

Beyond the Drivetrain: Motor Innovation in Electrified Off-Highway machinery

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Introduction to Danfoss



Three **business segments** geared for growth



Danfoss Power Solutions

- EUR 4.1bn annual sales
- 16,101 employees

43%
of Group
sales



Danfoss Climate Solutions

- EUR 3.1bn annual sales
- 11,039 employees

32%
of Group
sales



Danfoss Power Electronics and Drives

- EUR 2.4bn annual sales
- 7,868 employees

25%
of Group
sales



We continue to invest in building leading positions in our three segments

Power Solutions

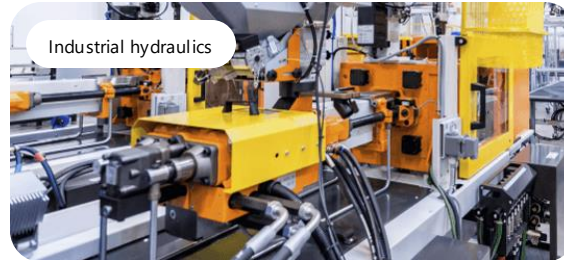
Construction machinery



Agriculture and autonomous machines



Industrial hydraulics

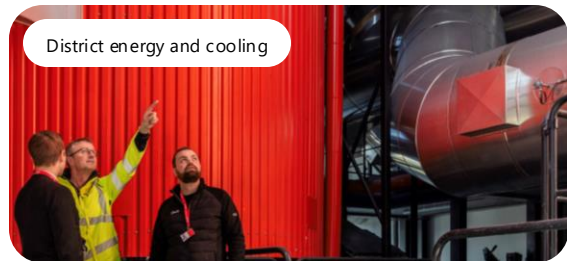


Full-electric excavators



Climate Solutions

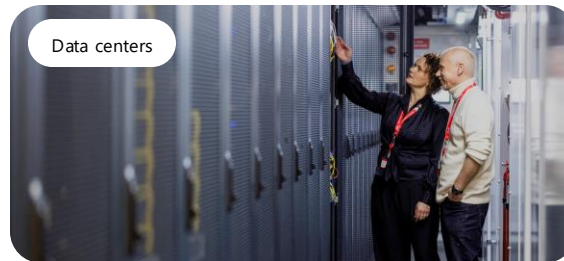
District energy and cooling



Heat pumps



Data centers

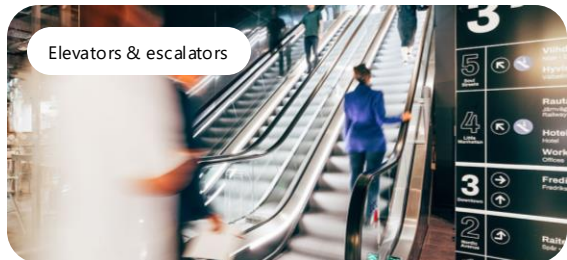


Connected supermarkets

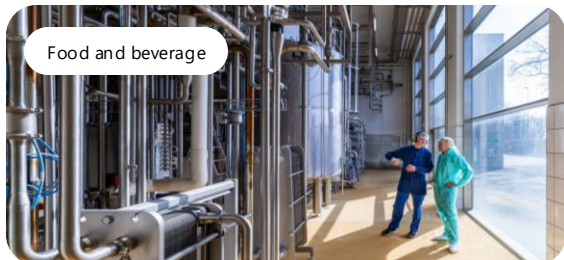


Power Electronics and Drives

Elevators & escalators



Food and beverage



Services



Marine electrification



Electrification portfolio for Off-Highway



Dedicated Off-Highway eSolution portfolio



1. eHydraulics

- Matching eMotor and hydraulic pumps
- Design flexibility
- Improved system efficiency

2. eMechanics

- Traction solution with axle and gearbox
- Highest productivity and efficiency
- Shorter time-to-market

3. PLUS+1 eSolutions

- PLUS+1® compliance blocks
- eWorkFunction software for eHydraulics
- Electric traction and power management

Editron offering

Full electric and hybrid systems

Editron offers full system solutions across various voltage platforms, including eDrives, Power Conversions, eHydraulics, and Vehicle Controls.

