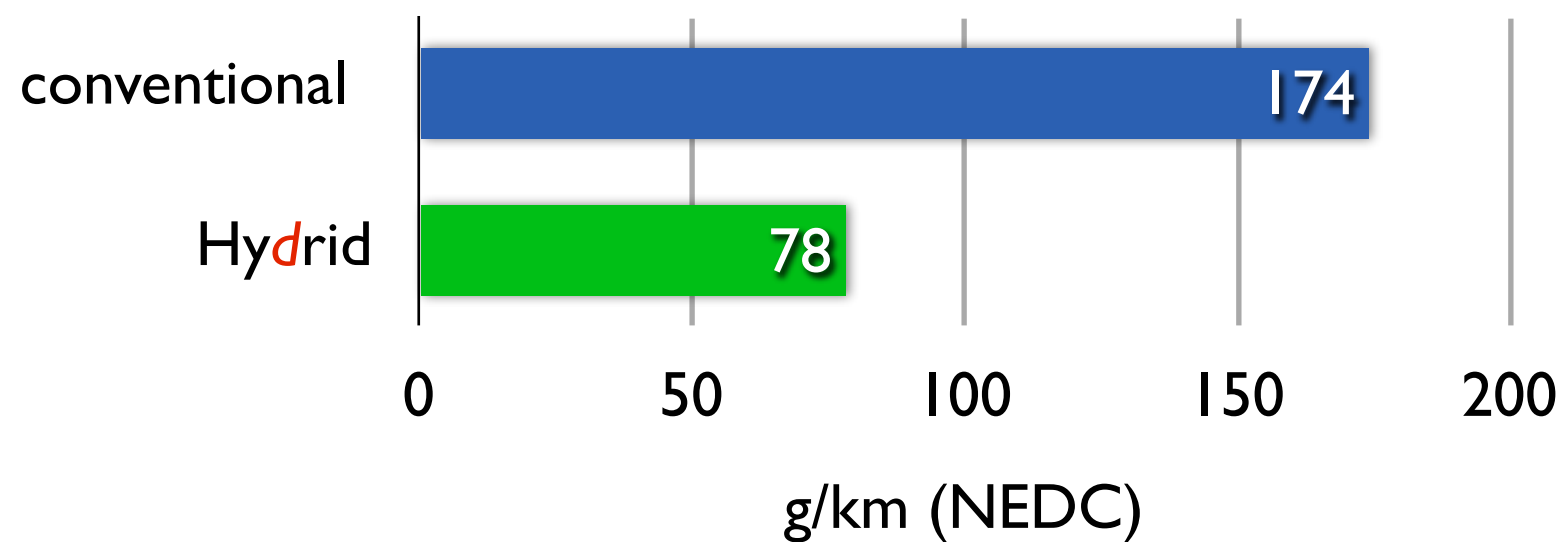
the Hydr**i**d

fuel consumption



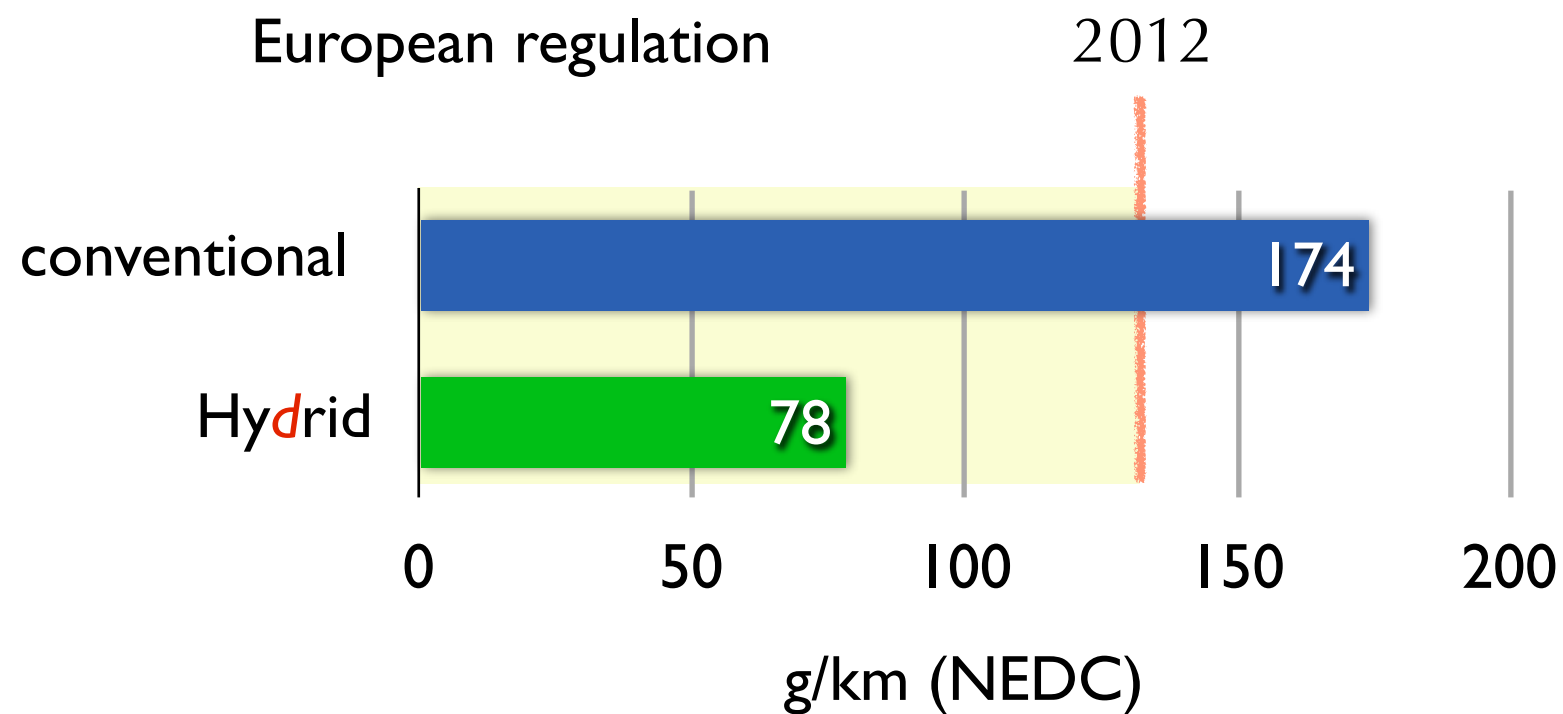
the Hydr**i**d

CO₂ emissions:



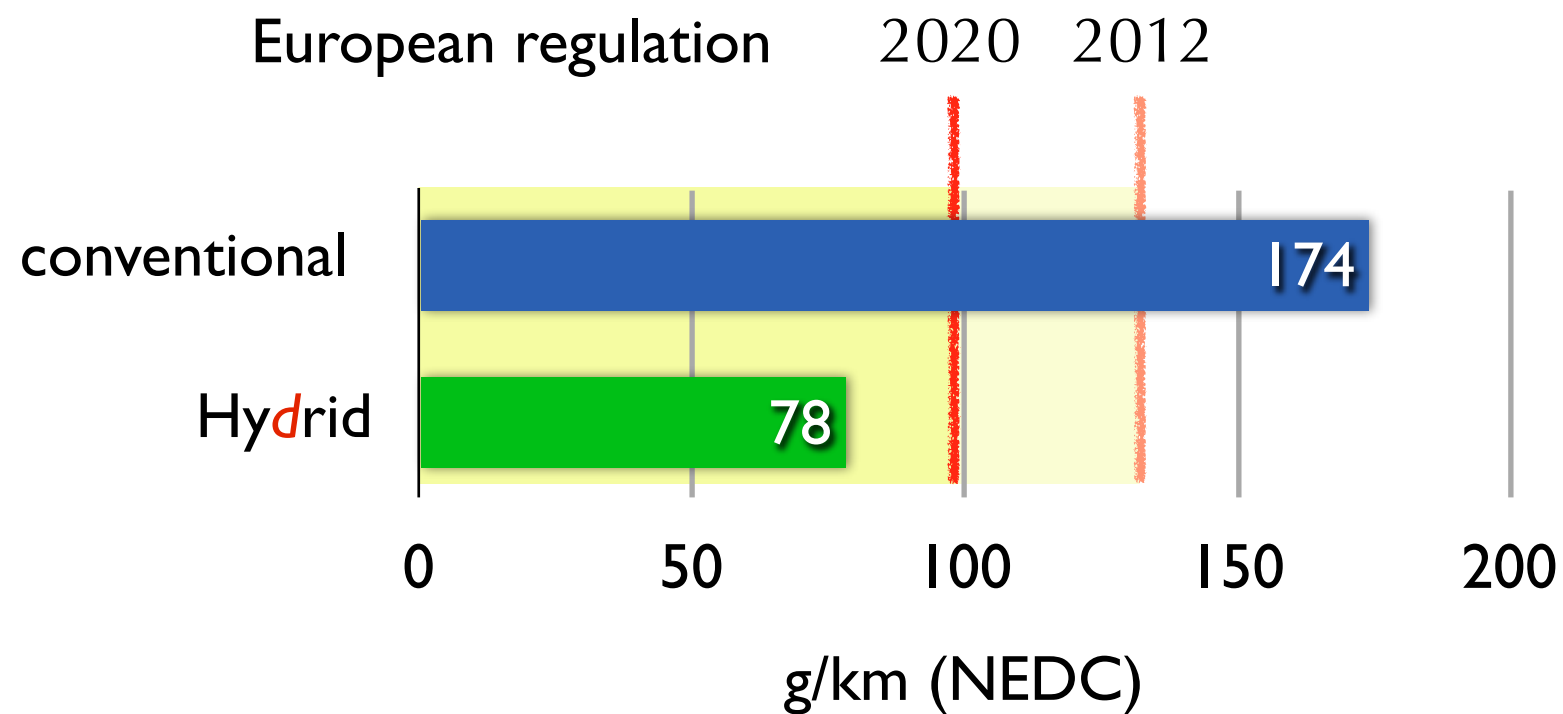
the Hydr**i**d

CO₂ emissions:



