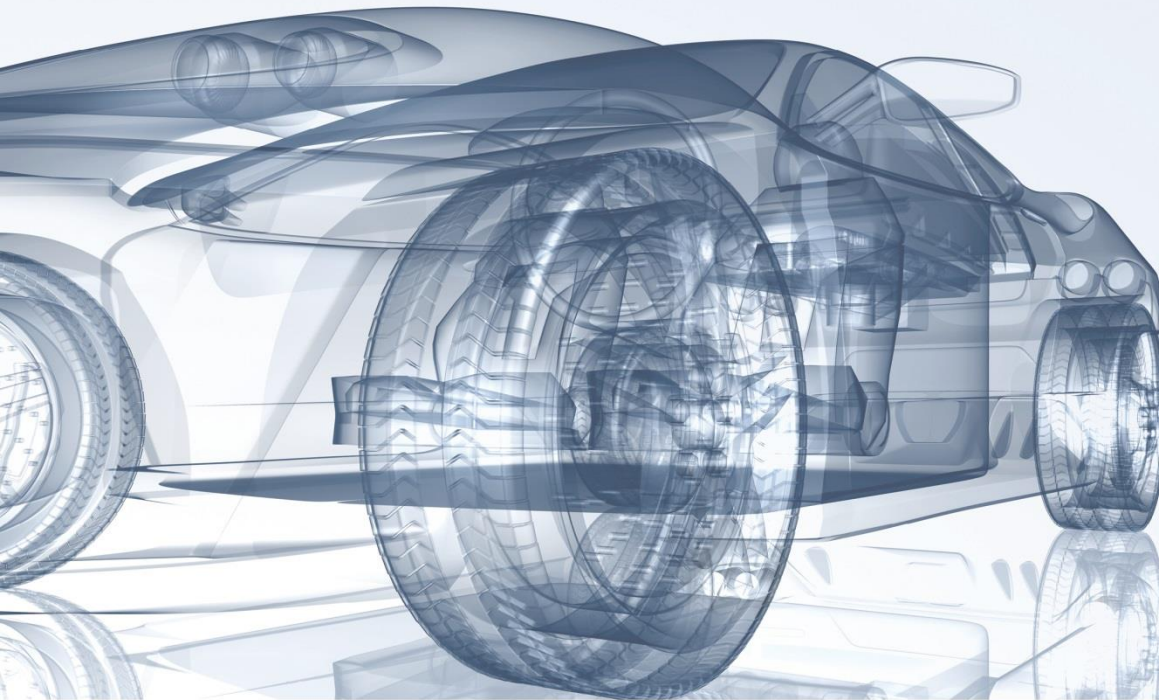


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# Multi-Speed Transmissions for Electric Drives

## **Authors:**

David Gagliardi – Head of Global HEV and E-Drives

Carlo Cavallino – Manager Advanced Engineering

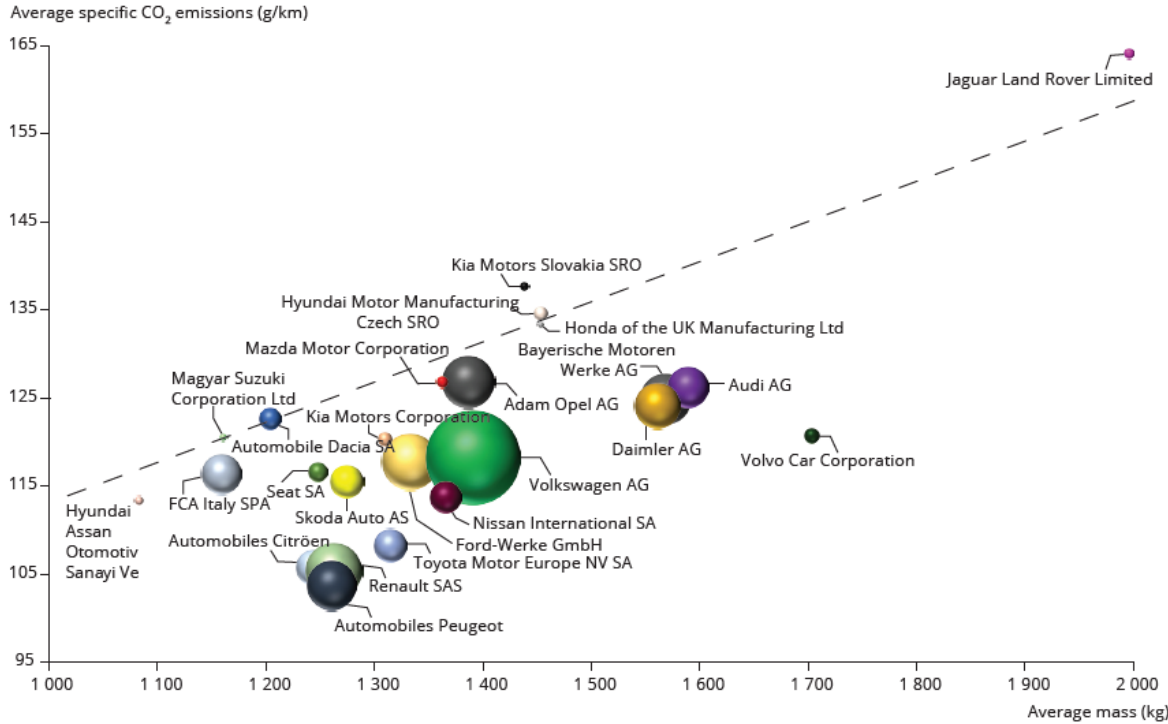
## Agenda

- Introduction
- Oerlikon 2 and 4 Speed Electric Drives
- Efficiency and cost considerations
- Conclusions

