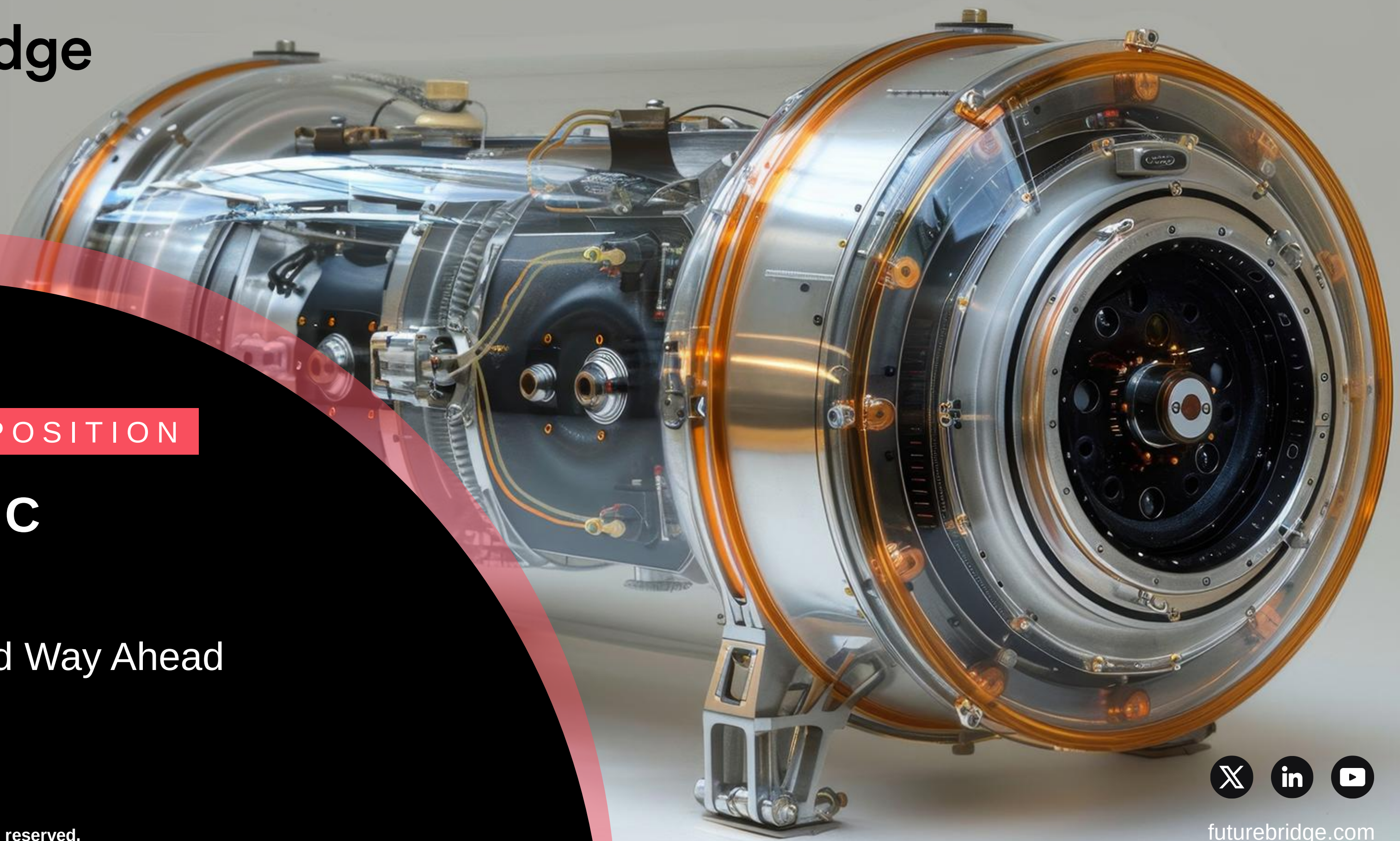
FutureBridge

VALUE PROPOSITION

ELECTRIC MOTORS

State-of-art and Way Ahead



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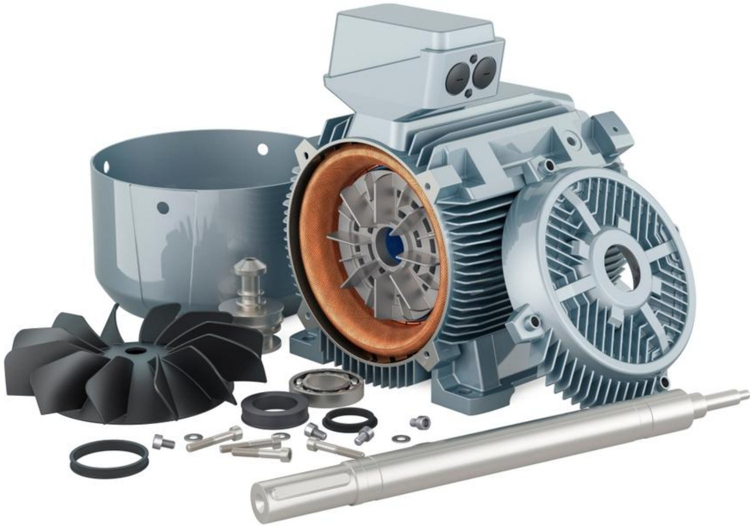


01

Current market and application areas of Electric Motors

Electrification is powering a new era of sustainability, transforming industries from transportation to manufacturing

STRATEGIC GROWTH FIELDS

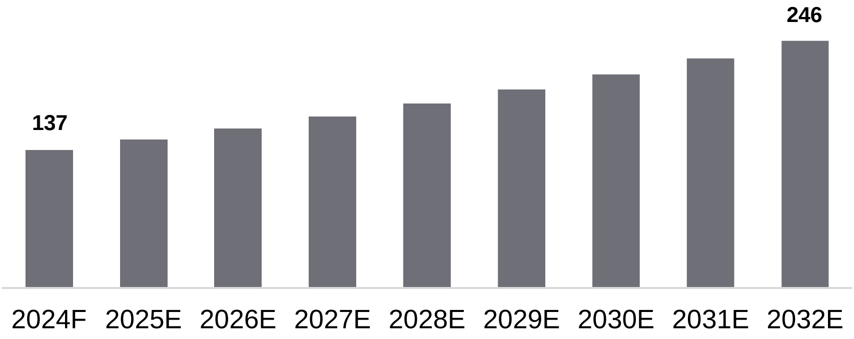
AI & Analytics	Industry X.0 & Digitalization	Automation and Robotics	Innovative Business Models	Sustainability
Intelligent Products & Equipment	IIOT & Digital Twins	Lights-out manufacturing	X-as-a-Service	Sustainable Manufacturing & Products
Process Control & Optimization	Smart Sensors	Robots	B2B shift to B2C	Electrification
Enterprise AI	XR: AR, VR, MR	Touchless Supply chain	Enhancing Consumer Engagement	Circularity
Generative AI	Traceability & Transparency	3D Printing	Valorising Data	ESG

