



Scaling Axial Flux Motor Technology – From Niche to Mainstream

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Turntide Technologies



CWIEME
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MESSE BERLIN



FOR ANYTHING THAT MOVES

Agenda

- Introduction to Turntide
- What is an Axial Flux Motor
- Technology of Axial Flux Motors
- Benefits of Axial Flux Motors
- Global Market for Axial Flux Motors
- Scaling the Axial Flux Technology
- Conclusion

We bring together decades of industry experience, deep expertise, and best-in-class technologies to deliver award-winning EV solutions:

innovative electric motors, power electronics, and energy storage solutions that optimize performance, reliability, and efficiency for all things that move.

- **300+ customers**
- **125+ patents**
- **70+ registered trademarks**
- **300K vehicles in the field** using our products



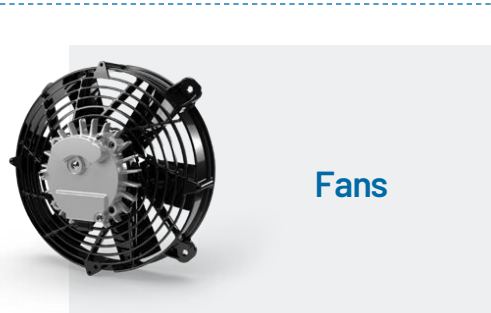
Decades of Electrification Experience

By acquiring three of the world's most innovative transport companies, Turntide has strategically accelerated the adoption of sustainable and energy-efficient technologies in the transportation industry worldwide.

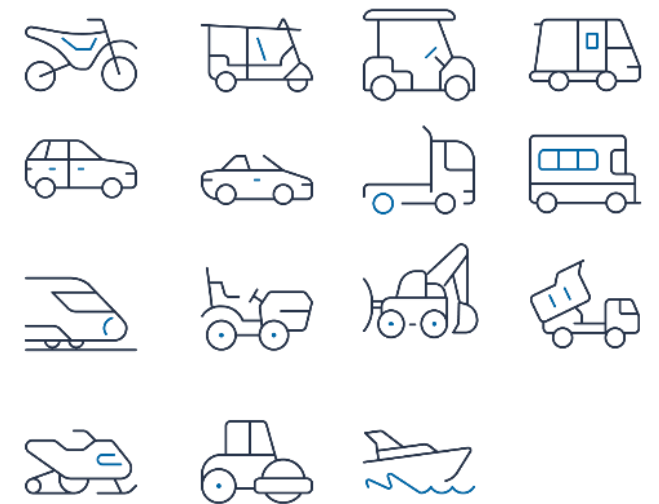
There are an estimated 300k+ vehicles in the field using products of our legacy companies.



Simplify Integration and Improve Performance



INTEGRATION



E-MOTORS

HV Axial Flux Motors

2-4x more power at 50%
less weight (Exceptional
power density up to
10kW/kg.)

Optional features to meet
customer requirements

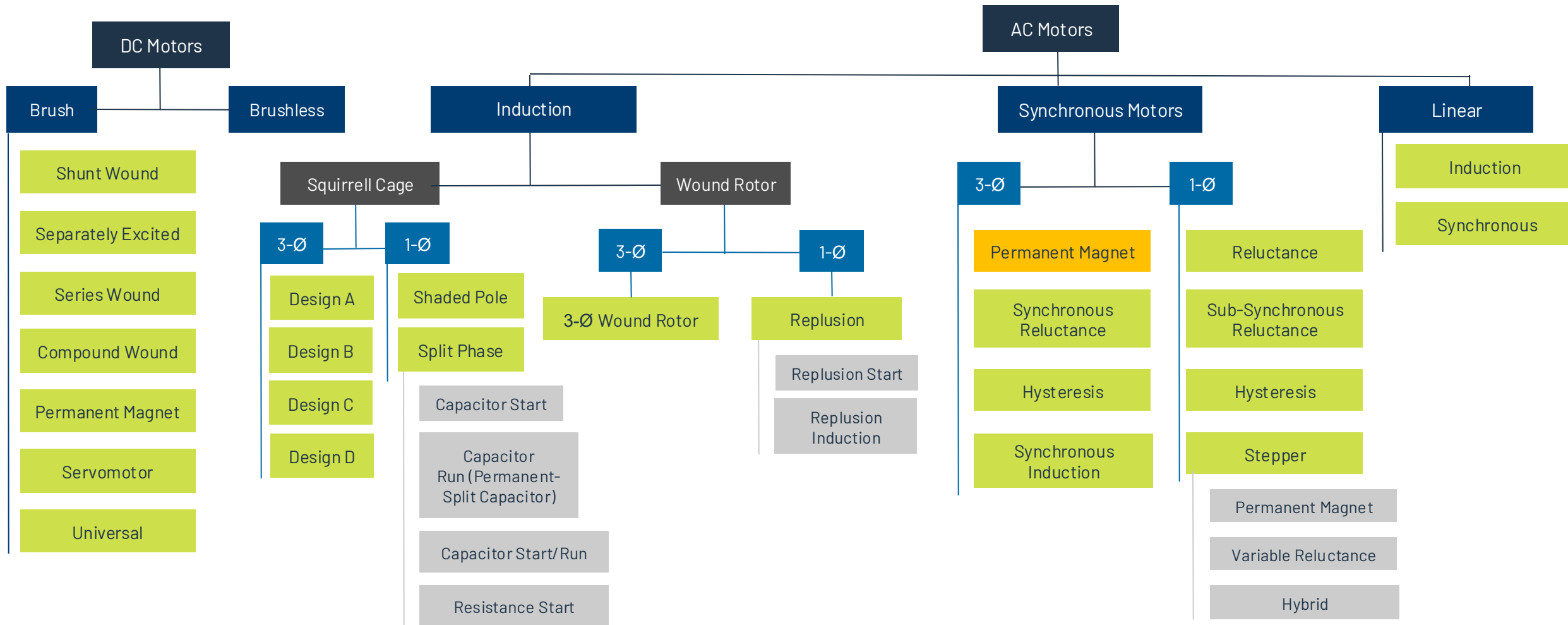


Scalable to be configured
according to the system
and space claim layouts

Wide range of operating
voltage up to 800V

Power-
Nominal 59kW to 376kW
Peak 100kW to 880kW

Electric Motor Classification

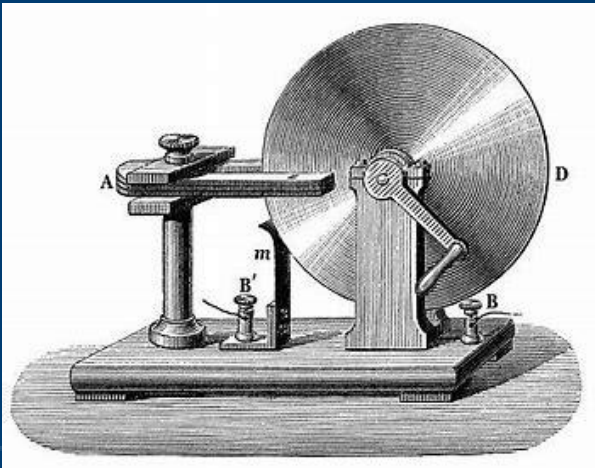


Let's start with some history

Do you know when Axial Flux Motors were invented?

