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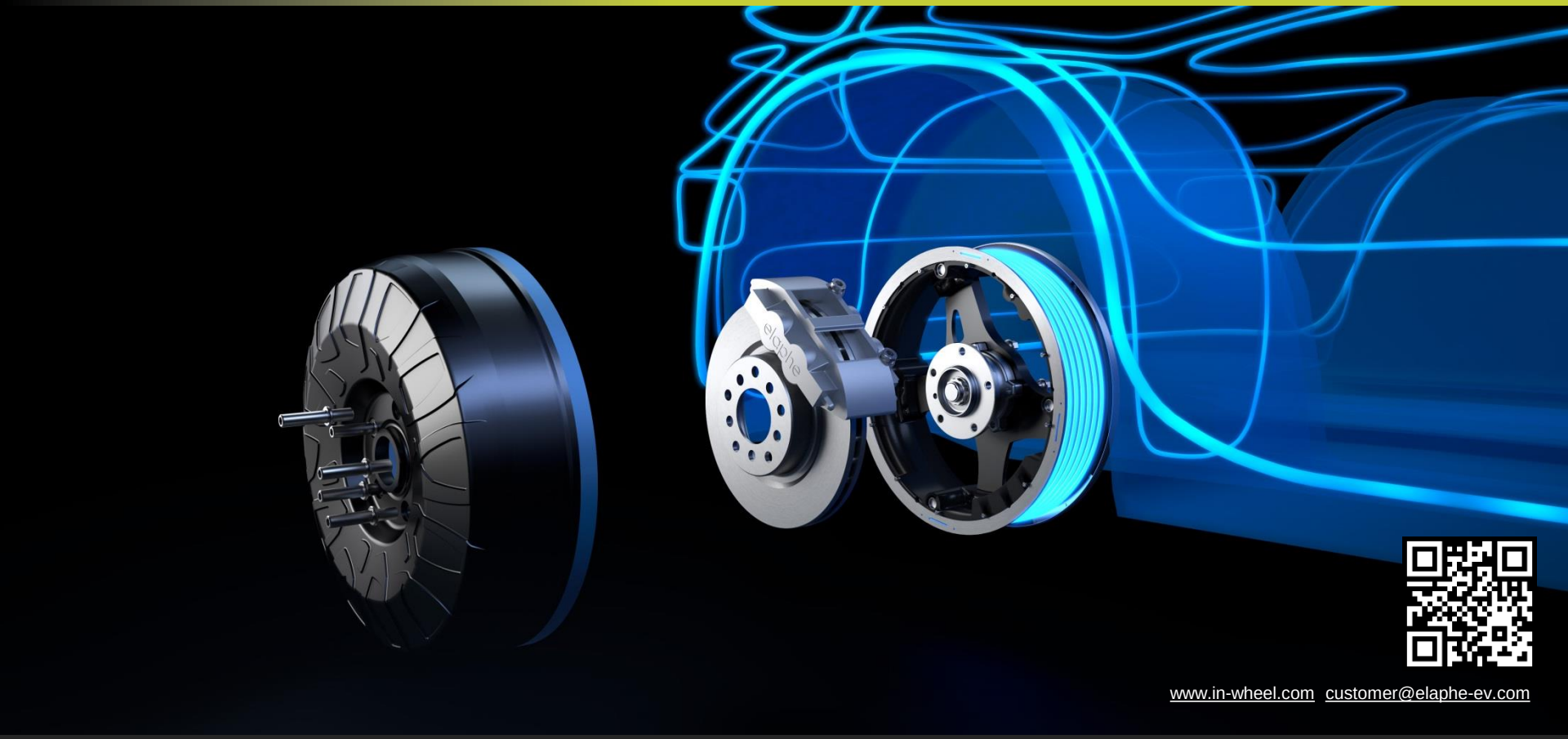
Can in-wheel powertrains reduce the costs of EVs?



www.in-wheel.com customer@elaphe-ev.com

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ELECTRIC IN-WHEEL MOTOR POWERTRAIN PLATFORM

Click the photo to see YouTube video

YouTube video

Elaphe Propulsion Technologies Ltd.