1kW-6000kW

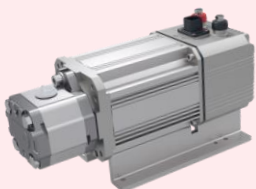
System power

24v-850v

Voltage platform

Low voltage solutions

ePowerpack



eDrive

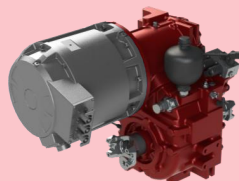


High voltage solutions

Motors & converters



eTraction solution



ePump solution



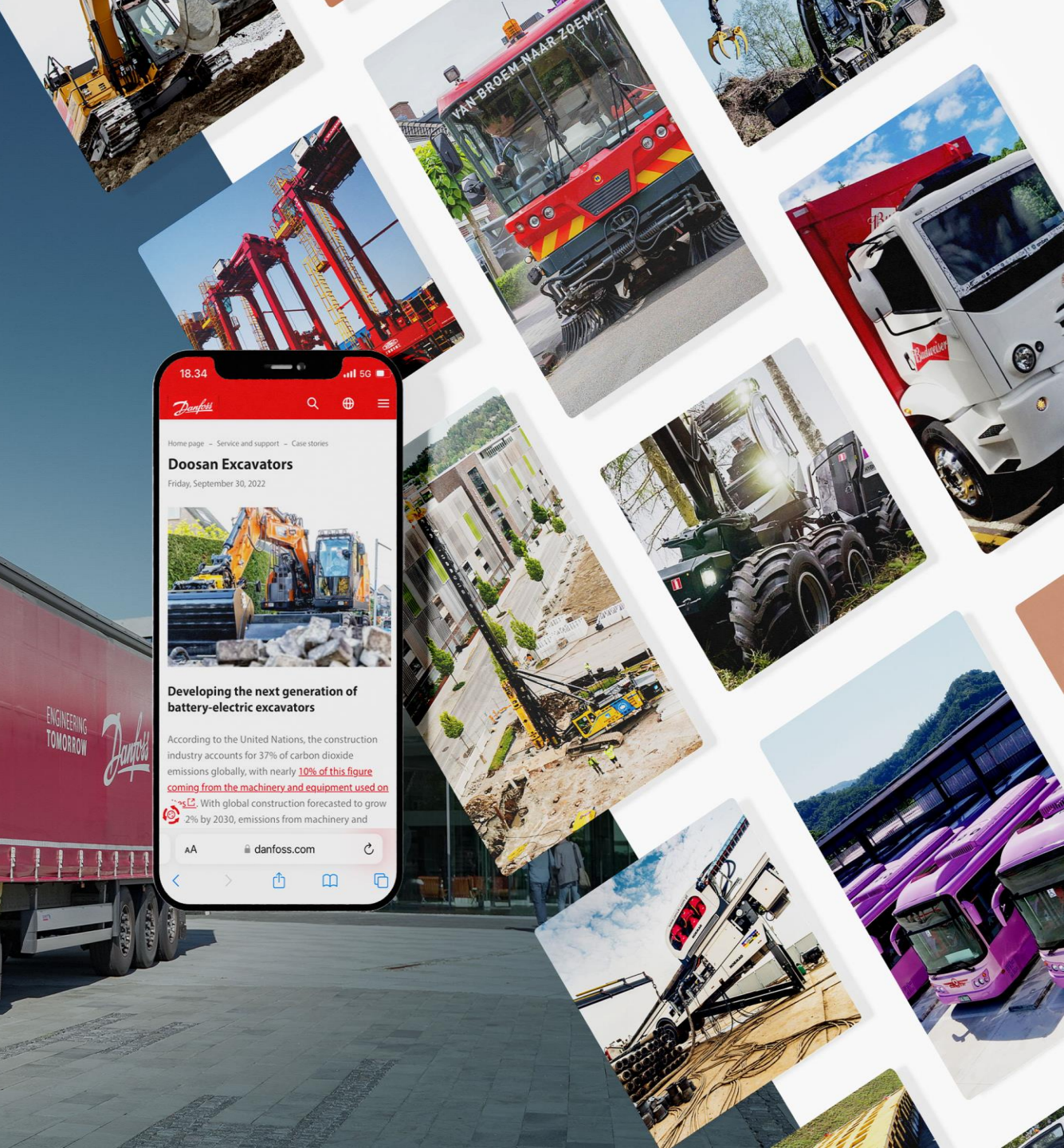
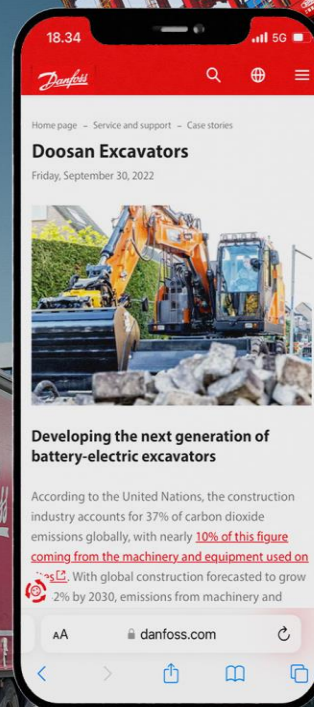
Power charging solutions

ED3 on-board charger



100+

Success Stories in electrification



Status quo of electrification in Off-Highway



Off-Highway: Electrification platform trends

Current



- Compact equipment
- Low duty operation
- Existing charging infrastructure



Short-term



- Mid-size utility & confined equipment
- Intermittent duties
- Incremental infrastructure changes



Mid/Long-term

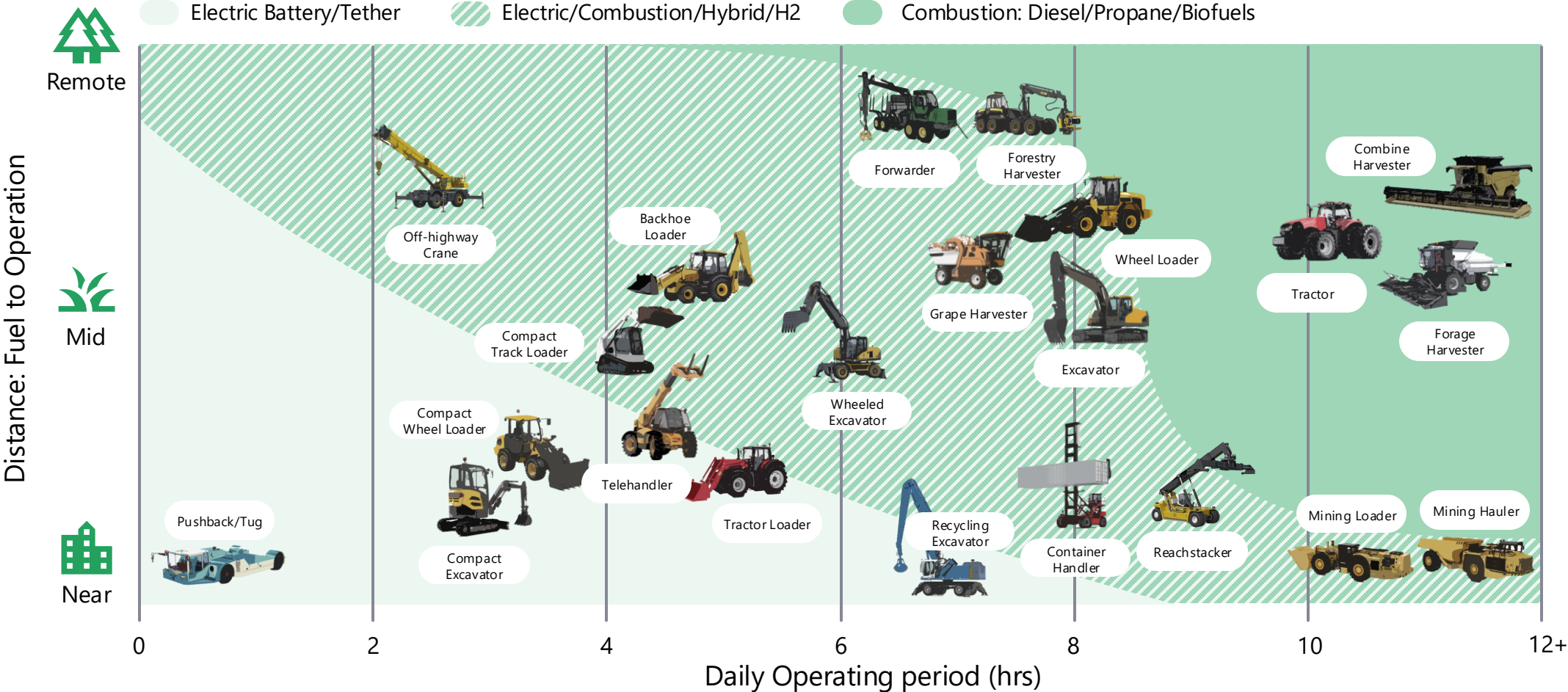


- Large platforms, independent operation
- High utilization, multi-shift
- Limited charging options/infrastructure



Voltage / Power / Runtime

Off-Highway: Powertrain platform trends



Barriers of electrification adoption in Off-Highway



TCO



Electric vehicles are more expensive, but operating costs lower. Customers expect an ROI of 1-2 years.

Vehicle and system complexity



Battery or hybrid-electric vehicles require new technologies and products. Not every sub-system is optimized yet.

Different vehicle types



Off-Highway vehicles with differences in size, duty cycle, use case, and varying requirements in architecture, robustness.



Charging infrastructure

Lack of charging power and charging infrastructure.



HV provisions

Electrification requires new competencies and skills.