The first motor invented by Michael Faraday in 1821 was an Axial Flux Motor

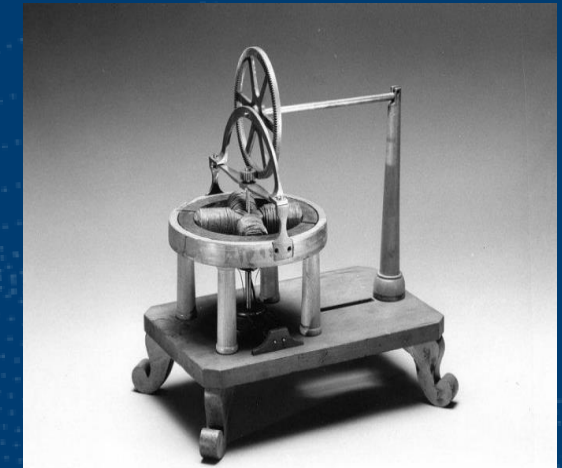
The radial flux motor (or the simple motor) was developed by Thomas Davenport in 1834



Faraday's "Axial Flux Motor", 1821



Latter Model of Faraday's "Axial Flux Motor"



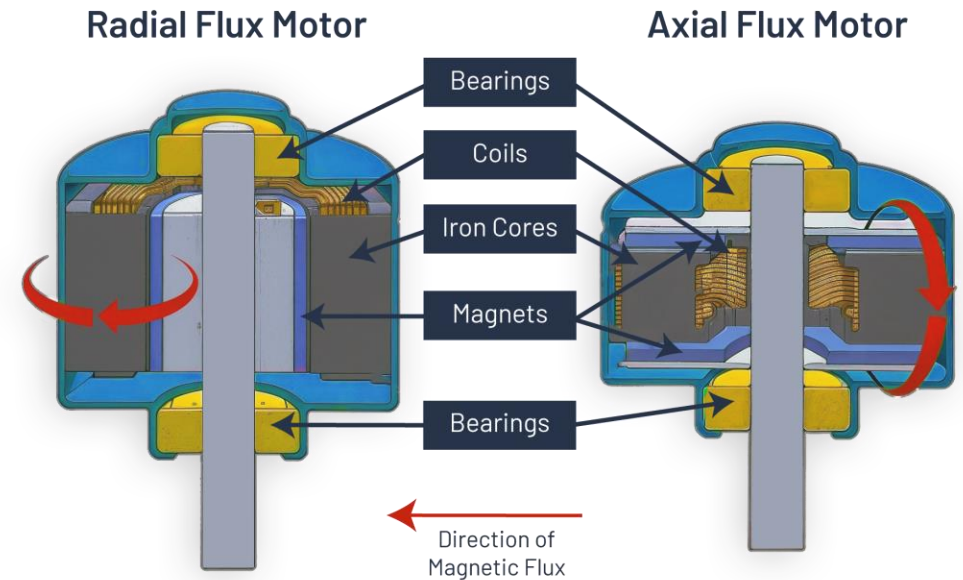
Davenport's Patented "Radial Flux" Electric Motor, 1834 – residing now at the Smithsonian

Axial Flux Motor – The Physics

Based on the orientation of the magnetic flux, electrical machines can be classified into two categories:

RADIAL FLUX – THE MAGNETIC FLUX DIRECTION IS RADIAL TO THE AXIS OF ROTATION

AXIAL FLUX – THE MAGNETIC FLUX DIRECTION IS PARALLEL TO THE AXIS OF ROTATION.

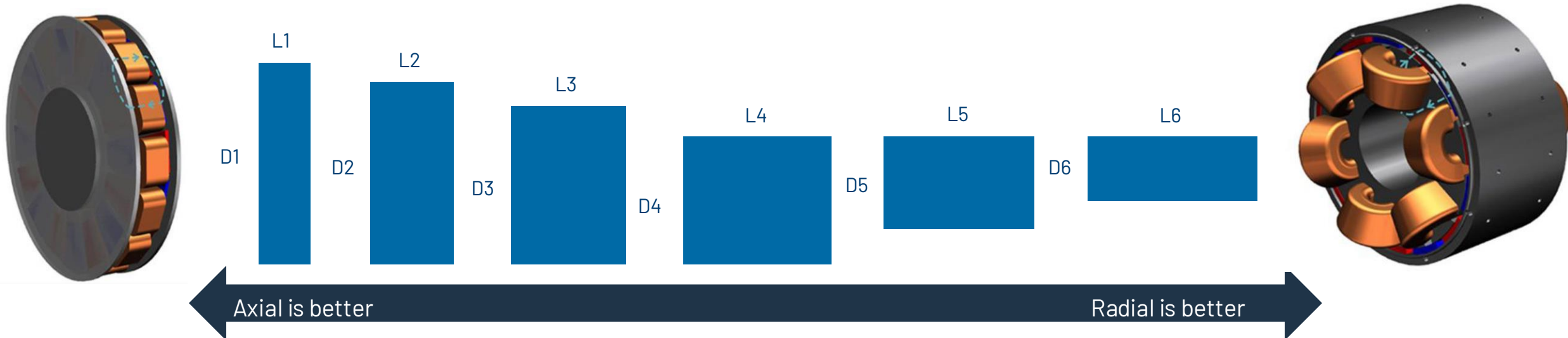


Axial Flux Motor – The Physics

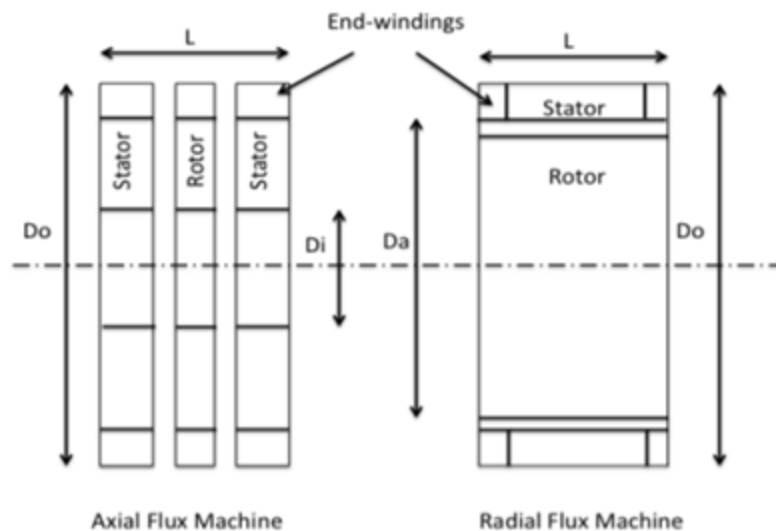
A key determinant of torque and power delivery and therefore efficiency of the electric motor is the Magnetic Field Strength

