AUMOVIO
Engineering
Solutions

The race for electrification technology advancement

To the track & back?

AUMOVIO Engineering Solutions, Neil Cheeseman

9/18/2025

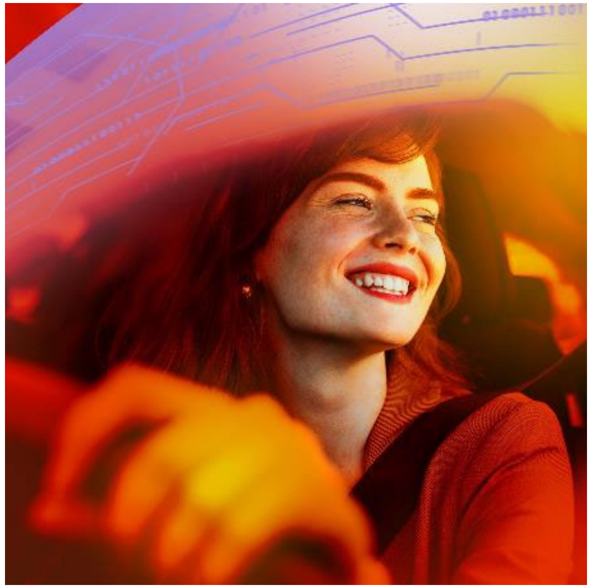
www.engineering-solutions.aumovio.com

AUMOVIO's purpose
We make mobility...

Safe

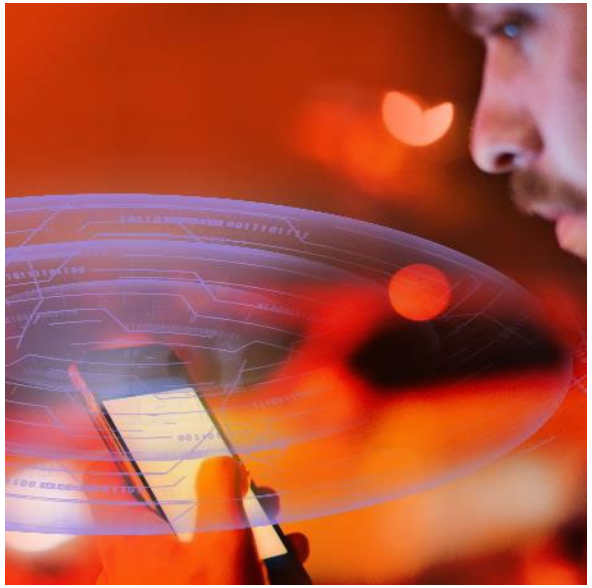
On the road—we have the right safety solutions.

Exciting



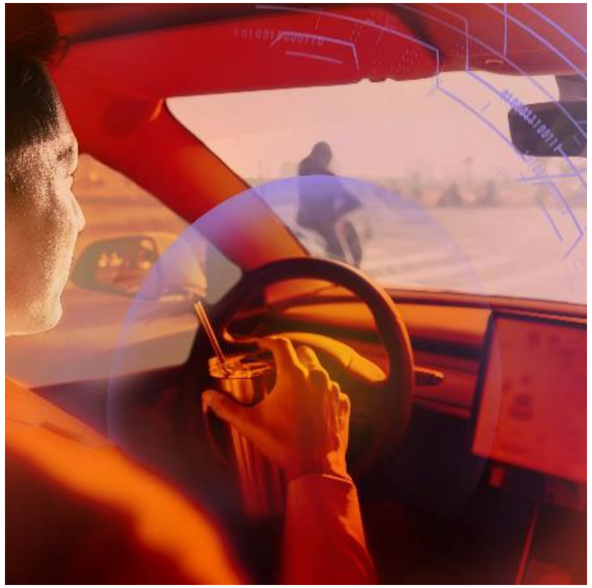
Perfect functions that inspire customers.

Connected



Modular systems and agile delivery.

Autonomous



Innovative solutions for the road to automated driving.

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AUMOVIO's business areas
Home of our expertise

Autonomous Mobility (AM)

Pioneering the autonomous future

~16%[1]

Architecture and Network Solutions (ANS)

Enabler of value driven architectures

~28%[1]

Safety and Motion (SAM)

Efficient safety powerhouse

~38%[1]

User Experience (UX)

The exciting differentiator

~17%[1]

1. AUMOVIO Group Sales 2024 based on the Consolidated Financial Statements of Automotive for the financial year ended December 31, 2024; segment sales share based on AUMOVIO Group sales. | The segment Contract Manufacturing (CM) is not part of AUMOVIO's core operational business and is not intended to be a permanent Business Area. The segment is expected to be terminated in full in 2026. Therefore, CM is not shown as a business area

CTO Organization
AUMOVIO Operations and Technology (AOT)

Managing every phase of the product life cycle is key to mastering market challenges and speed

Innovation → Development → Industrialization → Sales Production → Service/ Maintenance

Research and Development + Operations[1]

Artificial Intelligence & Digital Transformation

Inhouse Semiconductor Fabless Solutions

Innovation
(internally or via start-up catalyst co-pace)

Supply Chain Management

Intellectual Property & Sustainability

AUMOVIO Engineering Solutions (AES)