Operating time

High energy demand requires higher battery energy capacity to operate machine for a full shift of 8 hours.

Simplifying system complexity – System-level



Electrification is changing the supplier landscape



	Past	Today	
Hydraulic			Rationale • Off-Highway suppliers started to integrate electrification to offer full systems • Trend towards higher level of integration to improve cost, power density, size • New partnerships to reduce complexity • Off-Highway electrification still in the infancy, but will continue to standardize in next years • Dedicated product portfolio development for Off-Highway (duty cycle, robustness, installation space)
Mechanic			
Engine			

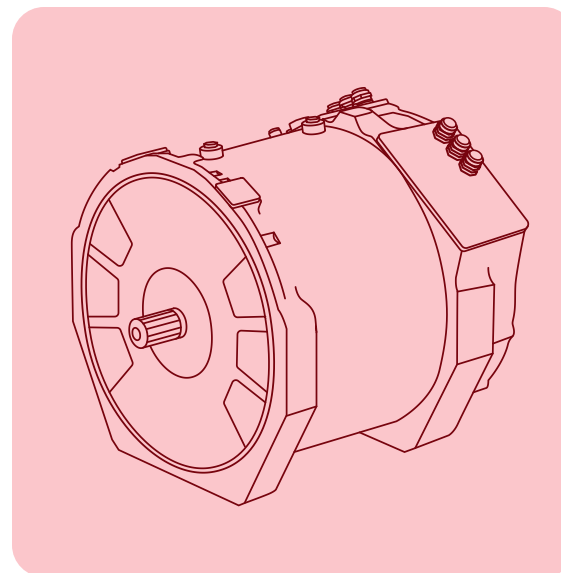
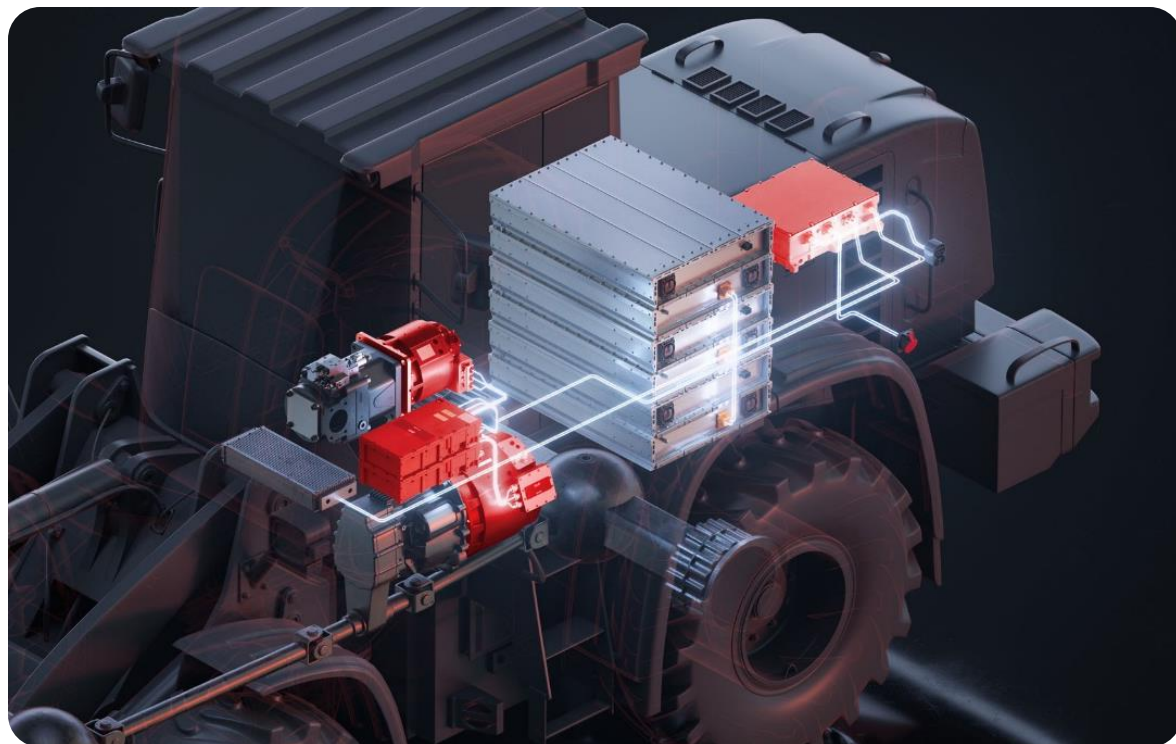
Sub-systems simplify system integration

Product overview

Power electronic products

Electric machines

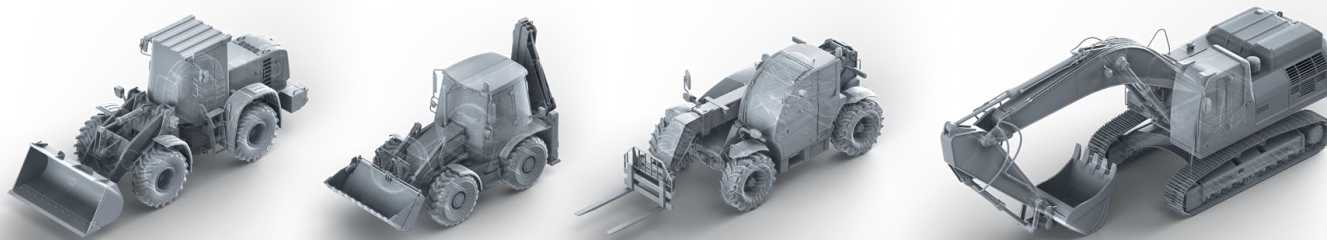
Sub systems



eMechanical solutions for traction



- Fully engineered, integrated & validated traction solutions
- Flexible architecture, common controller w/ integrated shifting
- Improved efficiency, productivity, & safety
- No torque interruption – SynchroShift & PowerShift
- Full SW capability - enables advanced vehicle controls