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# CO<sub>2</sub> emissions by OEMs in EU compared to 2015 targets



- 2016 average was 118 g/km CO<sub>2</sub>, below the target of 130 g/km
- By 2021 fleet average to be 95 g/km
- Penalties payments for emission in excess, up to 95€ from the third gramm above the limit
- Super credits for low emission vehicles (< 50 g/km)

Chart source: European Environmental Agency, Report No 27/2016

# BEV and PHEV sales forecast up to 2030

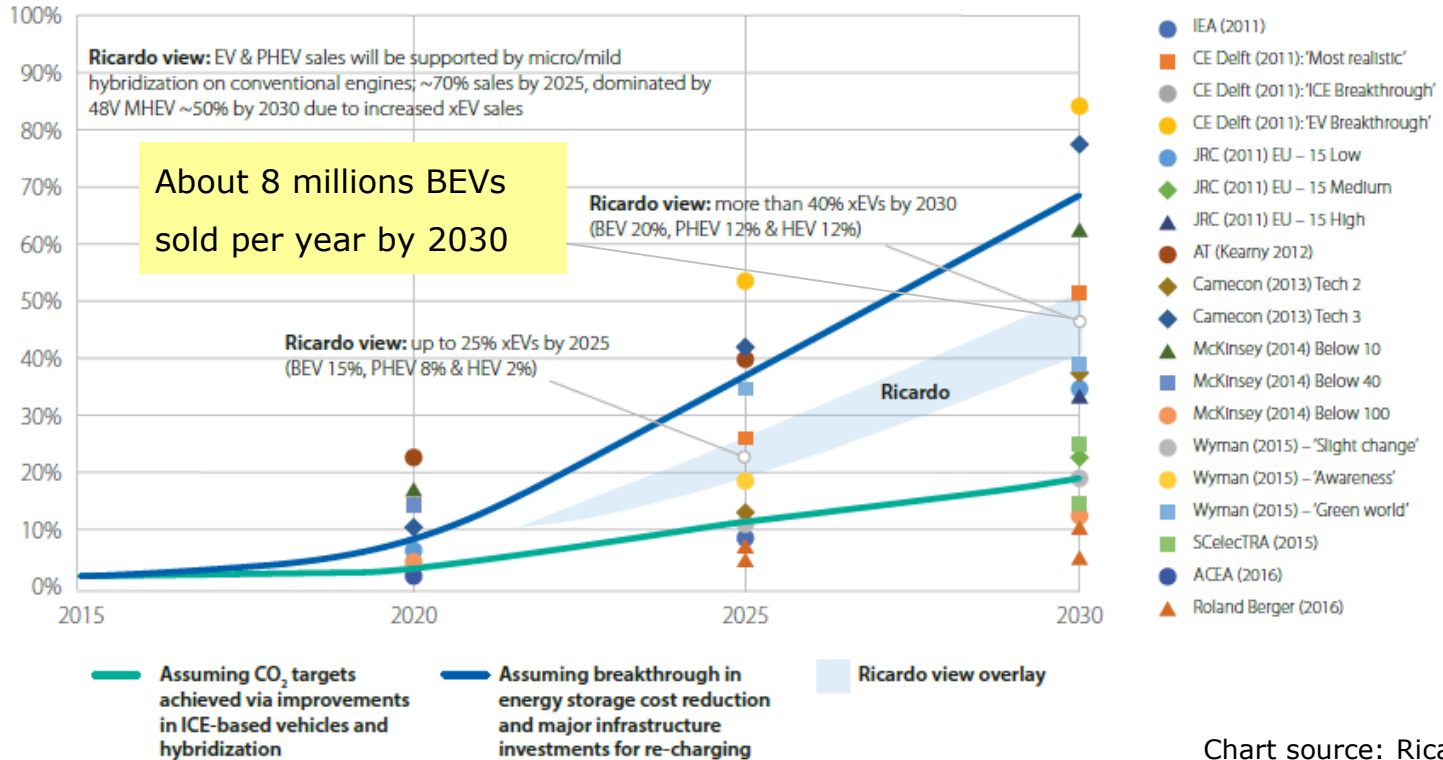
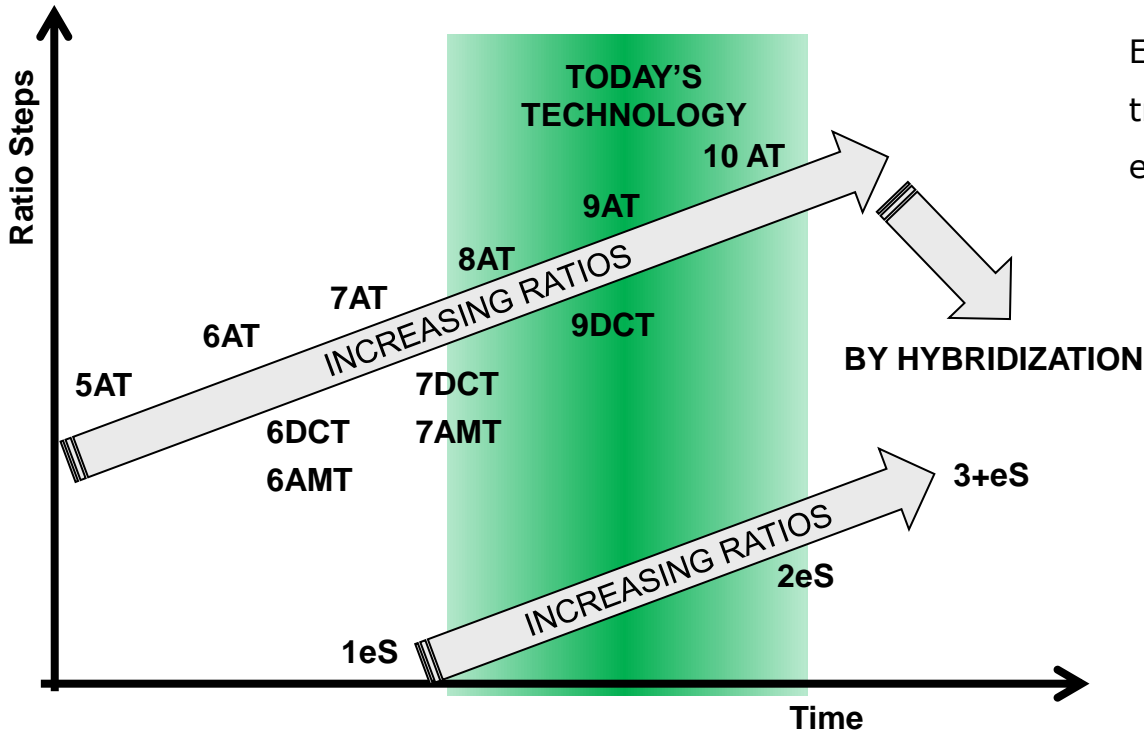


