Electric Motors for Electric Vehicles: Technologies and Market Outlook

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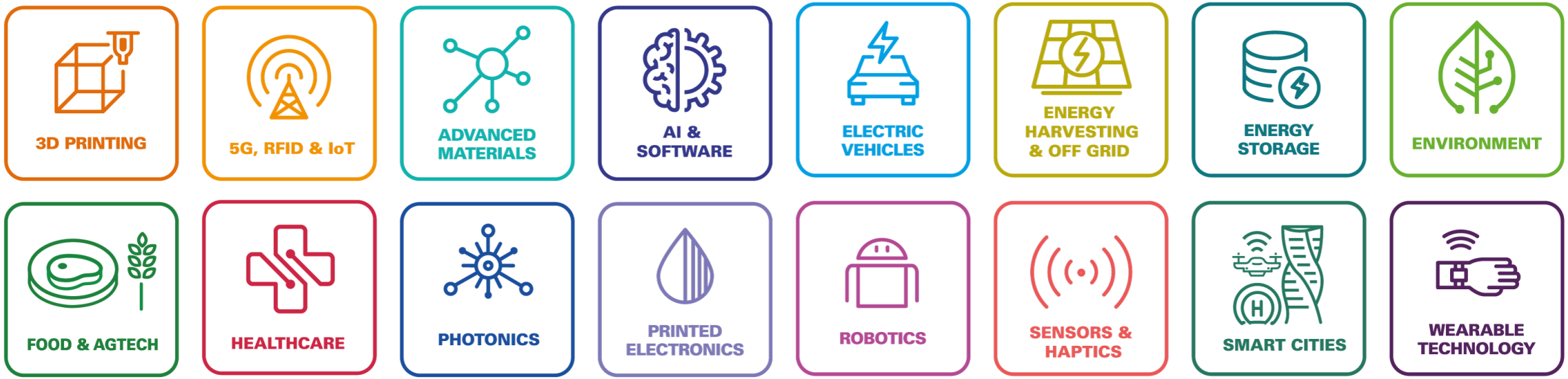
Benchmarking Scouting Profiling	Market sizing & forecasting End-user needs	Strategy guidance Introductions	Showcase your products	Timely analysis & data



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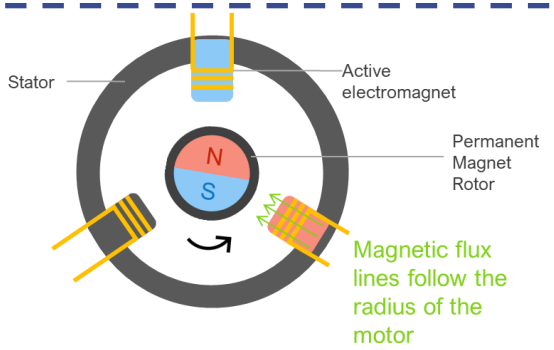
The Electric Motor Market

Summary of Traction Motor Types

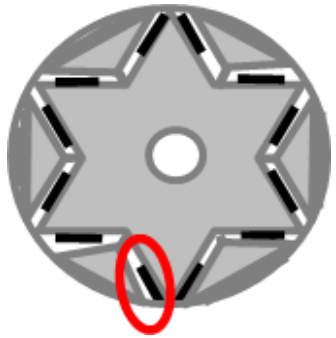
- All have inherent pros and cons:
  - Power/ torque density
  - Costs
  - Critical materials

Permanent magnets

Brushless DC (BLDC)



Permanent Magnet Motor (PM)

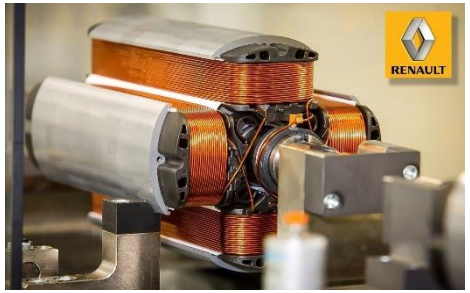


Magnet Free

Synchronous Reluctance

Switched Reluctance Motor (SRM)

Wound Rotor Synchronous Motor (WRSM)



AC Induction Motor (ACIM)

Image sources: Renault, Shutterstock, IDTechEx

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Tesla: Induction to PM/ ACIM Combo