- Aerospace and Defense
- Automotive
- Renewable Energy
- White Goods
- Industrial Equipment & Tools
- Marine
- Agriculture & Forestry
- Mining & Construction
- Medical Devices

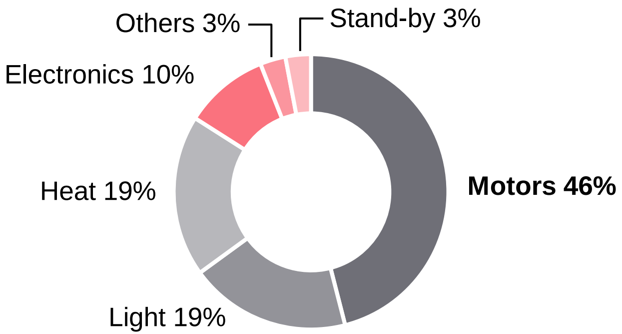
Policy, Regulation and Industries

Motors consume 46% of global electricity; a 1% efficiency gain can reduce tons of CO_2 emissions.

Market Size of Electric Motors (in Billion USD)



Global Electricity Consumption (by devices)



- The electric motor market is expected to grow from USD 137 billion in 2024 to USD 246 billion by 2032, at a CAGR of 7.7%.
- Growth is driven by increasing demand in both existing and emerging application areas.
- The market is highly fragmented, with a mix of established players and startups serving diverse sectors.

- Motors are the primary source of motion across applications, accounting for approximately 46% of global electricity consumption.
- Efficiency losses occur due to heat generation, friction, and worn-out components, leading to increased energy usage.
- Regular performance monitoring enables timely corrective actions to minimize excess power consumption.

Motors are essential to any motion-driven system, serving as prime movers across diverse applications. They are also increasingly used in wearable devices to provide user feedback.

Key Application Areas

Automobiles	Water Pumps	White Goods	Material Handling
Agriculture	Medical Devices	HVAC	Robots/ Cobots
Aerospace	Marine	Power tools	Electronic devices
Oil & Gas	Industrial Machinery	Earth Moving Equipment's	….

Key Emerging Application Areas

Electric Vehicles

EV's rely on efficient electric motors for traction. These motors replace internal combustion engines and provide reduced emissions, quieter operations, and lower maintenance costs.

eVTOLS

Electric vertical takeoff and landing (eVTOL) aircraft demand motors that combine lightweight properties with immense power to ensure efficient take-off, cruise, and landing operations.

Drones

Motors are used to spin the propellers of multirotor drones to enable them to fly.

Robots/ Cobots

Domestic cleaning robots and industrial robots used for manufacturing, assembly and material handling are witnessing high growth.

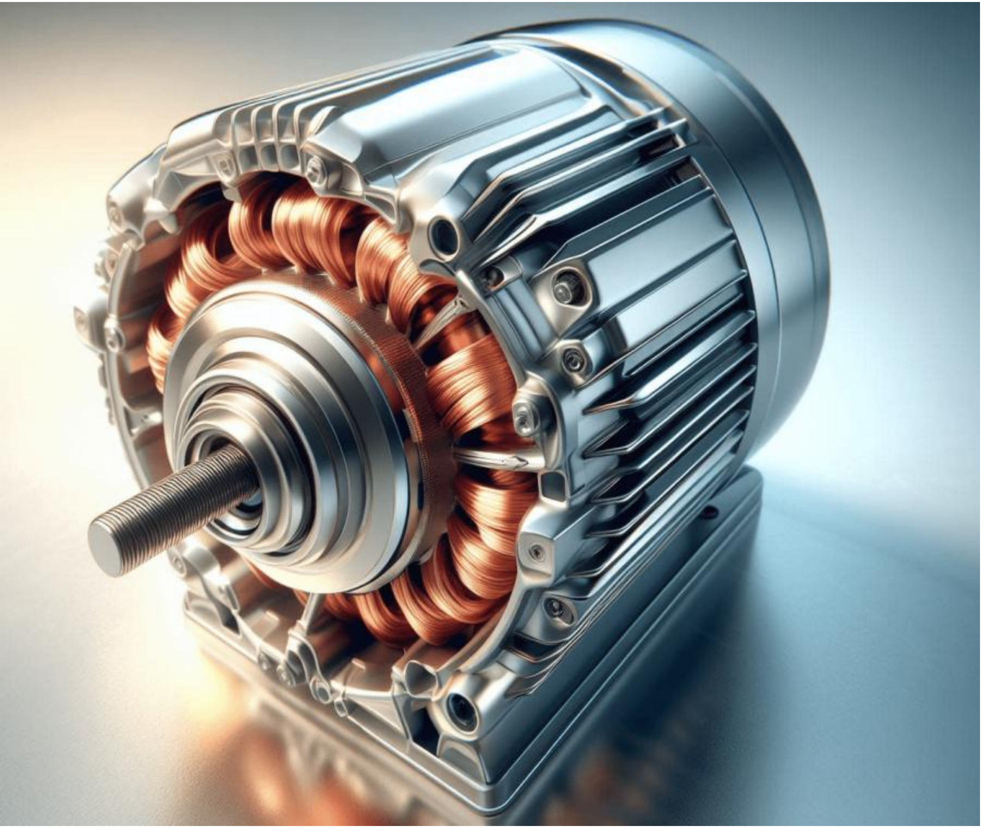
Wearables

Vibration motors are used to provide haptic feedback in wearables and smartphones

02

State of the art: e-motor applications, enabling technologies, high-speed motors, and emerging startups

Classification of electric motor drive systems



Electric motor drive systems are broadly classified into two main categories: DC motors and AC motors. While both categories include several subtypes, they differ significantly in their characteristics and functions

Prominent Motor Types

- **AC Induction Motor**: Most common type of motor due to its simplicity and robustness. Found in various applications, including household appliances, industrial machinery, and HVAC systems.
- **Brushless DC (BLDC) Motor**: Like DC motors but uses electronic switches to control the current, eliminating the need for brushes. They are commonly used in drones, electric vehicles, and high-performance applications.
- **Permanent Magnet Synchronous Motor (PMSM):** Uses permanent magnets to create a rotating magnetic field, resulting in high efficiency and power density. Found in applications like electric vehicles, wind turbines, and high-performance industrial drives.