Magnetic Field Strength will be higher if the magnetic flux path is shorter

Field strength increases with Diameter (D) of the rotor containing the magnetic material and reduces with length (L) of the flux path – a higher D/L ratio therefore provides a motor with a higher efficiency and a higher torque density



Axial Flux Motor – The Physics



$$T_r = \frac{D_a^2 \pi L}{2} G$$

$$T_{ax} = \frac{4\pi G}{3} \frac{D_a^3 - D_i^3}{8}$$

Radial Flux Machine	Axial Flux Machine
Torque increases to the power of <u>two</u> of the diameter.	Torque increases to the power of <u>three</u> of the diameter.
Torque density stays the <u>same</u> .	Torque density <u>increases</u> with motor size.
Heavy weight <u>high inertia</u> rotor	Light weight <u>low inertia</u> rotor

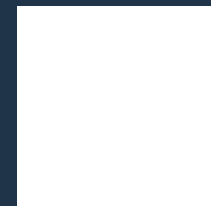
Axial Flux Motor – The Physics

For radial flux motor, the torque is proportional to square of diameter multiplied by the length while for axial flux machine the torque is proportional to the cube of the diameter and it has no significant influence on the length

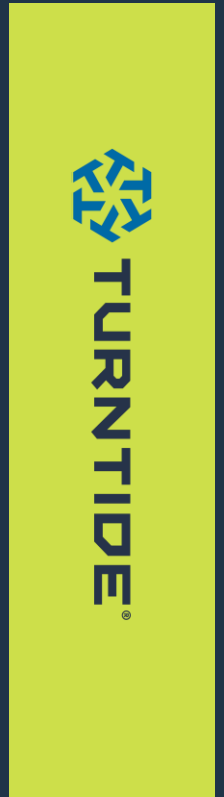
So the axial flux machine is the ideal candidate when we wish to have high torque and power delivery performance for a given weight and volume of the motor

Depending on the size of the motor, **Turntide Axial Flux** motors are **2 to 4 times more torque dense** than the standard radial flux motor – resulting in **50% weight and volume savings** for the powertrain

Torque Density Comparison
(Nm/L)

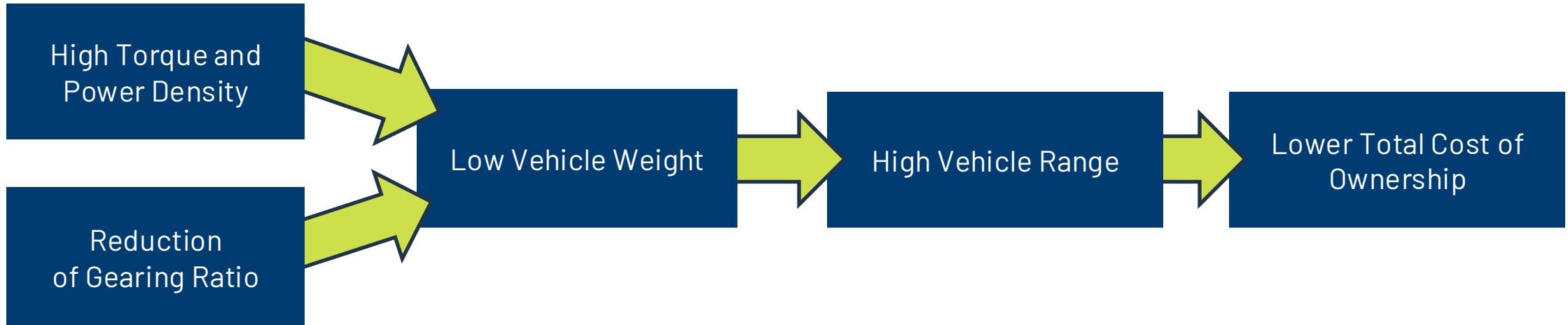


Radial Flux Motor



Turntide Axial Flux Motor

Axial Flux Motors: System Level Benefits



A 10% reduction in vehicle weight can improve the vehicle range by 13.7%

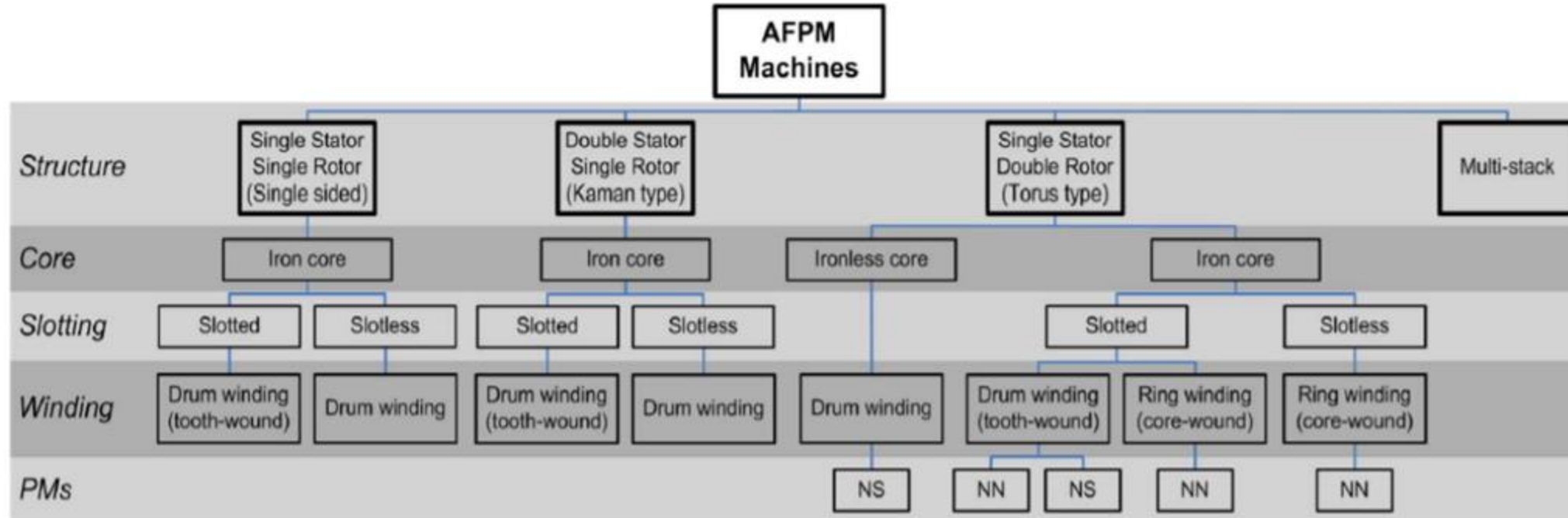
Also, the high torque – low speed operation suitability of axial flux motor allows for reduction elimination of gearing ratio, further reducing the vehicle weight and powertrain complexity.

With Turntide Axial Flux Motor, you can have 50% weight reduction in the Motor which leads to a virtuous cycle of powertrain and vehicle weight reduction and higher vehicle range resulting in lower total cost of ownership.