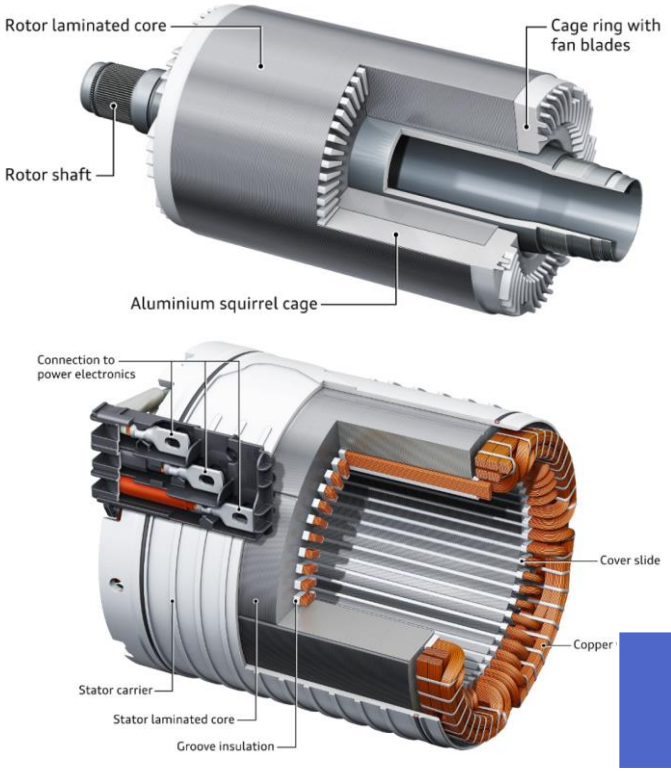
Source: Munro & Associates

Source: Electronics Stack Exchange

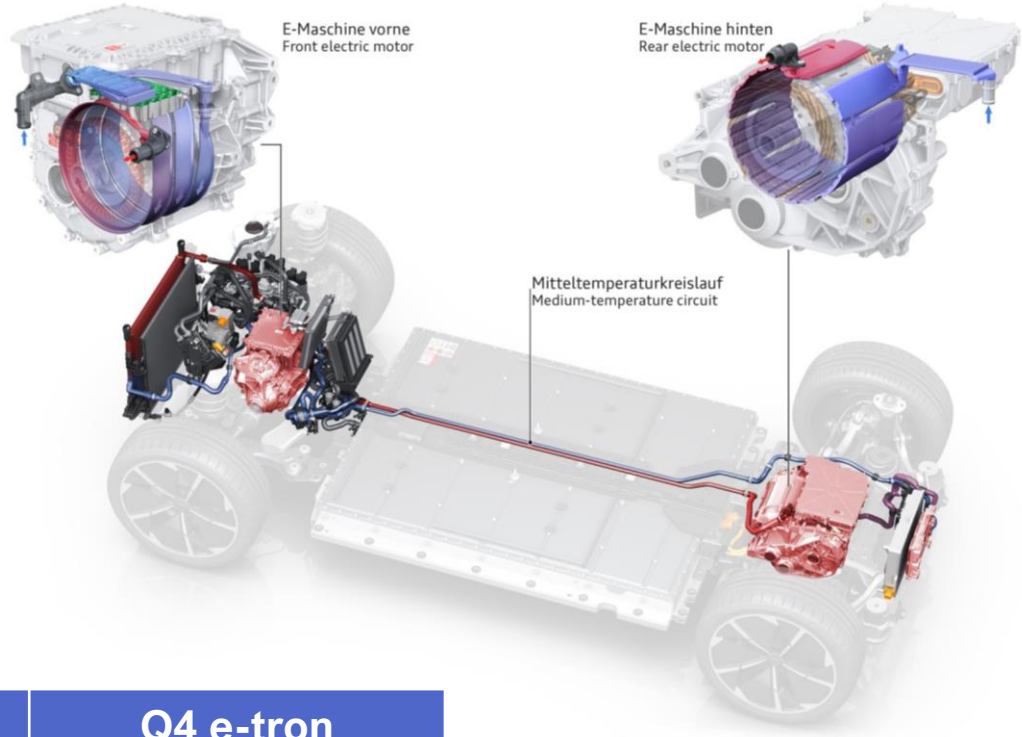
Source: Tesla

Source: Tesla

Audi: Induction to PM/ ACIM Combo



Source: Doerr, et al., The new full electric drivetrain of the Audi e-tron.



Source: Audi

Property	e-tron		Q4 e-tron	
	Front	Rear	Front	Rear
Motor Type	ACIM	ACIM	ACIM	PMSM
Peak Power (kWp)	125	140	80	150
Torque (Nm)	247	314	162	310

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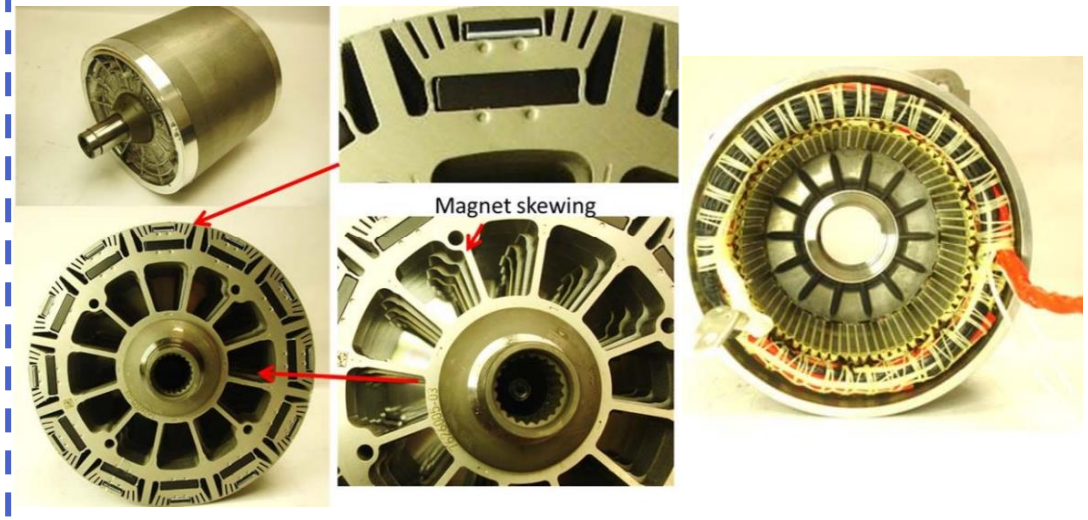
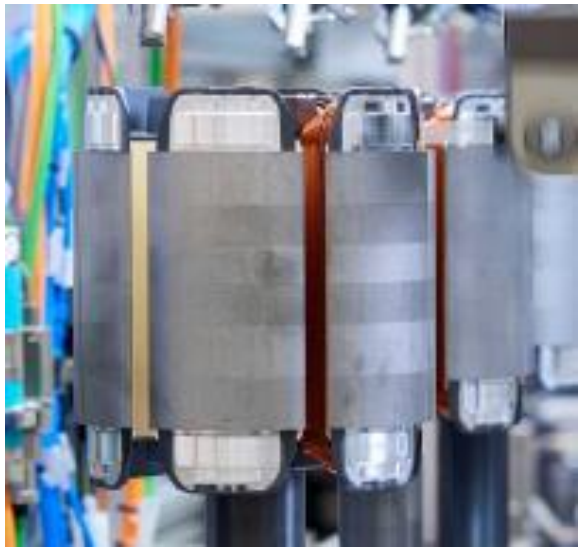
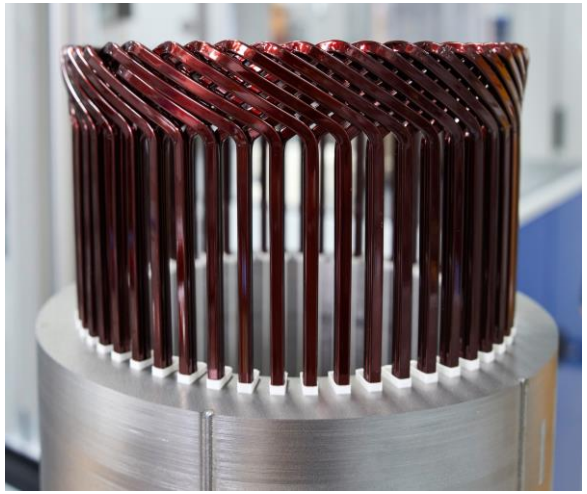
BMW: PM to WRSM