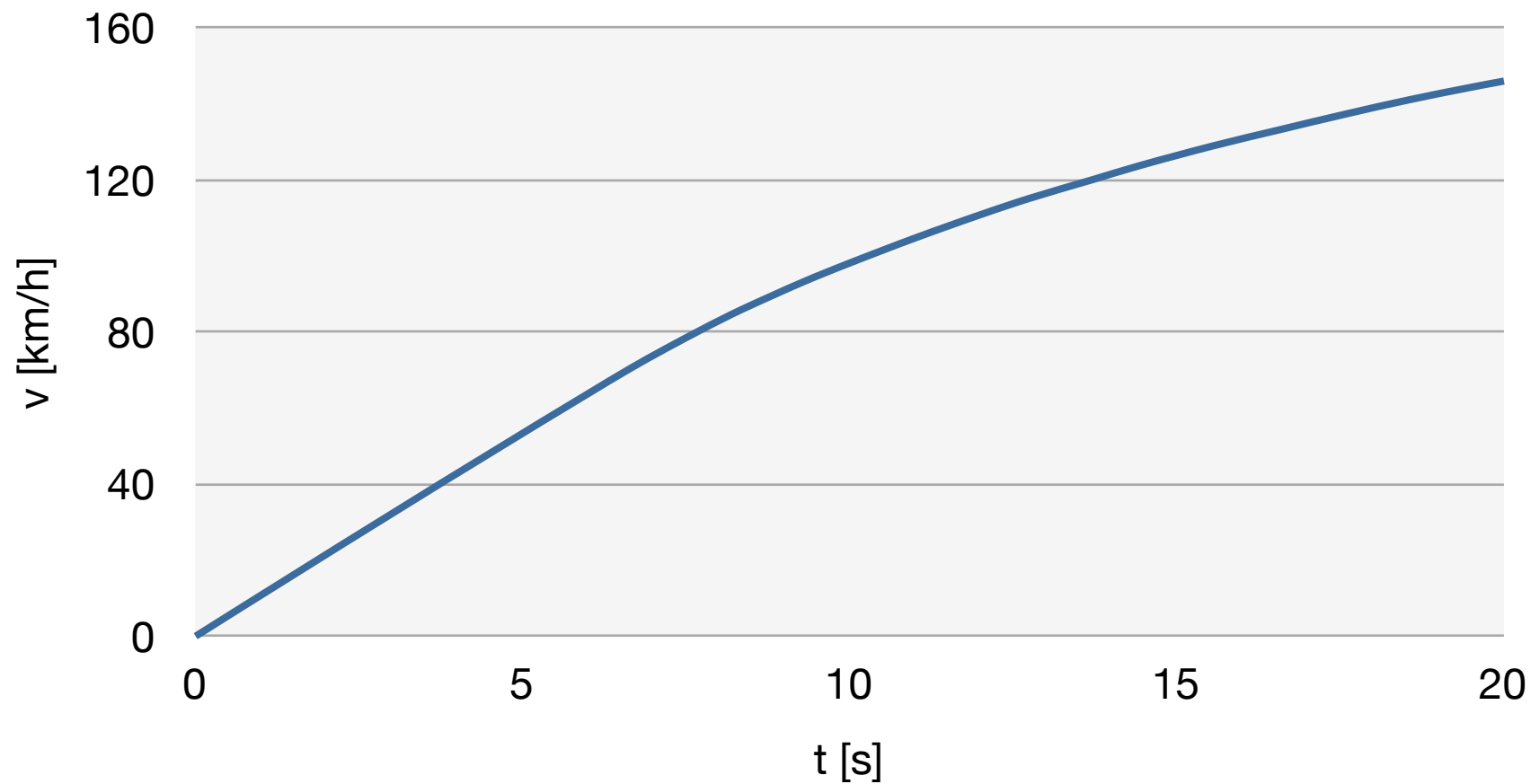
the Hydr**i**d

CO₂ emissions:



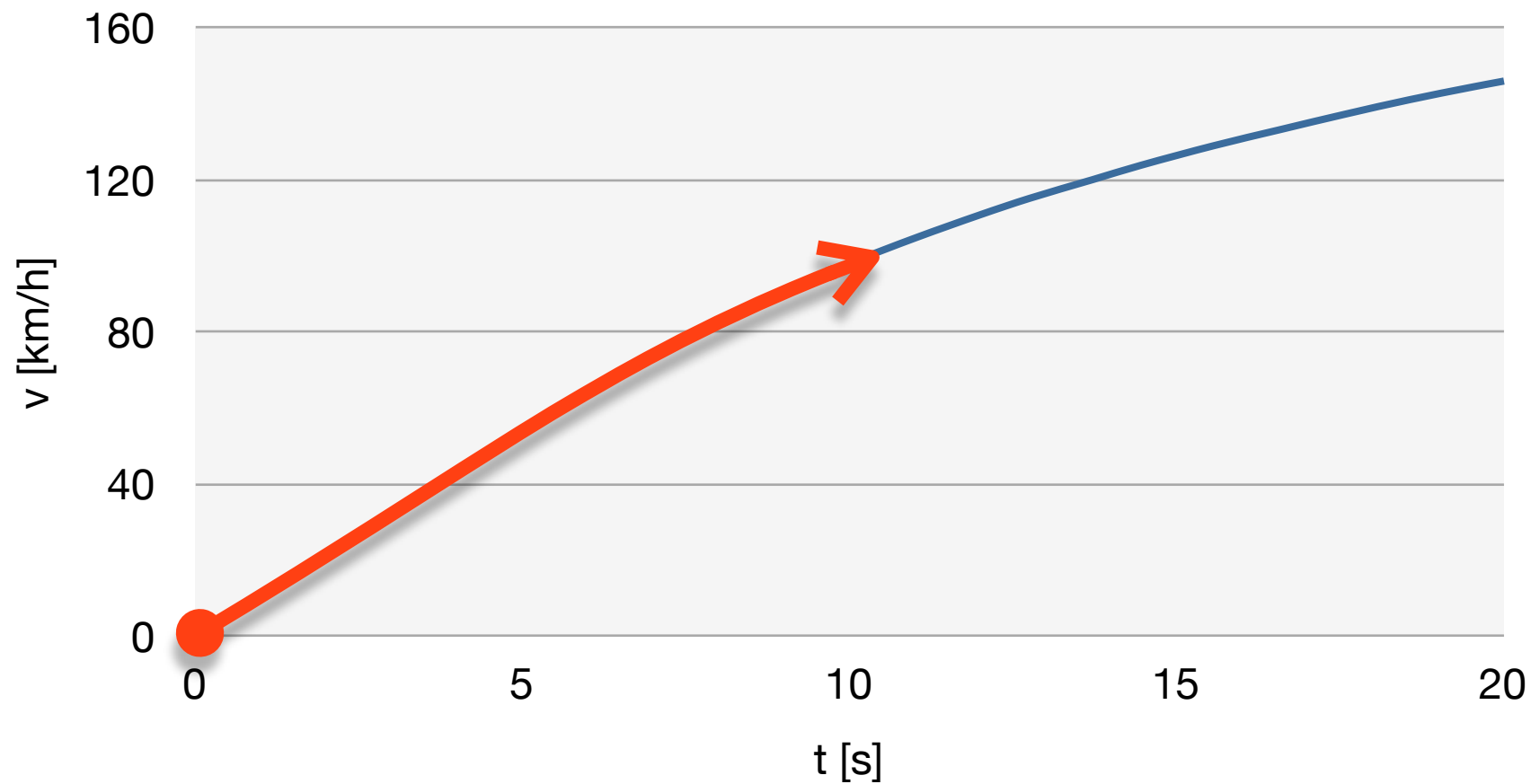
the Hydrid

acceleration performance:



the Hydr**i**d

acceleration performance:



0 □ 100 km/h

reference

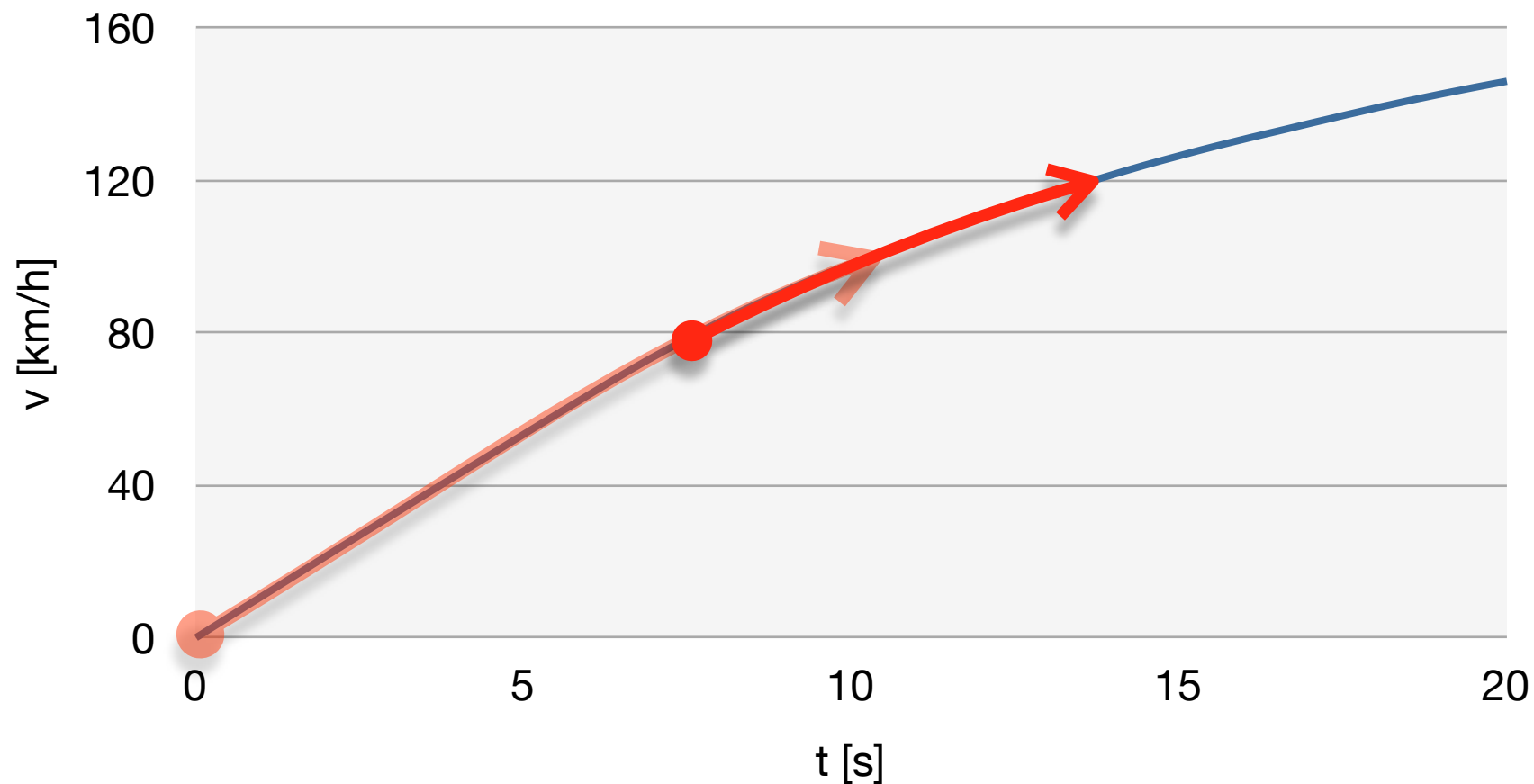
10 sec

Hydr**i**d

10 sec

the Hydr**i**d

acceleration performance:



0 □ 100 km/h 80 □ 120 km/h

reference

10 sec

13 sec

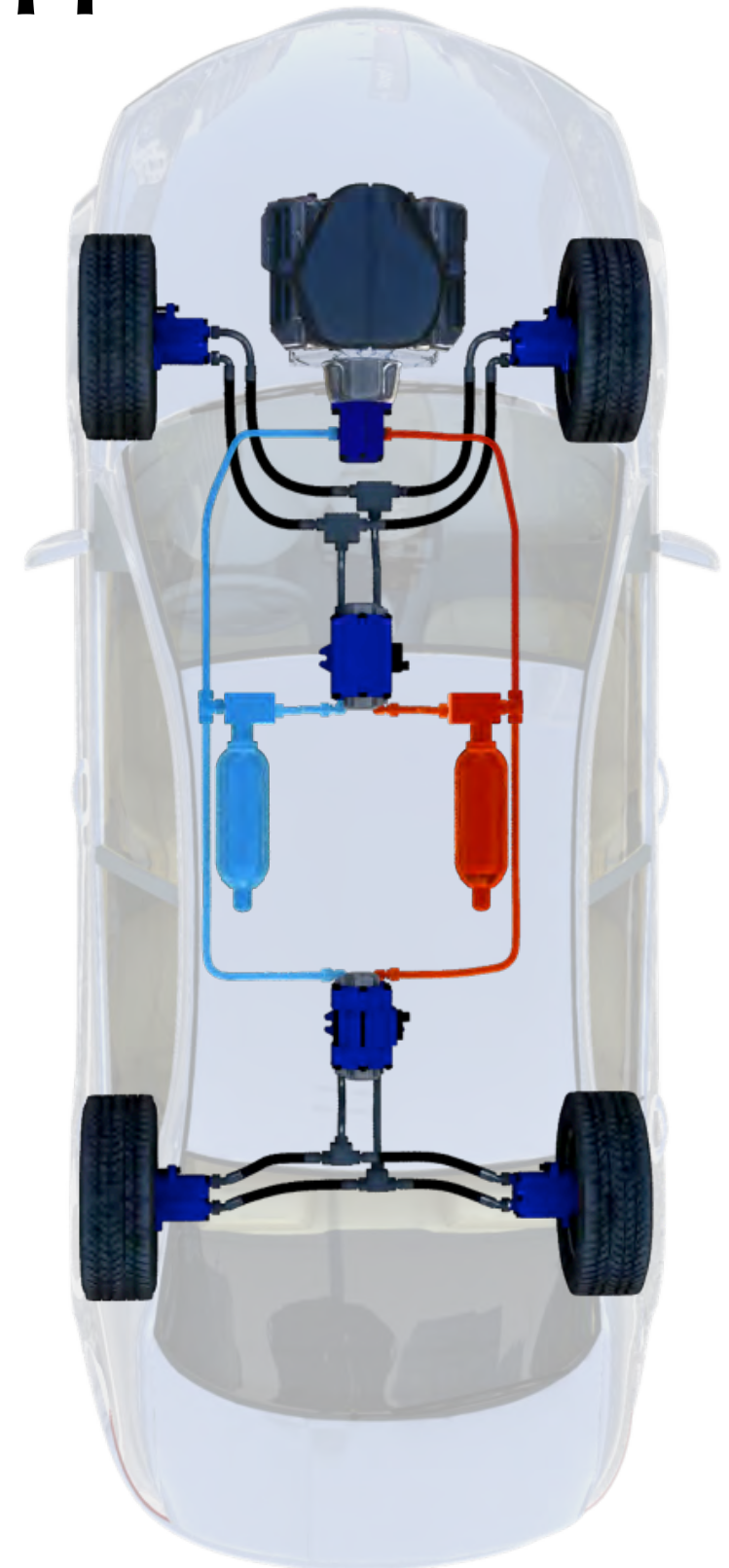
Hydr**i**d

10 sec

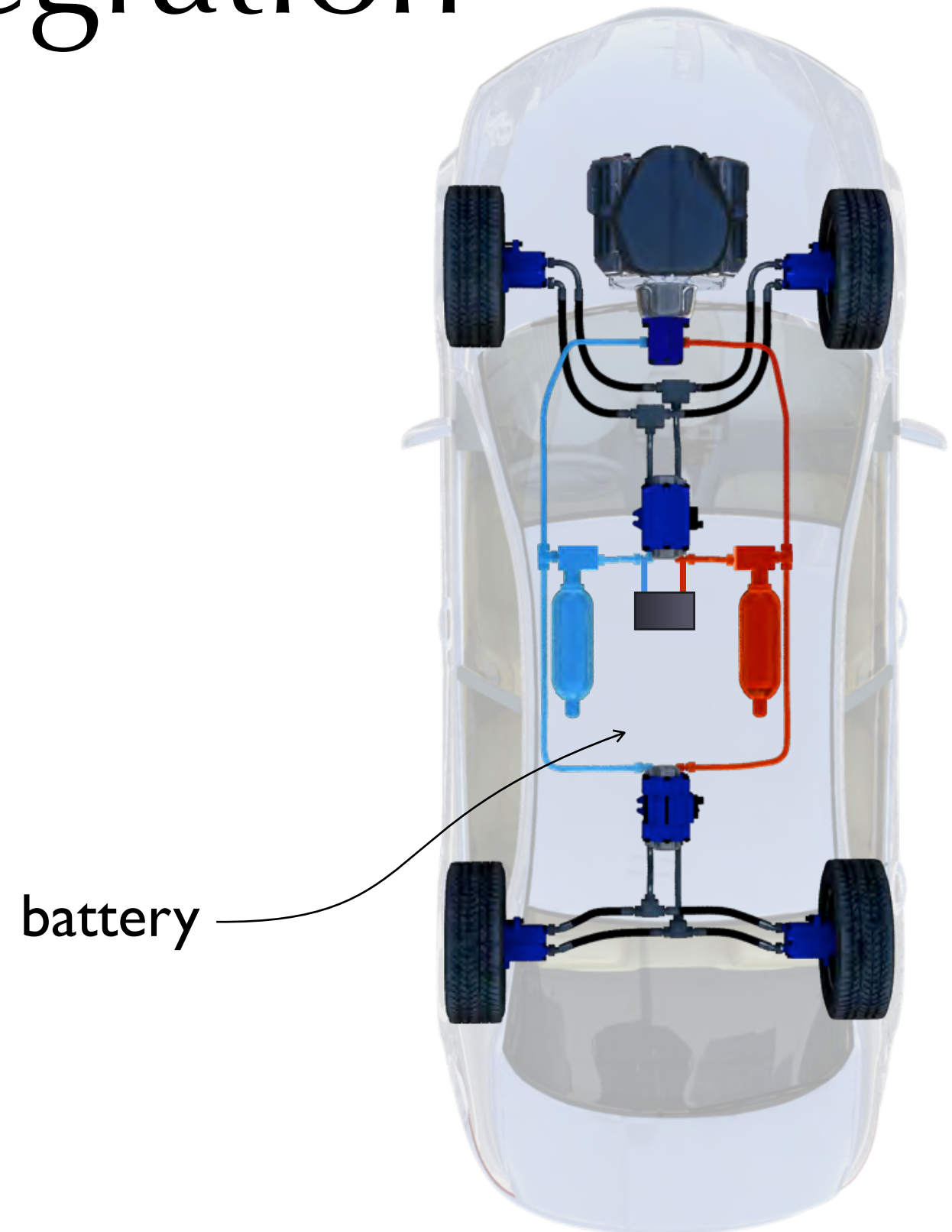
6 sec

the end of the battery?