1. Includes footprint optimization.

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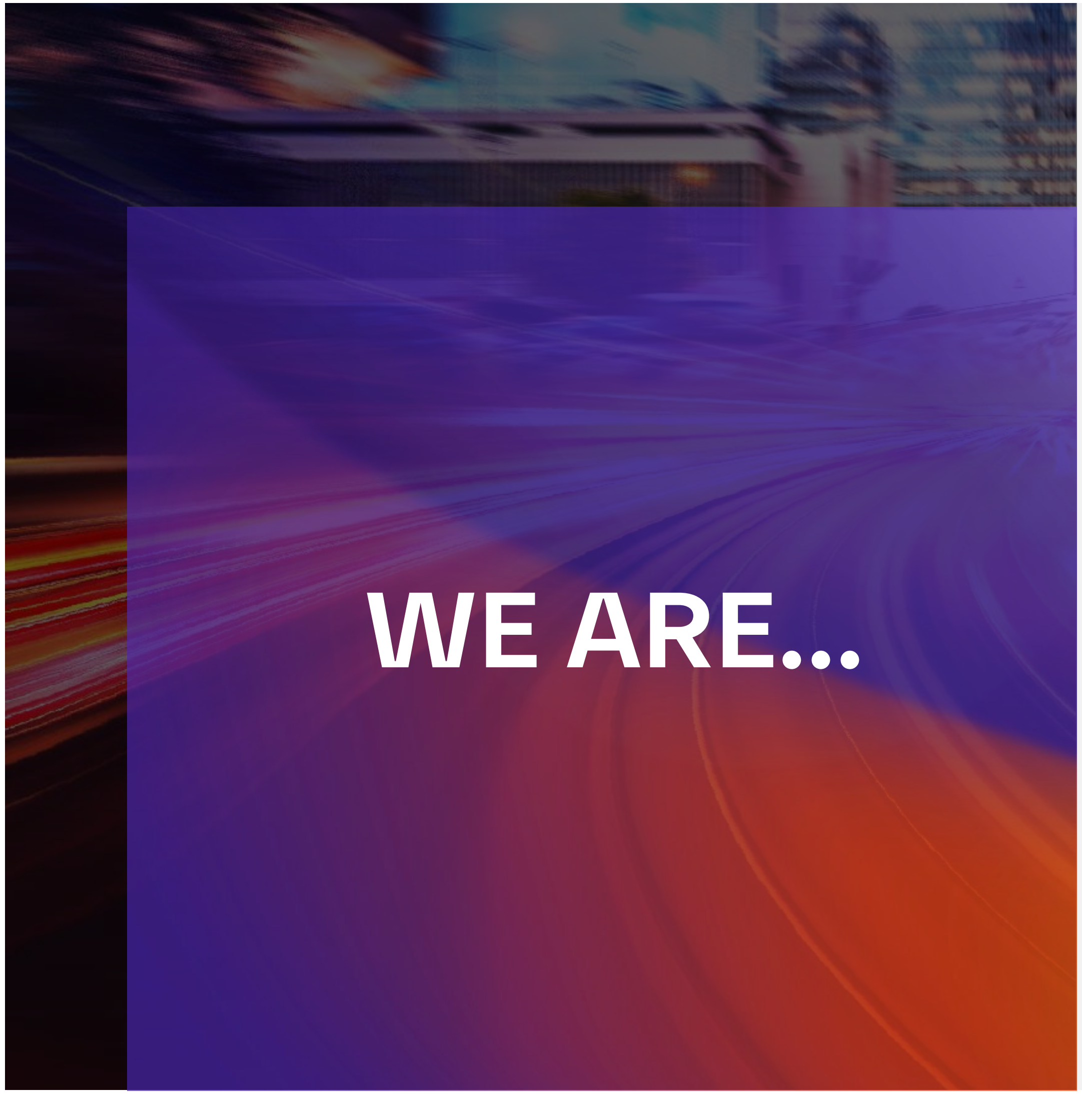

An engineering and technology provider.

A one stop shop – from the idea to the product.

A gateway to high volume automotive products.

More than 1,800 experienced engineers & specialists.

Developers of technology for future mobility.

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AUMOVIO Engineering Solutions

Our core topics

1 Network & architecture

2 Electrification & emission reduction

3 ADAS & autonomous driving

4 Chassis & brake technology

5 Human machine interface & connectivity

6 Digitalization, IT & data solutions

7 Software defined vehicle

8 New mobility ecosystem

9 Acoustic solutions

10 Production

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Introduction

A history of innovation – motorsport and automotive

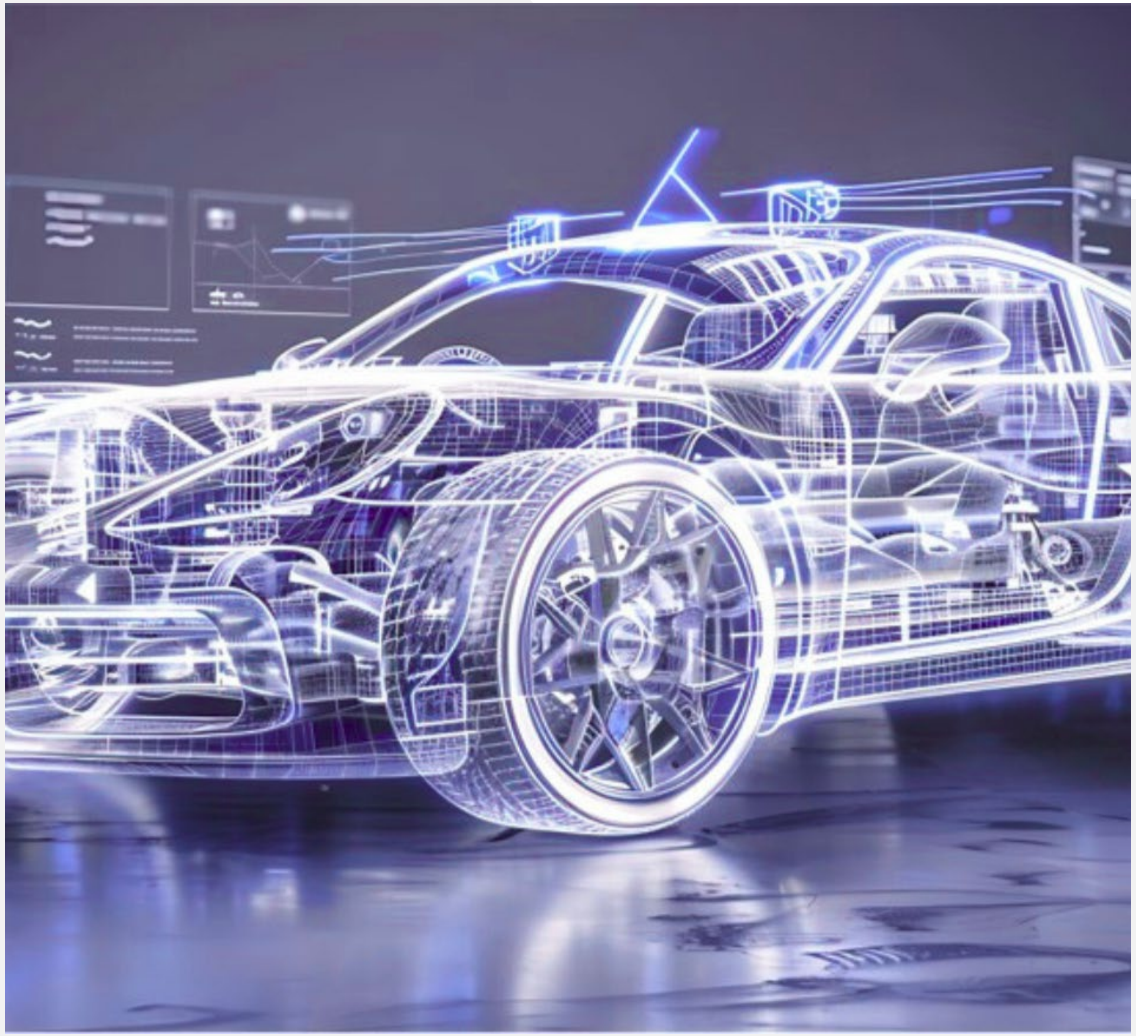
History

AUMOVIO Engineering Solutions (AES) have been involved with the development of electronic control systems for automotive and roadcar customers since the early 1980s

In the early 1990s these solutions were expanded to include hybrid and electrified drive systems for a wide range of customers

After 35 years, the development of advanced powertrain and control solutions remains core business for AES

How can we leverage our position in both fields to keep pushing technology advancement?