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Benefits

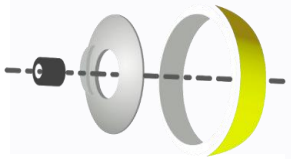
Highest in-wheel performance on the market

Manufacturing oriented design, short time-to-market

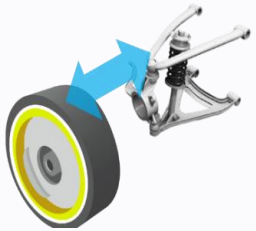
A plug & play modular powertrain platform

Use of standard rims, brakes and bearings

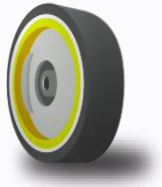
Light weight:
Global leaders in specific torque with the lightest electromagnetic design for high-performance direct-drive (up to 100Nm/kg)



Smarter packaging:
compact ring-shaped electromagnetic design (up to 460 Nm/liter) with less complexity



Modular & simple integration: unified, modular platforms reducing vehicle manufacturing and R&D costs.



Direct drive: no mechanical transmissions, less weight. Key benefits for optimizing precision and responsiveness

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Applications

SCALABLE	Across size, weight, performance and function, Light EVs and motorcycles to alpine snow rescue vehicles
VERSATILE	From small city EVs, to performance cars, from delivery vehicles to people movers and large public transportation
SW DRIVEN	New business models, unlocking potential through advanced functions
INTERCHANGEABLE	New feature, new user value. Upgradable and interchangeable.
CUSTOMIZABLE	Technology concept designed for maximal flexibility of servicing and mechanical interfaces
ENABLING TECHNOLOGY	A solution that simplifies and enables new forms of mobility and new types of vehicles.

Industry went from **Automotive → Mobility.**
Elaphe enables **all** with solutions.

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Components

- Custom development based on requirements
- Industrialized products off-the-shelf

Direct drive motors

- High-torque
- Standard brake integration possible
- Low voltage or high voltage
- Scalable

Power electronics

- Up to 200 kVA (high-performance)
- SW optimized for direct-drive

Multiple-Motor Control / ECU

- Traction control
- Torque vectoring
- Battery power control
- Condition monitoring
- Connected = DATA
- Autonomous-ready

HMI / Infotainment interface

- Driving mode selection
- User interface
- Propulsion control settings

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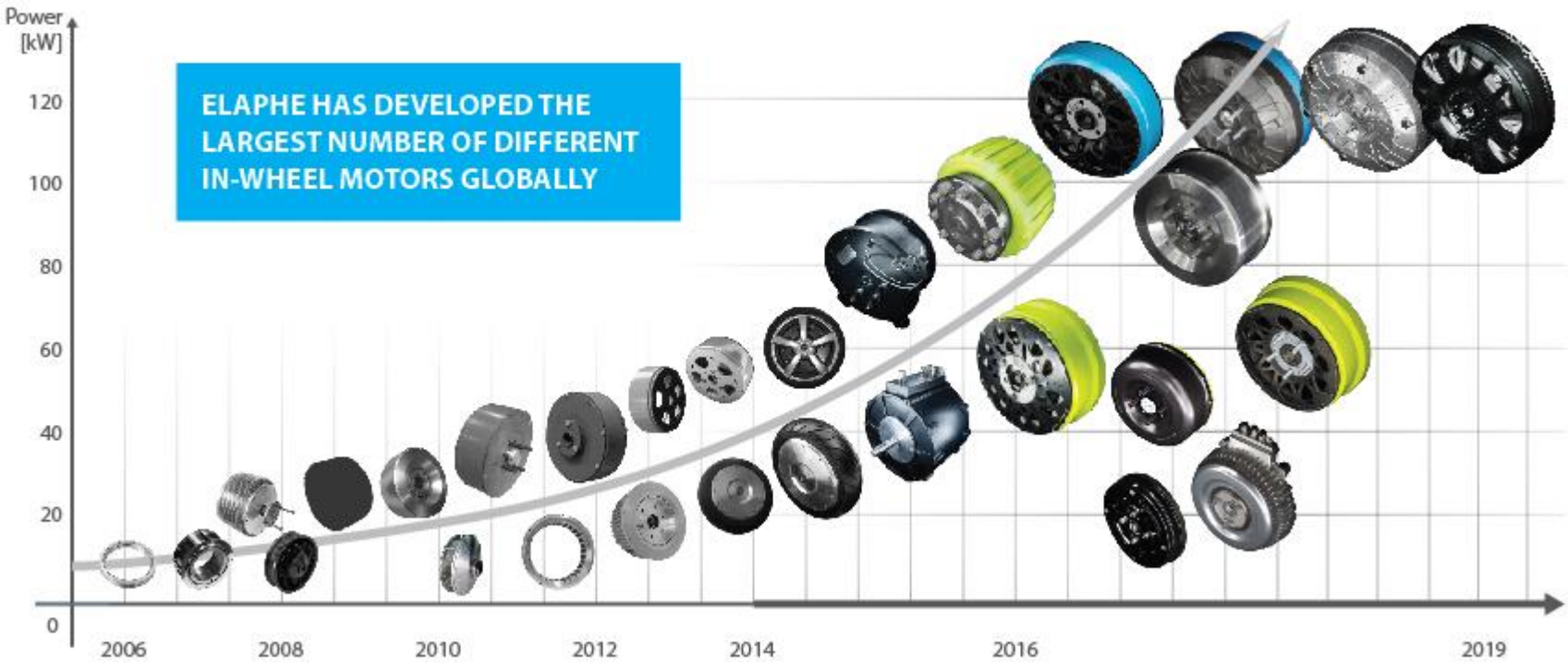
Versatile in-wheel motor design