Source: ORNL

	BMW i3
Power (kWp)	125
Torque (Nm)	250





Model	i4	i4 M50
Peak Power (kWp)	250	400 Combined
Peak Torque (Nm)	430	795 Combined

Source: BMW

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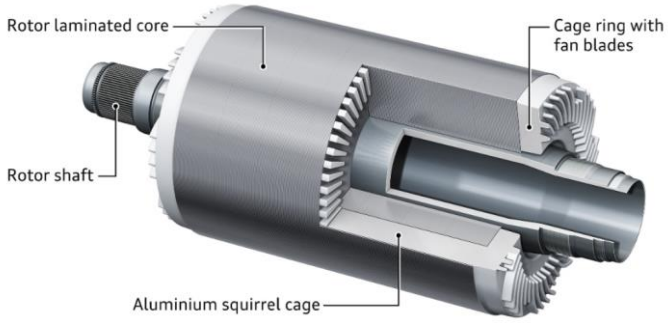
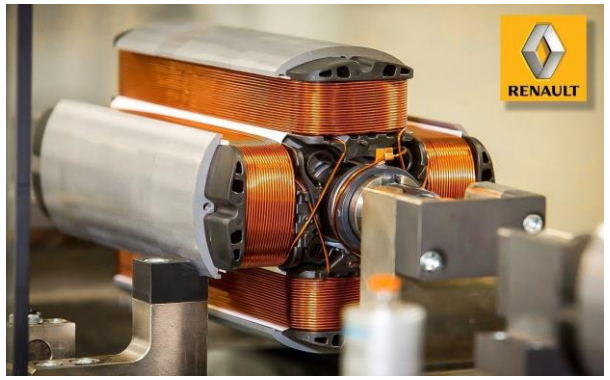
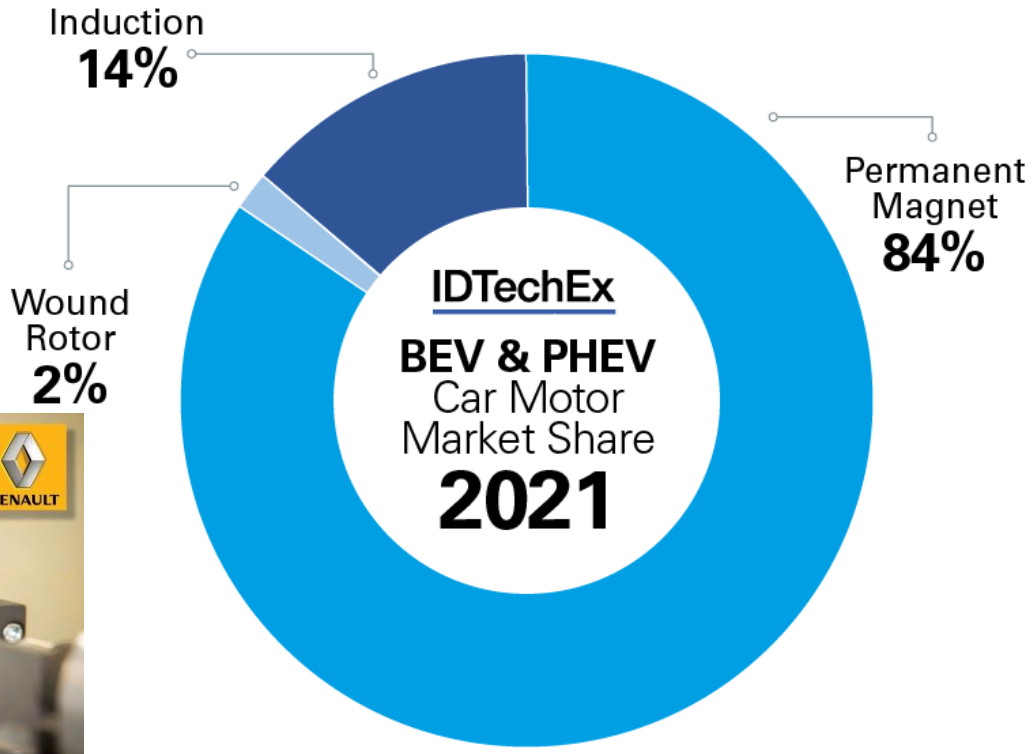
Motor Shares for the Car Market







Source: Electric Car Sales, Models & Technologies Database, IDTechEx

Image sources: Renault, Electronics Stack Exchange, Doer, et. al.