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First steps

The early days

History

Dedicated developments for motorsport:

- Large format NiCd cells, bespoke BMS
- High speed (20k rpm) electric machines, flooded stator, surface magnets with a carbon fibre rotor band
- In-wheel epicyclic gearbox/hub/brake assembly
- 3 phase Si-IGBT inverter, industrial and catalogue parts
- Single motor/wheel permits torque vectoring
- Which led to…

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First steps..
The early days

History

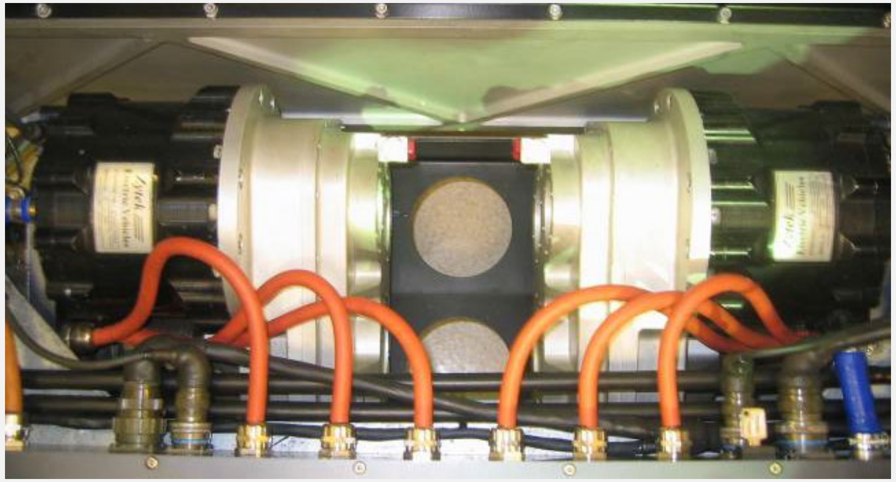
Adopted developments for road cars
- Revised drive system & battery
- Torque vectoring implemented

Is there a pattern emerging for technology transfer?

Note

Developments discussed in this presentation are primarily dedicated motorsport systems.

We will discuss how roadcar advancements have benefitted these systems



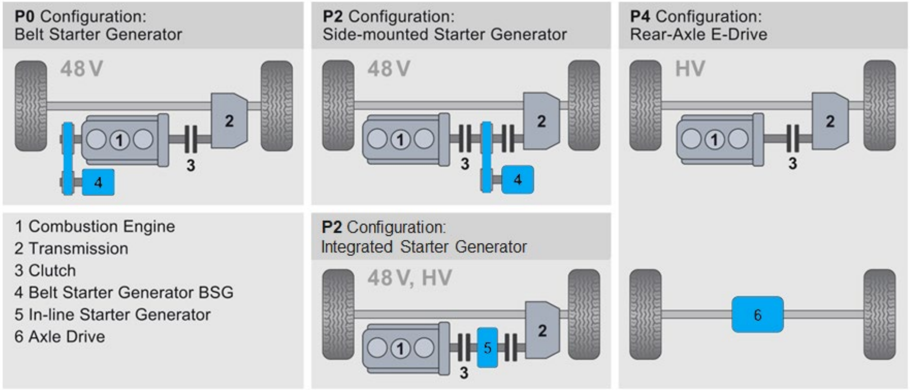
The development path
The challenge

The development of drive systems requires the prioritization of key metrics

- Size
- Mass
- Efficiency
- Cost
- NVH performance
- Cooling strategy
- Integration strategy
- Manufacturing strategy (linked to production volumes)

Different applications necessitate different priorities

- Roadcar
- Within roadcar applications



- Motorsport

The development path
Size & mass

Electric machines

- We are getting to a point where electric machines cannot get much smaller
- Power densities >40kW/kg
- Thermal performance is the limiting factor, so close matching of duty cycles is becoming key to optimizing drivetrains
- One way to decrease mass is to increase speed and utilise a gearbox to multiply torque
- Increased machine speeds can lead to higher losses, all materials need to work harder

Inverters

- Advancements in switching media and capacitor technology key to size reduction
- Current densities

The development path
Mass

Mass can be influenced by active material choice

- Electric machine
- Electrical steels
- Copper winding
- Magnet choice and application
- Inverter
- Power module
- Capacitor

As well as the pure mechanical parts

- Housing
- Shaft
- End plates
- etc

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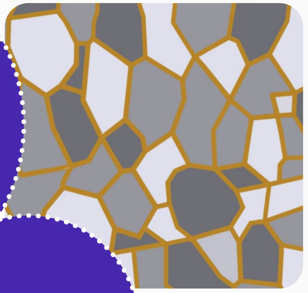
Development path
Electrical steels

Non-grain Oriented Electrical Steels **NGOES**



SiFe

- Very high availability/ low cost
- Strong mechanical properties

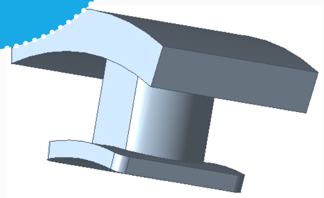
CoFe

- Very high torque density capability
- Low iron losses
- Weak mechanical proprieties
- Low availability/ expensive material

Amorphous Electrical Steels

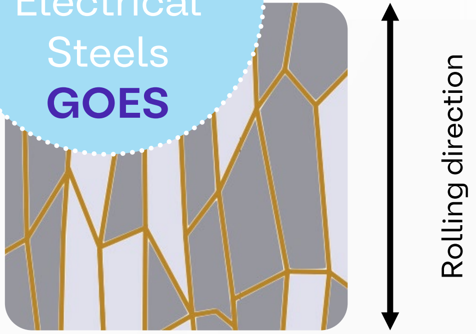
- Lowest iron losses
- Difficult to manufacture/ limited motor geometries
- Very weak mechanical properties