Axial Flux Motors Benefits – No Cogging Torque

- Cogging torque is a phenomenon that occurs in permanent magnet motors, where the rotor "cogs" or moves in discrete steps rather than smoothly rotating. This is caused by the interaction between the permanent magnets on the rotor and the stator teeth, which creates a pulsating torque that can be felt as the motor is turned by hand.
- Cogging torque can be a problem in applications where smooth and precise motion is required, as it can cause jerky movement and reduced efficiency.
- To mitigate cogging torque, motor designers may use techniques such as skewing the rotor magnets, adjusting the stator tooth shape, or implementing sensor less control algorithms.
- In comparison with competitor products, an area of distinct advantage for Turntide is NVH performance. Segmented teeth design of stators has higher cogging torque and poor Noise and Vibration performance. **Turntide design is much better and has very little to no cogging torque (immeasurably low) and therefore much better NVH performance.**

Axial Flux Motors – Topologies



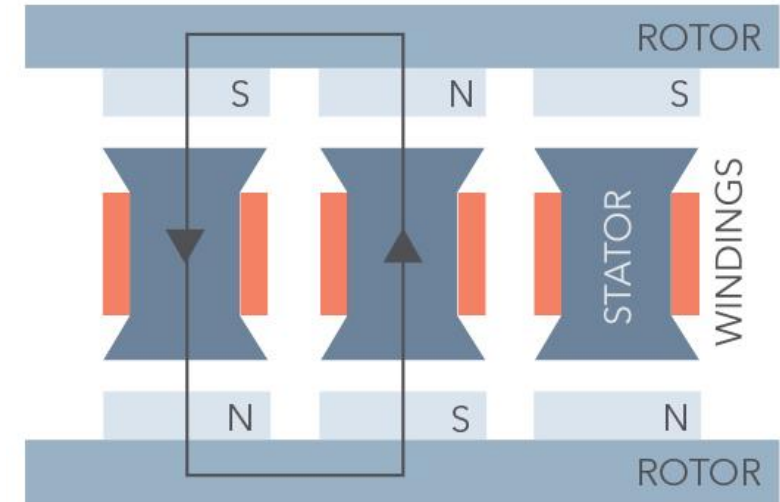
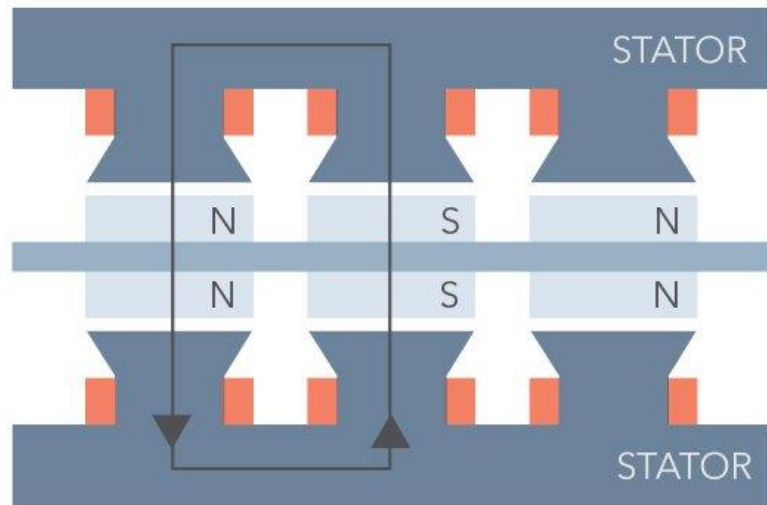
SELECTION FEATURES:

- 1) D/L Ratio – short machines with large diameter
- 2) Design modularity due to multi-stacking

DESIGN CONSIDERATION:

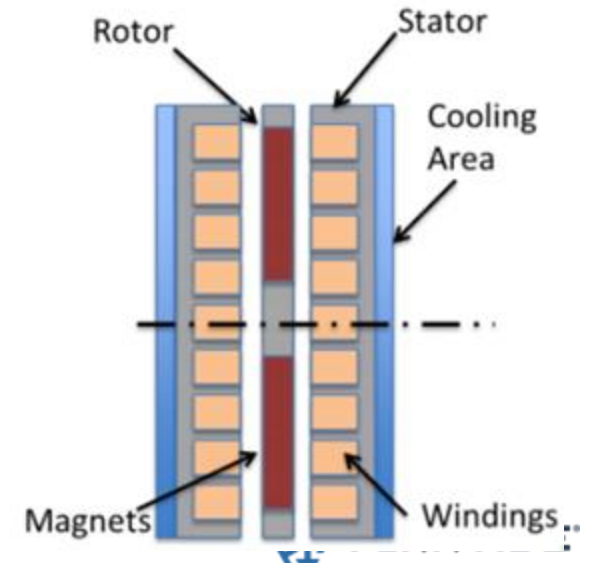
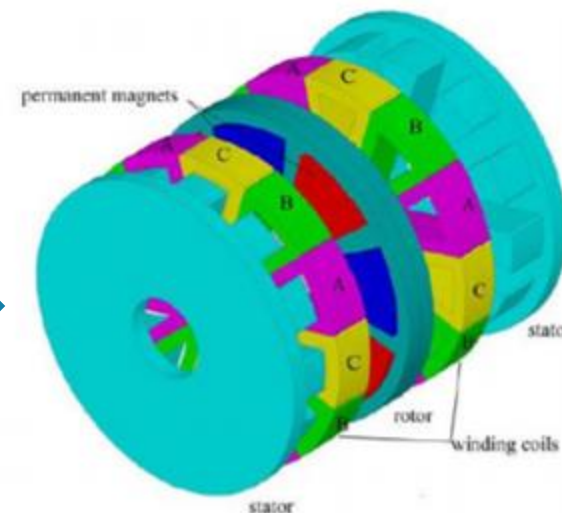
- 1) Strong axial magnetic stator-rotor attraction force
- 2) Mechanical design and manufacturing technology for production scaling