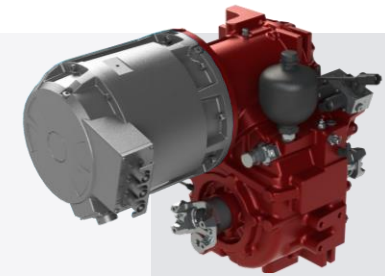


EC-C Inverter

Electric



EC-C Inverter



EM-PMI Motor



SynchroShift



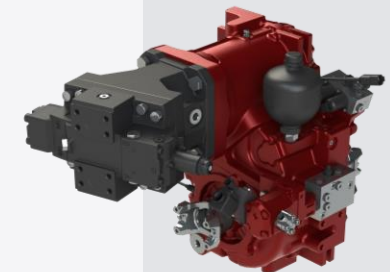
CARRARO



Hydrostatic



H1P Pump

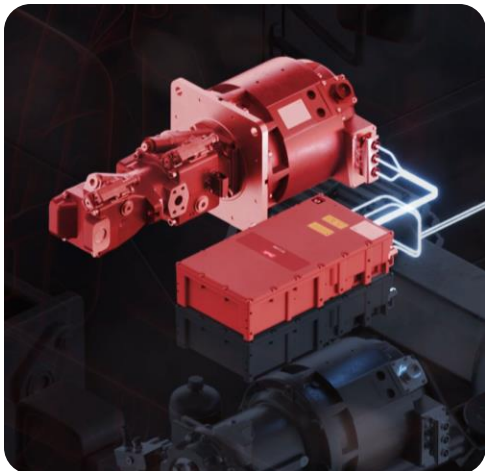
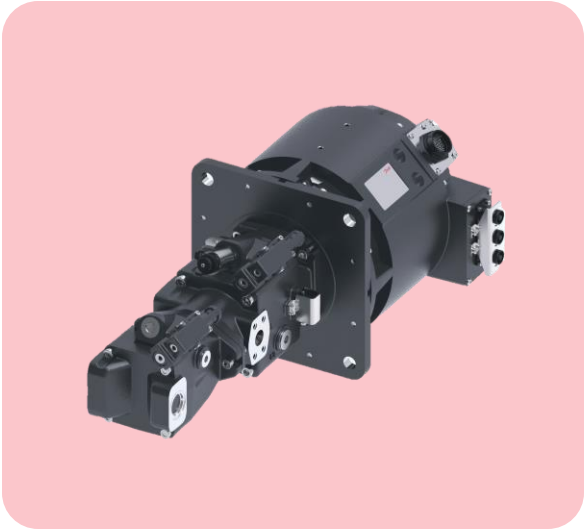


H1B Motor



260 PowerShift

Electrified hydraulics for work function



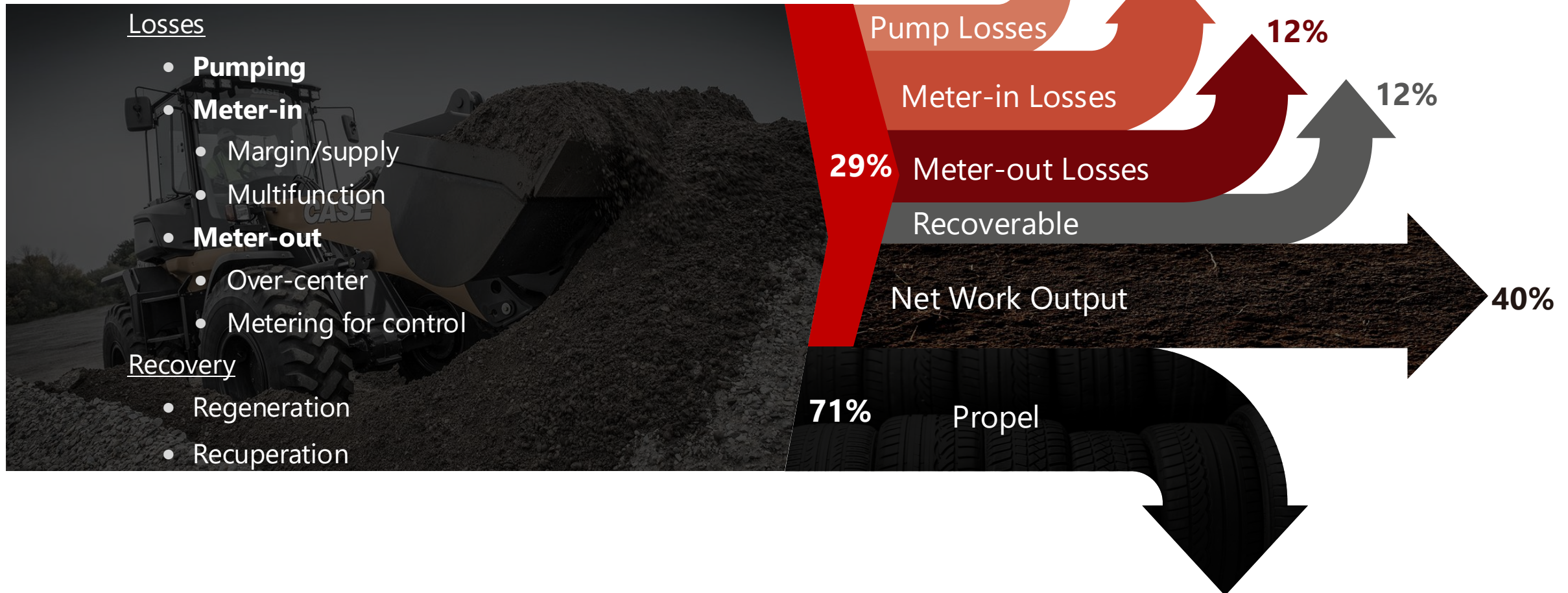
Motor Type	SRPM Technology Synchronous Reluctance assisted Permanent Magnet
Power	up to 303 kW
Nominal Voltage	500 VAC
Maximum Speed	4000 RPM
Pump Types	Axial Piston, Bent Axis, Gear, Vane, Tandem
Displacements	18-260 cc
Flow	up to 600 lpm
Pressure	up to 350 bar
IP Rating	IP65 (IP67 Option)