…. and others

Overview of motor types: applications, advantages, and limitations (1/2)

Induction Motor (IM)

APPLICATION AREAS

- Industrial applications (pumps, fan, traction, etc.)
- Whitegoods
- Automotive
- HVAC
- Elevators

ADVANTAGES

- Low cost of material and manufacturing process
- Line-start capability

LIMITATION

- Low power factor
- Highly probable bearing fault

Permanent Motor synchronous Motor (PMSM)

APPLICATION AREAS

- Precise control and high-speed performance (traction, robotics, aerospace, medical, etc.)
- Automotive

ADVANTAGES

- High performance in wide speed range operation

LIMITATION

- Rare-earth material usage

Synchronous reluctance motors (SynRm)

APPLICATION AREAS

- Industrial applications (pump, fan, traction, etc.)

ADVANTAGES

- Reliable and highly efficient due to cold rotor operation
- Highly dynamic and overloadability
- Very high-speed capability

LIMITATION

- High torque ripple
- Severe low power factor

Switched Reluctance Motor (SRM)

APPLICATION AREAS

- High speed application areas
- Automotive
- Oilfield & Mining machinery
- Mechanical presses

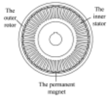
ADVANTAGES

- High fault tolerance
- Continue to run with disabled or shorted poles
- Less weight & complexity
- Improved thermal capabilities

LIMITATION

- Require higher phase current
- Less torque and noisy

In-Wheel Motor (IWM)



APPLICATION AREAS

- Electric vehicles
- Aircraft landing gear
- Off-road vehicles
- Direct drive systems

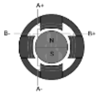
ADVANTAGES

- High torque

LIMITATION

- Increase unsprung mass
- Cannot be retrofitted
- Complex control system

Stepper Motor



APPLICATION AREAS

- Printers, scanners, plotters, tape drives
- Industrial robotics, material handling, wafer handling

ADVANTAGES

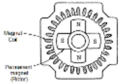
- Precise positioning over full or half rotation with speed control
- Start, stop and operate at constant angular velocity

LIMITATION

- Less torque as compared to brushed DC motors
- Driver circuit to function which increases cost

Overview of motor types: applications, advantages, and limitations (2/2)

Servo Motor



APPLICATION AREAS

- Robotics
- CNC machines
- Medical equipment
- Automated manufacturing
- Wood and metal working

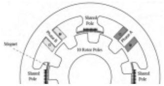
ADVANTAGES

- High output power relative to motor size and weigh
- 5-10 times more rated torque for short periods
- Quiet working

LIMITATION

- Need of complex controller
- Requires gearbox to deliver power at high speed

Linear Motor



APPLICATION AREAS

- Automation – Robotic arms
- Sliding opening door
- Metallic belt conveyors
- Precision machining

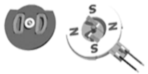
ADVANTAGES

- Increased efficiency
- Enhanced precision & control
- Low Maintenance

LIMITATION

- Complex thermal management
- Need for more space
- High cost

Vibration Motor



APPLICATION AREAS

- Touch screen haptics
- Vibration for healthcare
- Dosing of granular product
- Vibration alerts

ADVANTAGES

- Low maintenance
- Low energy consumption
- Lightweight

LIMITATION

- Heating while running
- Needs control system to vary the vibrations
- ERM motors are big in size

Key Insights

- SRMs have emerged has highly efficient, reliable and cost-effective solutions for use in electric vehicles and wind energy systems.
- SynRM do not have rotor cage losses or PM losses, thus provide continuous torque higher than the torque of an Induction Motor (IM) of the same size.
- Induction motors have eddy current loss and low efficiency at high speed, and more weight and size as compared to other motors. This factors promotes the use of other motors in electric vehicles.
- PMSMs rely on use of rare earth elements for producing permanent magnet, hence alternate motors are explored to overcome this key challenge.

New topologies such as axial flux and transverse flux motors are being explored to address the limitations of conventional motor designs.

Motor Topologies

	Radial Flux (Traditional)	Axial Flux (Innovative)	Transverse Flux (Innovative)
Innovations	▪ **Trapezoidal coils** are **pre-wound** mounted on the stator to create a **high fill factor**. **Weight** and **size** are **reduced by 50%** for same output >> ▪ Implement 3D printed hairpin design into the innovative e-motor with SMC based stator core >>	▪ Compact and lightweight stator structure using **SMC technology** results in **98% peak efficiency** and reduce production **cost by 30%** >> ▪ Use of **mechanical field-weakening increases speed** at the **cost of torque** >>	▪ Soft Magnetic Composite (SMC) materials are made of pure iron powder particles having an electrically isolating coating that remains active even after pressing and curing. >>
USP	▪ High Torque capacity| Easy to install and construct | Cheaper | Cost effective	▪ High Efficiency | Thin & Flat | Compact and Lightweight | High power density >>	▪ Low electrical losses | High torque at low RPM | Eliminates gearbox | Reduced heat generation
Preferred Application	▪ Washing machine, Refrigerator, Power steering, HVAC	▪ Electric Vehicles | Electric aircraft | wind and hydro energy power generation, Drones	▪ Positive Displacement Pump, Robotics and Automation, Urban Air Mobility, Wind Turbine
Key Companies	EVR Motors, Elaphe, Turntide	YASA, Agni Motors, EMRAX, Traxial	Rolls Royce, Servax, ETM

Innovation across motor components to improve efficiency, performance and reduce dependency on rare earth elements

Innovation In Motor Systems

Windings
- Multi-material insulation systems
- Continuous Hairpin Windings
- 3D Printed Windings

TAU | BBS AUTOMATION | ADDITIVE DRIVES

- *Tau offers a range of multi-material insulation solutions that combine different materials to achieve optimal performance.*
- *BBS Automation provides entire CHPW (Continuous Hairpin Winding) process including wire forming, paper insertion, etc.*
- *Additive Drives have developed innovative techniques to 3D print copper coils directly, creating highly efficient and motors.*

Bearings
- Ceramic hybrid bearings
- Magnetic bearings
- Smart bearings with integrated sensors

SKF | CALNETIX

- *SKF has developed ceramic hybrid bearings, which combine traditional steel races with ceramic rolling elements.*
- *Calnetix Technologies Active Magnetic Bearings (AMB):Powerflux™ and Xcelflux™ magnetic bearings suspend the rotor in a magnetic field, eliminating contact and allowing for extremely low friction.*

Thermal Management
- Direct oil cooling of windings/end-windings
- Integration of PCMs (phase change materials)
- Advanced cooling channel designs
- Combined air/liquid cooling solutions

RUBITHERM | MIKROS

- *Rubitherm offers a range of PCM products with different melting points, allowing customization based on specific temperature requirements for various motor applications.*
- *Mikros Technologies' microchannel designs can dissipate over 1 kW/cm² with minimal temperature increases, optimizing thermal management for traction drives and inverters*