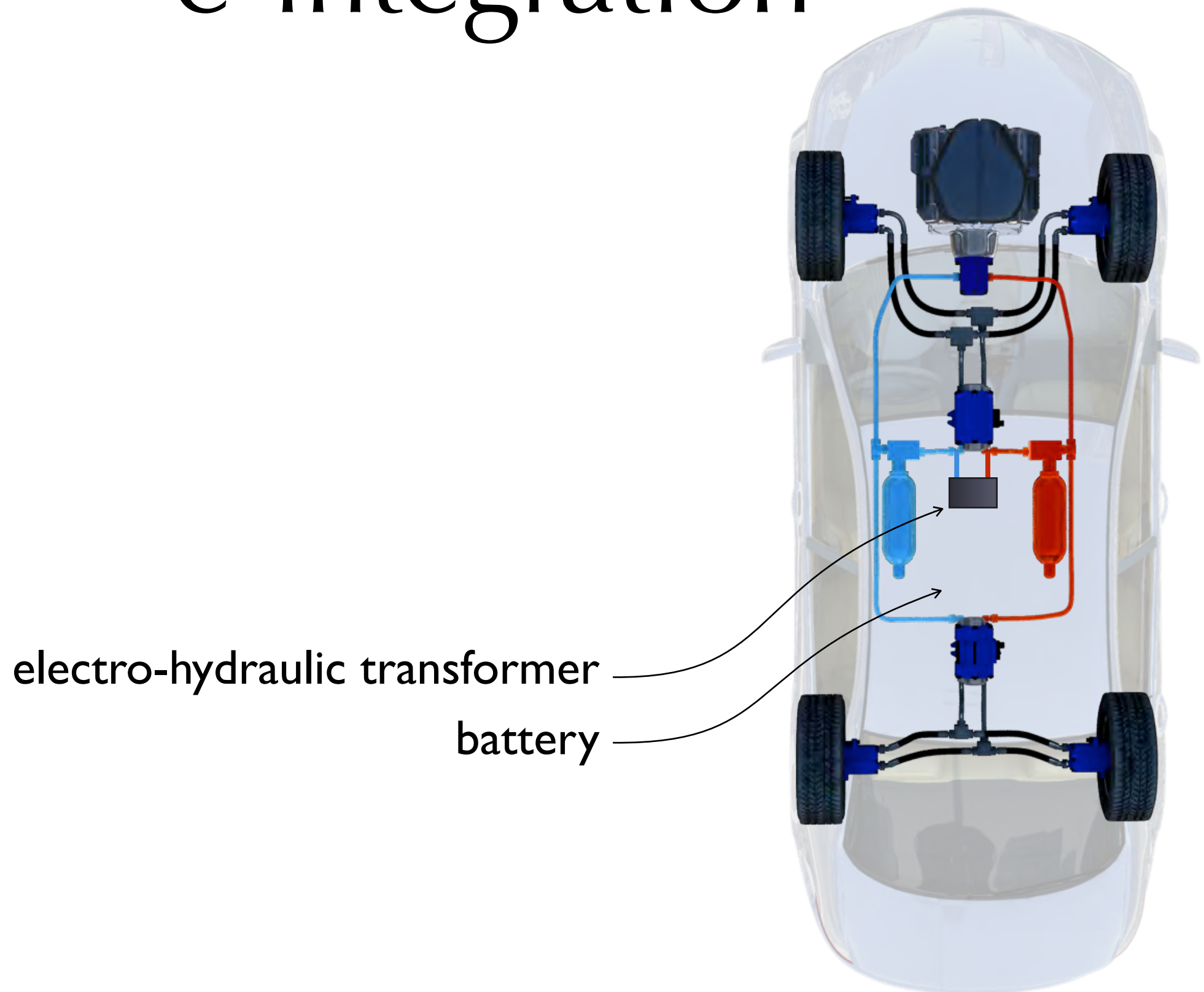
e-integration



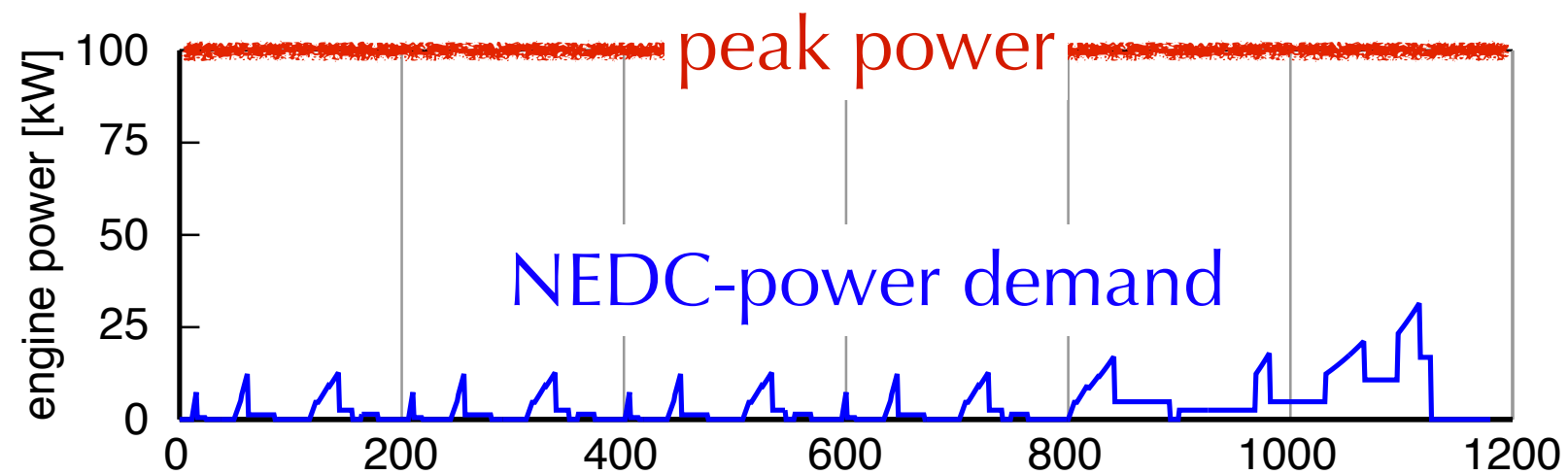
e-integration



e-integration

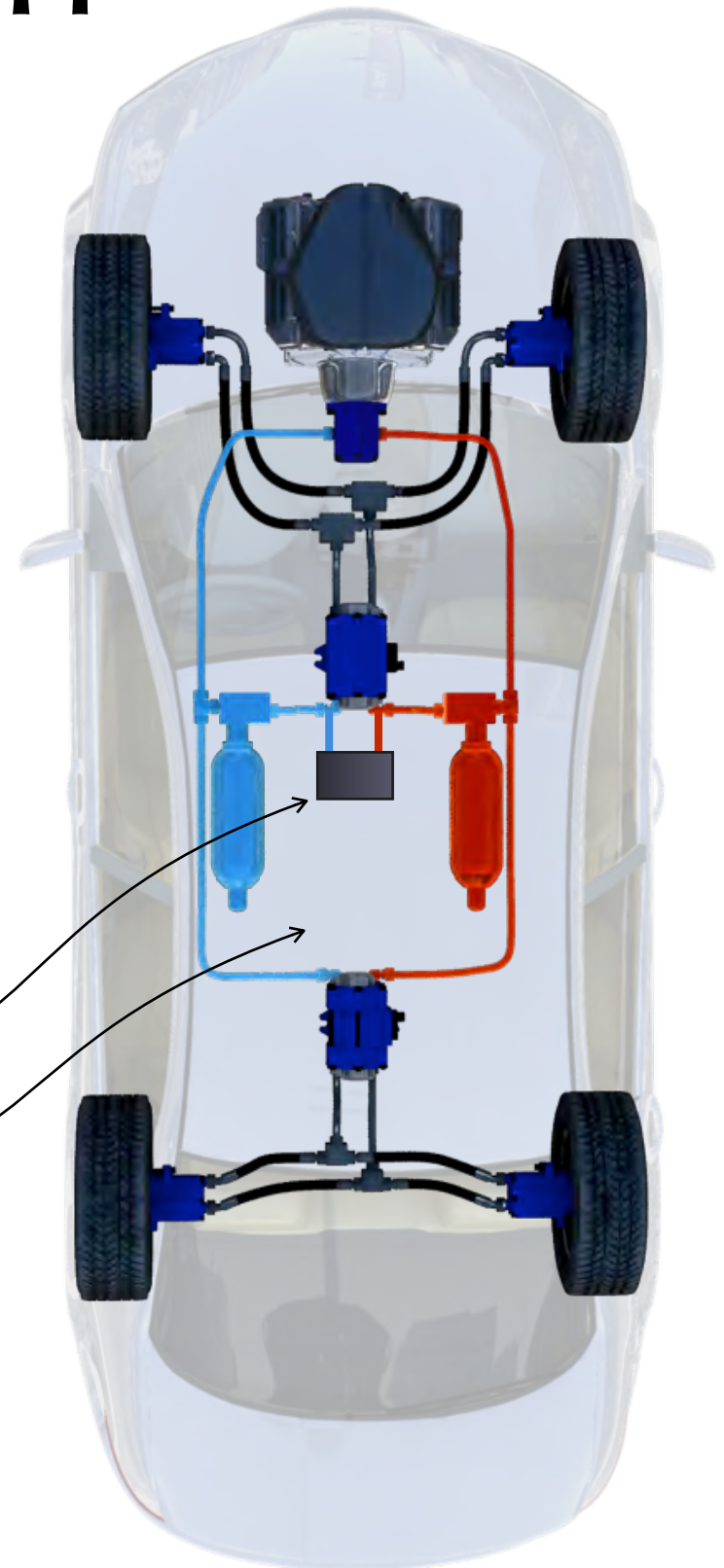


e-integration

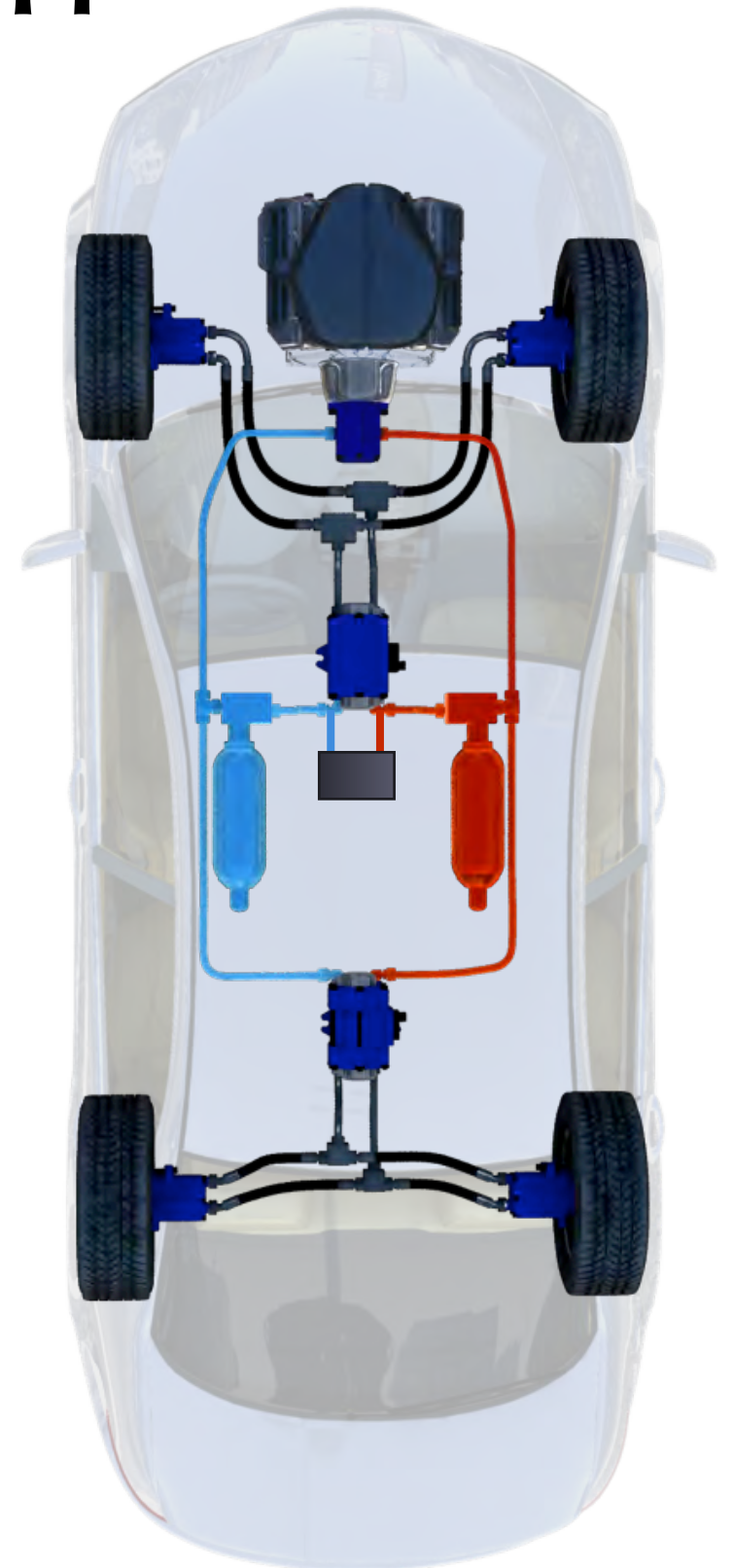
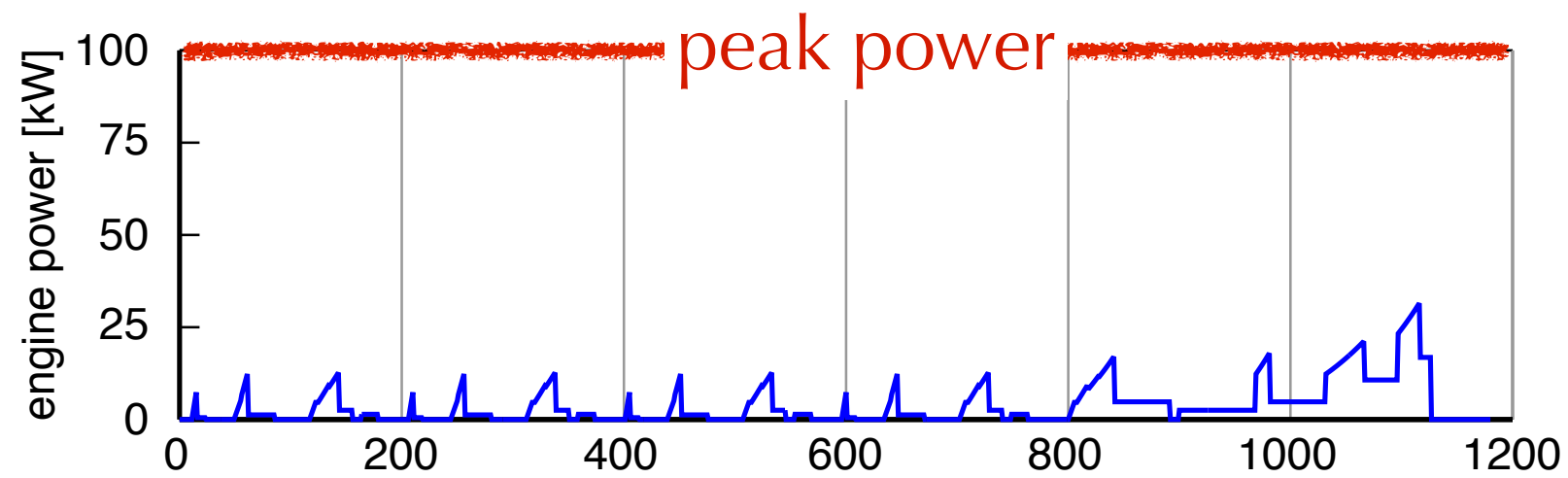