Chart source: Ricardo plc

# Hybridization already demonstrated the potential for reduction of number of speeds



Evolution of single-speed transmissions for BEVs and e4WD:

- Very cheap solution, assuming fixed cost of eMotor, inverter and battery
- Originally expected that the eMotor to be efficient 'enough' over full operating range

## Motivation

- Maximize efficiency
- Improve pull-away performance
- Improve gradeability
- Increase top speed
- Downsize electric motor, inverter and battery, reducing overall cost and weight

## Main requirements

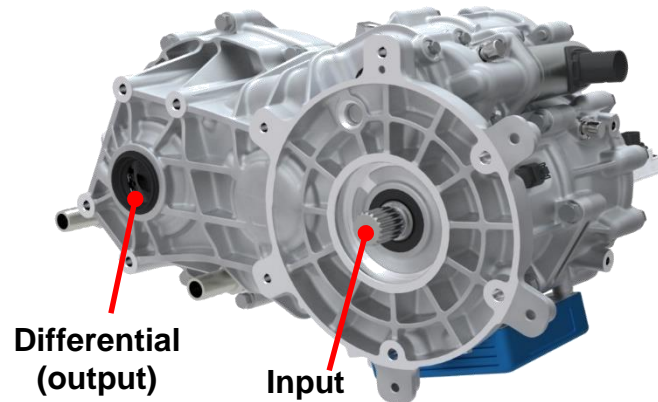
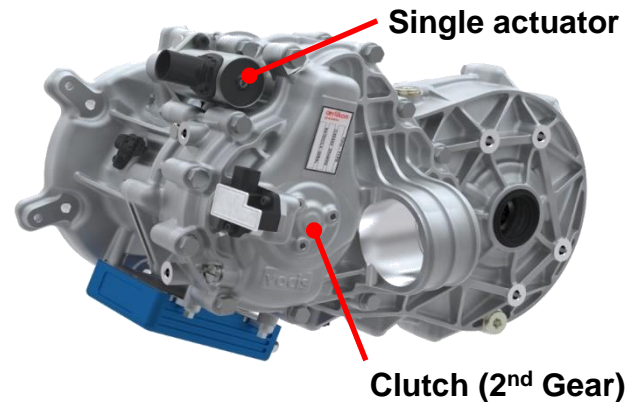
- Shifting without torque interruption (power-shifting)
- Low-complexity to reduce cost and weight increase compared to single speed transmissions