Soft magnetic composites



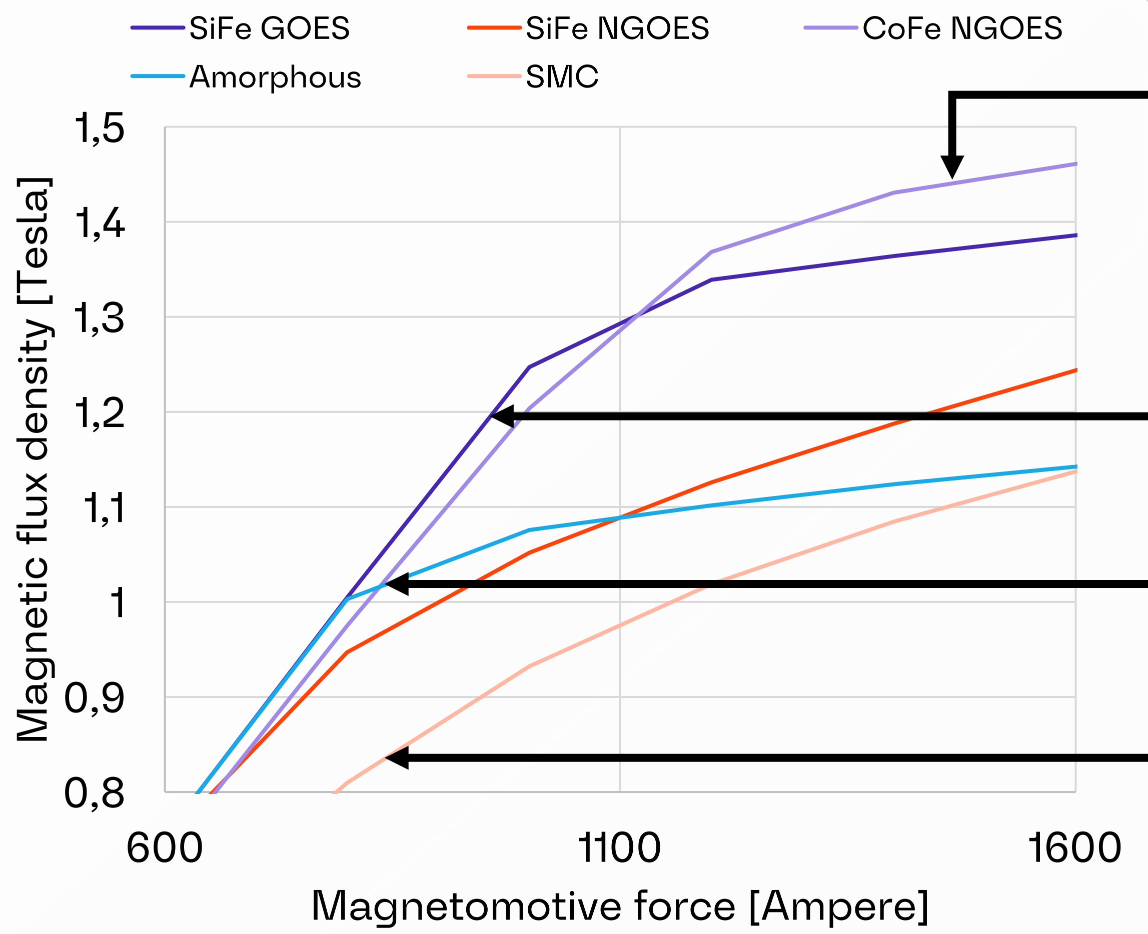
- Enables complex 3-D motor geometries to be designed
- Manufacturing/ recyclability ease
- High iron losses/low torque density capability

Grain Oriented Electrical Steels **GOES**



- Magnetic properties optimized in the rolling direction
- High torque density capability
- Low iron losses
- Limited motor geometries

Development path
Electrical steels



CoFe NGOES
Highest peak torque/power density capability, due to:
- Higher magnetic saturation
- Higher magnetic permeability
- Low iron losses

SiFe GOES
Highest continuous power density capability, due to:
- Same output power as CoFE NGOES (induction below 1.2 T), but at lower electrical current – Improved efficiency.
- Identical iron losses as CoFe NGOES

Amorphous electrical steel
Highest efficiency capability, due to:
- Lowest in-class iron losses

SiFe NGOES and SMC
Better suited for mass production, due to:
- High material availability
- Low material costs

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Development path
Copper winding strategy

Random wound winding

- Preferable for industrial mass production motors
- Slot fill factor (40% – 50%)

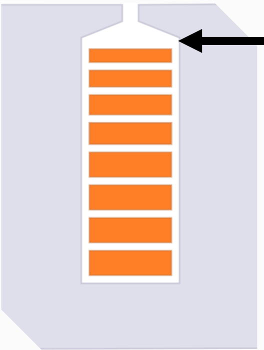
Hairpin winding

- Preferable for low-speed/high-torque/high-efficiency/cost-effective applications
- Slot fill factor (60% – 80%)

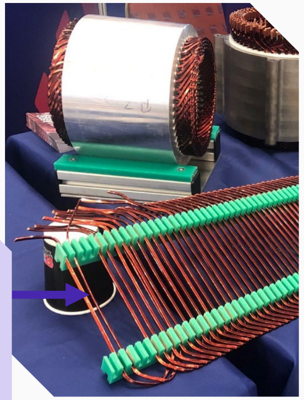
Tooth-concentrated winding

- Better suited for very high-torque/power density
- Slot fill factor (60% – 80%)

Hairpin winding



Variable bar thicknesses for reduced high-frequency Joule losses

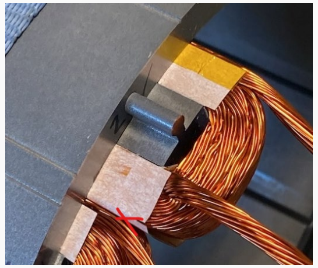


Continuous hairpin winding – For ease assembly and more compact end-winding

Tooth-concentrated compressed coil

Solid stator

Segmented/Modular stator



Development path
Copper winding strategy

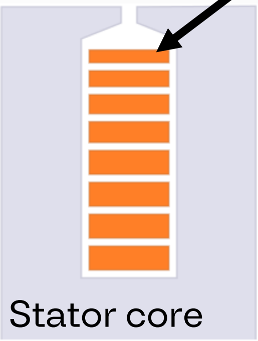
Winding

1. Coils with variable cross-sectional area:
   - Variable bar thickness – Reduced high-frequency losses
   - Variable end-coil width – Reduced coil average resistance
2. Hollow conductors – Enable direct oil cooling (best solution for high-speed motor applications)
3. Better suited solutions for tooth-concentrated winding configurations