electro-hydraulic transformer

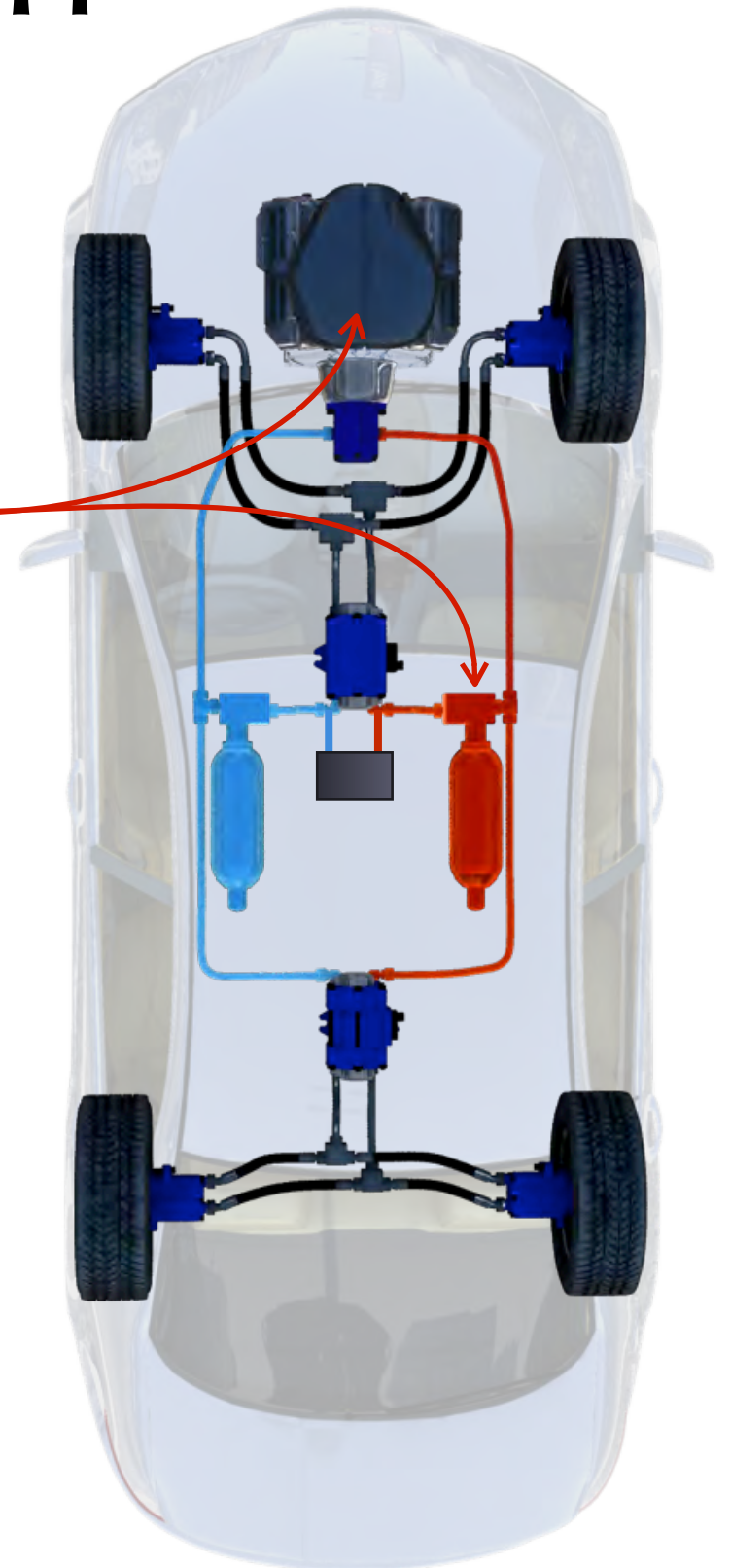
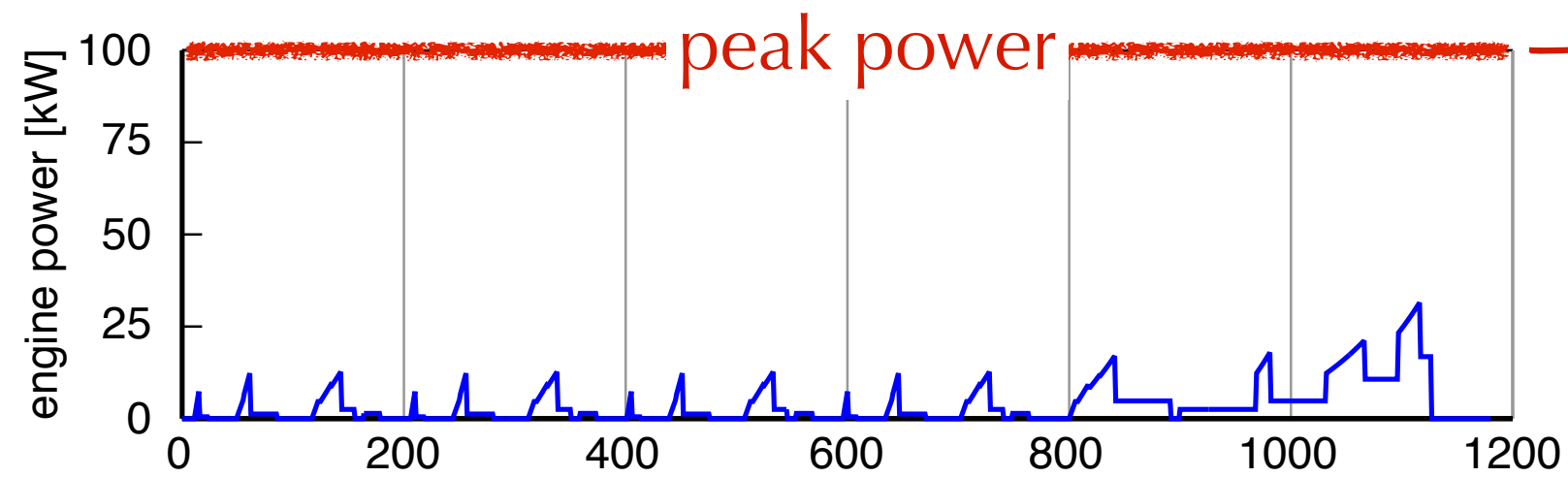
battery