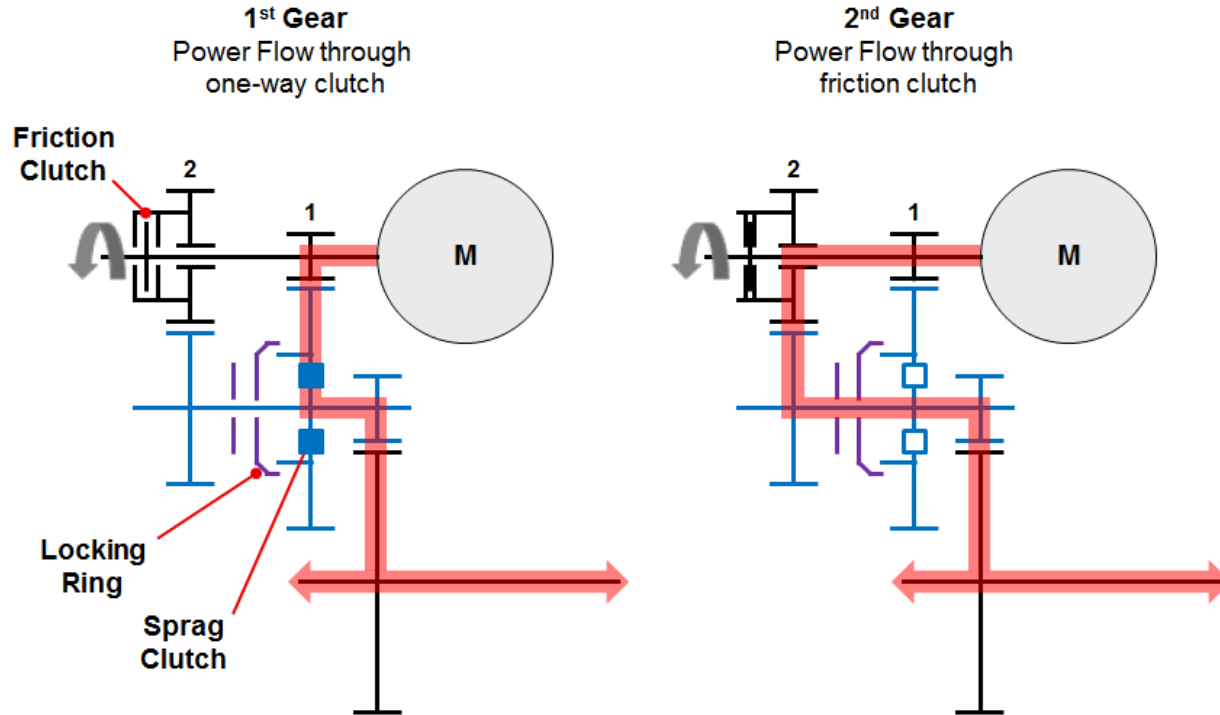
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## 2 Speed Electric Drive (2SED)

- A 2-speed seamless shift design for electric vehicles or hybrid 4WD, one traction motor
- Design for maximum efficiency (splash lubrication, gear design, bearings, etc.)
- On demand electromechanical actuators, no continuous energy supply, no hydraulics
- Sprag clutch with locking ring
- Dry plate friction clutch
- Park lock achieved by engaging both locking ring and friction clutch (no additional mechanism)
- Production-intent software for system control and gear shift functionality
- Fully functional design proven in demonstrator vehicle