Axial Flux Motors – Dual Stator Single Rotor (DSSR) Topology

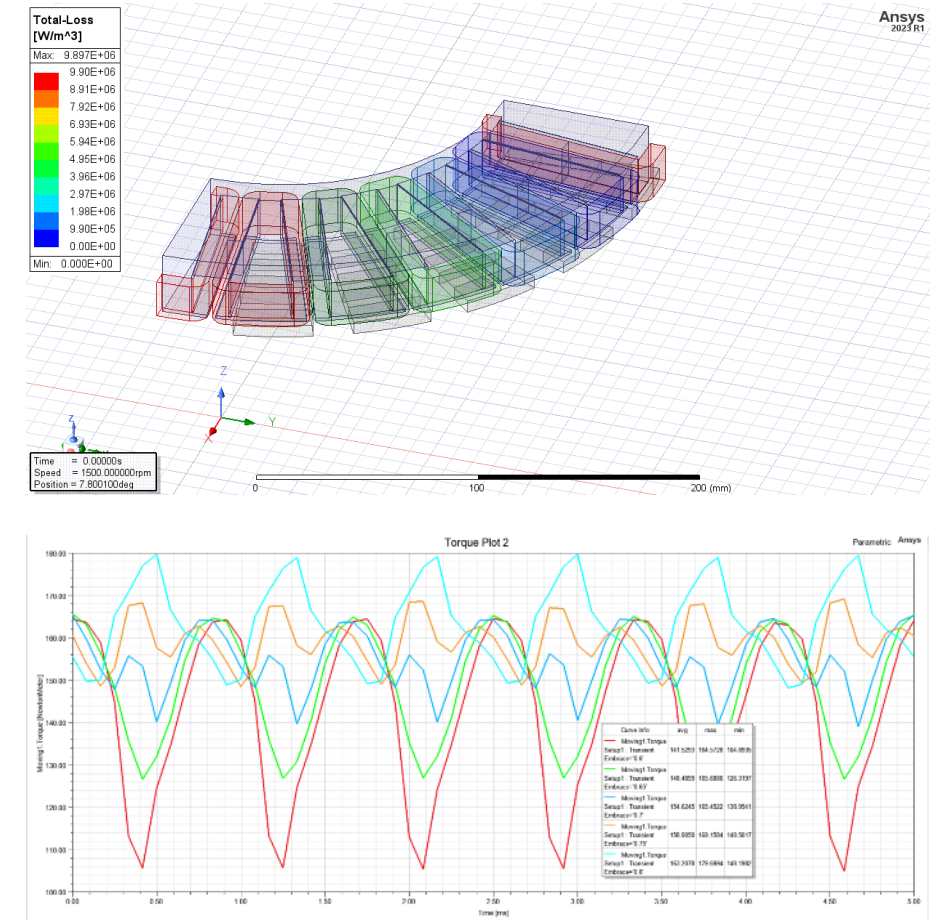
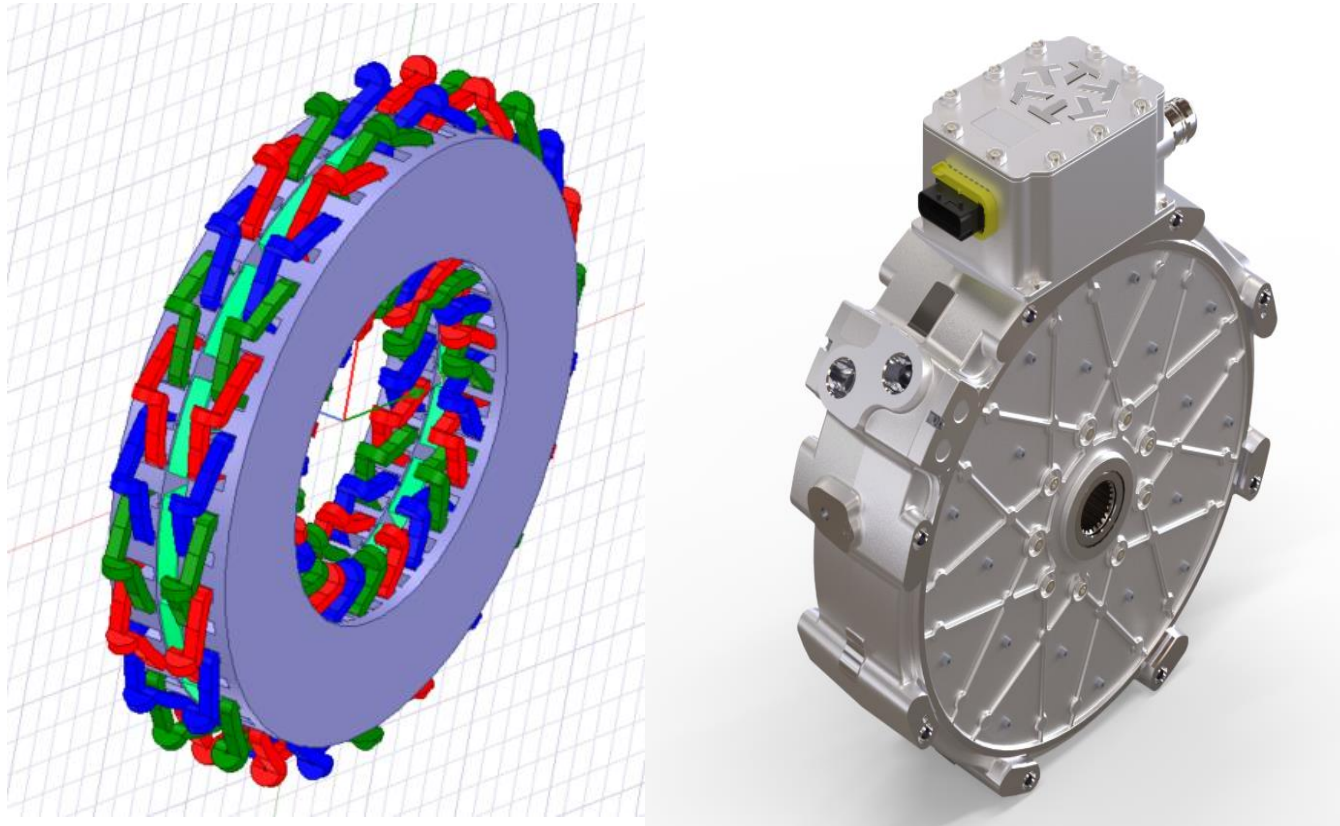