Improving system efficiency to improve TCO

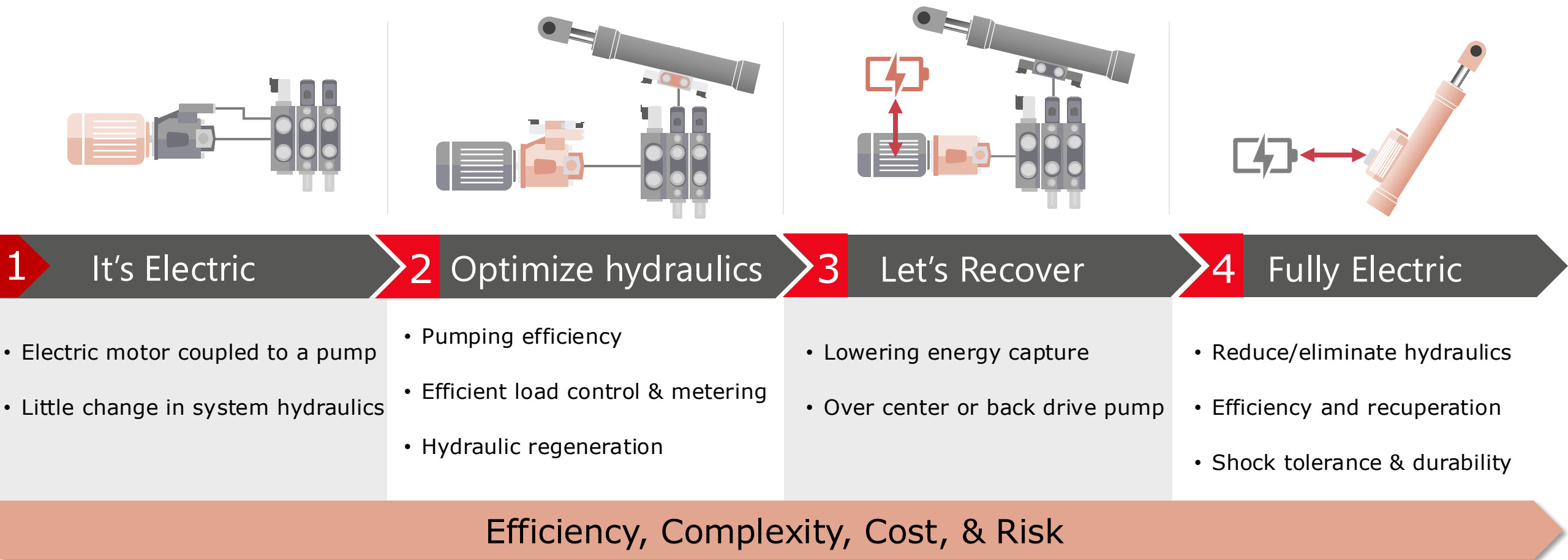


Wheel loader: System efficiency example

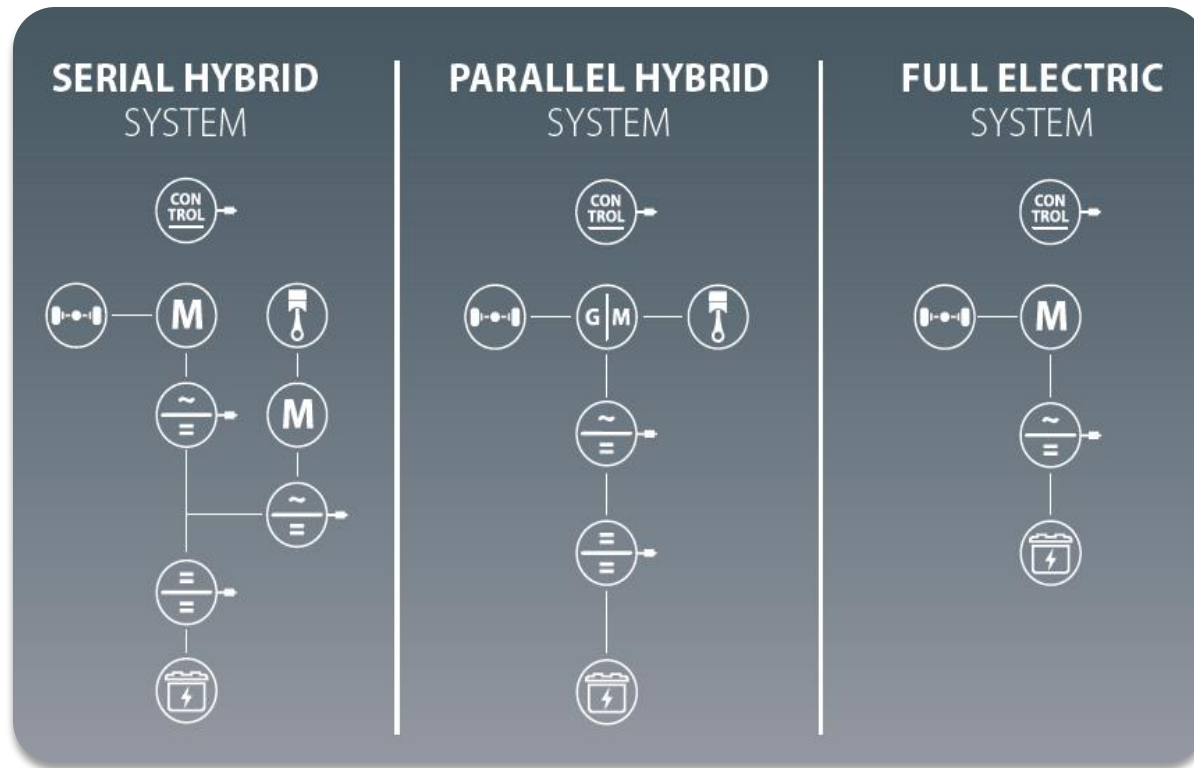
- Baseline hydraulics work well, but are inefficient



Off-Highway: Machine journey for work function



Architecture options for Off-Highway machinery



Serial/Parallel-hybrid | Full electric

Architecture is selected based on:

- **Legislation** - Zero/partial emission operation
- **Cost** - Initial investment vs lifetime cost
- **Time to market** - Retrofit vs redesign
- **Goals** - Fuel saving, performance, emissions or TCO reduction

Why the electric motor play's critical role?