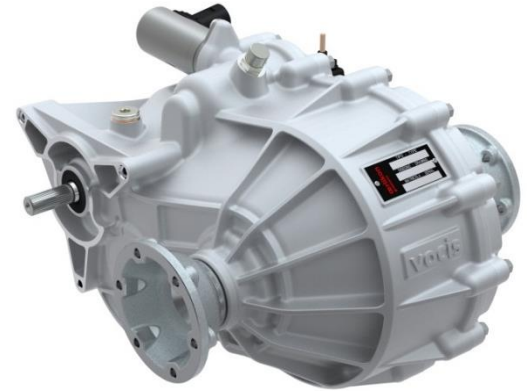


## 2SED: Main characteristics and key parameters

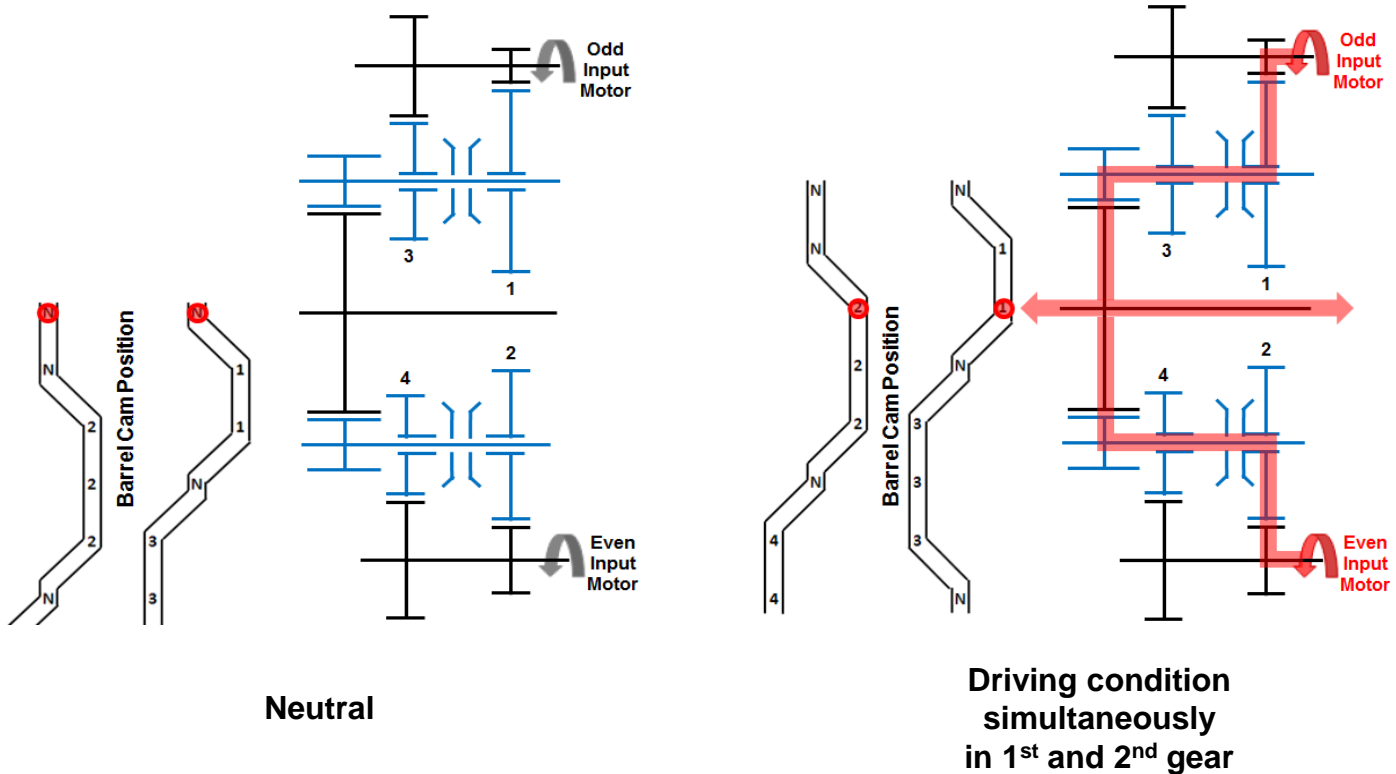
Parameters		Existing prototypes	Under development
Max input speed	[rpm]	15000	16000
Max input torque	[Nm]	310	550
Abuse torque @ output (ABS, park lock, etc.)	[Nm]	6150	11000
Peak power	[kW]	210	320
1st Gear Ratio		15:1	15.6:1
2nd Gear Ratio		9.5:1	8.1:1
Weight (dry)	[kg]	~ 38	tbd
Oil volume needed	[l]	0.95	tbd
Clutch type		Dry (normally closed)	Wet (normally closed)
Actuation type (clutch and park lock)		Electromechanical	Electromechanical
Mechanical differential		Yes (open)	Yes (open/LSD)
Park lock functionality		Yes	Yes

## 4 Speed Electric Drive (4SED)

- A patented 4-speed powershifting transmission for vehicles with 2 traction motors
- Single electromechanical actuator, on-demand
- Very simple gearbox - mechanically more simple than a manual: clutch-less, synchroniser-less
- Motor control during gearshifting critical to successful operation of transmission, in particular
  - For synchronisation
  - Dog-angular engagement
  - Torque-infill
- Fully functional design proven in demonstrator vehicle



# 4SED: Example of powerflow, including barrel cam position for gear actuation – 7 driving modes possible



## 4SED: existing demonstration vehicle

- Vehicle unloaded mass: 2200 kg
- Max. power: 2x 35 kW
- Max. torque: 2x 75 Nm
- Max. input speed: 15.000 rpm
- Total transmission weight: 24 kg
- Splash lubrication

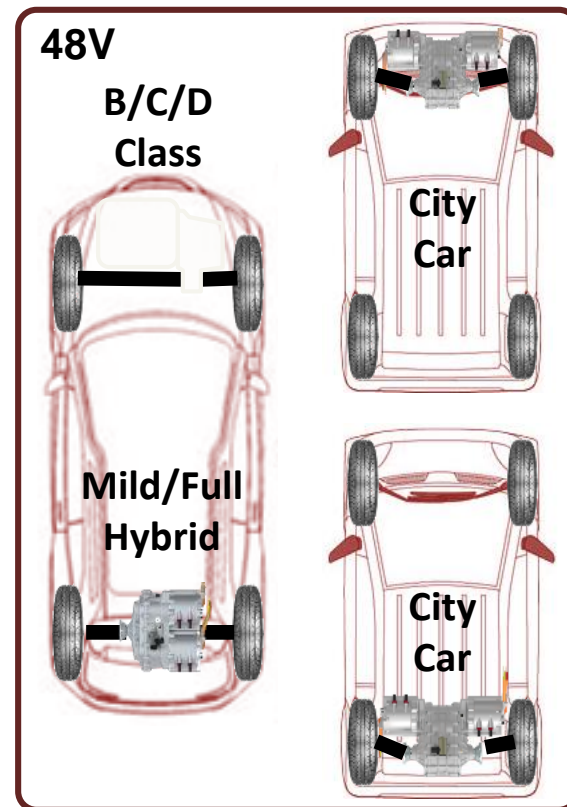
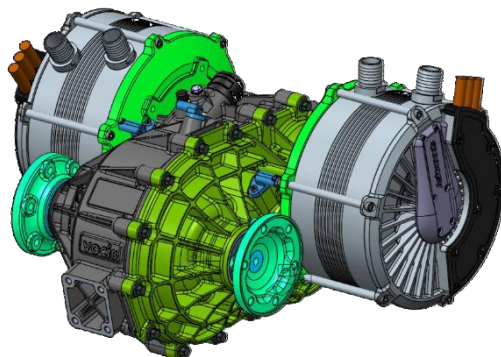
**Very good driveability  
despite high vehicle weight  
and relatively low electric  
motor power**