Axial Flux Motors

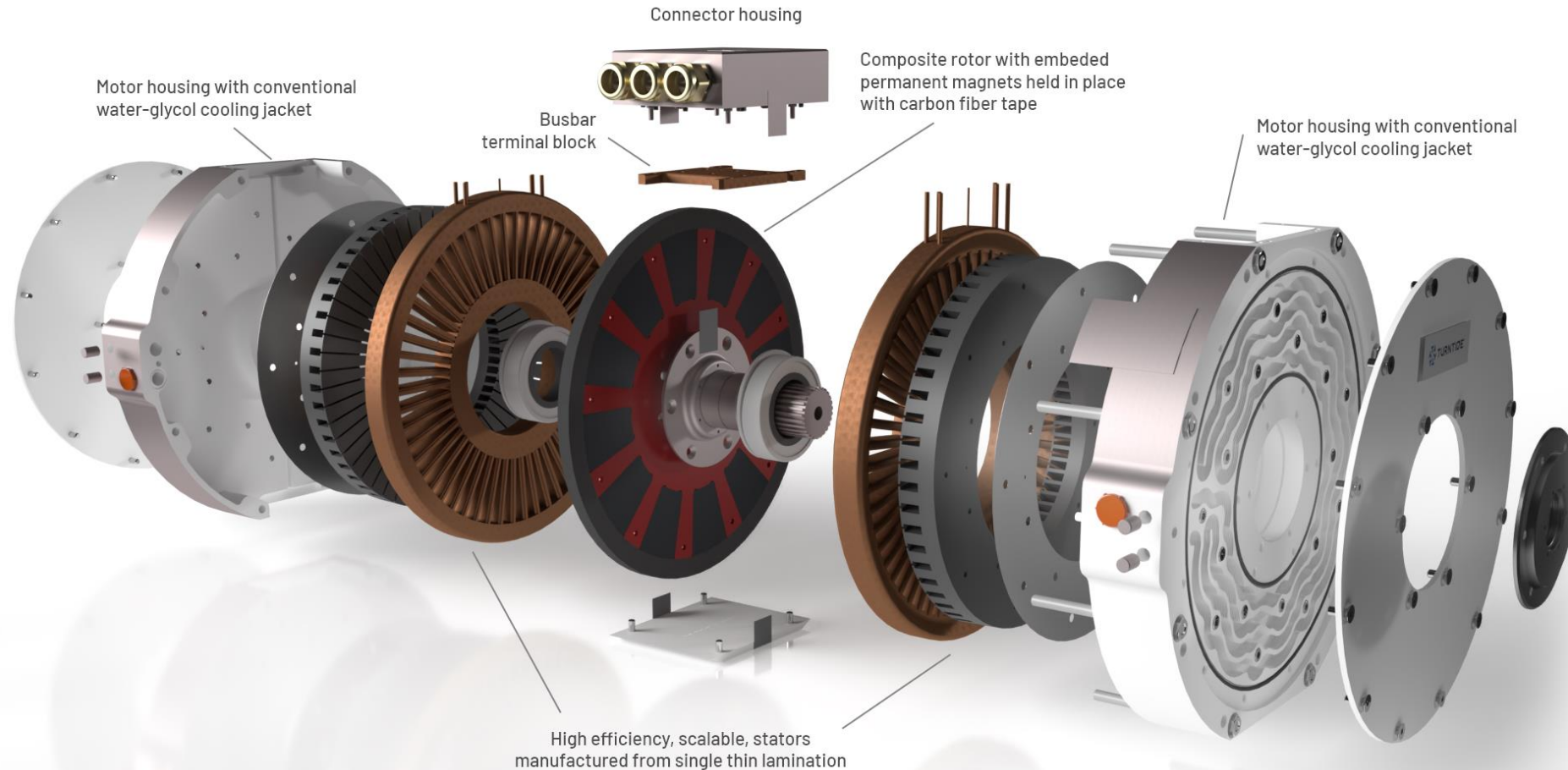
- 1) DSSR TYPE WITH INTERIOR PM STRUCTURE WITHOUT STEEL DISC
- 2) SHORTER MACHINE LENGTH
- 3) EFFECTIVE WINDING COOLING



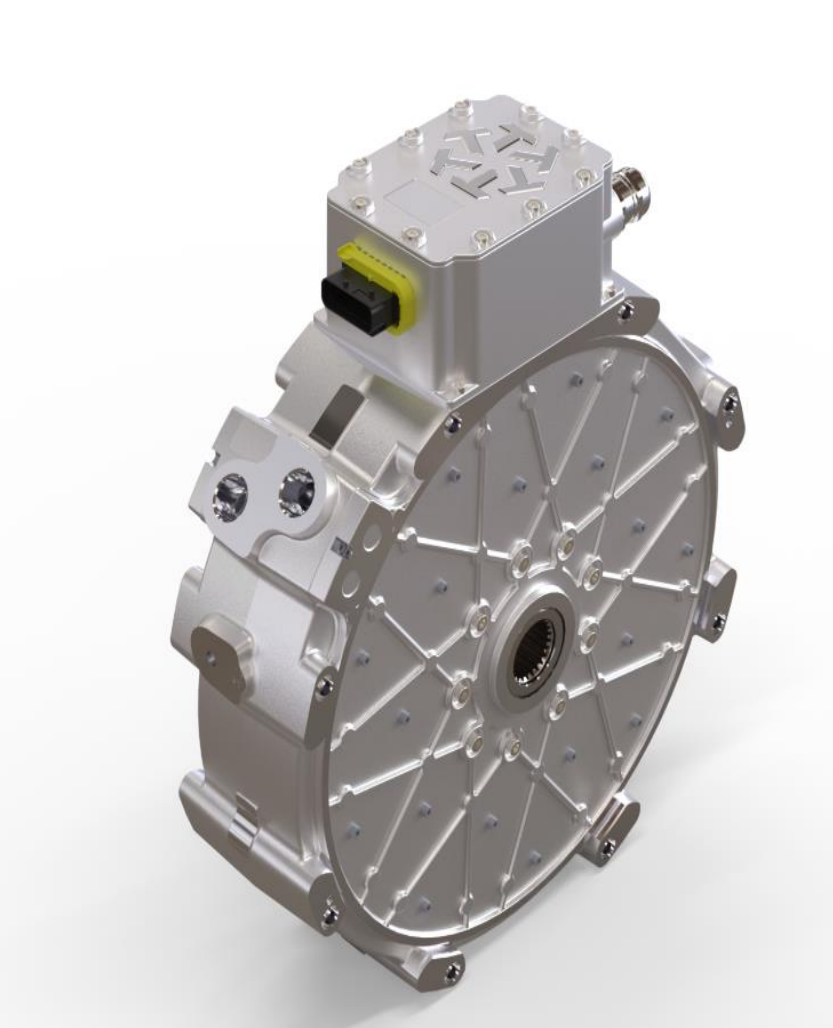
Turntide Axial Flux Motors – Robust Use of Simulation in Design



Turntide Axial Flux Motors: DSSR Topology Construction



Axial Flux Motors: Value Proposition



- ❑ Axial flux technology enables high power and torque in a very thin design making it the primary motor technology for high performance or space critical applications
- ❑ Design scalability modularity and flexibility
- ❑ Peak Efficiency >96%
- ❑ Cooling is with the commonly used water-glycol mix allowing common cooling circuits with the inverter and power electronics