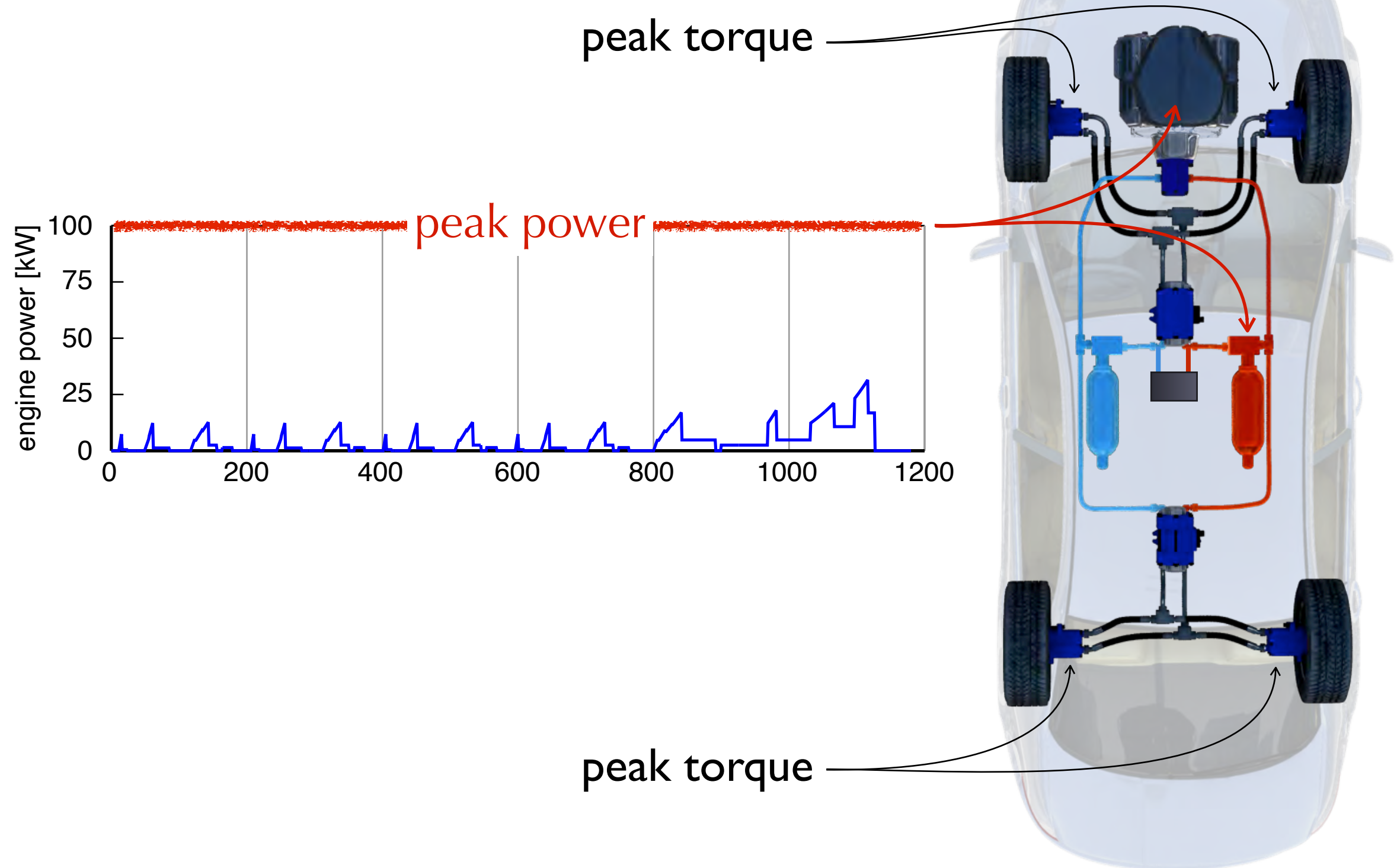
e-integration



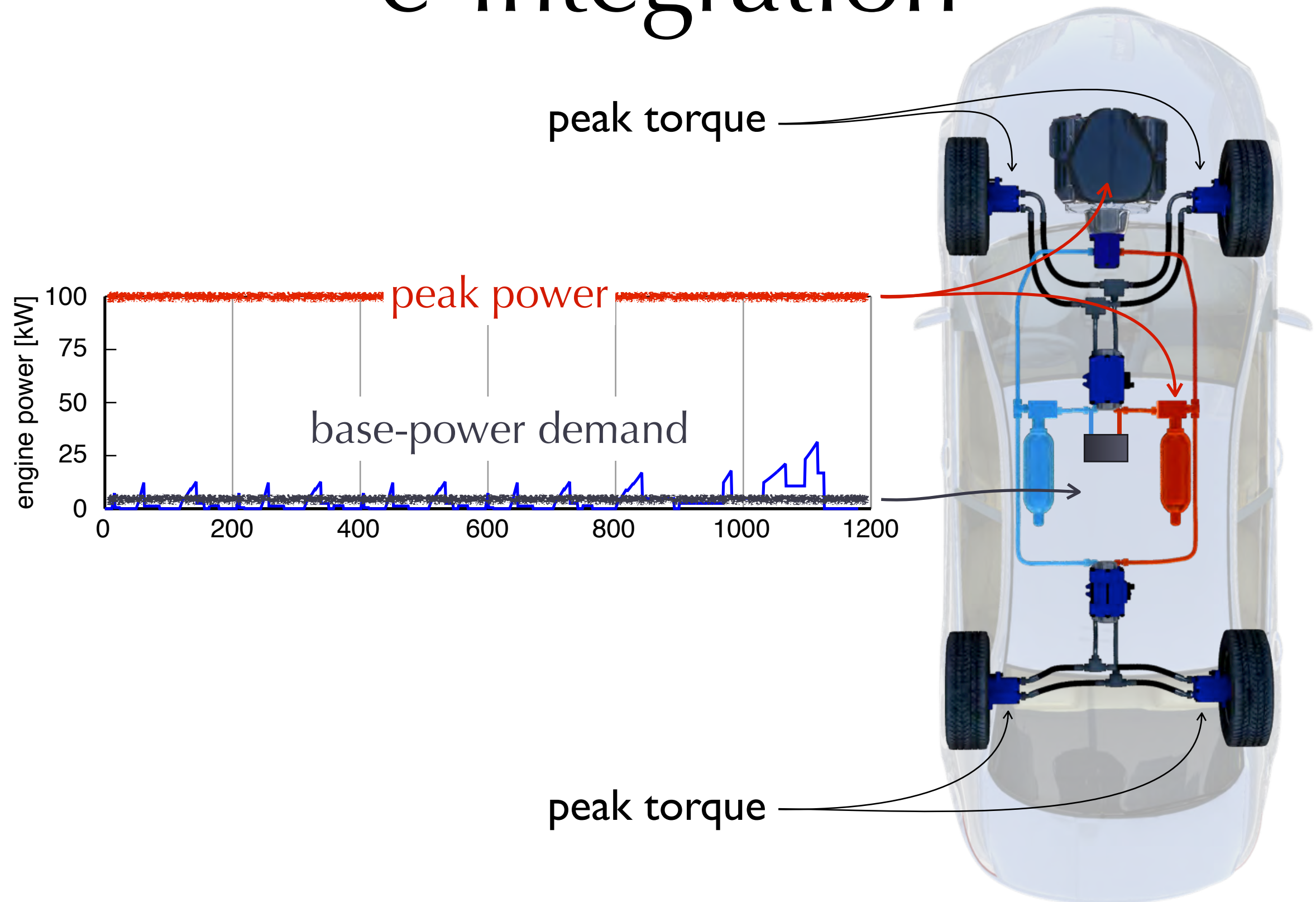
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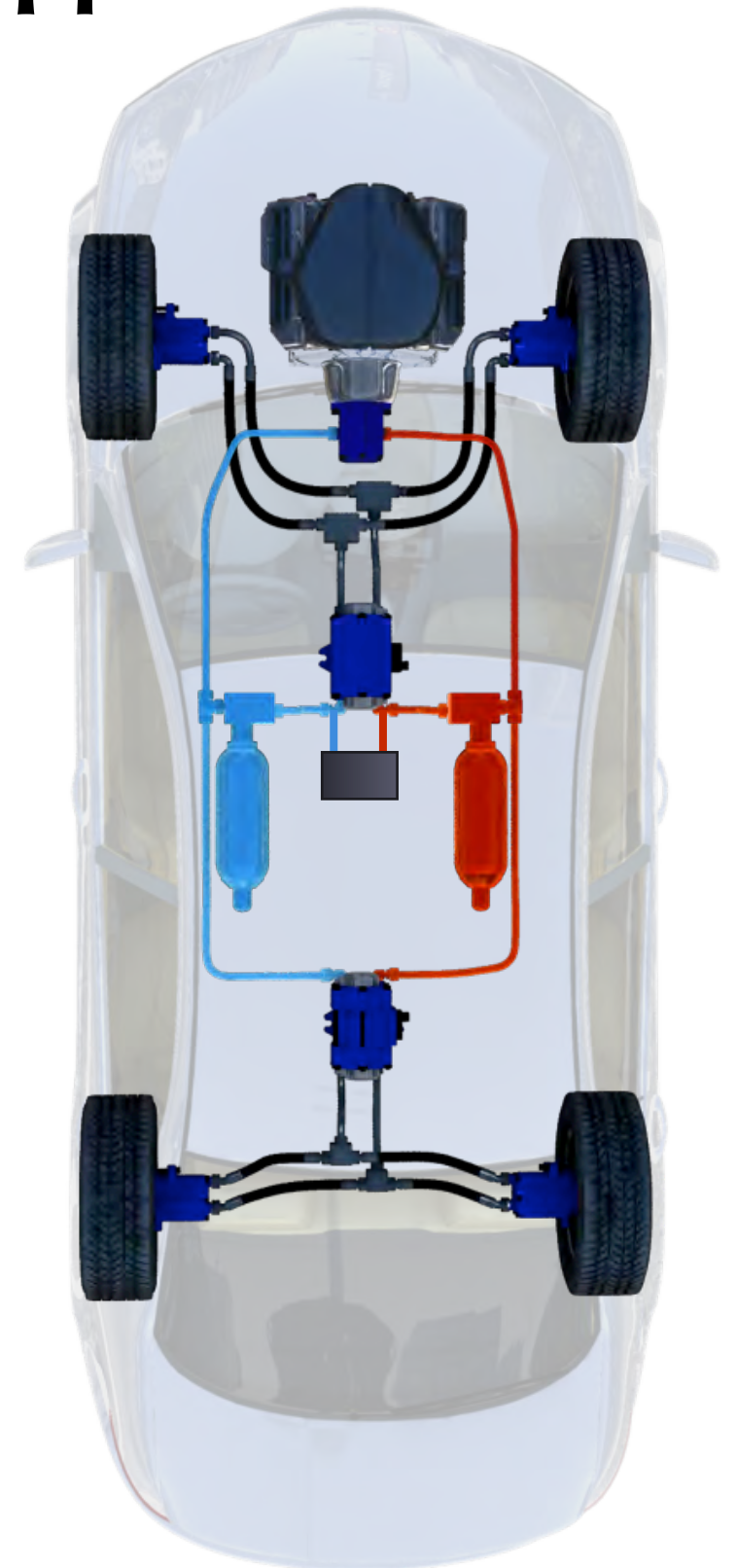
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e-integration