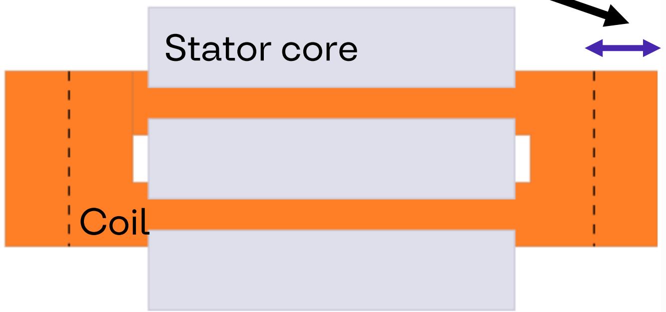
Stator core

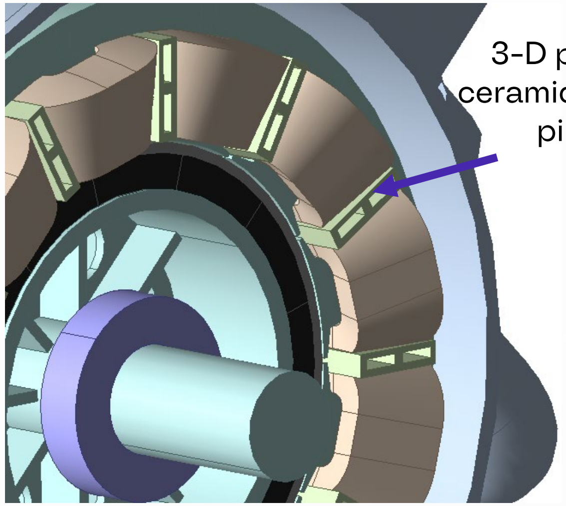
Novel cooling solutions for enhanced power density

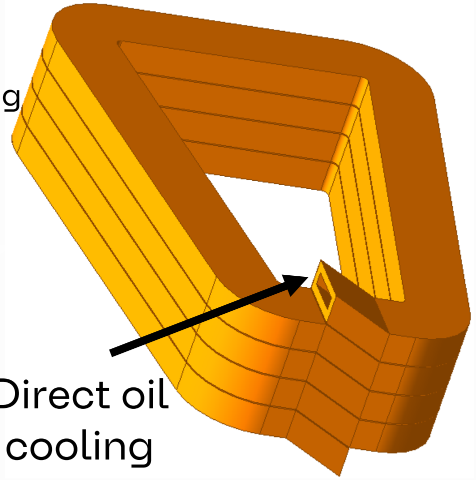
Variable bar thickness



Variable end-coil width





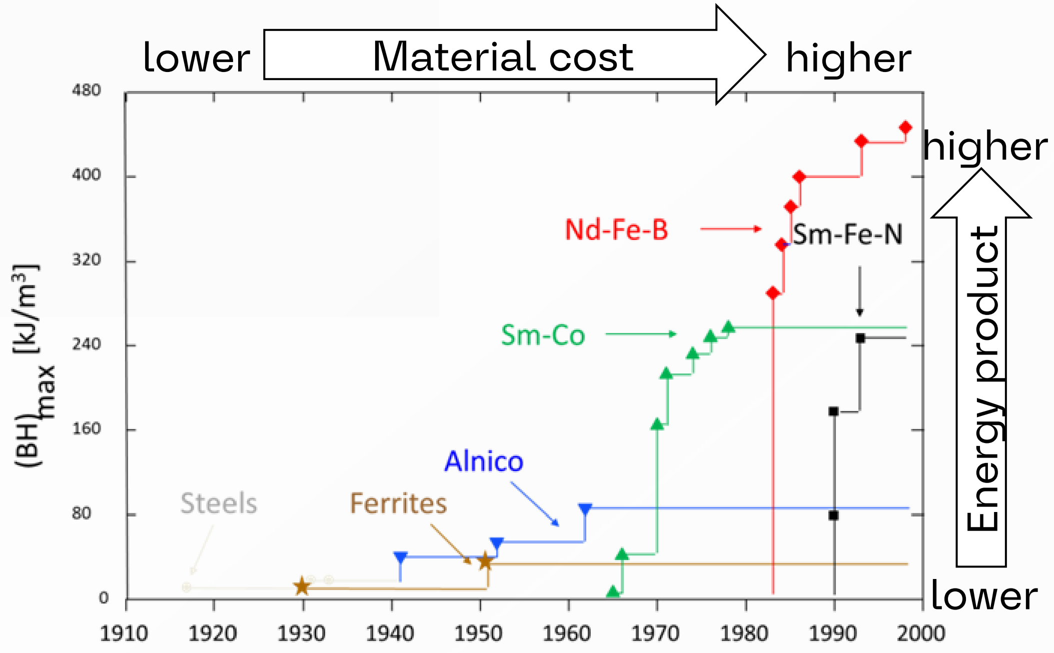


75 – 50 A/mm²

Development path
Magnet choice

PM selection

- **Magnet selection by manufacturing process:**
  - Sintered/fully dense – Maximum energy product
  - Injection molded – Shape flexibility
  - Compression bonded – low cost manufacturing
- **Magnet selection by material:**
  - Neodymium-Iron-Boron – High energy
  - Samarium Cobalt – High temperature performance
  - Ferrite – Low cost material
- **Design considerations:**
  - A single magnet block shape is better for lowering the BOM list costs
  - Magnet segmentation reduces eddy current loss inside the magnets, but increases manufacturing costs



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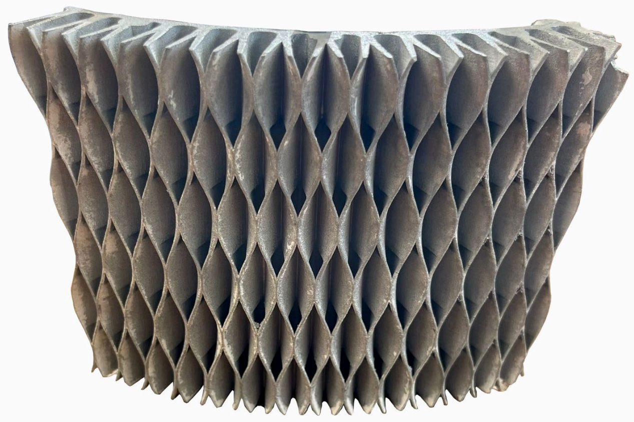
Development path
Mass

Additive manufacturing

- **Conventional cooling for radial flux machines:**
  - Cast housing with internal cooling matrix
  - Inner coolant sleeve and outer case, both machined, which form a coolant jacket
  - Flooded stator, using machined external case and inner sleeve
- **Conventional additive manufacturing:**
  - Lighter mass cooling jacket with internal fluid cooling
- **Thin wall, high strength casting utilizing additively-manufactured cores:**
  - Casting using either
    - Printed furan or phenolic sand (3-2mm wall section)
    - PMMA indirect AM + Sylatech block investment process (2-1mm wall thickness)