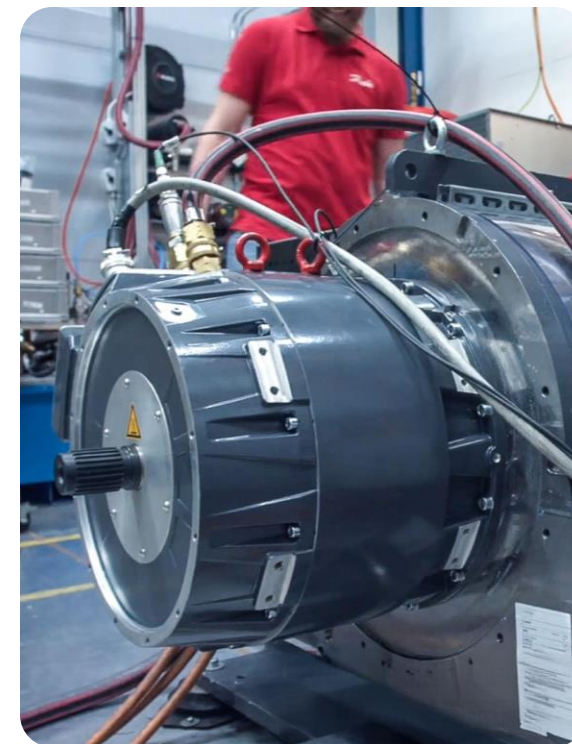
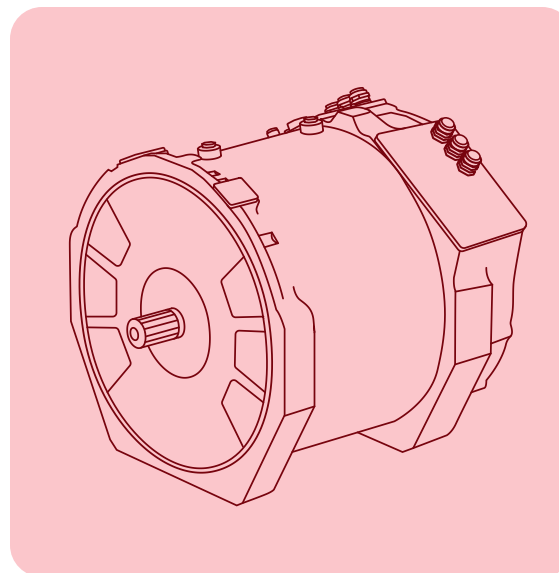
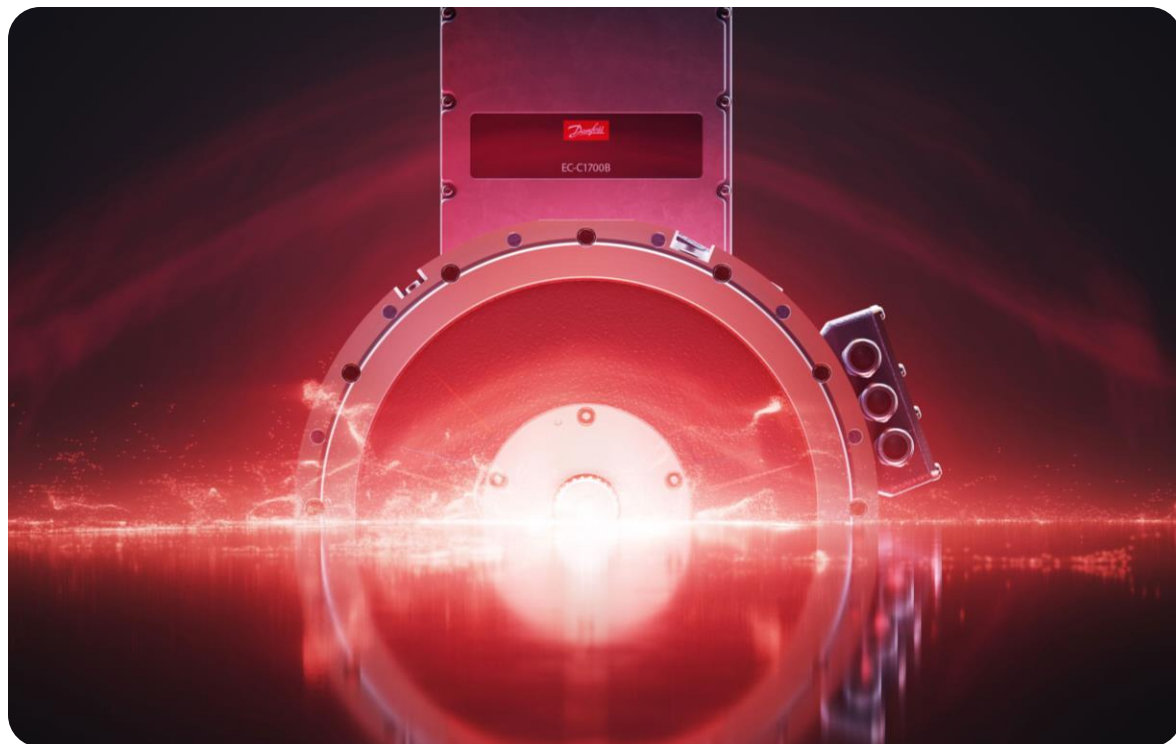
Electric Machines

Product overview

Power electronic products

Electric machines

Sub systems



Wide motor range required for Off-Highway



Electric machines

Electric machines from 30 kW up to 6 MW



EM-PMI240-T180



EM-PMI318B *



EM-PMI300-T310 *



EM-PMI375-T200



EM-PMI375-T500



EM-PMI375-T800



EM-PMI375-T1100



EM-PMI540B-T1500



EM-PMI540B-T2000



EM-PMI540B-T3000



EM-PMI540B-T4000



EM-PMI580 *



EM-PMI880 *



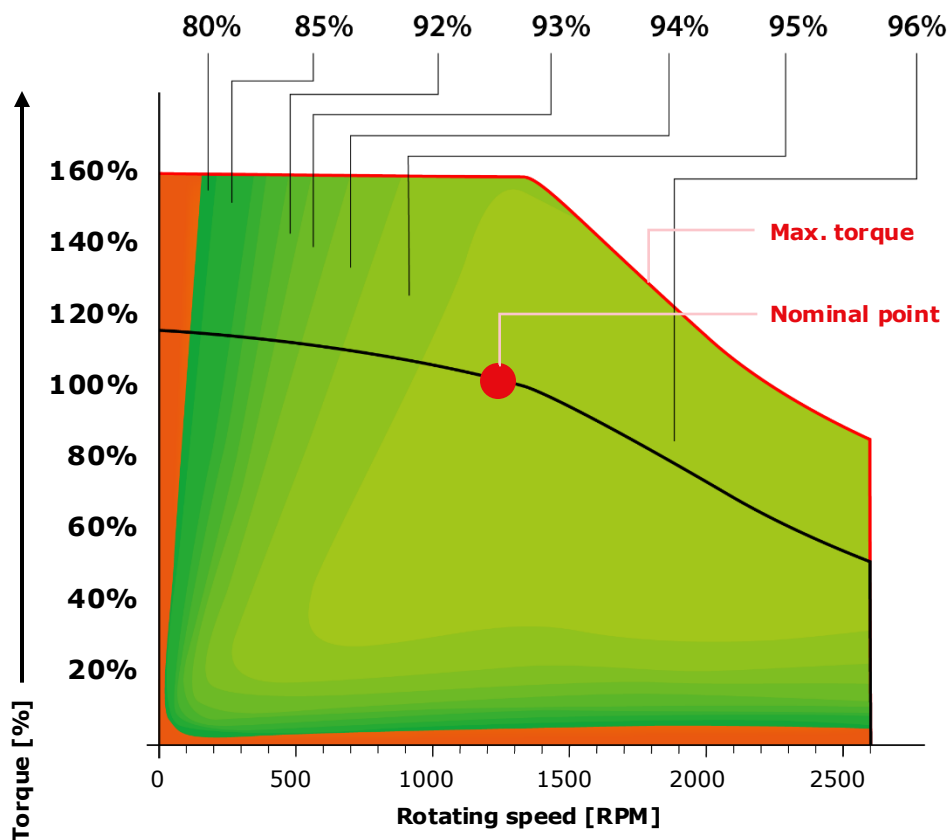
EM-PMI1240 *



Restricted Sales

Electric motors – Technology development (SRPM)

Efficiency optimization and improved power density to enable electrification



- High efficiency on wide operating range
- Loads are usually cyclic and machines are operated at different speeds and torque loads
- Efficiency should be looked over the whole operation and not only from one operation point
- Higher efficiency: **less batteries** or **less fuel** for same operation