- Different applications of same product
- Scalable motor design
- Experience with wide variety of motor design (water/air cooling, integrated/on-board inverter, slim/standard bearing, in-wheel/near-wheel motor), etc.

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State-of the-art development with embedded innovations

- **Based on cutting-edge in-wheel technology R&D projects**
- **Delivering the most performant motors in various vehicle segments**
- **Elaphe™ M700 in advanced stage of industrialization, L-type and S-type in design validation**

Elaphe™ S-type	Elaphe™ M-type	Elaphe™ L-type
• 460 Nm peak torque	• 800 Nm peak torque	• 1500 Nm peak torque
• Fits inside 14“ rim	• Fits inside 16“ rim	• Fits inside 19“ rim
• Low voltage (120 V)	• Voltages up to 420 V	• Voltages up to 420 V
• 7“ Drum brake	• Disc and 9“ drum brake versions ready	• Disc brake
• Speed up to 1440 rpm	• Speed up to 1500 rpm	• Speed up to 1260+ rpm

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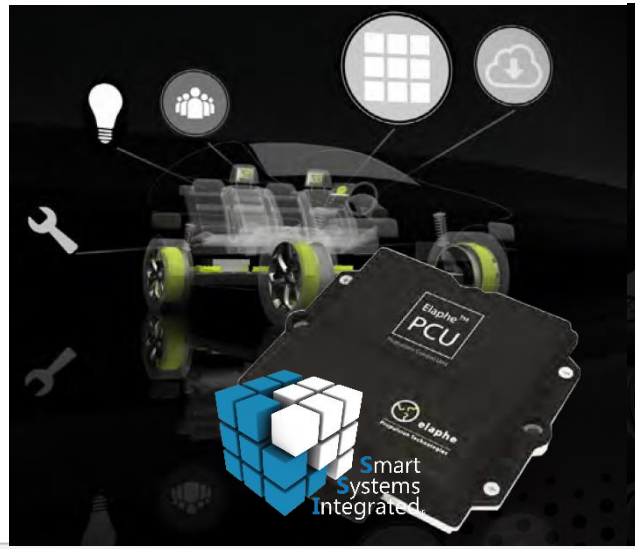
Electronics

Condition monitoring & logging	Torque distribution	Wireless human-machine interface	Intelligent PCU	Elaphe Connected Car module

Multiple Motor Control Unit



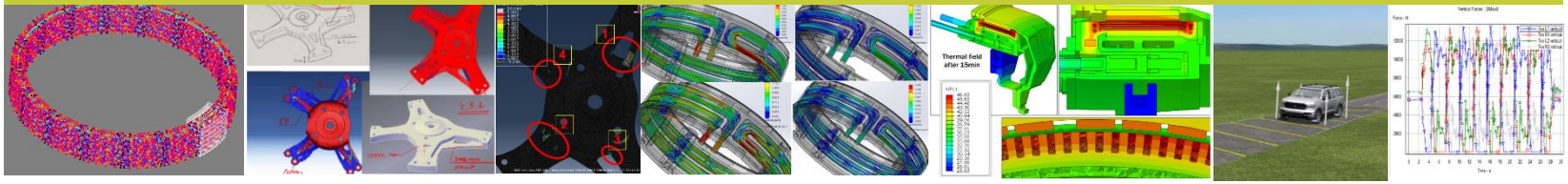
THE POWERBRAIN

MULTIPLE-MOTOR PROPULSION CONTROL

Traction Control	Torque vectoring	Anti-lock regenerative braking system (ARBS)	Configurable motor control	Complete propulsion APIs
Connected & Safely integrated	Battery power control	Condition monitoring	Data logging & Drive analytics	Various driving modes