**Demonstration vehicle realised on the base of a Mercedes Vito minivan**

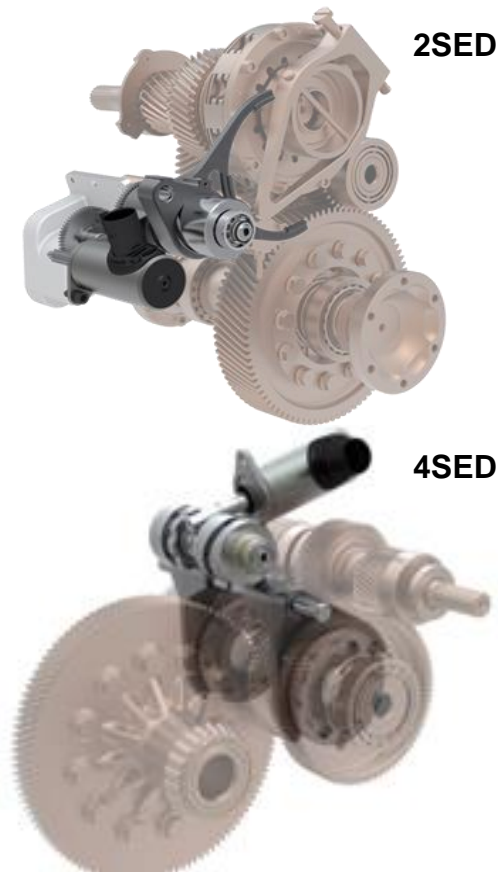
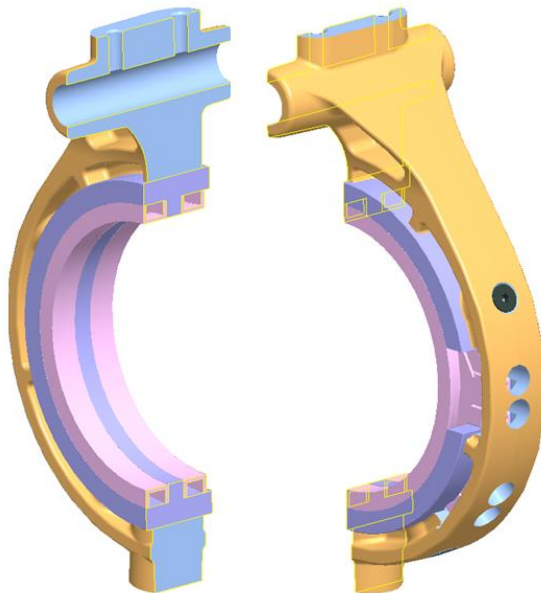
## 4SED: 48V demonstration vehicle, under development

- Max. power: 2x 18 kW
- Max. torque: 2x 80 Nm
- Max. input speed: 7.000 rpm
- Gear ratios:
  - 1<sup>st</sup> = 4.130
  - 2<sup>nd</sup> = 2.806
  - 3<sup>rd</sup> and 4<sup>th</sup> = 1.408
- Targeted donor vehicle for demo: VW eUP!



## Novel actuation system, some considerations

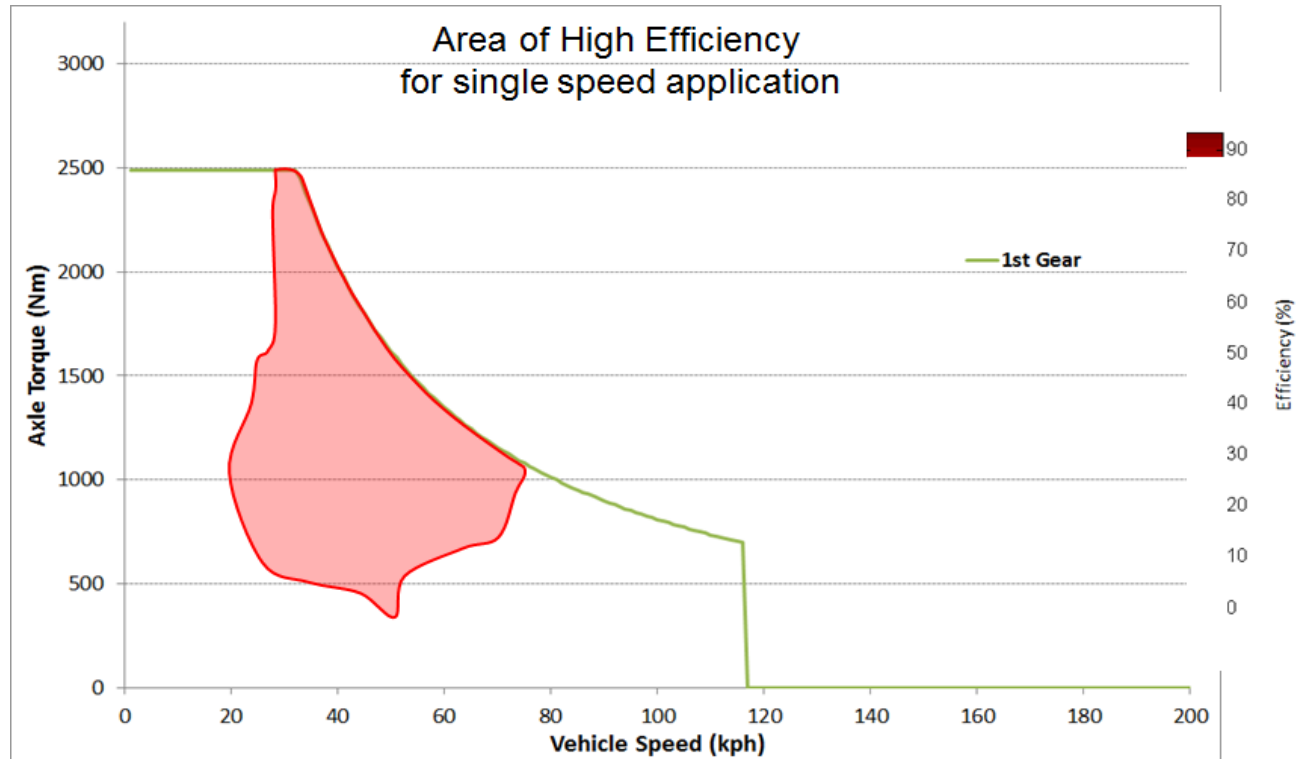
- Fork actuation realised by a linear actuator integrated in the fork itself, reducing the number of mechanical parts, improving efficiency, reliability and cost
- A position sensor can be integrated in the available package
- 900N pushing force achievable with a current of 30A
- Suitable for operation at 12V, 24V and 48V
- Prototypes available