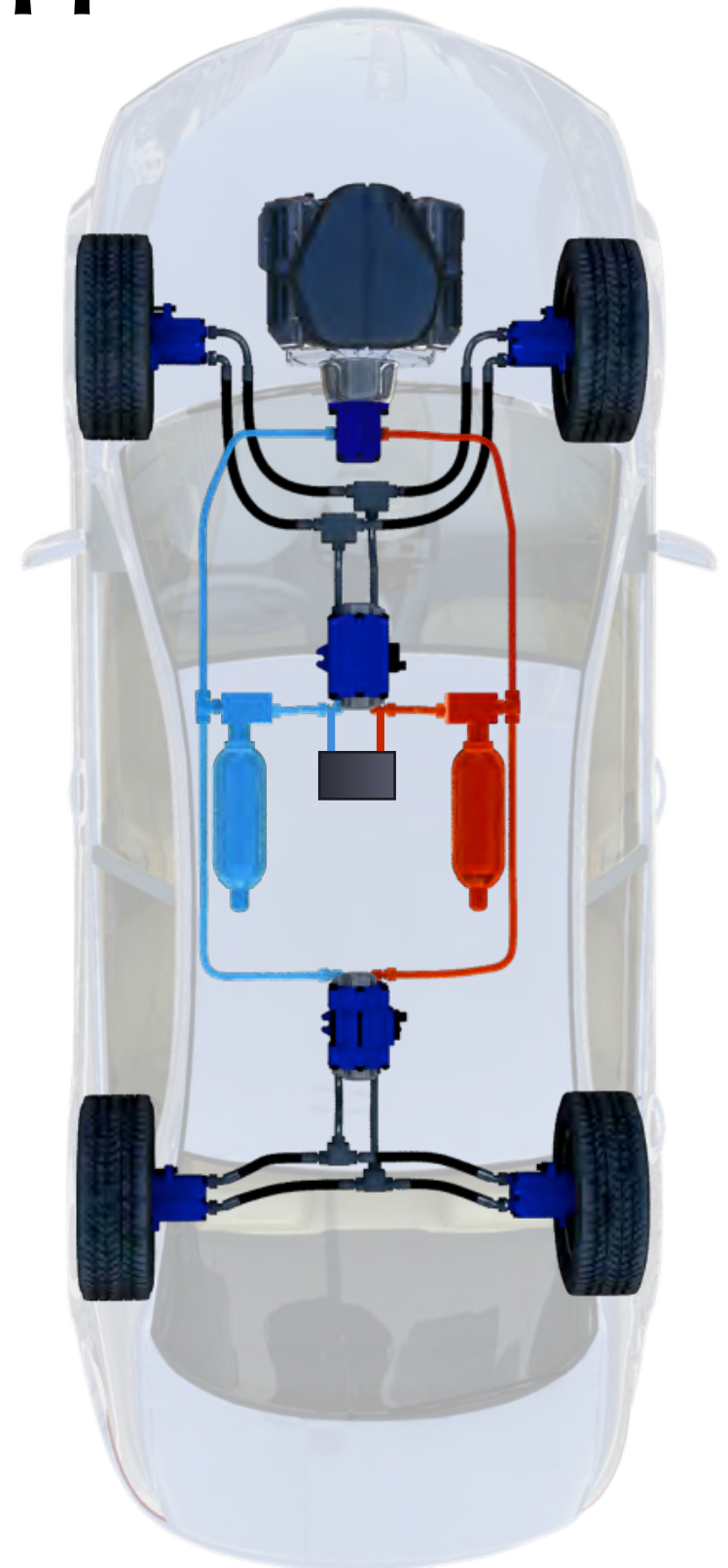


e-integration



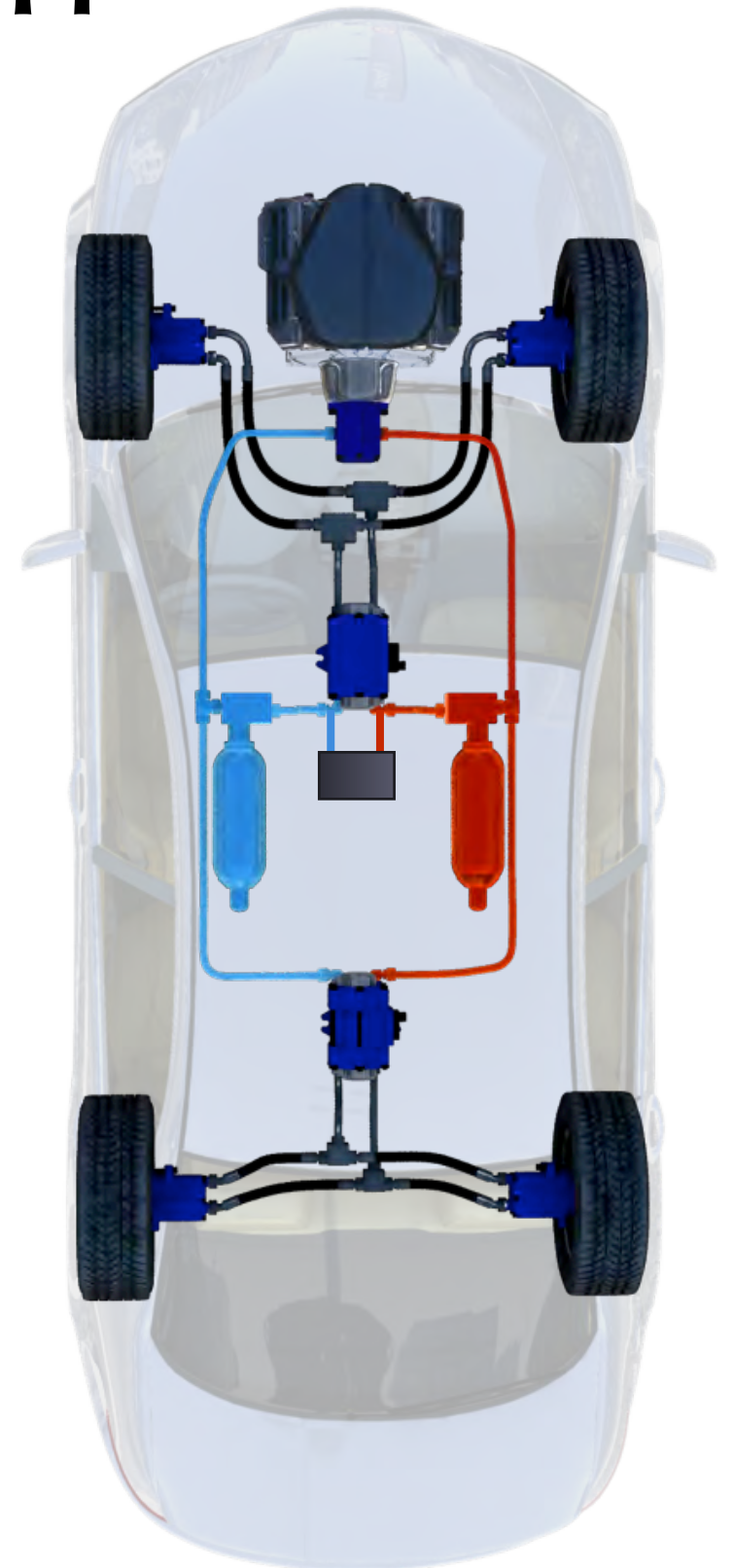
e-integration

- ❖ the hydraulic system replaces the mechanical drive train



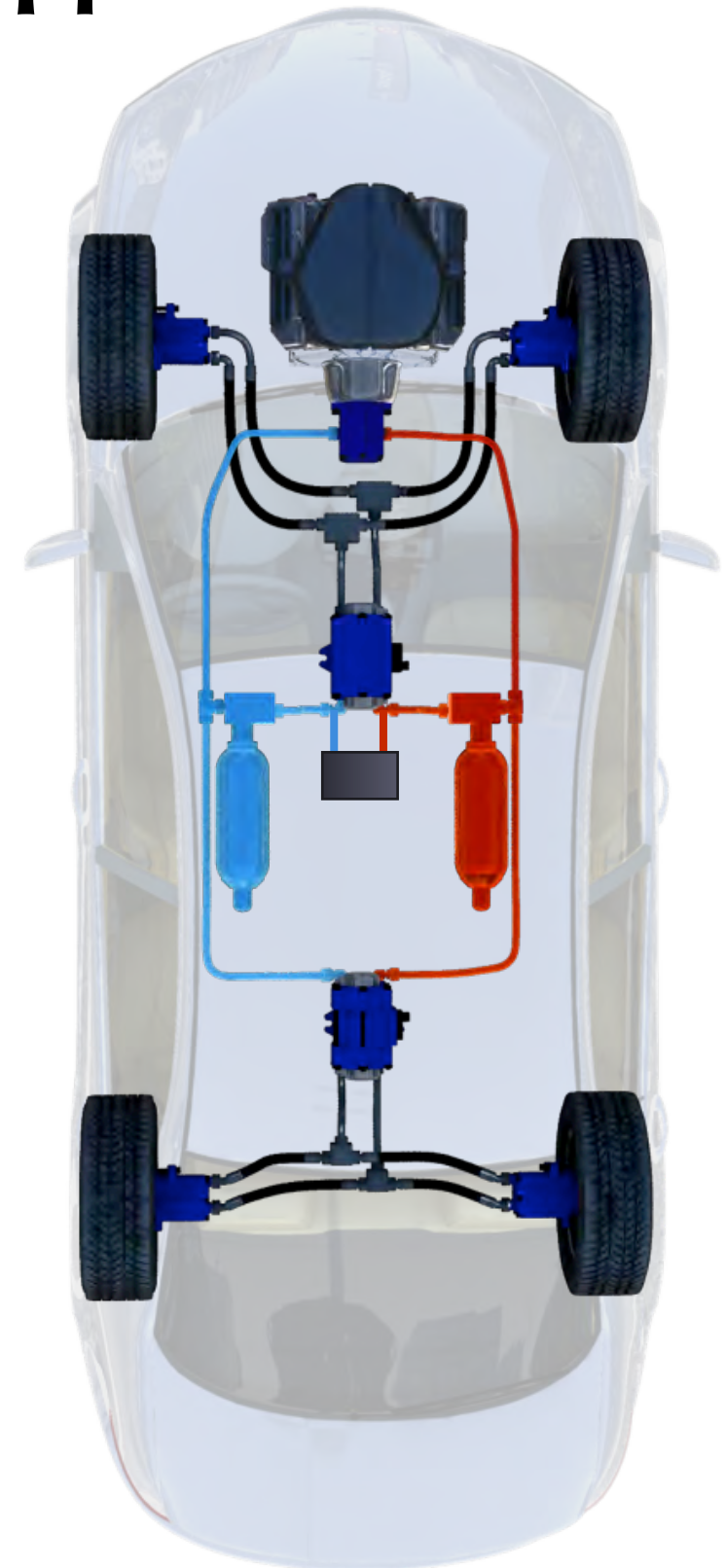
e-integration

- ❖ the hydraulic system replaces the mechanical drive train
- ❖ enables power management



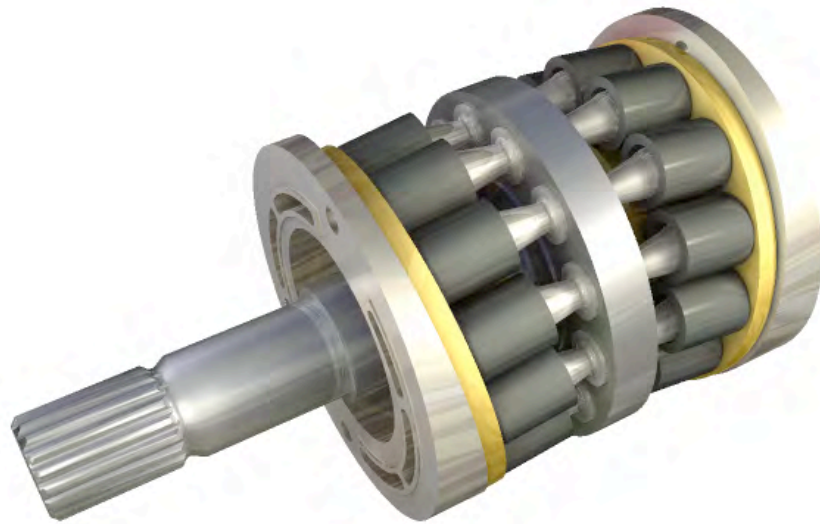
e-integration

- ❖ the hydraulic system replaces the mechanical drive train
- ❖ enables power management
- ❖ E-system can be a small, efficient and light base-load system