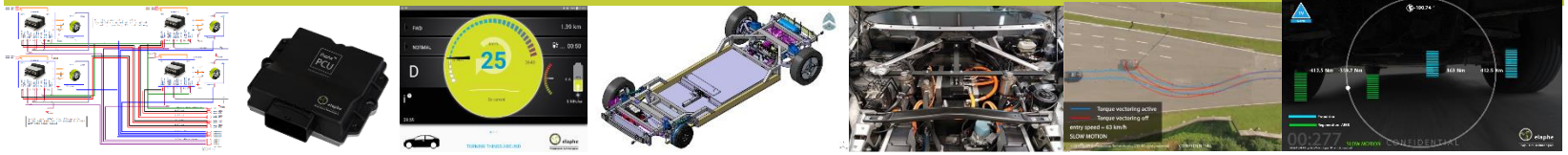
From concept to mass production

Proprietary tool development, product development with state of the art CAE



Standards, requirements, validation plan, validation procedures, execution and analysis

Powertrain control unit, system engineering, vehicle level advanced functions



Production processes, machines and line

COST OF POWERTRAIN COMPONENTs

In-wheel

2x e-motor
2x inverter

Near-wheel

2x e-motor
2x inverter
2x reduction gear

E-axle platform

1x e-motor
1x inverter
1x reduction gear

Rivian

Cons and pros – is there a need?

Higher powertrain BOM cost

Is there a need ?

Durability

Unsprung mass

Front trunk possible

No gearbox

No half-shafts

Advanced maneuvering capabilities

Vehicle energy consumption

SW upgradeable advanced functions add-ons

Weight reduction

Powerful regenerative braking

Short supply chain

Integrated corner possible

No mechanical losses

Packaging - Increased cabin or battery space

Leader in space of the given segment

Direct drive – superior grip control, unbeatable safety pro

Shorter assembly lines

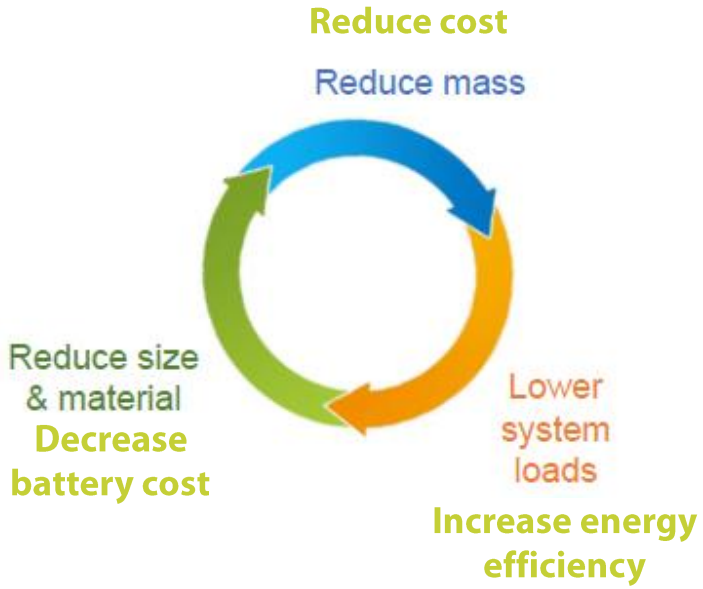
Other

In-wheel powertrain mass benefit

COST CASE:
Used average for large reductions: 10 EUR/kg
Used increased efficiency from less weight: 2-3% (assume 2%)

Total mass saving (single iteration):
- **150 kg powertrain weight reduction @ 2500 kg GVW: -1500 EUR**
- **Reduced battery cost@100kWh range: (-2kWh) - 185 EUR**
- **Additional reduced vehicle weight from reduced battery size - additional 10-14 kg - 120 EUR**