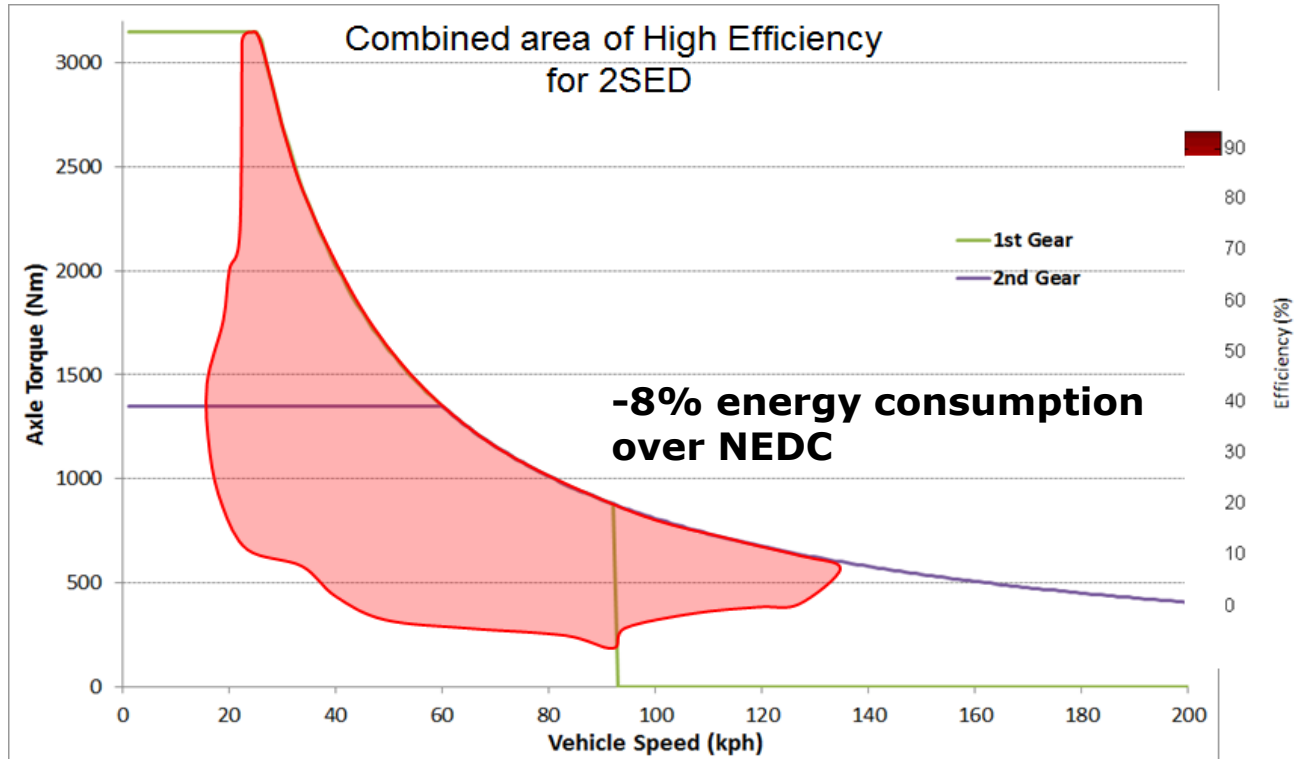


## Agenda

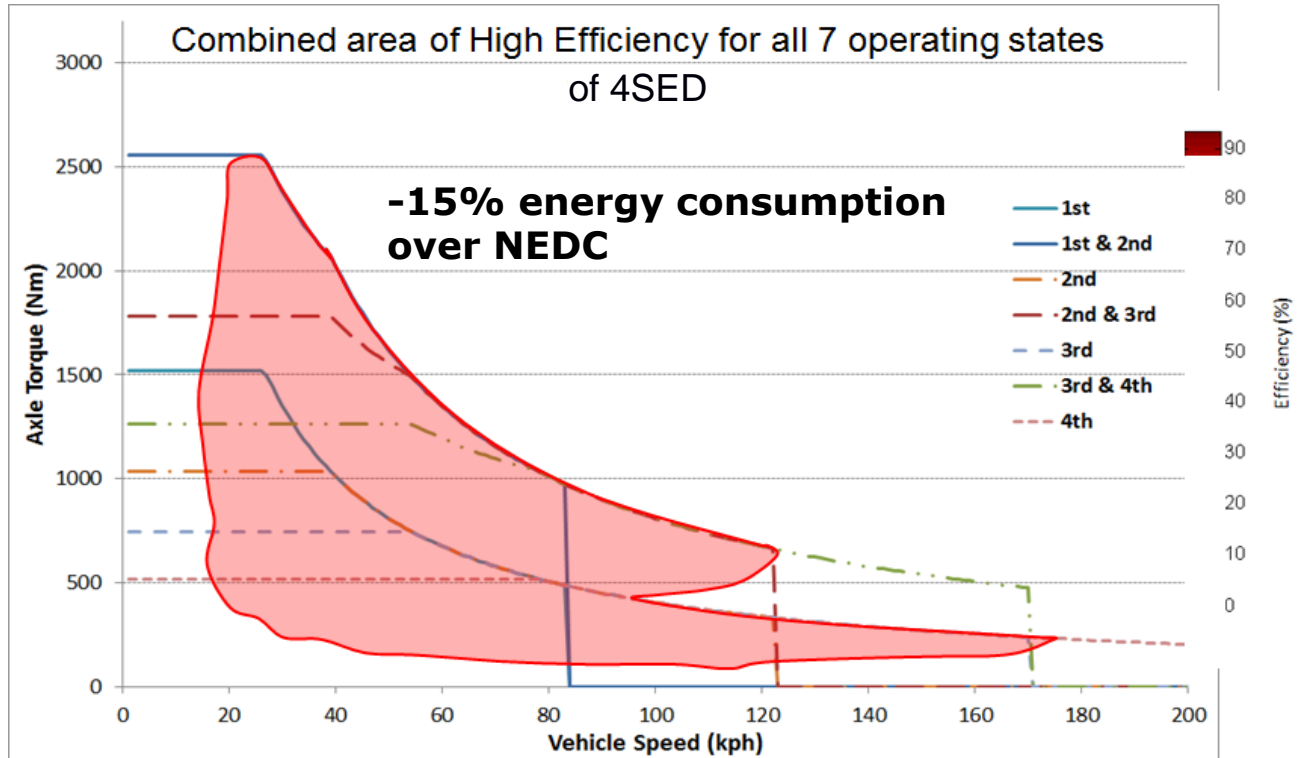
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# Efficiency of a typical one speed Electric Drive (70 kW)





# Additional improvement combining 7 operation modes of 4SED (35 kW x 2)



# General cost considerations at system level...

	Single Motor – Single Speed		Single Motor – Two Speed		Dual Motor – Four Speed	
<b>Motor Cost</b>	1off 70kW		1off 70kW		2off 35kW	
<b>Inverter Cost</b>	1off 70kW		1off 70kW		2off 35kW	
<b>Battery Cost</b>	Highest energy requirement		Savings on energy use. Predicted -8% on NEDC *		Max. saving on energy use. Predicted -15% on NEDC *	
<b>Transmission Cost</b>	Cheapest		Increased, but still <10% of complete system		Increased, but still <10% of complete system	
* Internal simulation study						

## ...and a concrete example

- Assumed battery capacity: 40 kWh (Nissan Leaf: 30 kWh, Tesla Model 3: 50-75 kWh)
- Assuming 15% efficiency improvement, same electric range can be achieved with 34 kWh, saving 6 kWh
- Assuming 150 EUR/kWh battery cost, 6 kWh less means 900 EUR cost savings
- Additional cost savings can be achieved by optimisation of size and technology of electric motor and inverters, estimated to be in the range of 100-200 EUR, depending on volumes and applications
- This “allowance” of >1000 EUR, although roughly calculated, is showing a concrete potential for multi-speed transmissions to become an attractive alternative to one-speed transmissions, not only for high performance applications

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## Conclusions

- 2 power-shifting and low-complexity transmissions for Electric Drives have been presented, 2SED and 4SED, able to
  - Maximize efficiency
  - Improve pull-away performance and gradeability
  - Increase top speed
  - Downsize electric motor, inverter and battery, reducing overall cost and weight
- Multi-speed transmissions are suitable for 48V systems (good driveability with low electric motor torque and power under real conditions)
- Achievable efficiency improvement up to 15% makes multi-speed transmissions suitable for a wide range of automotive applications

**Thank you for your interest**

**Any question?**

	Drive Systems
<b>David Gagliardi</b> Head of BD Automotive German Market Head of Global HEV & E-Drives Director	Gmünder Straße 65 73614 Schorndorf Germany M +49 175 5754976 david.gagliardi@oerlikon.com
Drive Systems	<a href="http://www.oerlikon.com/graziano">www.oerlikon.com/graziano</a>