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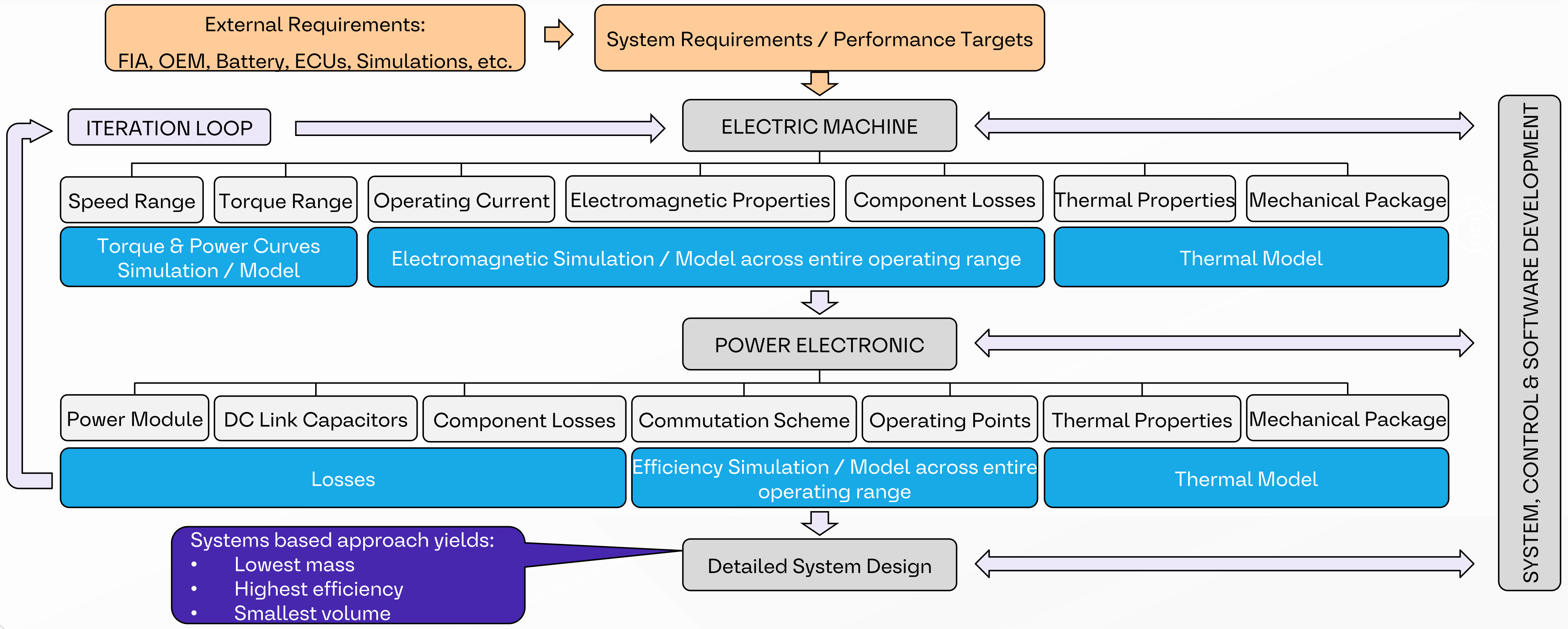
Development path
Efficiency

Design loop for system-based engineering



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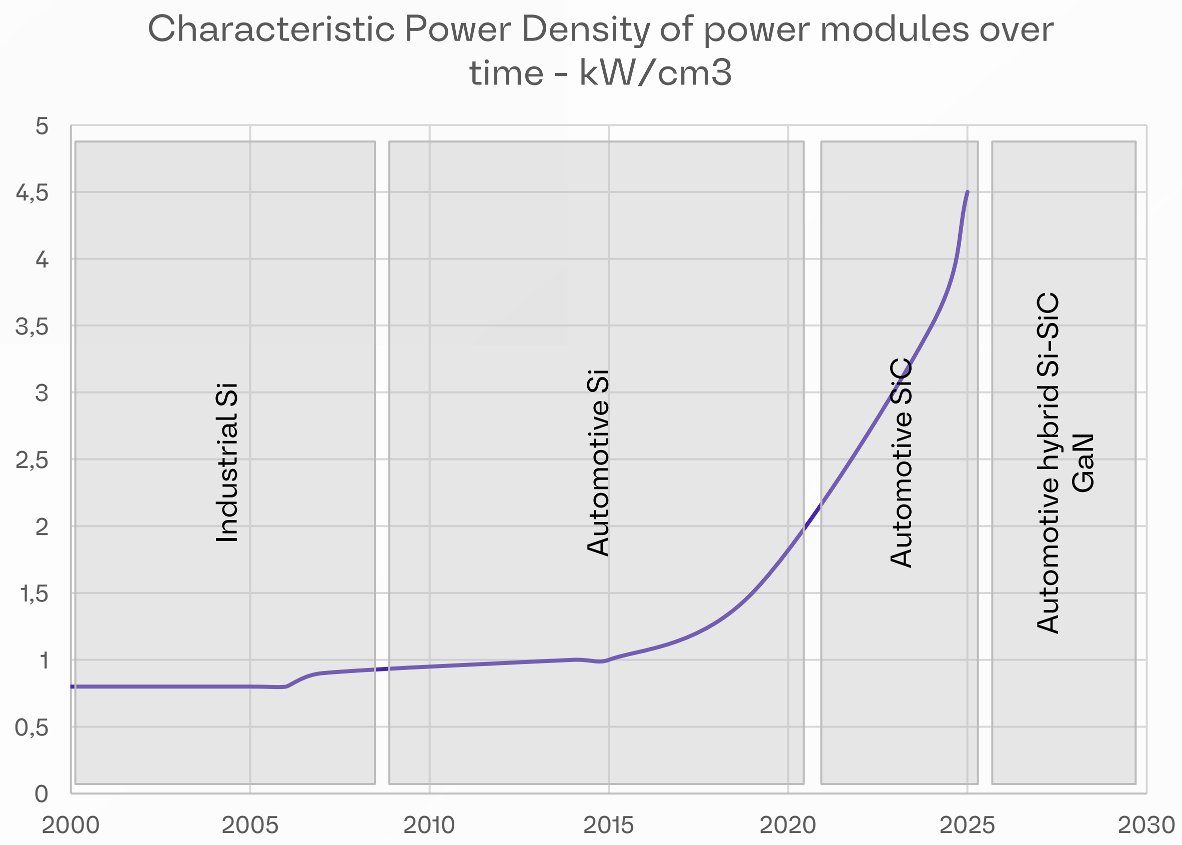
Inverter

Development

- **Up to mid 2000s:**
  - Electric & hybrid vehicles seen as niche
  - Test and demonstration vehicles used industrial components
- **End 2000s – late 2010s/early 2020s:**
  - Range of Si power modules becoming available from number of manufacturers
  - Developments on power density started mid 2010s
- **Early 2020s-today:**
  - SiC power modules starting to become more widespread
  - Significant developments in power density
- **Future:**
  - Hybrid power modules utilizing both SiC and Si technology
  - Introduction of GaN



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Development path
NVH

Probably the one area where markets are the most diverse

- Integer slot machines
- Fractional slot machines
- Inverter commutation strategies