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Emerging Alternatives

Radial Flux vs Axial Flux Motors

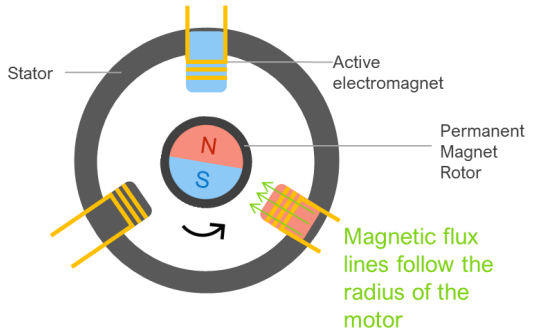
Advantages

- Increased power and torque density
- Pancake form factor
- Potentially improved thermal management

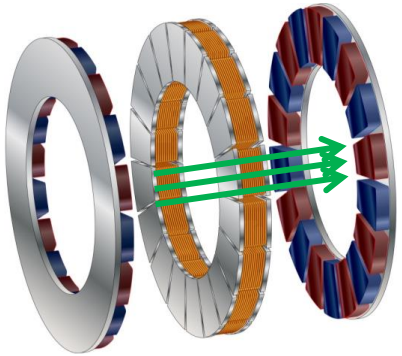
Disadvantages

- Still has the price, heat and assembly problems of permanent magnets
- Manufacturing time is longer
- High costs in manufacturing

Radial flux motor



Exploded view of a torus axial flux motor



	BMW i3 motor	Magnax AXF225
Motor Type	HSM Radial Flux PM	Yokeless Axial Flux PM
Weight (kg)	46	16
Peak Power (kWp)	125	200
Peak Torque (Nm)	250	250
Magnet Weight (kg)	**2**	**1.2**
Power Density (kWp/kg)	**2.7**	**12.5**

Image sources: Shutterstock, IDTechEx

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Axial Flux Motors Enter the EV Market

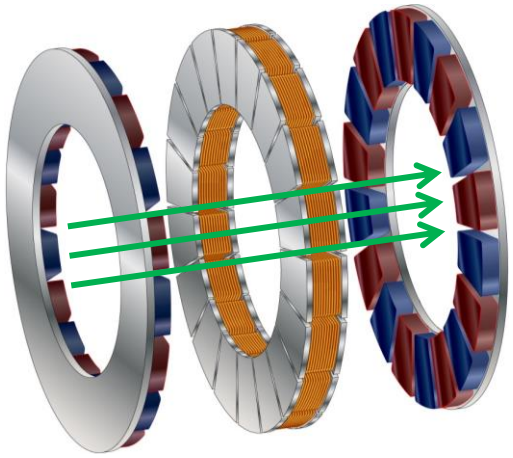
WHYLOT Electromechanical Solutions → RENAULT

- Initially applied to hybrids with the aim of reducing costs by 5% and CO_2 under WLTP by 2.5 g.
- "Renault Group will be the first manufacturer to produce an axial flow electric motor on a large scale from 2025" – Renault press release.

YASA → DAIMLER

- YASA has worked with Mercedes-Benz since 2019.
- Provide Mercedes-Benz's AMG.EA electric only platform with scope to continue development for the wider group.

Automotive Axial Flux Motors Demand



Source: Electric Motors for Electric Vehicles 2022-2032, IDTechEx

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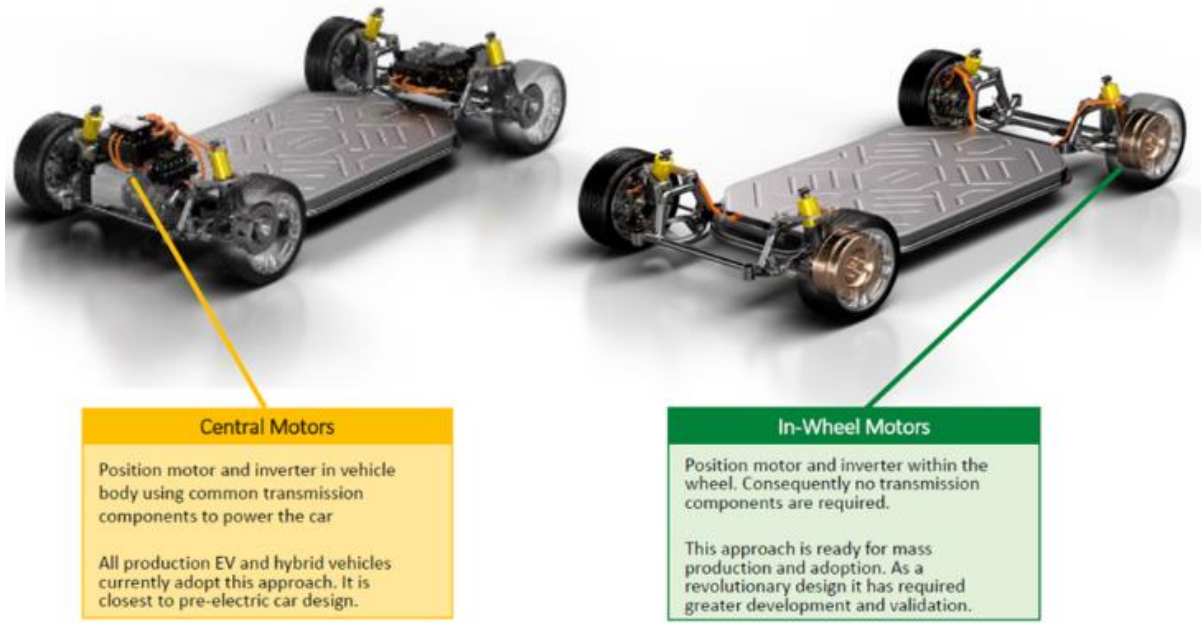
In-wheel Motors