Scaling the Axial Flux Technology

Simulation Driven
Optimisation

Component Mechanical
FEA



Cooling Channel CFD



Full Assembly Thermal
FEA



3D Electromagnetic FEA

Automated
machine winding

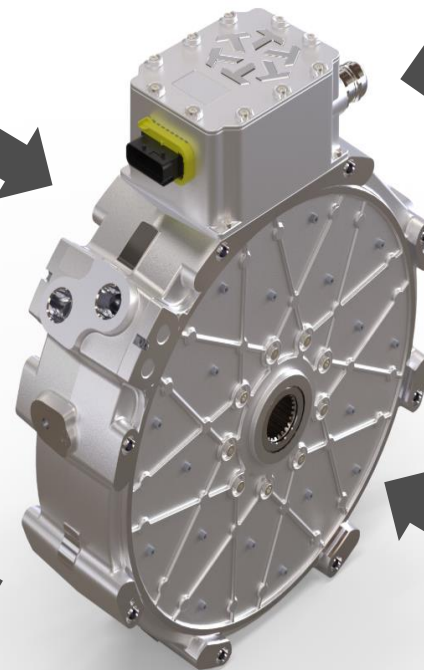
Thermal Path
Optimisation

DFM Housing
Optimisation To Allow
High Volume Tooling

High Voltage Quick
Connectors

High Durability Design –
Lifetime &
Environmental Limits

High Volume Shaft
Manufacturing Design &
Process



Turntide New Breakthrough Axial Flux Motors

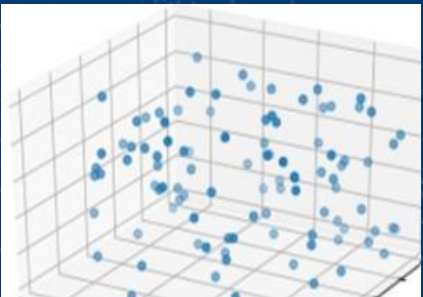
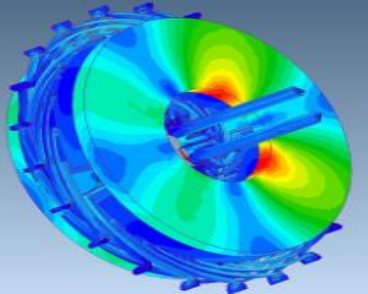
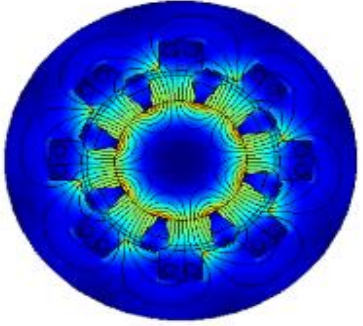
New breakthrough axial flux motors designed to meet the unique needs associated with the electrification of industrial equipment and performance vehicles, from off-highway to premium automotive.

Specifications at 800V _{DC}	"S" series			"D" series		
Model	AF300S	AF400S	AF430S	AF300D	AF400D	AF430D
Maximum Speed (rpm)	8,000	5,000	3,700	8,000	5,000	3,700
Continuous Maximum Torque (Nm)	194	285	428	388	570	857
Maximum Torque(20s)(Nm)	452	565	966	905	1,130	1,933
Continuous Maximum Power (kW)	73	109	110	146	217	220
Maximum Power(20s)(kW)	324	300	350	648	600	700
Dimensions* LxD (mm)	124x334	134x382	125 x 435	233x334	249x382	250x435
Weight**(kg)	28.4	40	52	57.8	80	105



Benefits through Electromagnetic Optimisation

Tech Innovations



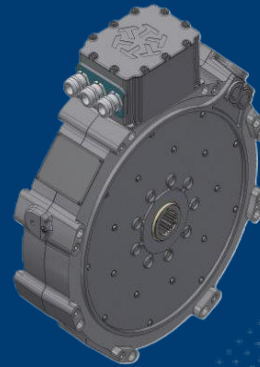
Optimisation of
Stator Slot and Rotor
Pole combinations

Optimised Winding
DFM

Material and
Geometry
Optimisation to ease
manufacturing

Detailed multi
dimensional Design
of Experiments

Leading to



End User Benefits

Enhanced NVH
performance

Low Total Cost of
Ownership

Enhanced Vehicle
Range

Product Benefits

Optimised use of active material, power
and Torque Density enhancements – up
to 4 times radial flux motor counterparts

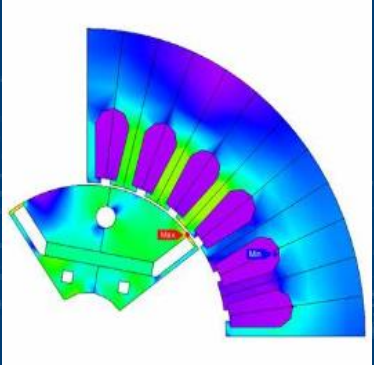
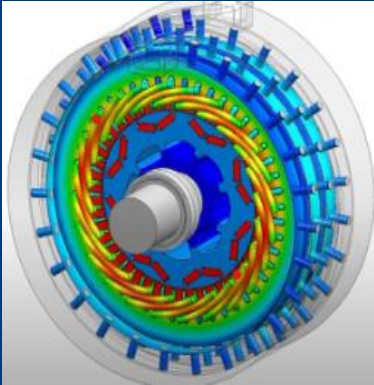
Optimised performance in both 400V and
800 V vehicle architectures

Best in class efficiency – achieving IE4
efficiency class

Enabling

Benefits through Thermofluidic Optimisation

Tech Innovations



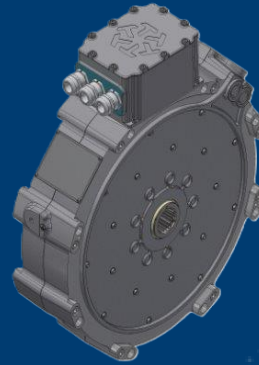
Detailed Conjugate Heat Transfer Analysis for high performance

Detailed Motor Pressure Drop Analysis for multi stack motors

Channel and coolant port design optimisation for casting

Thermofluidic Optimisation for multi stack motors

Leading to



Product Benefits

Thinner and lighter cooling plate giving better thermal performance and enhancing power and torque density

Optimal thermal performance unlocked in high volume manufacture friendly die cast design

Optimal thermal performance even in multi stack motor design

End User Benefits

Optimal performance in high-temperature environment

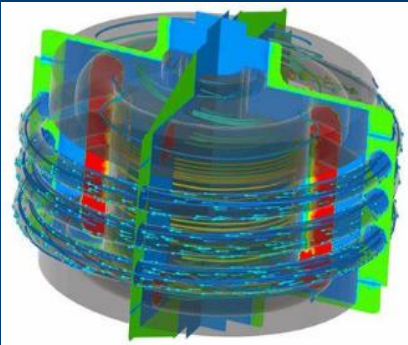
Low total cost of ownership

Enhanced Vehicle Range

Enabling

Benefits through DFM and Reliability Enhancements

Tech Innovations



Detailed shaft stress analysis assuming infinite lifetime

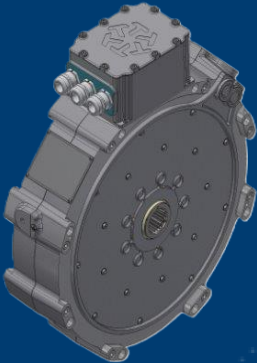
Detailed Mechanical FEA to ensure rotor stiffness

Detailed validation through durability test rig, spin test rig, and wire insulation reliability models

Extensive DFM on all sub-assemblies and components to achieve part count reduction

Die cast design with customer friendly configurations on shafts and interfaces

Leading to



Product Benefits

High reliability product with a long life that is validated to industry standards

Ease of integration in various vehicle platforms including pure EVs, Hybrids, and Generator Applications

Ease of manufacture and optimised supply chain to enable high volume manufacturing

End User Benefits

Long product lifetime – up to 50,000 hours for reference duty cycle

Enabling

Low total cost of ownership

Turntide Axial Flux Electric Drive Unit (EDU)

Engineered as a complete package, the Axial Flux EDU ensures that motor, inverter and differential operate in perfect sync.