- **TOTAL saving: at least: - 1805 EUR**



E-axle:
Study with two OEM customers for an 4WD SUV shows:

4WD conventional powertrain = 312 kg

weight status BEV

- Current weight for powerunit incl. side shafts and mounts:

e-motor/gearbox/inverter front	130 kg	158 kg
side shaft front	16 kg	
mounts/brackets for e-powerunit front	12 kg	
e-motor/gearbox/inverter rear	130 kg	154 kg
side shaft rear	16 kg	
mounts/brackets for e-powerunit rear	8 kg	
total	**312 kg**	

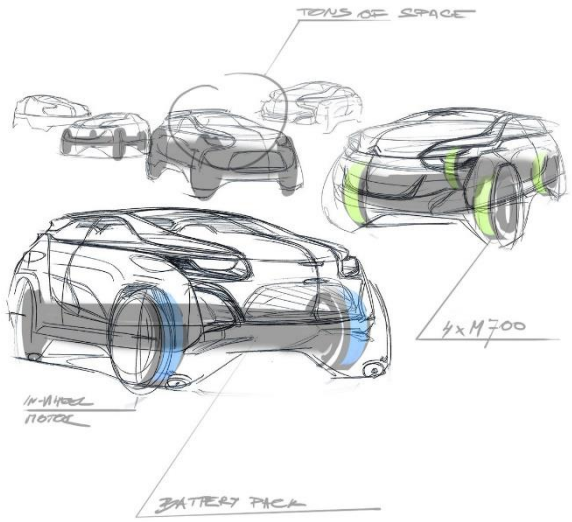
In-wheel motor powertrain:
Study with two OEM customers for an 4WD SUV shows:

4WD in-wheel powertrain = 150 – 160 kg

Weight status BEV
- Current weight for power unit

Front motors and inverters	76 kg
Rear motors and inverters	76 kg
Total	**152 kg**

Packaging – parts (in-wheel)



COST CASE:

On-board volume cost:	0,7 EUR / liter
E-axle volume:	300 liter / axle x 2 axles
IWM volume:	15 liter / axle x 2 axles

- **Lower outer vehicle dimension for same interior**
- **Better battery packaging and safety options**
- **Lower vehicle weight by at least 100 kg**
- **Lower cost of battery, increased efficiency**

COST CASE:	**SAVING**
• Volume cost (body + chassis):	**- 400 EUR**
• Reduced weight @10 EUR/kg:	**- 1000 EUR**
• Reduced battery cost@100kWh range:	- 1 kWh
• Battery pack cost 111 USD/kWh	**- 93 EUR**
• Battery weight: 5-7 kg/kWh (assume 5 kg/kWh)	- 5 kg
• Used average for large reductions: 10 EUR/kg	**- 50 EUR**
• **TOTAL saving:**	**at least: - 1543 EUR**

Continental

Continental study of space-saving technologies (small crash zones, in-wheel motors…) showed than an interior size of VW Golf can be achieved in the outer dimension of VW Up. So the difference is two classes of vehicle types. (Golf – Polo - Up).

Elaphe propulsion mule car conversion: Removed 565 kg of original drivetrain

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Cycle Energy efficiency (not including weight benefits)

COST CASE: **SAVING**

- >2% better IWM overall efficiency
- Reduced battery cost@100kWh range: - 2 kWh
- Battery pack cost 111 USD/kWh **- 185 EUR**
- Battery weight: 5-7 kg/kWh (assume 5 kg/kWh) - 10 kg
- Used average for large reductions: 10 EUR/kg **- 100 EUR**

- **TOTAL saving: at least: - 285 EUR**

Battery losses	2%
Inverter efficiency	8%
Motor efficiency	7%
Transmission	3%

Simulated EV Power Consumption

Source: Drive System Design Ltd. (drivesystemdesign.com)

E-axle losses:

- 1-5 % inverter minimal losses
- 4-10% electric motor minimal losses
- 2-8 % transmission minimal losses
- ---
- TOTAL: 78 – 93 % e-axle efficiency @ OPTIMAL PEAK

IWM losses:

- 1 - 5% inverter minimal losses
- 6-9 % motor minimal losses (inc. seal friction)
- 0 % transmission losses
- ---
- TOTAL: 86 – 93 % IWM axle efficiency @ OPTIMAL PEAK

Up to 8% better peak efficiency of IWM axle vs. e-axle!