Advantages:

- Torque control for each wheel
- No need for differential
- Torque vectoring and traction control enhancements
- In-wheel systems are more efficient at higher load
- Due to being exposed rather than inside the vehicle, cooling is potentially improved
- More space inside the vehicle by removing drivetrain components

Disadvantages:

- Unsprung mass
- Environmental durability
- Limited motor speed limits power density



Source: Protean

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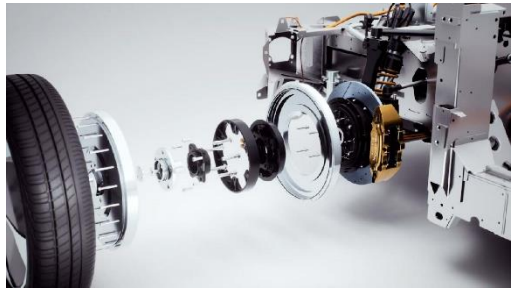
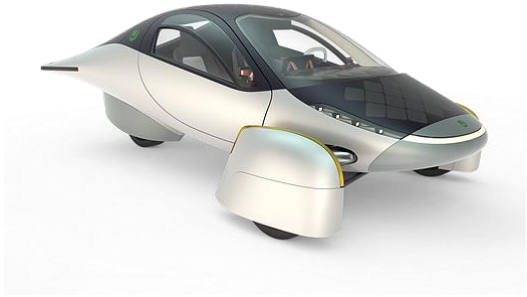
In-wheel Motors Enter the EV Market

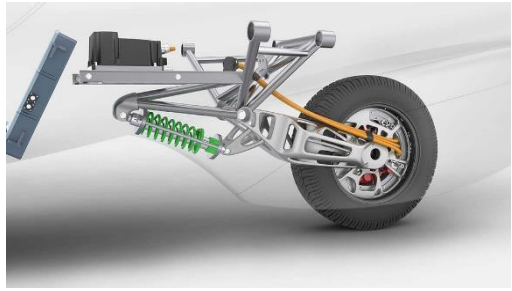
- **Lordstown's Endurance** pickup truck uses 4 in-wheel motors with tech licensed from Elaphe totalling 450 kWp.
- The **Lightyear One** is a long range solar electric vehicle.
- **Aptera** partnered with Elaphe for in-wheel motors for their 3-wheeled solar car.
- **Local Motors** is a company producing autonomous electric shuttles. They use 2 Pd18 in-wheel motors from Protean to total 180 kWp. Local Motors ceased operations in 2021.

Source: Lordstown



Source: Lightyear





Source: Aptera

Source: Local Motors & Protean

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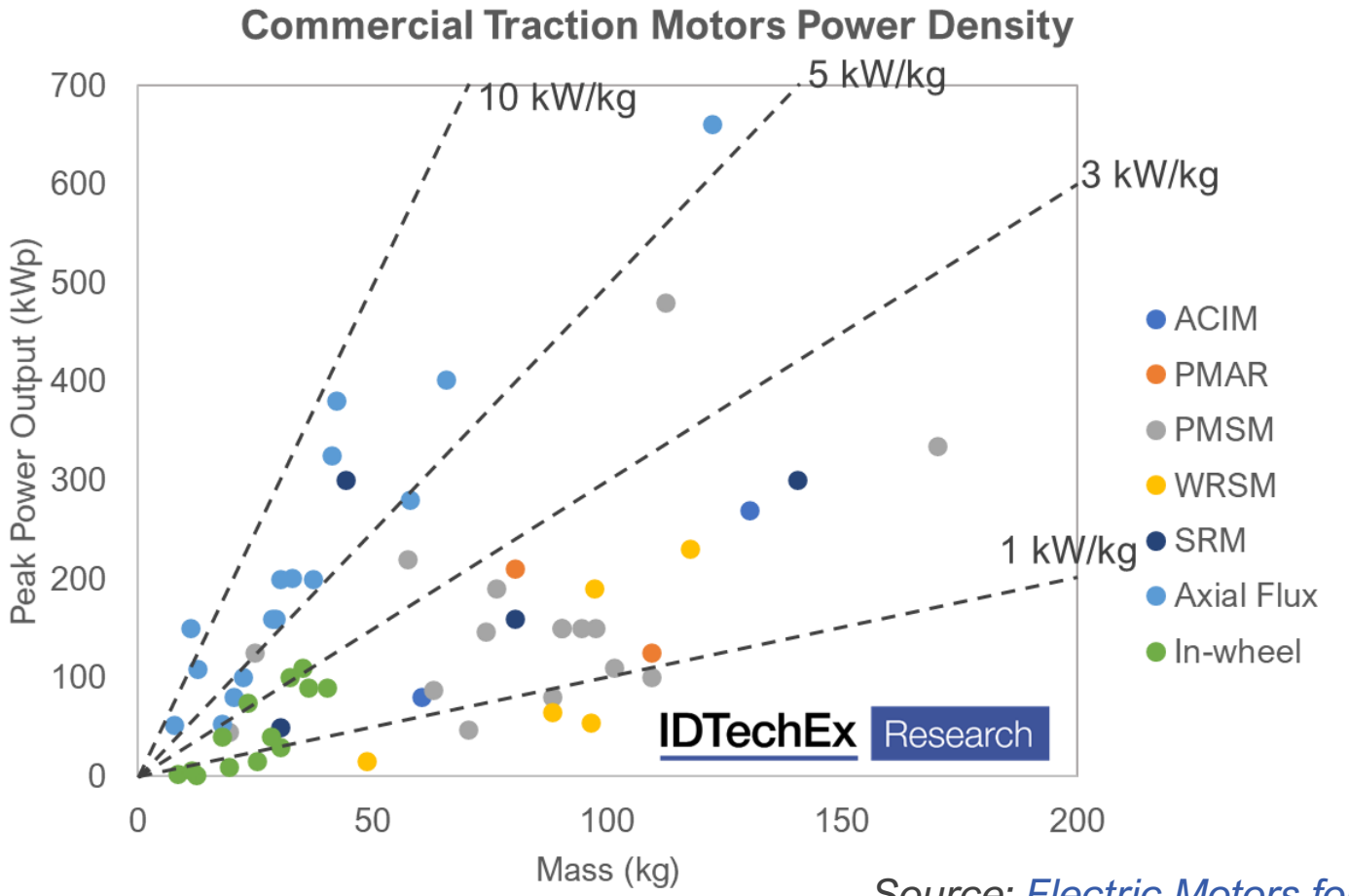
Benchmark against BEVs