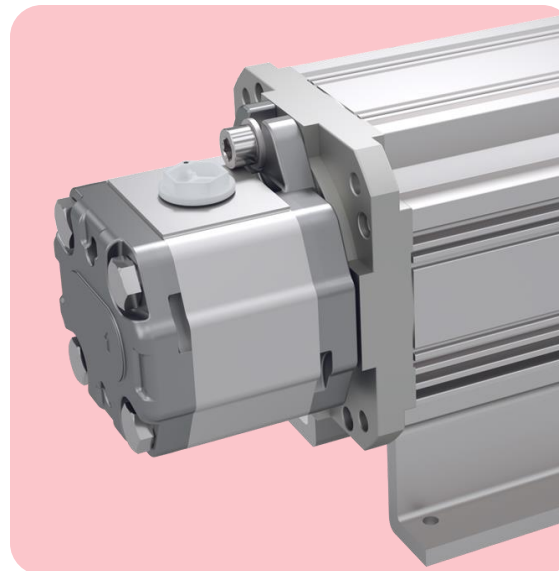
Low voltage portfolio

Product overview

Power electronic products

Electric machines

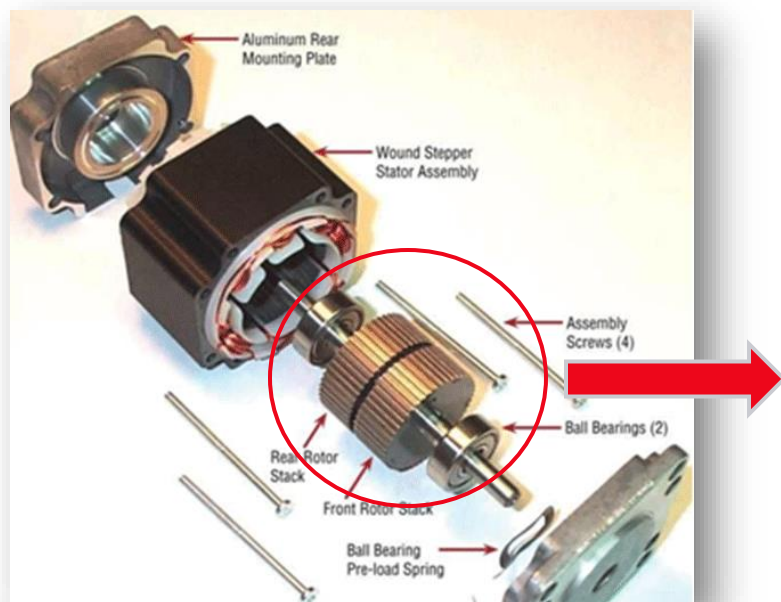
Sub systems



Value Proposition | PMSM technology brief introduction



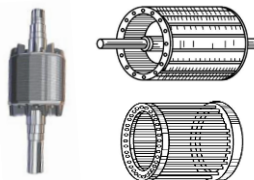
All Editron Low Voltage products exclusively adopt PMSM technology



ACIM: wound rotor



ACIM: squirrel-cage rotor



PMSM: Interior PM rotor



PMSM advantages over ACIM:

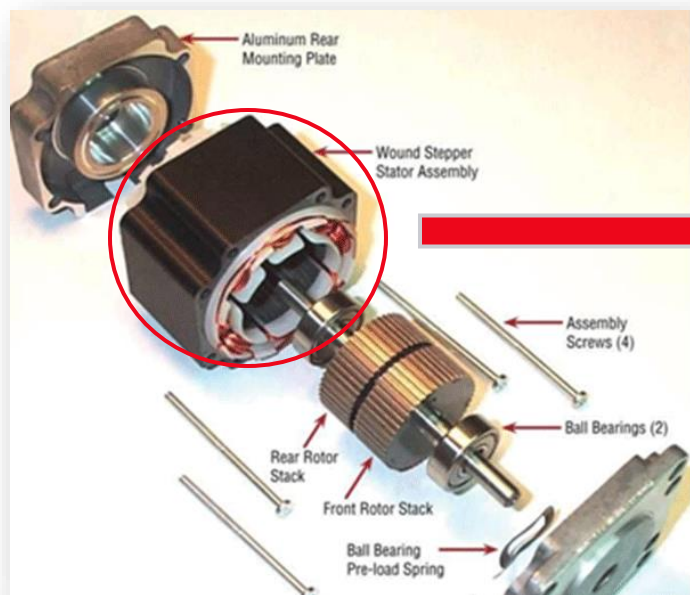
1. Higher overall system efficiency -> less battery/longer range
2. Higher power density -> Compact size
3. High precision speed control
4. Fast dynamic response

Image sourced from the internet, for internal learning purposes only.

Value Proposition | Hair-Pin technology brief introduction



All newly-developed Low Voltage motors adopt Hair-Pin (flat-wire) winding technology.



Round-wire stator



Hair-Pin (flat wire) stator



Hair-Pin advantages over Round Wire:

Thanks to the rectangular copper-wire design, the flat-wire motor packs more copper into the same space, delivering a higher slot-fill factor (+20%). As a result:

1. Higher efficiency
2. Higher torque
3. Faster heat dissipation

The barriers of Hair-Pin vs. Round-Wire

1. Greater design complexity
2. More demanding manufacturing processes
3. High upfront equipment investment

Image sourced from the internet, for internal learning purposes only.

Target Application Sample | Scissor lift



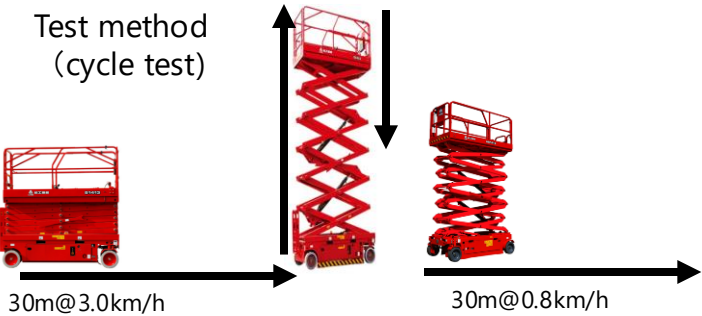
Higher Efficiency

20%+

Efficiency improvement compared with ACIM and DC Motor

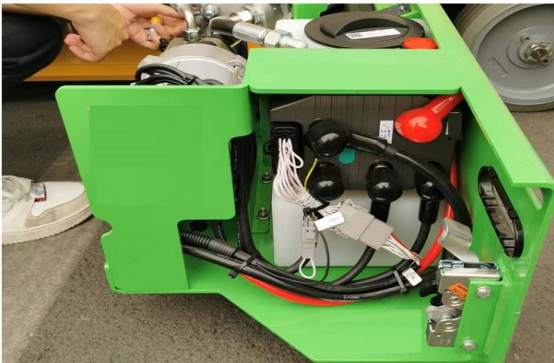
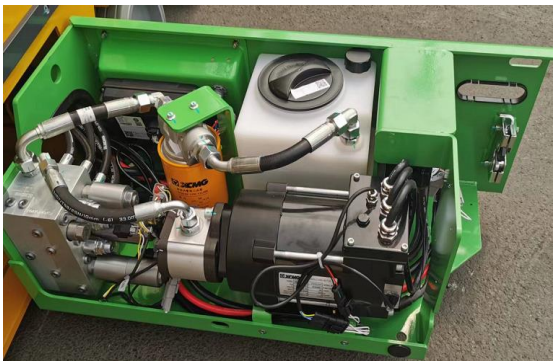
- Longer working time
- Reduce battery capacity
- Extent battery life cycle
- Decarbonation