Study with two OEM customers for an 4WD SUV shows:
E-axle: 4WD conventional powertrain efficiency = 83%@WLTP
IWM: 4WD IWM powertrain efficiency = 85%@WLTP

Power electronics, boost converter	96-99%	Lower conversion efficiency for higher voltage steps	
Power electronics, DC/AC converter	Peak 95-99%	Higher voltage and lower switching frequency give higher efficiency.	SiC power electronics (Ch. 3) with very high conversion efficiency > 99%
Electric motor/ generator	Peak 90-96%	Lower conversion efficiency at either low torque or low speed. Higher voltage and motor speed give higher efficiency.	Considerable loss reduction unlikely. Trade-off with cost, size and materials' availability.
Transmission	92-98%	Avoiding gearbox increases efficiency. High motor speed may require reduction gear. Differential necessary if not in wheel motors.	Elimination of transmission by in-wheel motors possible development
Total driveline	Peak eff. = 73-88%. Instant efficiency is the product of driveline component efficiencies, which vary with working point	Depends on the technology as well as the driving pattern. Avoidance of high speeds and frequent and strong accelerations/decelerations will increase efficiency.	The driveline involves many conversions between components, each with high efficiency, which need to be, and can be, even more efficient

Source: System Perspectives on Electromobility, Chalmers University of Technology, Sweden

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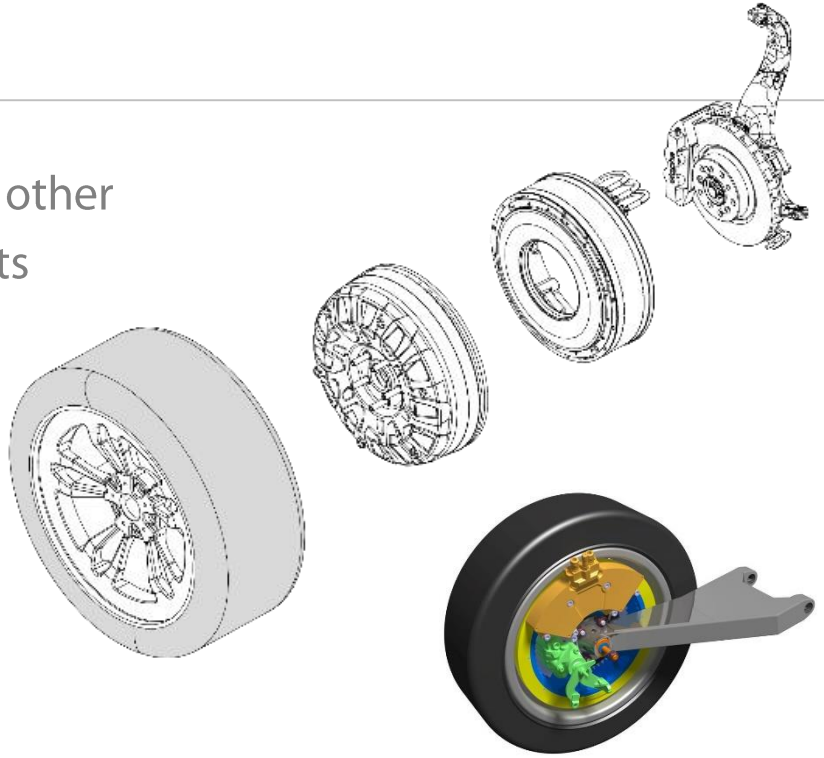
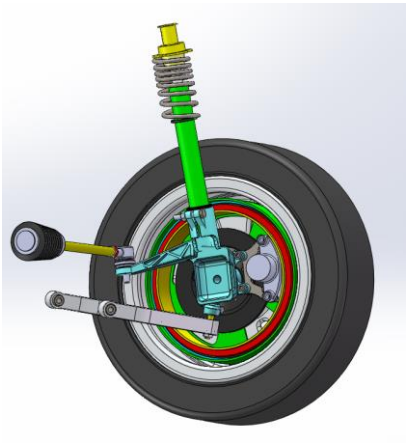
Other financial and cost benefits

- Torque vectoring, lower center of gravity and other performance and safety improvement benefits
- Vehicle development cost reduction
- Strong regenerative braking
- Ground clearance increase
- Advanced steering and redundancy
- Modularity of IWM platform
- Chassis simplification
- Powertrain modularity
- Shorter vehicle assembly line
- Lower investment into production line
- Supply chain savings



TOTAL saving: 1500 EUR



How to combine this data, know-how?