Rotor/ Stator
- Segmented stator designs
- Advanced lamination materials and manufacturing
- Integrated cooling channels in stator core
- Hollow shaft rotors

Lammotor | EMAG

- *Lammotor's segmented stator designs simplify winding processes, improve material utilization, and enhance reluctance torque, making them suitable for modern electric motor applications*
- *EMAG's produce hollow, assembled rotor shafts that significantly reduce weight while maintaining structural integrity.*

Magnets
- Heavy rare-earth free permanent magnets
- Halbach array configurations
- Bonded magnets
- Development of recycling processes

Niron Magnetics | STANFORD MAGNETS

- *Niron Magnetics raised $21.3M to Commercialize Rare-Earth Free Magnets for a More Sustainable Electric Economy*
- *Stanford Magnets utilize Halbach arrays to create a sinusoidally varying magnetic field, which improves the torque and efficiency of electric motors.*

Control Systems
- Model predictive control
- Sensor less control algorithms
- Advanced power electronics integration
- AI-based adaptive control systems

BORGWARNER | KEB

- *BorgWarner's 800-Volt Silicon Carbide Inverter enhances efficiency and extends battery range by utilizing advanced semiconductor technology,*
- *KEB America Offers "Sensor less Closed Loop" (SCL) technology that provides dynamic motor performance without additional hardware like encoders.*

Innovations across windings, thermal management, power electronics, and control systems are reshaping electric motor components.

Windings

Fraunhofer IWU

- **Slot filling factor is increased** from the current average of **50 percent to over 80 percent** by means of **position-matched windings**.
- In the **trapezoidal groove**, a **flat and wide design** of the winding while on the **short base side** a **narrow wire geometry** suits best for maximum **utilization of space**. >>

ELMOTEC STATOMAT – A Schaeffler Company

- Compared to traditional hairpin process, the **flat wire wave** is processed into a **continuous mesh**, significantly **reducing** the **number of welds, which is** the primary cause of **motor failure**. The windings are **compact and have low electrical loss.** >>

3D Printing

University of Sheffield; Wisconsin; TU Graz

- Developed a **prototype** electric motor using metal **powder bed fusion 3D printing technology.**
- 3D-printed electric motor using **high-silicon steel** to reduce energy loss. Circular stator with prongs for wire winding.
- 3D printing of **ferrite-based material** >>

Control Systems

ecm; Tata Elxsi; Renesas

- ECM unveils **fully integrated electric motor controller** that enables IE5 efficiency and is customizable via CAD
- Tata ELXSI and Renesas have collaboratively developed **a cutting-edge Motor Control Unit (MCU) on the RH850C1M platform**, offering advanced motor control, safety, and performance features >>

Thermal Management

Georgia Tech

- Two-Phase Thermal Management System for Integrated Motor Cooling -The technology employs wicks with micropillar pattens on polydimethylsiloxane (PDMS) substrates to enable thermal management of stator windings via evaporative cooling >>

LUVATA

- Using **hollow conductors enables more efficient cooling** is accomplished as the **cooling fluid or gas** is **circulated in direct contact** inside of the conductor. This allows for significantly **higher stator currents** and therefore **smaller, more compact** motors. >>

Power Electronics

exro

- Exro's Coil Driver™ uses next-gen coil switching technology in its traction inverter to enhance EV performance.. >>

VisIC Technologies

- They have developed innovative **Gallium Nitride High voltage transistors** with **unique D3GaN** (Direct Drive D-Mode) technology, an enabler of **high efficiency and power density**. >>

Magnets

University of Michigan; AML

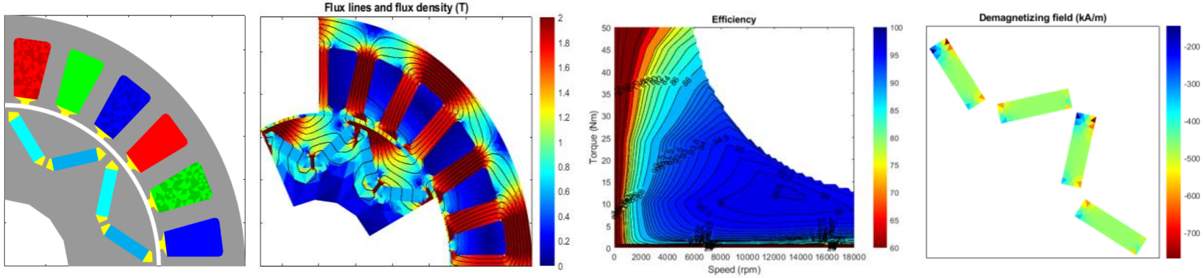
- 3D-print of nanocrystalline soft magnetic cores
- PM-Wire Creates a New Frontier for Magnet Applications
- CorePower Magnetics' patented combination of advanced manufacturing processes and novel materials result in up to 10x reductions in weight

With new application requirements, new concept designs are inevitable

Traction motors – Example

’Light EV IPM motor’ (amalgam of several projects)

Specifications:
- 8-pole IPM motor
- N42SH magnets
- Distributed stator winding
- 30 kW or so
- 6000-9000 rpm rated speed
- ~20 krpm max speed
- Water-jacket cooling



Aviation motors – Examples

Concept design optimization for an urban aircraft
- Low-speed direct-drive
- Hollow-conductor liquid cooling
- Efficiency vs. mass optimization

ARPA-E ASCEND project
- Megawatt-level high-efficiency motor concept

The ASCEND program has the potential to accelerate innovations and cause disruptive changes in the emerging electric aviation field.

Related Projects

Wright	Ultra-lightweight motors, generators, and batteries for aerospace and defense; second-generation motor for large electric aircraft propulsion systems
GE VERNOVA	Electric flightworthy lightweight integrated thermally-enhanced powertrain system (eFLITES) for narrow-body commercial aircraft
AML	Advanced Magnet Lab (AML) seeks to develop high-power density permanent magnet motors.