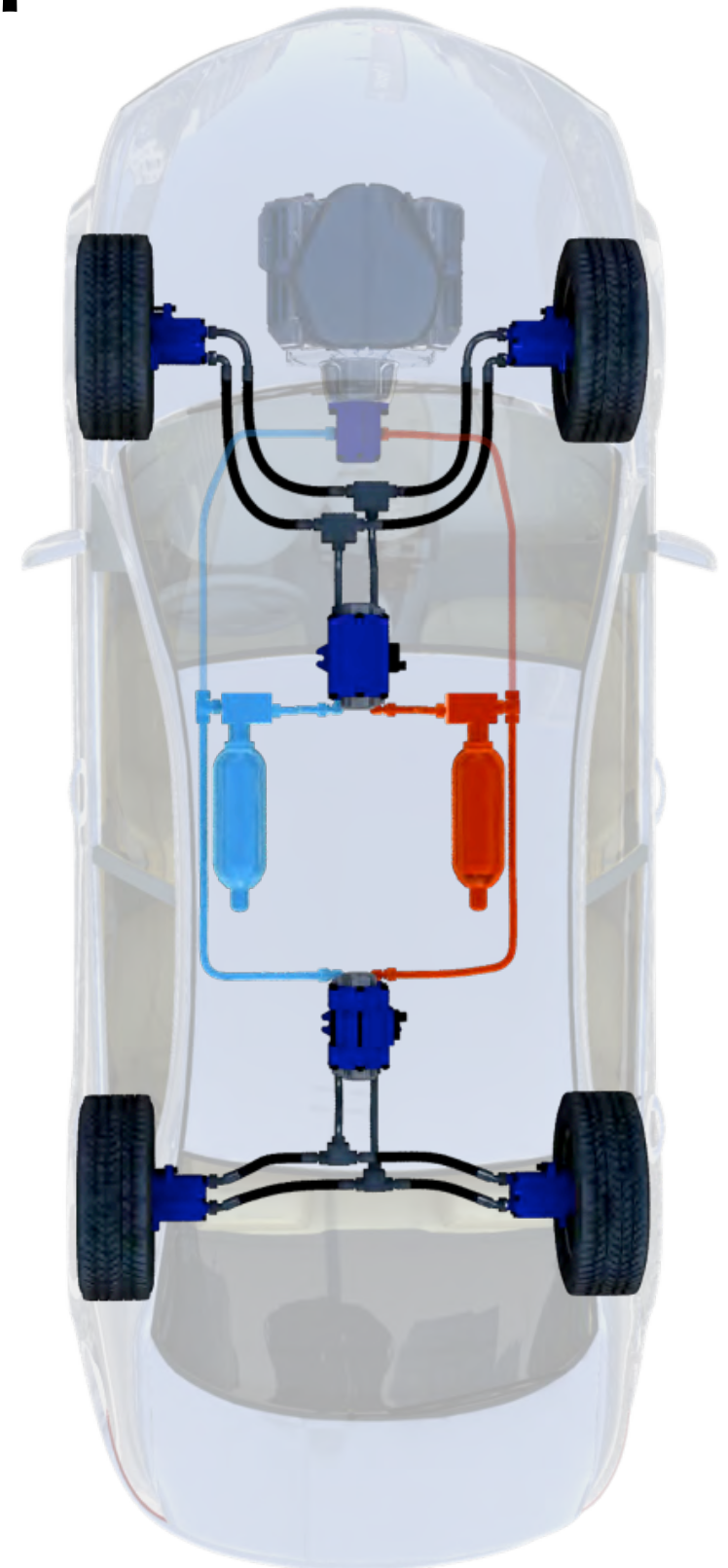


Conclusions

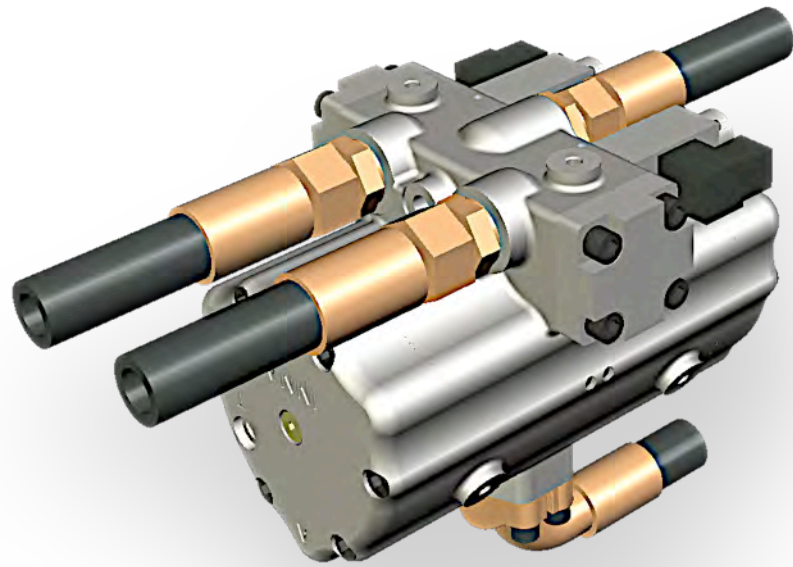
the Hydrid



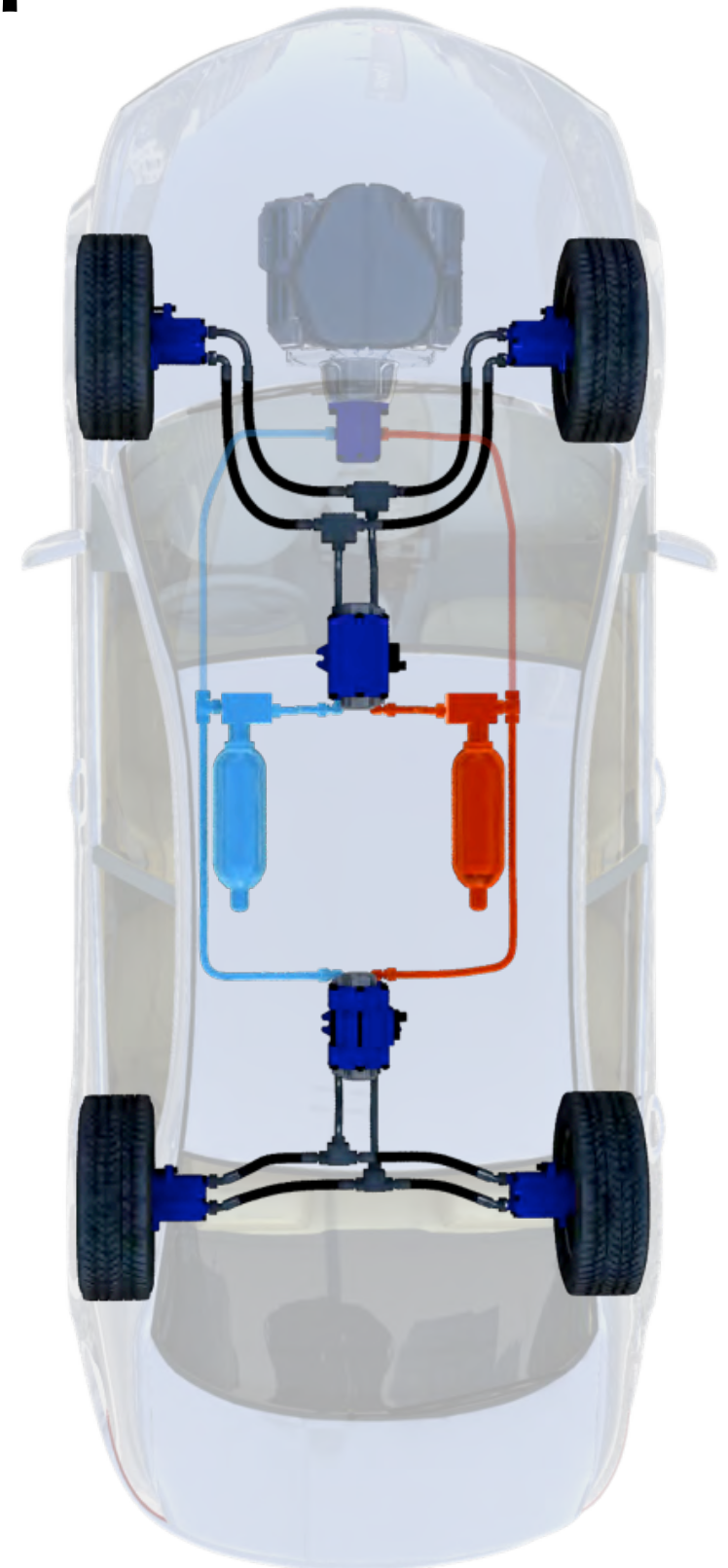
- ❖ floating cup components:
 - ▶ efficient
 - ▶ low NVH
 - ▶ cost effective



the Hydrid

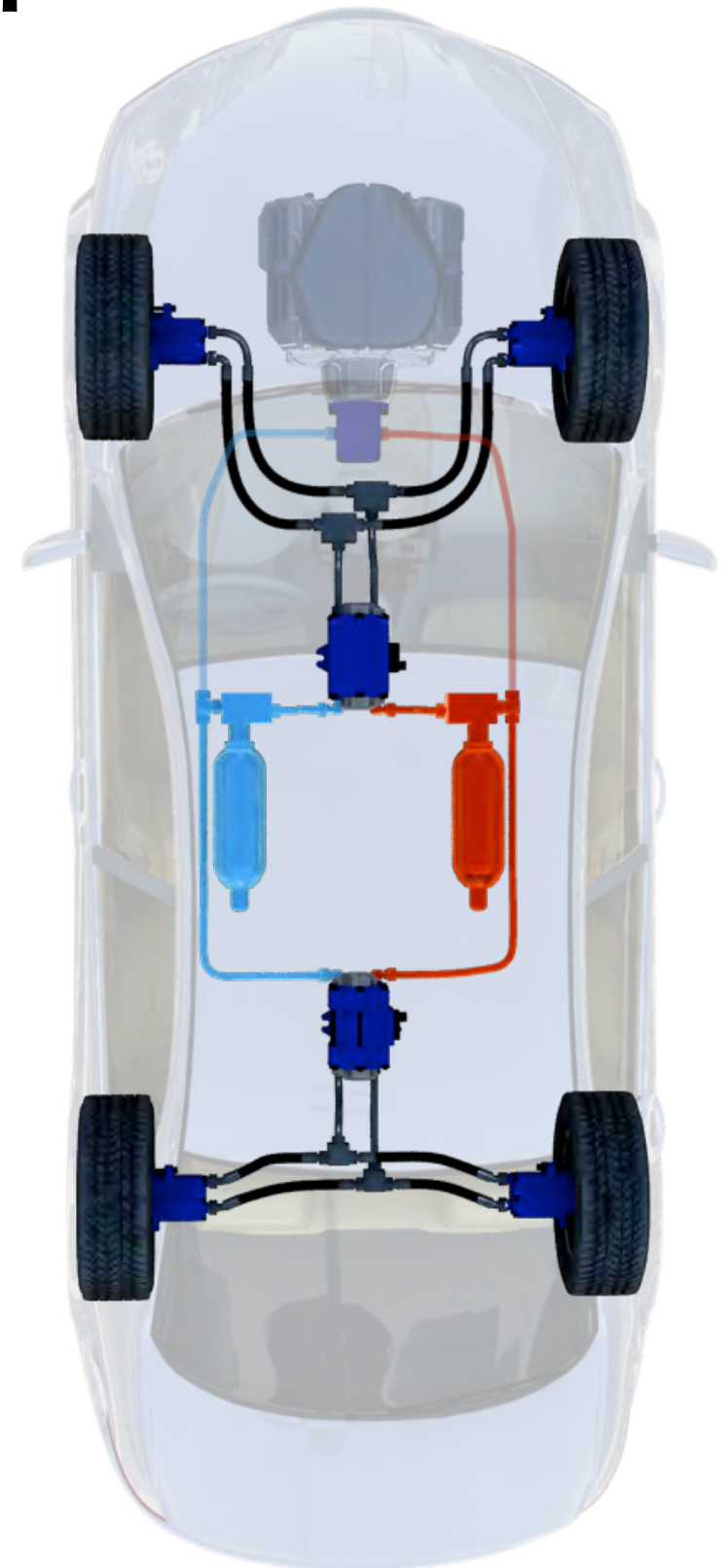


- ❖ transformers:
 - ▶ can create boost torque
 - ▶ defined 4-mode operation
 - ▶ cost effective



the Hydrid

- ❖ common pressure rail:
 - ▶ separates the engine from the load
 - ▶ accumulators for power management and energy recuperation
 - ▶ enables e-integration



the Hydr**id**

- ❖ same performance
- ❖ small weight and cost increase
- ❖ NEDC (and US FTP75):
<50% fuel consumption &
<50% CO₂-emission
- ❖ higher fuel consumption while
driving at high speeds