- Axial flux motors present power and torque density benefits.
- In-wheel motors tend to struggle with power density due to the limited speed. But have excellent torque density and other beneficial characteristics.

Source: Electric Motors for Electric Vehicles 2022-2032, IDTechEx

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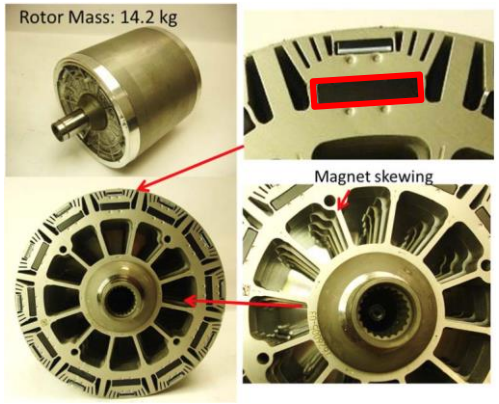
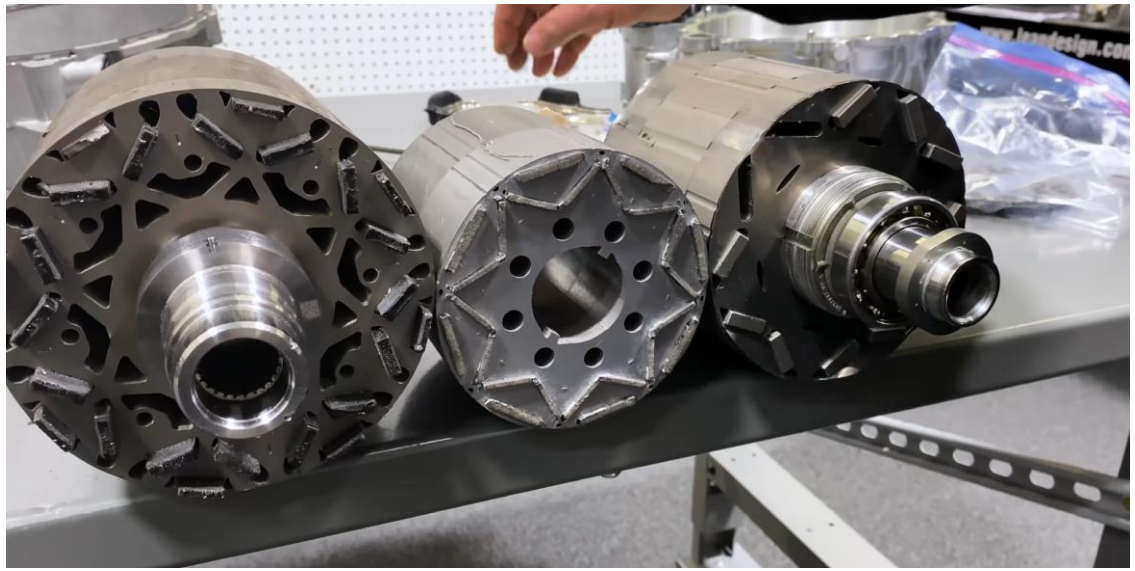
Rare Earth Magnets