High-speed electric motors: redefining power, efficiency, and compactness

High-speed electric motors are specialized machines designed to operate at very high rotational speeds, typically exceeding 10,000 revolutions per minute (RPM)

What does “High Speed” mean

There is no clear definition as to what constitutes a 'high-speed' electrical machine (motor or generator)

However, there are 3 key figures that can be considered:

- **RPM**: 10-20000 rpm and above
- **Rotor Surface Speed**: 60-200 m/s and above
- **Frequency**: >450 Hz

It can be usually defined by a combination of at least the above two considerations

Why High-speed

It is often easier to reach high power densities and high efficiencies with the use of high-speed motors

Possibly lower raw material cost and volume per kW
Unless e.g., need to switch from NeFeB to SmCo

For given motor size, at maximum feasible flux density:

- Torque ~ current (density)
- Shaft power = Torque x Angular velocity
- Efficiency = Shaft power / (Shaft power + losses)

Increasing the speed directly improves power density

Challenges of High-speed Motors

One of the key barriers to the broader adoption of high-speed machines lies in the significant engineering challenges they present. Designing such machines is highly complex, requiring expertise across multiple disciplines

Thermal management

- High power density <-> high loss density
- Rotor cooling particularly important

Mechanical considerations
- Centrifugal stresses in rotor
- Bending vibrations
- Vibration resonances

Eddy-current management
- Windings
- Solid bodies

Inverter

Manufacturing
- Typical bearings only good up to 20 krpm
- Carbon-fiber sleeves, etc.

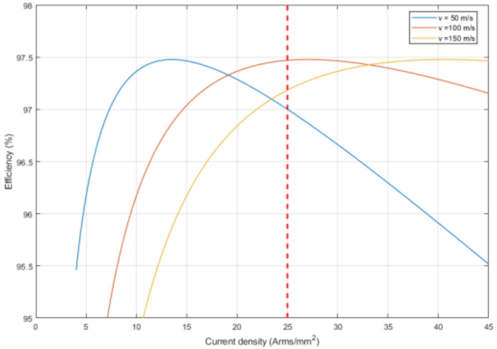
Efficiency of High-Speed Motors

Losses

- DC losses proportional to current squared
- Iron losses mostly dependent on speed, between linear and quadratic relationship
- Windage losses ~ speed3

Increasing the speed does not always increase the efficiency

Best efficiency is often reached at increased current density



High speed electric motors represent a critical technological frontier, promising transformative improvements across multiple industries through enhanced performance

Major Applications of High-Speed Electric Motors

Aerospace and Defense
- Drones and UAVs (Unmanned Aerial Vehicles)
- High-speed aircraft generators and actuators
- Aircraft electric propulsion systems

Automotive
- Electric vehicle traction motors
- Turbocharger electric compressors
- High-performance hybrid powertrains

Industrial Manufacturing
- High-precision machining equipment
- Semiconductor manufacturing tools
- Robotics and automation systems

Medical
- Surgical equipment
- Dental instruments
- Medical imaging device spindles

Energy
- Turbo expanders for power generation
- Wind turbines for lightweight generators
- Oil and gas industry (downhole tools, compressors)

Technology Trends in High-Speed Electric Motors

The research by **Jianguo Bu** focuses on **optimizing motor design** to balance **performance**, **efficiency**, and **mechanical reliability**. The study identifies critical speeds and corresponding vibration modes. Adjustments, such as altering rotor length or diameter, are made to improve stability and avoid resonance. >>

The paper by **Qiping Shen** examines the **advancements** and **challenges** in designing high-speed permanent magnet (PM) motors. Techniques like **thermal-structural coupling** and enha**nced material selection** are used to improve rotor resilience. >>

The paper by **Honglin Yan** explores a detailed **optimization methodology** for High-Speed Permanent Magnet Motors (HSPMMs). It uses a **Multiphysics** approach, **integrating stress**, **electromagnetic**, and **thermal** analyses to improve performance. >>

UNSW engineers have built a new high-speed motor which has the potential to increase the range of electric vehicles. The design of the prototype IPMSM type motor was inspired by the shape of the longest railroad bridge in South Korea and has achieved speeds of 100,000 revolutions per minute. >>

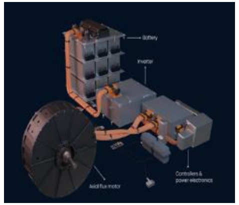
Garrett Motion's innovative control technology designed for electric vehicles, offer better thermal management and faster response times, crucial for meeting the demands of modern e-motor systems. >>

Startups have developed patented technologies to facilitate electrification of heavy vehicles, maritime and aviation

4QT

Founded: 2020
HQ : Switzerland

High power electric drives for heavy equipment. >>



4QT has developed the 4QT Paris Hybrid™ drivetrain, which equipment manufacturers can offer to end customers.

Partnership ETH zürich

Target Application: Construction, Défense

Celeroton TurboCell

Founded: 2024
HQ : Switzerland

Ultra high-speed electric compressors >>

Celeroton TurboCell is a Swiss based technology leader developing and manufacturing ultra-high-speed electric turbo compressors and drive systems for fuel cell applications.

Target Application: Muti Applications from material handling and commercial vehicles to marine, rail and power generation

H3X

Founded: 2020
HQ : US

Lightweight Electric Aircraft Motors >>

Manufacturer of high-power density electric propulsion systems intended for aviation and the urban air mobility market.

Target Application: Aviation, Defense, Heavy Industrial

- The current landscape of emerging electric motors reflects a strong focus on efficiency, cost-effectiveness, and integration with smart technologies, supporting the demand for sustainable and adaptable electric motor solutions across industries
- Emerging applications in new mobility (EVs, E-Aviation, E-Marine) and industrial sectors (Construction, Manufacturing, Mining)
- Axial Flux is gaining more traction across industries

03

Electric vehicles – a prominent application area for e-motors

Electric motors and power electronics account for ~20% of total EV cost. Incremental improvements can reduce battery load and help address range anxiety.

E-Motors are cornerstone for EVs

Electric vehicles (EVs) are a significant market for new motors due to several factors that distinguish them from internal combustion engine (ICE) vehicles, driving demand for innovation in motor technology

Efficiency Demands

EVs require highly efficient electric motors to maximize range. Innovations like permanent magnet synchronous motors (PMSM), induction motors, and switched reluctance motors cater to different needs, improving energy efficiency and performance over traditional motors.

Demand for Compact, Lightweight Designs

New motor designs focus on achieving optimal power-to-weight ratios, which is critical for range and handling in EVs

Cooling and Thermal Management

Innovations include liquid-cooled and integrated thermal management solutions to prevent overheating and extend motor lifespan.

High Reliability and Longevity

Advanced motor designs are tailored to meet these high torque demands at lower speeds, a key requirement for responsive driving experiences.

Cost and Material Constraints

Research into alternative materials and motor types (e.g., induction motors without rare earths) help reduce costs and reliance on limited resources.