This integration simplifies development while delivering consistent, high-performance results.

Key performance figures

Available with "S" and "D" series

Maximum motor rpm

Up to 8,000 rpm

Power

Continuous power from 73kW to 220kW

Peak power from 300kW to 700kW

Output Torque

Continuous from 490Nm to 4650Nm

Peak torque from 1,150Nm to 10,500Nm

Reduction ratios

2.72 to 5.89

Questions? Contact at electrificationsales@turntide.com

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Key product benefits



Modular Architecture

Motor, inverter and differential in one integrated package: Multiple configurations for OEM-specific designs



High Torque Density

53% higher torque density and 56% less size/weight vs EDU with radial flux motors



Simplified Gear Design

Smaller, simpler and more reliable gearing due to low-speed, high-torque performance



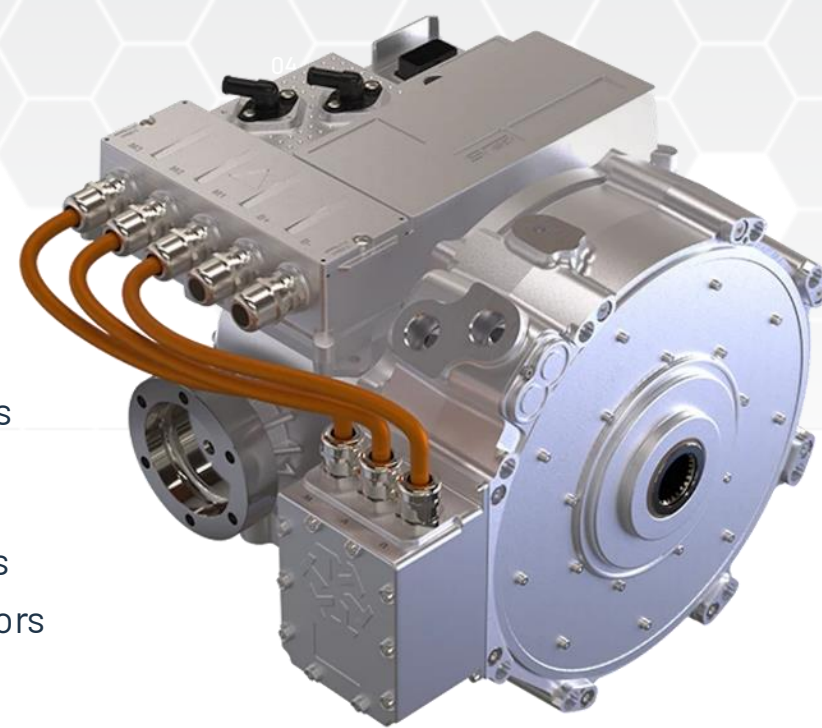
Shared Cooling System

Integrated cooling loop for motor & inverter simplifies installation and improves performance

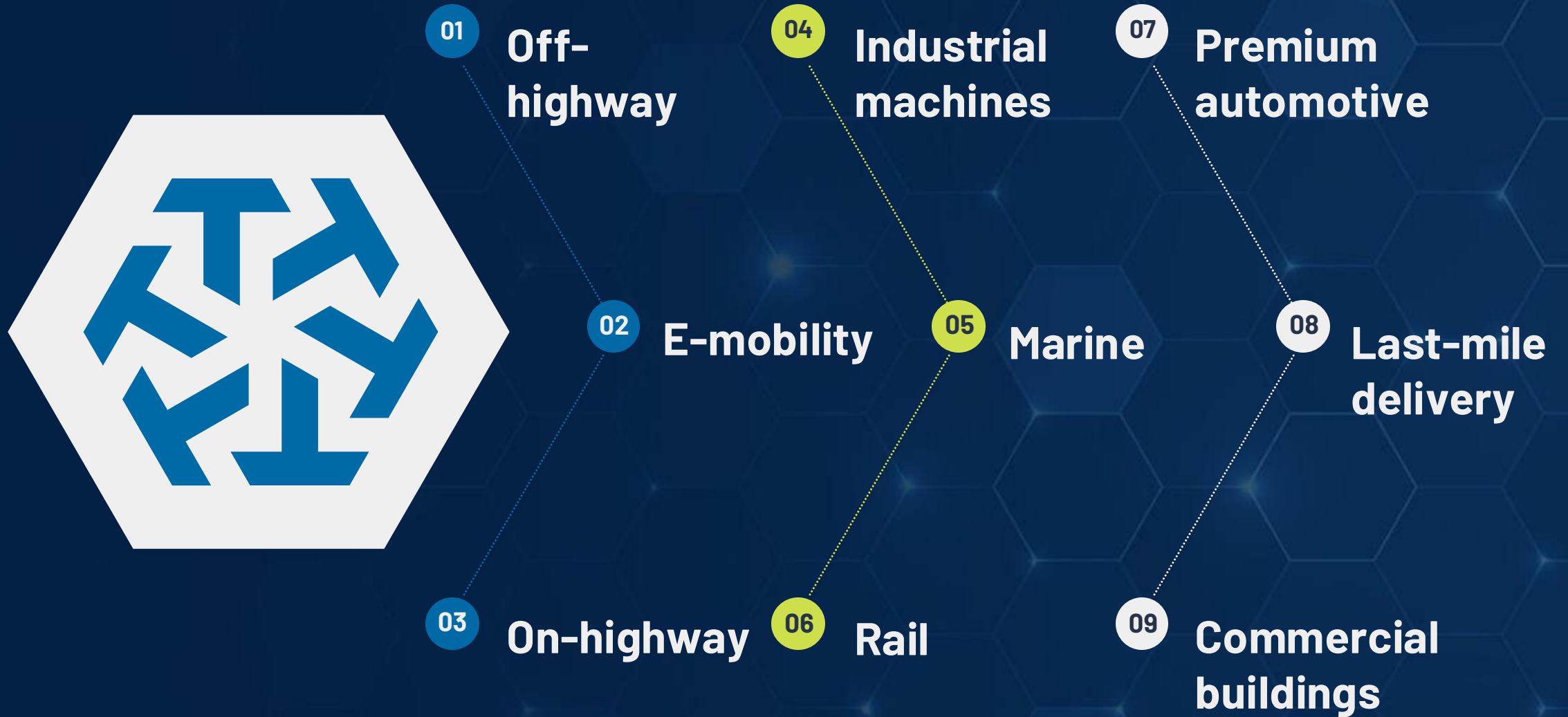


Independent Serviceability

Component-level access reduces downtime and maintenance cost



| Industries



Conclusion

Axial flux motors are an inherently superior technology offering higher performance leading to smaller, lighter, higher efficiency, and more powerful motors.

Turntide is leading the way in improving core technology and manufacturing methods to enable multiple market sectors and applications to reap the revolutionary benefits of axial flux motors.





Thank you

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Q+A

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