Integer slot electric machines

- Number of slots/pole/phase is a whole number
- Distributed winding
  - More bulky
  - Heavier
- Lower cogging torque
- Lower torque density
- Better NVH
- Traditionally preferred for road car traction applications

Fractional slot electric machines

- Number of slots/pole/phase is a fraction
- Concentrated winding
  - More compact
  - Lighter
- Higher cogging torque
- Higher power density
- Poorer NVH
- Traditionally preferred for high performance applications

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Development path
Manufacturing strategies

Motorsport split into 2 categories

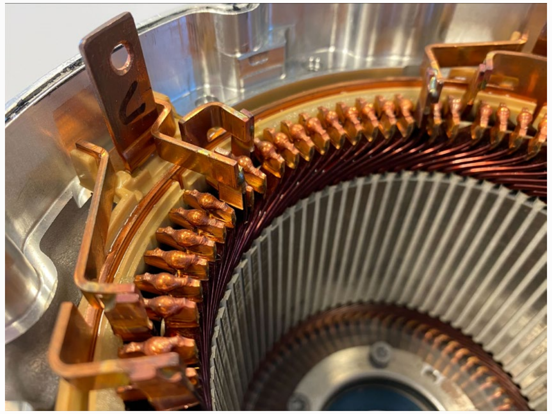
- Adopt and modify high volume roadcar solutions
- Dedicated high performance solutions

- When adopting roadcar products:
  - Downsides include
    - Duty cycles higher in motorsport
    - Environment can be more aggressive
    - Limited modifications, housing
  - Advantages include
    - Availability
    - Cost

- When designing for high performance, additional manufacturing strategies can be considered

Roadcar technologies

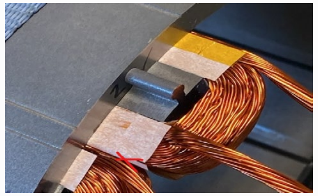
Hairpin stator



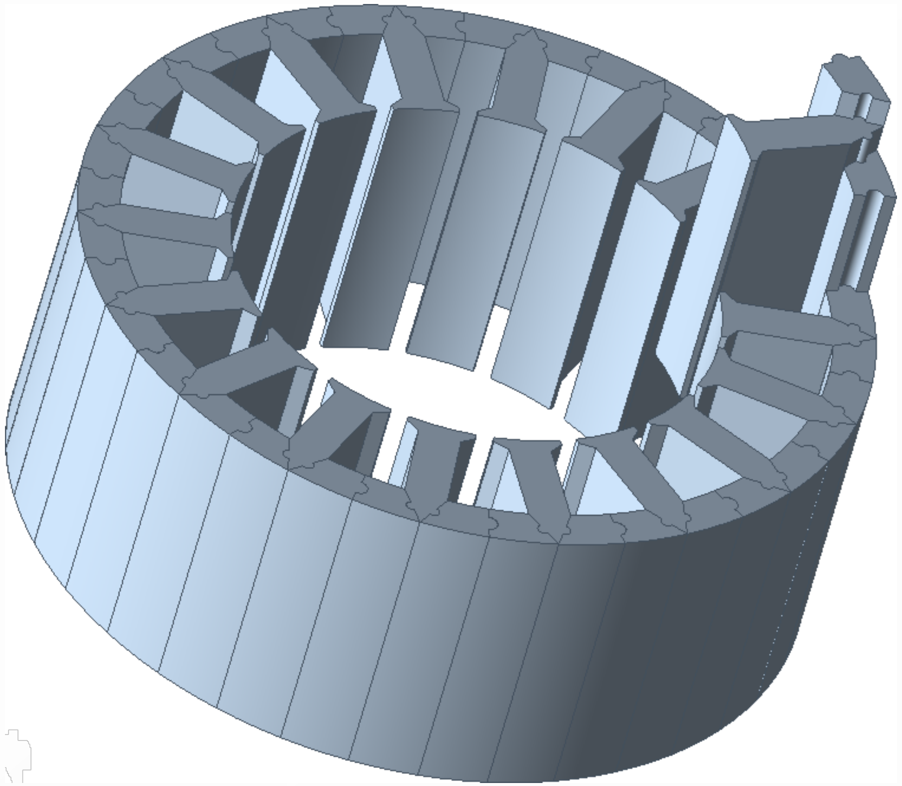
Dedicated solution

Solid stator

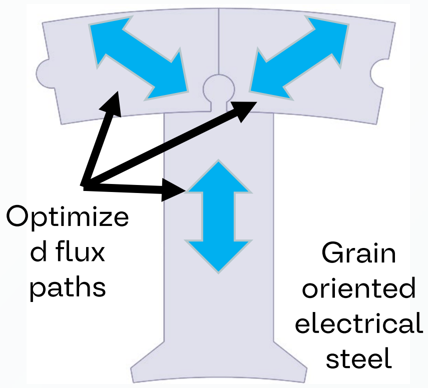
Segmented/Modular stator

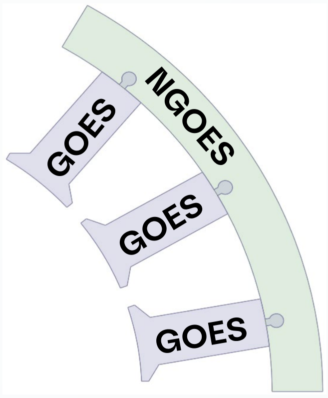


Development path
Manufacturing strategies



Enhanced material utilization





- Improved torque capability due to higher saturation and magnetic permeability of the GOES
- Lower iron losses
- Higher manufacturing costs due to tight tolerances

- Improved performance by benefiting from the best qualities of different materials
- Different thermal expansion coefficients may limit the multi-material utilization

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Development path
Cooling strategies