Current Challenges

- Range Anxiety
- Raw Material Cost
- Weight/Efficiency Trade Off
- Manufacturing Complexity

Market Demands

- New Motor Development
- Strategic Supply Chain
- Manufacturing Excellence
- Fostering Innovation

All the Major OEMs have embedded Electrification Strategy followed by high influx from EV Vehicle Startups

Ecosystem – New motor topologies for the prime mover

Companies and start-ups are actively researching and developing new motor topologies

Axial Flux Motors

MAGNAX, YASA, EMRAX, Evolito, SAIETTA, PANGOOD, AROGEN, BEYOND, AXIFLUX, φ-power ag, WHYLOT, MAXIMA, ECM, PROTEAN, Lucchi R., FASTSTREAM TECHNOLOGIES, 仪坤动力 YIKUN POWER, marathon Motors, LAUNCHPOINT, QuantEon, Torev, LEONARDO DRS, TRAXIAL, AGNI MOTORS, Allied Motion, TORUS ROBOTICS, ATRESA, SEMOTOR

Transverse Flux Motors

ETM Electric Torque Machines, GKN SINTER METALS, HONDA, HIGEN MOTOR, ROLLS ROYCE, SERVAX, HORIZON TECHNOLOGY

In-Wheel Motors

PMW Dynamics, BMW, QSMOTOR, GEM motors, PROTEAN Electric Automotive Technology, elaphe Propulsion Technologies, ORBISELECTRIC EV / PHEV FOR EVERYONE, REE, DeepDrive, SCHAEFFLER

Synchronous Reluctance Motors

Bonfiglioli, REULAND, MAHLE, TMEIC, MACON, WONDER Since 1988, RegalRexnord, TOSHIBA, ZF, Danfoss

Switched Reluctance Motors

Advanced Electric Machines, TURNTIDE, MACON, enedym, Nidec LEROY-SOMER, RICARDO, OSWOS, CHIARA, KEHUI

PMaSynRMs

DELTA, DENSO, Nidec LEROY-SOMER, WEG, TESLA, SIMO

Hunstable Electric Turbine

Linear Labs

Dual Rotor Motors

DeepDrive

Raxial Flux (Radial + Axial)

Koenigsegg

Trapezoidal Topology

EVR MOTORS

Most of the car market is still using permanent magnet motors.

OEM Strategies

- Mercedes-Benz → YASA
- RENAULT → WHYLOT
- BMW → DeepDrive
- DONGFENG → PROTEAN Electric Automotive Technology

Companies, both established and emerging, are actively researching and developing new motor topologies to enhance the performance, efficiency, and affordability of electric vehicles

Most of the Automotive market is still using permanent magnet synchronous motors, with new topologies emerging

Recent technological advancements in Motor Space

Tesla has launched the carbon-wrapped motor as the most advanced, highlighting its debut in the Model S Plaid. The motor, featuring a carbon overwrap rotor, required Tesla to create a custom machine to overcome thermal expansion challenges between carbon and copper. This innovation boosts torque, max RPM, and electromagnetic efficiency, enabling a tighter gap at high revolutions. >>

BMW along with Munich-based company DeepDrive is testing a new type of in-wheel electric motor technology which features dual rotors and could be used to improve the efficiency and range of its electric cars >>

Some OEMs collaborate with specialized suppliers or leverage group-wide technologies to enhance their electric drivetrains

Latest adoption of electric motors by OEMs

Proponents PMSM

Proponents IM

Proponents SynRM-IPM

Proponents of Axial Flux | In-wheel motors | Raxial Flux

Emerging

- Induction motors and PMSM are the key motors used in current electric vehicles.
- PMSM are preferred more over IM's due to its high power-to-weight ratio, higher efficiency, small size, full torque at low speed, and has no mechanical collectors and brushes to wear like induction motors.
- Axial flux motors have been currently adopted in high-end cars due to its limited production and high cost. Yokeless axial flux motors are low cost and will help in increasing its adoption in e-vehicles.

Major EV manufacturers develop and produce their own PMSMs to maintain control over performance and integration. The Chinese counterparts in EV ecosystem like BYD and Xpeng are proponents of Permanent Magnet Synchronous Motors wherein, NIO is advocating asynchronous permanent magnet motors(IMs).

C-Motive's electrostatic motor technology eliminates critical rare-earth metals and reduces copper usage by over 90%, while Torev's affordable axial flux motor achieves an impressive 97.8% efficiency

SAMPLE PLAYER PROFILE

Torev

The stator design, **made using SMC materials,** was one-third the length of traditional radial flux motor, making it more compact and lightweight.

Broad Application Segments

Automotive | Marine | Industrial

Technology

mpp

- **Patented double axial flux electric motor**
- **Unique stator structure using a powdered-metal sintering process**
- **Utilizing MPP's advanced Soft Magnetic Composite (SMC) technology**

GAMIC 2024

Winner of 2024 – GAMIC Awards

The product is yet to be commercialized.

The axial flux motor's compact size, saving 30% in overall weight, lower production cost made it ideal for modern application

Source: MPP, Website

C·MOTIVE

C-Motive's electrostatic motors **use printed circuit boards** instead of magnets, rotors and stator

Broad Application Segments

Industry 4.0 | Manufacturing | HVAC | E-Mobility | Renewable Generation

Product Breadth*

1 – 5 HP

Scalable up to multi-megawatt size with the same design principles

C-Motive's electrostatic motors are made with a simplified, regional, and **secure supply chain**

Percent of Total Machine Weight by Materials			
	Permanent Magnet Motor	Induction Motor	C-Motive's Electrostatic Motor
Copper	10% - 20%	15% - 35%	1%
Electrical Steel	30% - 40%	40% - 60%	
Magnets	3% -10%		

C-Motive machine could save up to $1,400 a year in energy costs with high efficiency and high torque

Source: Design World, Website

04 Emerging application areas, motor types, and key players

Powering more than just vehicles

APPLICATION AREAS:

Beyond electric vehicles, electric motors play a pivotal role across industries, powering applications in manufacturing, robotics, HVAC, aerospace, and renewable energy solutions worldwide.