Solution	Li Battery	Cycle times
AC motor	210Ah	40
Danfoss EP130	173Ah	42



More Compact

Competitor AC Solution



Danfoss Solution



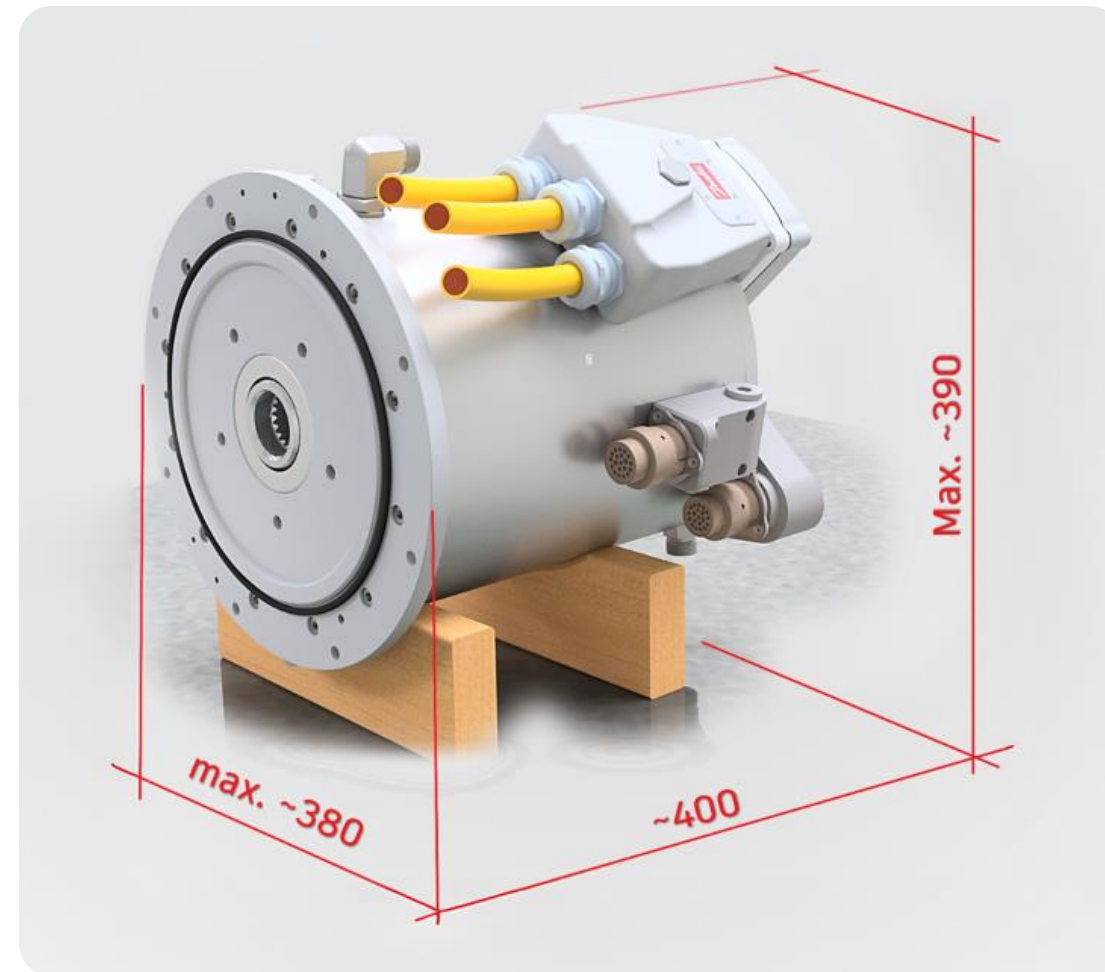
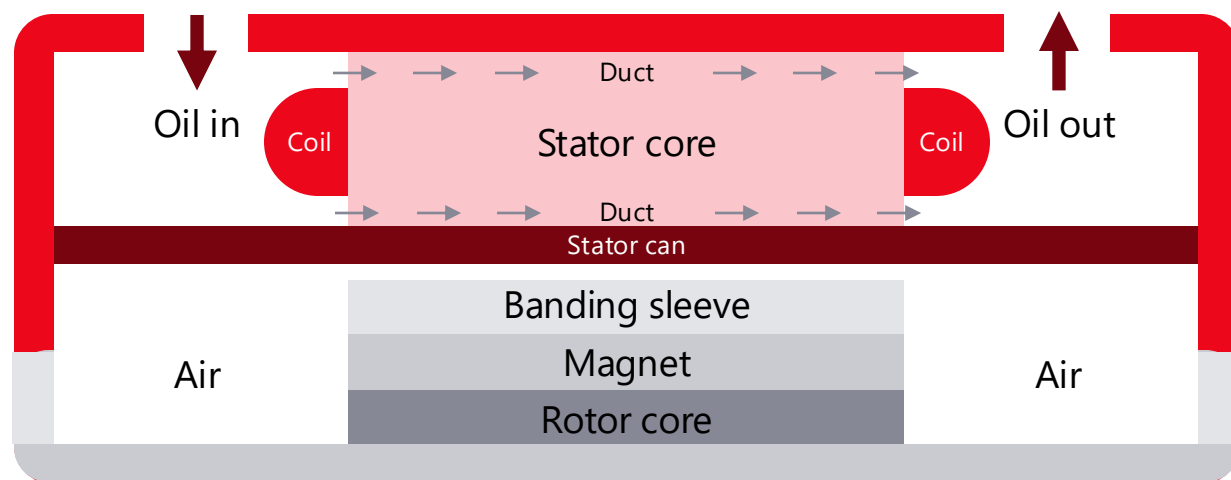
What's next in technology?



Editron Motor Technology

Next Generation State of The Art

- Direct Liquid Cooling (DLC), e.g. oil, current densities up to 20-25 A/mm²
- 800 V hairpin winding technology
- Improved utilization of the slot area
- Design for Automation
- Added rotor reluctance, reduction in the permanent magnet content
- Power comparable to an equivalent rated water-jacket cooled motor in ~1/3 of the size



Electric Motor Technology

Introduction

- Current State of The Art
- Next generation State of The Art
 - Advances in power and torque density (hairpin winding)
 - Advances in cooling technologies (Direct Liquid Cooling)
 - Advances in manufacturing technologies (Design for Automation)
- Performance comparison
 - Water-jacket vs. Direct Liquid Cooled
- Magnet free solutions
 - Synchronous Reluctance (SyRM)



System-level development & Scalability





Together we succeed

Our ADCs are ready to
accelerate your business wins.

90%

of machine
conversions led
to business wins



Developing



Remodeling



Testing



Validating



Demonstrating