Magnetic Material Distribution in Rotors



BMW i3. *Source: ORNL*

2016 Chevrolet Volt.
Source: General Motors



ID4 Leaf Model 3

Source: Munro & Associates

2002, 2010 and 2017 Toyota Prius. *Source: ORNL*

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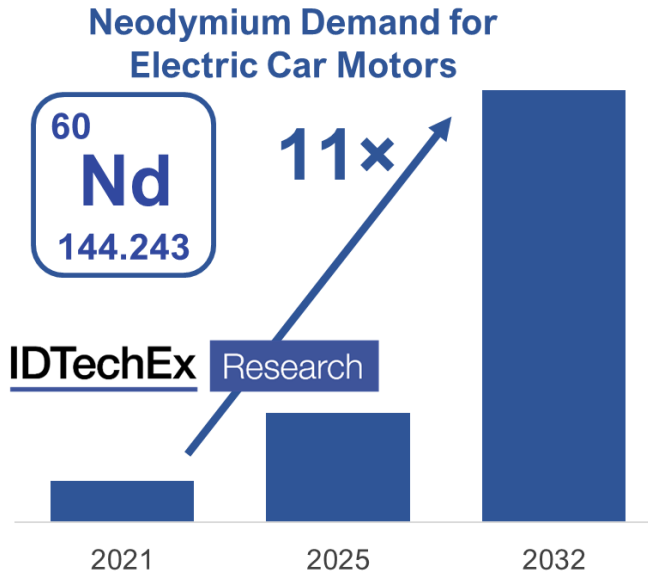
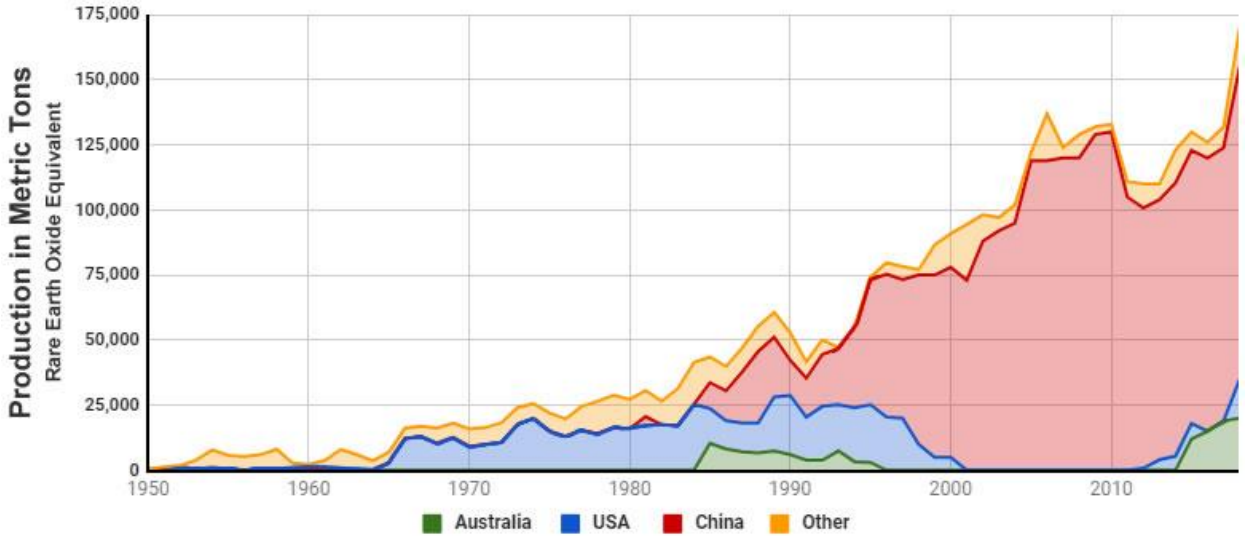
Magnet Price Increase Risk

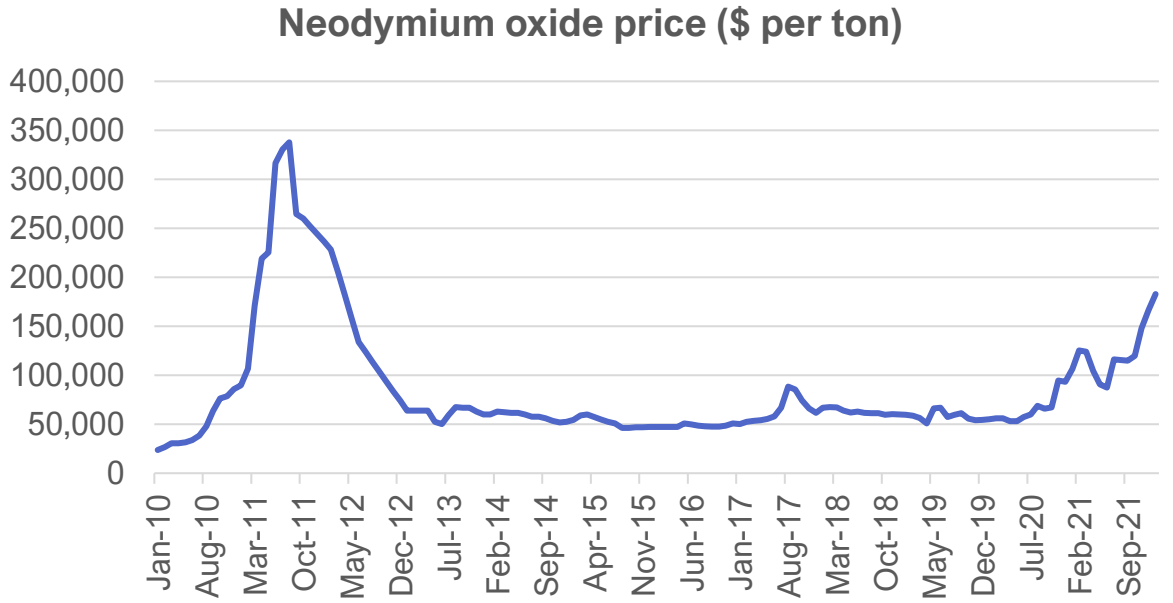
- China is the largest producer of rare-earth metals and hence controls supply and price.
- In 2011/2012 we saw massive price rises.
- Prices settled but are now increasing again.
- IDTechEx expects an 11 fold increase in demand for neodymium from EV electric motors.