> **Beyond electric vehicles, electric motors are foundational across diverse sectors, driving efficiency, precision, and innovation.**
>
> *"From brushing up your smile to soaring through the skies, electric motors are the unsung heroes that take us from pearly whites to flight heights!"*

Companies are actively researching various motor topologies for areas with high growth potential

As technology continues to advance, electric motors are becoming even more efficient, powerful, and versatile, driving innovation across various industries. Some of the major industries apart from electric vehicles are:

AEROSPACE

Motor type	Companies
	ARC Systems Inc., FAULHABER, T-MOTOR, Portescap, PDS, AMETEK, maxon, RegalRexnord
Permanent Magnet DC Motors	Collins Aerospace (An RTX Business)
Axial Flux Motors	Evolito, Nidec
	GE Aerospace, Rolls Royce

WHITE GOODS

Motor type	Companies
Permanent Magnet Synchronous Motor	WAT, Longbank, CJC
Induction Motor	cebi, Longbank
Brushless DC Motors	WAT, cebi, SUNON, HeTai MOTOR, CJC, Newmotech
Internal permanent magnet	Nidec
AC shaded pole motor	Longbank

HVAC

Motor type	Companies
Electronically Commutated Motors Brushless	Electromotive Power Drives, Panasonic INDUSTRY
Low Voltage motors	RegalRexnord, ABB, HOYER
Shaded pole permanent split capacitor motors	JOHNSON ELECTRIC
Others	Nidec, C-MOTIVE

OIL & GAS

Motor type	Companies
Brushless Servo motors	Nidec, WOLONG, TECO Westinghouse
Permanent Magnet DC	maxon, Nidec, WEG, WEICHAI
Single- and Three-Phase Induction Motors	Nidec, WOLONG, ELIN Motoren, WEICHAI
Synchronous Motors	Nidec, ABB, WEG, WEICHAI
Low voltage asynchronous motor	ABB

ROBOTS/ COBOTS

Motor type	Companies
Stepper Motors	Portescap, LIN ENGINEERING
Brushless DC motors	FAULHABER, Portescap
Radial/Axial – BLDC Micromotors	MIRMEX MOTOR
Linear Motors	TOYO, Celera Motion
Others	T-MOTOR

Aerospace – eVTOLS, urban air mobility, aircrafts and helicopters are heading towards use of electric motors as prime movers

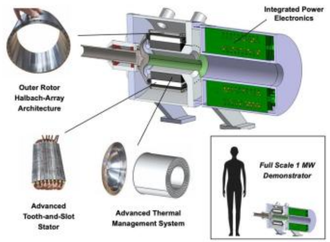
- Electric motors are explored as a prime mover in application such as urban air mobility, aircrafts and helicopters, etc. to reduce CO2 emissions.
- They drive the propellers of electric vertical take-off and landing (eVTOL) system to create the lift and thrust necessary to fly.
- The key focus of motor companies is to reduce motor weight and improve torque and power to facilitate its use as prime mover and various other peripheral systems

Application Areas

- eVTOLS
- Urban Air Mobility
- Helicopters
- Aircrafts

Breakthrough Development

Massachusetts Institute of Technology



- Researchers at MIT have designed a **1 MW electrical motor** capable of **electrifying larger aircraft**. The motor comprises of key enabling technologies such as high-speed permanent magnet outer rotor, a low loss tooth-and-slot stator, an advanced heat exchanger, and integrated, high-performance power electronics. >>
- The motor weighs **57.4 kilograms**, which equates to a **specific power of 17kW per kilogram.**
- They have designed an **air-cooled heat exchanger** made from **aluminum alloy** that sits inside the stator. It features a **honeycomb of small air channels** which is **3D printed** and helps to achieve **efficiency like liquid** cooling.

Challenges in Motors for Aerospace

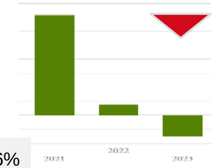
- **High Power Requirement** - **Electric vehicle motors** may deliver **220kW**, but a **90-seater aircraft** would require around **8MW** of power
- **High Heat Dissipation** - Even if we achieve 99% efficiency, **1% inefficiency at 8MW** generates **considerable heat** to **dissipate**. >>
- **Cooling Technologies -** Reduced air-density complicates heat dissipation and high-power systems are likely to require liquid cooling
- **Corona Effect at High Altitude –** The Corona effect creates movements of charge not seen at ground level, which need to be mitigated

Motor Developers

GE Aerospace
EMRAX Innovative E-Motors
SAFRAN
NASA
Collins Aerospace
ARC Systems Inc.
SIEMENS
maxon

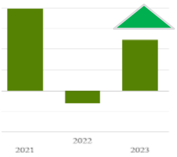
05 Trends – supply chain, export statistics, and recent developments

Export statistics reflect rising global demand, driven by rapid mechanization and sustainability efforts, with China leading. Regionalization and supply chain strengthening remain key priorities.



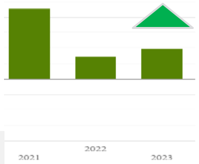
Growth YoY:-7.6%
Value: 14K Mn

Growth YoY



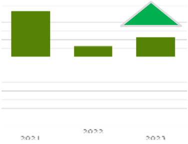
Growth YoY:6.1%
Value: 4.8K Mn

Growth YoY



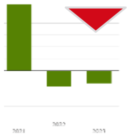
Growth YoY:9.9%
Value: $739 Mn

Growth YoY



Growth YoY:5.7%
Value: $9.3K Mn

Growth YoY



Growth YoY:-5.3%
Value: 3.5K Mn

Growth YoY

Though China leads in export volume, there has been 7.6% decline in YoY 2023 Growth

Despite the positive trajectory, Chinese electric motor manufacturers face several challenges. Trade tensions, geopolitical uncertainties, and concerns about intellectual property rights are among the hurdles that could impact global market dynamics.

Chinese manufacturers are heavily investing in research and development to enhance motor efficiency, durability, and performance, as evidenced by the growing number of patents and innovations emerging from China in magnet technology, motor design, and smart control systems. Over 100+ players in Axial Flux Ecosystem.

Countries like India, Vietnam to benefit from the international tensions.

Broader trends

Geographic Diversification

- **Reducing dependency** on single-region suppliers, especially China
- **New manufacturing hubs emerging** in: Eastern Europe (Hungary, Poland)Southeast Asia (Vietnam, Thailand)North America (Mexico, USA) and India
- **Regional supply chain** development to support local EV production

Vertical Integration

- Major automakers establishing **in-house motor production**
- **Strategic acquisitions** of component manufacturers
- **Joint ventures** between OEMs and suppliers
- **Investment in raw material** sources and processing

Material Sourcing Methodologies

- Development of **recyclable motor designs**
- **Urban mining initiatives** for rare earth materials
- **Alternative material** qualification programs
- **Long-term supply** agreements for critical materials
- **Investment** in sustainable mining practices

Source: TrendEconomy, Electric Motor & Generators

E-motors value chains – Magnets, Copper, E-steel are backbone materials

Permanent magnets represent a high value component used in PMSM traction motors

China has a market share of over 85% for neodymium magnets, although new supply is coming online from Myanmar, USA, Australia, and Canada Source

After magnets, electrical steel (e-steel) and copper have the biggest influence in e-motors

Replacing copper by transitioning to aluminum presents design challenges

Trends

- **Rare Earth Magnet free Motors** – Induction Motors, SRMs etc.
- **Reduced Magnet Content-** Halbach Arrays, Hybrid Magnet Designs
- **Alternative Magnet Materials** – Ferrite Magnets, Bonded Magnets
- **Improved Winding Designs**
- **Strengthening supply chain with Recycling**

- **Alternative Winding Materials-** Aluminum, Cast copper-clad aluminum, CNT conductors
- **Design optimization-** Hairpin winding, concentrated winding
- **Alterative motor architecture-** SRMs, Axial Flux
- **Manufacturing Innovation**
- **Emerging Technologies-** HTS motors, PCB motors, Graphene based conductors

FutureBridge Comments

The increasing demand for electric motors across various industries has led to a growing concern about the reliance on rare-earth magnets, which are often expensive, scarce, and have geopolitical implications.