GOALS and ASSUMPTIONS

- Qualitative -> Quantitative
- Rough estimations
- Combination of drawbacks and benefits
- Averages for the early majority
- Time: State of the Art -> implemented in the future

The mathematical model

INPUT

- Cost
- OEM need
- Mass
- Space
- Efficiency
- Other
- @ different Vehicle types
- & changing with time (years)

	A	B	C	D	E	F	G
1		CostDiff	Need	Mass	Space	Energy	Other
2	year			1,6	1,5	0,3	1,5
3	2010,0	-20,00	-10,00	0,00	0,00	0,00	0,10
4	2015,0	-10,00	-5,00	0,00	0,00	0,10	0,20
5	2018,0	-5,00	-4,00	0,10	0,00	0,20	0,23
6	2019,0	-3,00	-2,00	0,15	0,00	0,30	0,26
7	2020,0	-2,00	-2,00	0,20	0,10	0,40	0,30
8	2021,0	-1,50	-1,00	0,25	0,15	0,50	0,32
9	2022,0	-1,20	-1,00	0,30	0,20	0,60	0,34
10	2023,0	-1,00	-1,00	0,35	0,25	0,65	0,36
11	2024,0	-1,00	-0,50	0,40	0,30	0,70	0,38
12	2025,0	-1,00	-0,50	0,45	0,35	0,75	0,40
13	2030,0	-1,00	0,00	0,60	0,40	0,85	0,50
14	2035,0	-1,00	0,00	0,70	0,45	0,90	0,60
15	2040,0	-1,00	0,05	0,80	0,60	0,95	0,70
16	2045,0	-1,00	0,10	0,90	0,70	1,00	0,80
17	2050,0	-1,00	0,10	1,00	0,80	1,00	0,90

	A	B	C	D	E		
1		CostDiff	Need	Mass	Space	Er	
2	year			0,4	0,5		
3	2010,0	-5,00	-10,00	0,00	0,00		
4	2015,0	-4,00	-5,00	0,00	0,00		
5	2018,0	-2,00	-2,00	0,10	0,00		
6	2019,0	-1,00	-1,80	0,15	0,00		
7	2020,0	-0,80	-1,60	0,20	0,10		
8	2021,0	-0,40	-1,40	0,25	0,15	0,50	0,32
9	2022,0	-0,38	-1,30	0,30	0,20	0,60	0,34
10	2023,0	-0,36	-1,20	0,35	0,25	0,65	0,36
11	2024,0	-0,35	-1,10	0,40	0,30	0,70	0,38
12	2025,0	-0,35	-1,00	0,45	0,35	0,75	0,40
13	2030,0	-0,35	-0,50	0,60	0,40	0,85	0,50
14	2035,0	-0,35	0,00	0,70	0,45	0,90	0,60
15	2040,0	-0,35	0,05	0,80	0,60	0,95	0,70
16	2045,0	-0,35	0,10	0,90	0,70	1,00	0,80
17	2050,0	-0,35	0,10	1,00	0,80	1,00	0,90

8	2021,0	-3,00	0,00	0,30	0,80	0,50	0,32
9	2022,0	-2,00	0,00	0,35	0,90	0,60	0,34
10	2023,0	-1,50	0,00	0,38	1,00	0,65	0,36
11	2024,0	-1,50	0,00	0,40	1,00	0,70	0,38
12	2025,0	-1,50	0,10	0,45	1,00	0,75	0,40
13	2030,0	-1,50	0,10	0,60	1,00	0,85	0,50
14	2035,0	-1,50	0,10	0,70	1,00	0,90	0,60
15	2040,0	-1,50	0,10	0,80	1,00	0,95	0,70
16	2045,0	-1,50	0,10	0,90	1,00	1,00	0,80
17	2050,0	-1,50	0,10	1,00	1,00	1,00	0,90

IN-WHEEL MOTOR BASED PLATFORM

Prepare for uncertainty
Leverage partnerships
Drive transformational change
Redefine the value proposition

Thank you!

CONTACT

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