Source: Electric Motors for Electric Vehicles 2022-2032, IDTechEx



Source: Geology.com



Data source: Trading Economics

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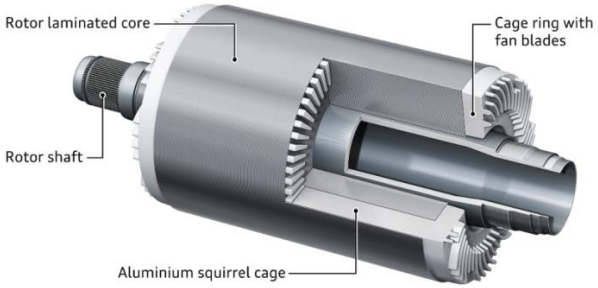
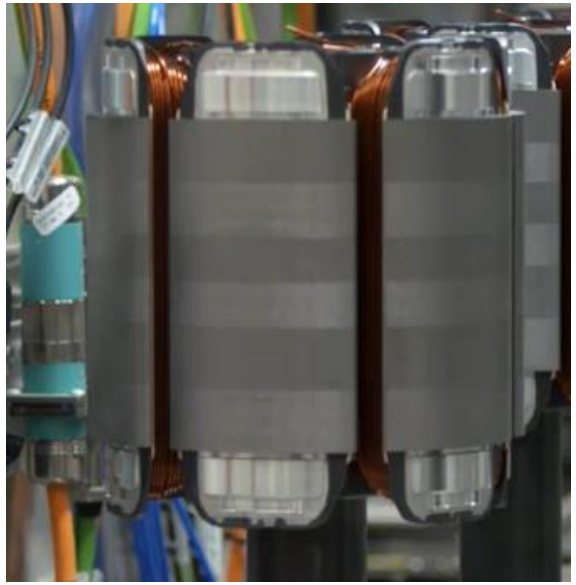
Eliminating Rare-Earth Usage in Electric Motors

- **Audi** opted for the use of induction motors in the e-tron to avoid magnetic materials. However, their Q4 e-tron (shared platform with VW's MEB) utilises PMs.
- **Renault** utilise the WRSM motor originally provided by Continental so they only use copper for generating electromagnetic fields.
- The 5th generation drive train from **BMW** is rare-earth free.
- Alternatives such as those presented by Advanced Electric Machines (**AEM**) providing a reluctance type motor free of magnets and copper.



Source: Doerr, et al., The new full electric drivetrain of the Audi e-tron.



Source: BMW Group

Source: AEM

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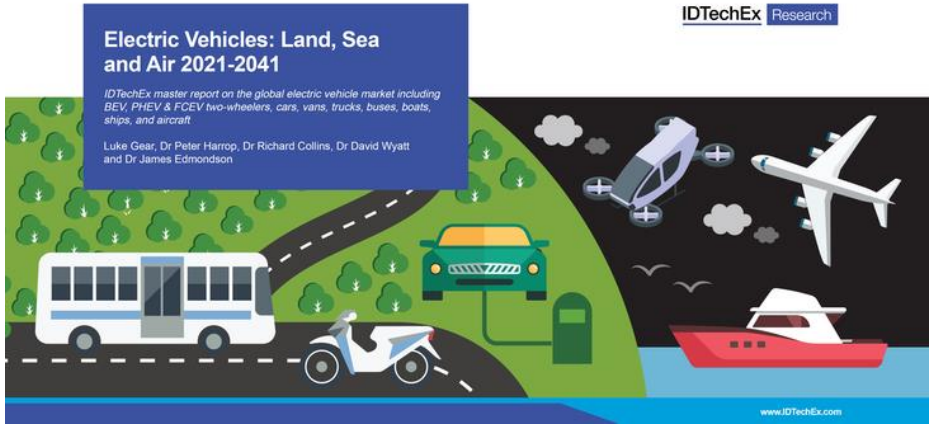
Summary

- The electric motor market has largely converged on permanent magnet motors
- There are still trends happening with motor design and adoption of new designs
- Materials in EVs are a critical consideration and motors are a key part of this
- Future opportunity for motor cost reduction will largely be in the material choices



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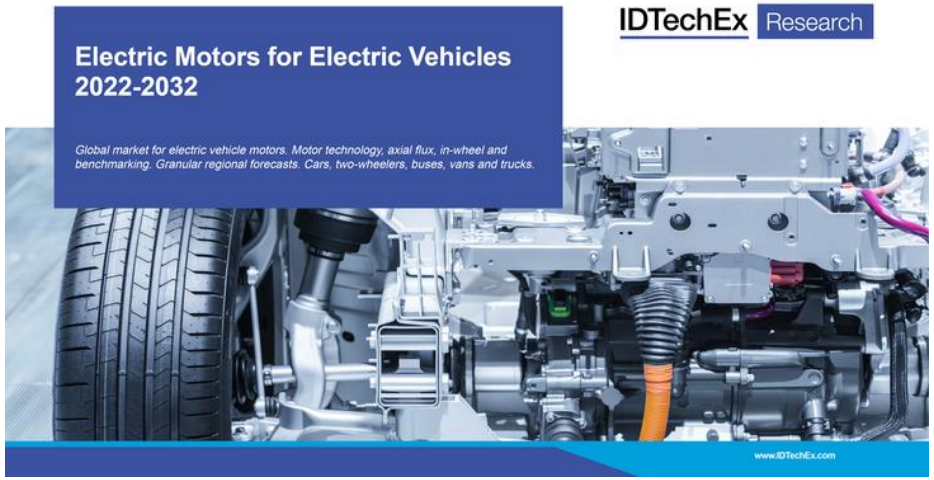

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