Hairpin winding technology replacing traditional wire windings, reducing copper usage by 10-20%

Strategic investments and cross-industry collaborations are catalyzing transformative breakthroughs in electric motor technologies, accelerating innovation.

Collaborations/ Partnerships

Sr No.	Motor Company	Company	Type of Motor
1	EVR MOTORS Re-Imagining Electric Motors	Multiple Indian OEMs	Radial Flux Permanent Magnet
2	Valeo, MAHLE	European OEM	Magnet free electric motors
3	Nidec	Ashok Leyland	E-drive motors
4	INNOVATE	EVAGE MOTORS	Electric motor
5	Equipmake	H55	Permanent Magnet Motor
6	Nidec	air	-
7	LILIUM	Honeywell, DENSO	Jet-motor

Funding/ Investments

Sr No.	Investor	Acquired/ Invested	Deal Value
1	weg	Volt electric motors	USD 88 Million
2	KPS Capital Partners, LP	INNOMOTICS A Siemens Business	USD 3.8 Billion
3	BMW i Ventures	DeepDrive	USD 33.5 Million
4	gm	Niron Magnetics	Undisclosed
5	RS, Chevron, Applied Ventures, Aventurine, Cottonwood technology fund, Energy Innovation Capital, Rockwell Automation, CATERPILLAR	Infinitum	USD 80 Million
6	中国中车 CRRC	EMV The Electric Motor Vehicle Company	Undisclosed

06 The way ahead: Future of Electric Motors

As technology advances and environmental concerns intensify, the classification of e-motors becomes crucial for understanding market trends, identifying emerging technologies, and making informed decisions

Global E-motor Trends

Technology Trends	
Higher Power Density	*Advanced Cooling*
	Novel Topologies
	Winding Innovations
Advanced Materials	*SMC*
	Silicon Carbide
	Innovative Dielectric
Integration & Packaging	*Integrated Drives*
	Modular Design
	Compact, Lightweight
Control & Intelligence	*Precision Control*
	AI Integration

Market/Application Trends	
Electrification Wave	*E-Mobility*
	Industrial
	Consumer Goods, HVAC
IoT Integration	*Smart Monitoring*
	Maintenance
	Remote Control
Application Specific Design	*High Torque Density*
	High Power-to-Weight Ratio
	Wide Speed Range
Market Consolidation	*M & A*
	Funding / Investments

Manufacturing Trends	
Advanced Manufacturing	*Automated Hairpin Winding*
	Additive Manufacturing
	Quality Control
Supply Chain Disruptions	*Regional Production*
	Vertical Integration
	Strategic Partnerships
Automation	*Integrated Drives*
	Modular Design
	Compact, Lightweight
Digital Twins	*Precision Control*
	AI Integration

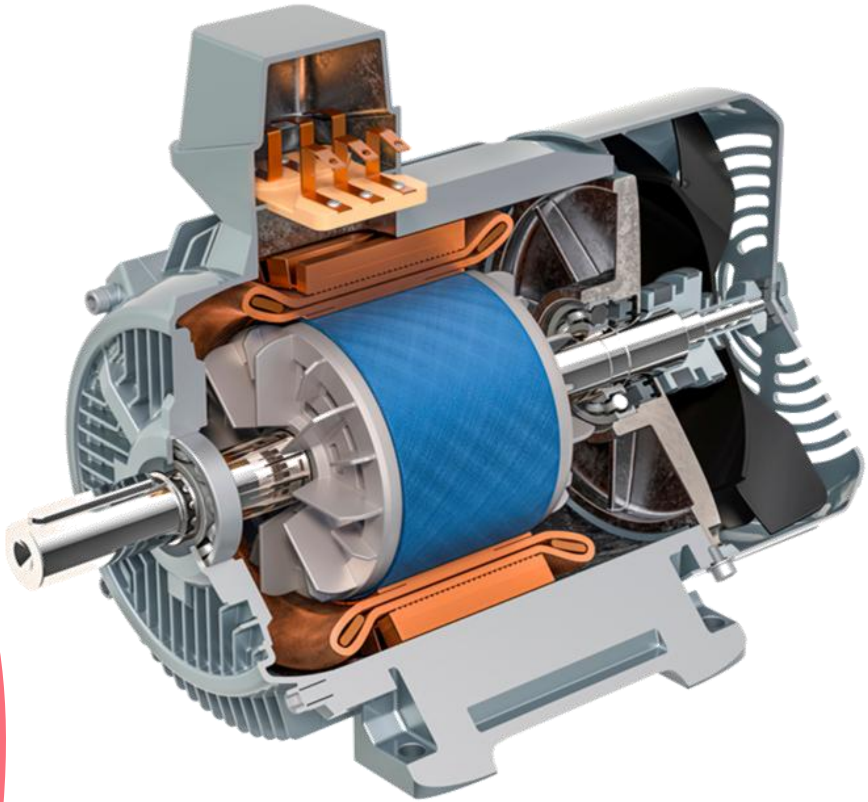
Sustainability Trends	
Material Sustainability	*Rare Earth Reduction*
	Magnet- Free Designs
	Recycled Materials
Efficiency Standards	*Efficient Designs*
	Advanced Control
	Regulations
Sustainable Supply Chain	*Ethical Sourcing*
	Carbon Monitoring
	Transparent SCM
Life cycle Assessment	*Eco-Design*
	End-of-Life Recycling

FutureBridge experts are ready to assist you with all your E-Motor queries and guide you through emerging trends in the electric motor ecosystem.

Conclusion – Way Ahead For Electric Motors

- According to FutureBridge Research, new motor topologies and innovations are heading towards commercialization and will cannibalize the traditional motors market.
- Innovations in electric motors are enabling its exploration and driving its growth in emerging application areas.
- Features desired in upcoming electric motors
  - Higher efficiency designs
  - Rare earth free solutions
  - Smarter motors | Intelligent controls
  - Hybrid topologies

> The electric motor industry is undergoing radical transformation driven by electrification trends, sustainability demands, and digitalization. Success requires balancing technology innovation (efficiency, power density) with application-specific solutions while adapting to new business models focused on systems integration and lifecycle services.



Thank you

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