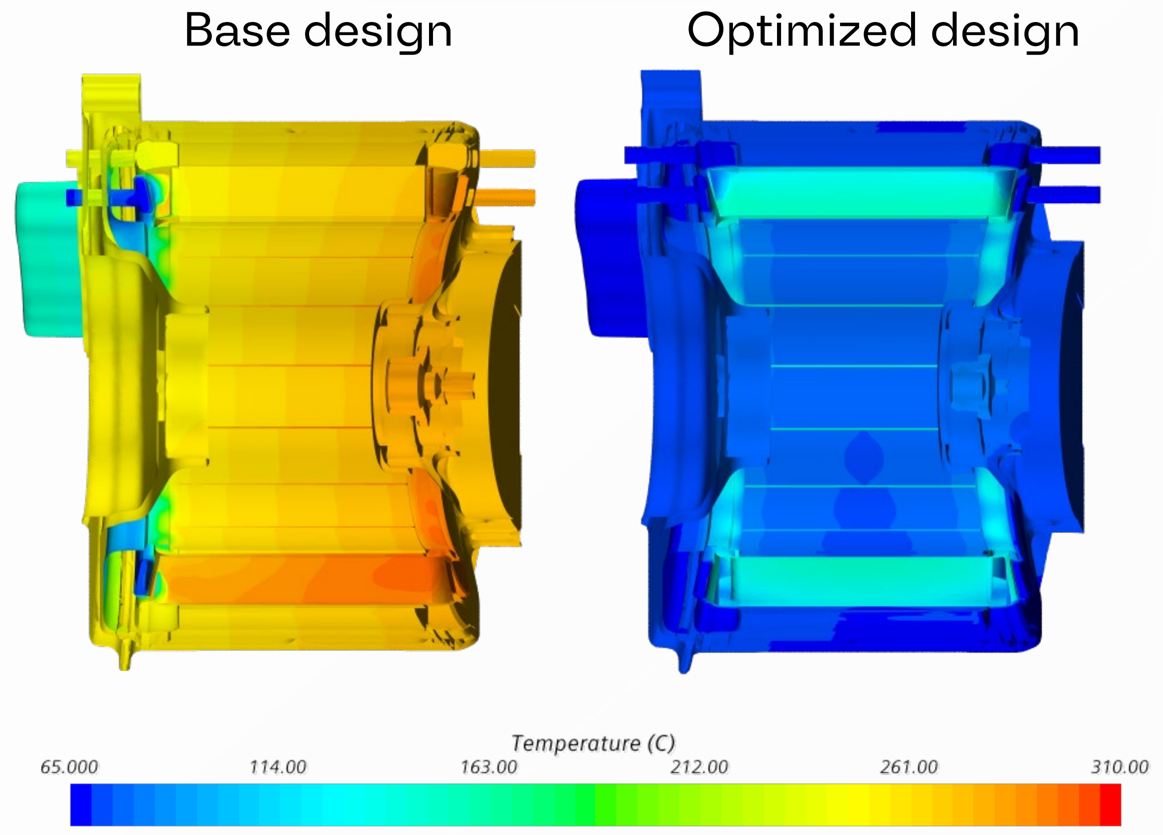
Area where motorsport leads development activities, where dedicated thermal systems are employed, due to higher duty cycles

Electric machine

- Flooded stator designs common (though not essential)
- If indirect cooling, maximizing surface areas in contact with the sleeve
- Rotor cooling employed

Stator core

- Flooded designs possible (though not essential)
- DC link capacitor cooling required
- Latest designs of SiC etc switch module



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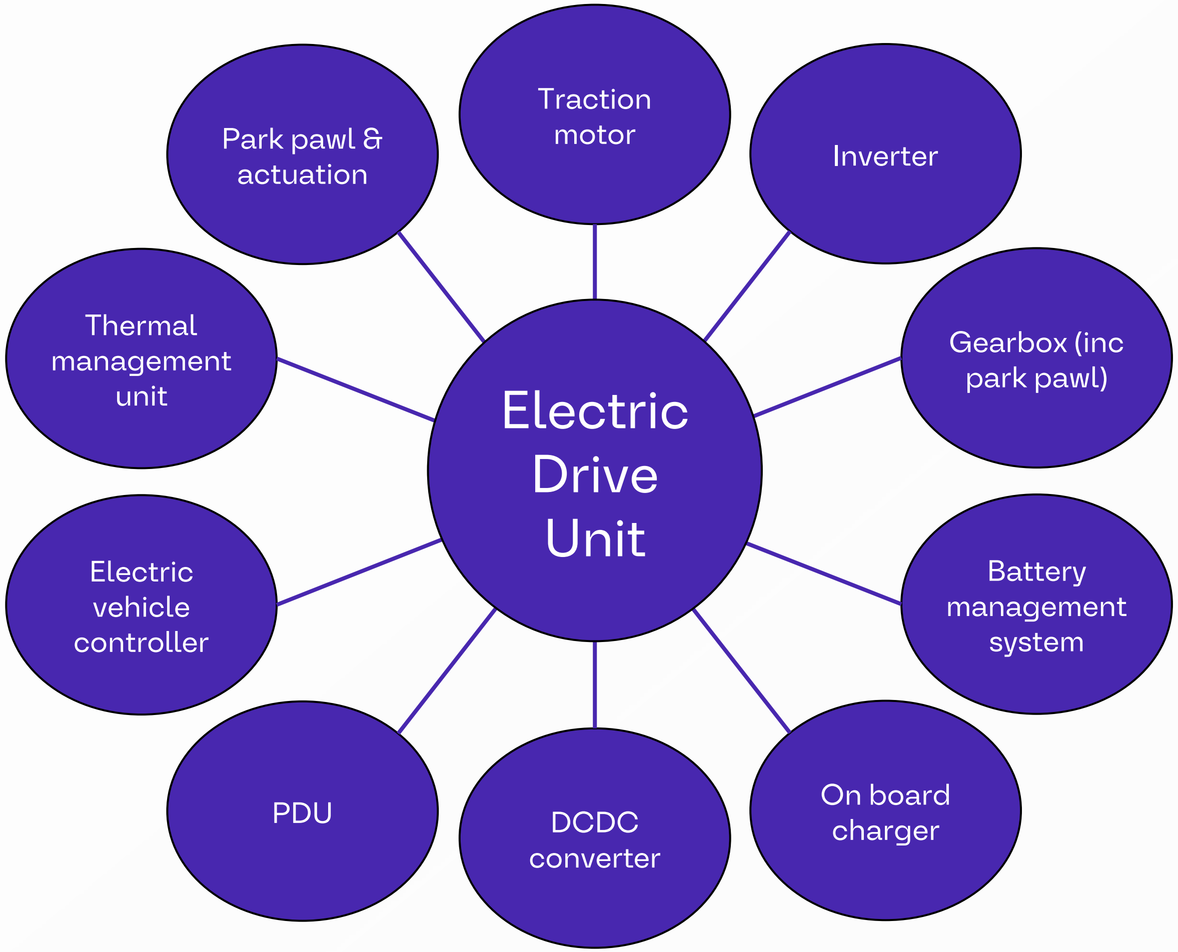
Development path
Integration strategies

Motorsport influenced by unique challenges

- Regulations
- Mass distribution
- Cooling media
- Component count
- Not all motorsport is the same

Road cars have additional requirements

- Modularity (2WD & 4WD performance variants)
- X-in-1 powertrains that combine multiple functions into a single unit



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Summary
Bi-directional technology transfer

Conclusions

- There are undoubtedly areas where motorsport drives electrification technology development forwards at pace
  - Simulation environment(s)
  - Thermal management
  - Control techniques
- There are similarly areas where investment required in technologies only makes sense for roadcar programmes
  - Inverter switching technologies
- Very few series offer the opportunity to innovate
  - F1, Formula E, high end track cars
- To keep apace with all such developments, engineering service providers should be active in all areas of development
- To the track and back

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Contacts
Any questions?

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