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International Copper  
Association  
Copper Alliance

CRM4EV  
CRITICAL RAW MATERIALS  
ELECTRIC VEHICLES

# Rare earth-free drives for electric mobility

REFREEDRIVE PROJECT – APRIL 2022



# ReFreeDrive Project Overview

EU Project in Horizon2020

**Title:** Rare earth free e-Drives featuring low-cost manufacturing

**Acronym:** ReFreeDrive

**Grant Agreement No:** 770143

**Topic:** GV-04-2017

- **Goal:** avoid the use of rare earth magnets through the development of a next generation of scalable electric drivetrains

ReFreeDrive project runtime: Oct 2017 – Mar 2021

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# ReFreeDrive Project Overview

13 partners, 6 European countries

Motor Design & Manufacturing



UNIVERSITAT DE LLEIDA



Motor Design Limited



ifp Energies nouvelles



TECNOMATIC Group

Power electronics



UNIVERSITAT DE LLEIDA



B3 TECHNOLOGY



ifp Energies nouvelles

Vehicle integration & testing



Fundación cidaut  
Investigación y Desarrollo en Transporte y Energía



privr  
programmazione ricerca innovazione veicoli elettrici



ifp Energies nouvelles

OEM Validation



JAGUAR



LAND ROVER

Project coordination



Fundación cidaut  
Investigación y Desarrollo en Transporte y Energía

Copper



European Copper Institute  
Copper Alliance



Aurubis

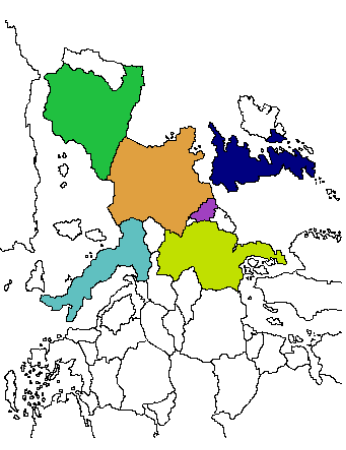


breuckmann

Steel



CSM  
Centro Sviluppo Materiali



# Why rare earth elements free solutions?

## Strong demand growth of Nd, Pr, Dy

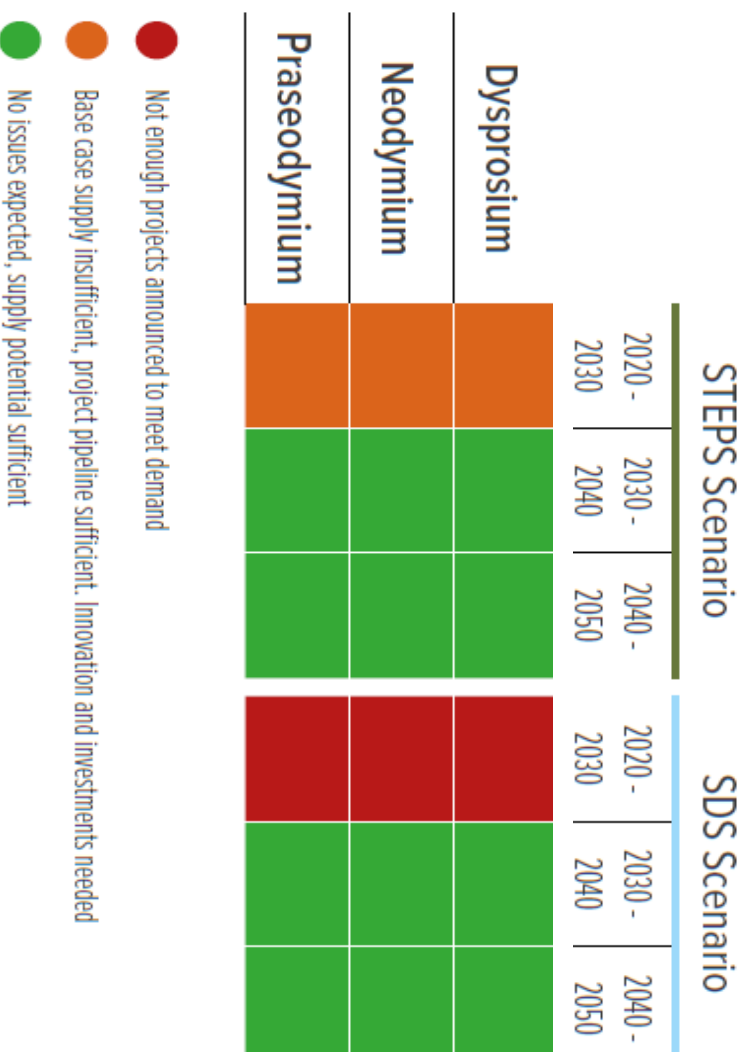
### Global total demand



Figure 37. REE (dysprosium, neodymium, praseodymium) global total demand by scenario (STEPS and SDS)

# Why rare earth elements free solutions?

Global material scarcity expected, notably in the 2020-2030 decade



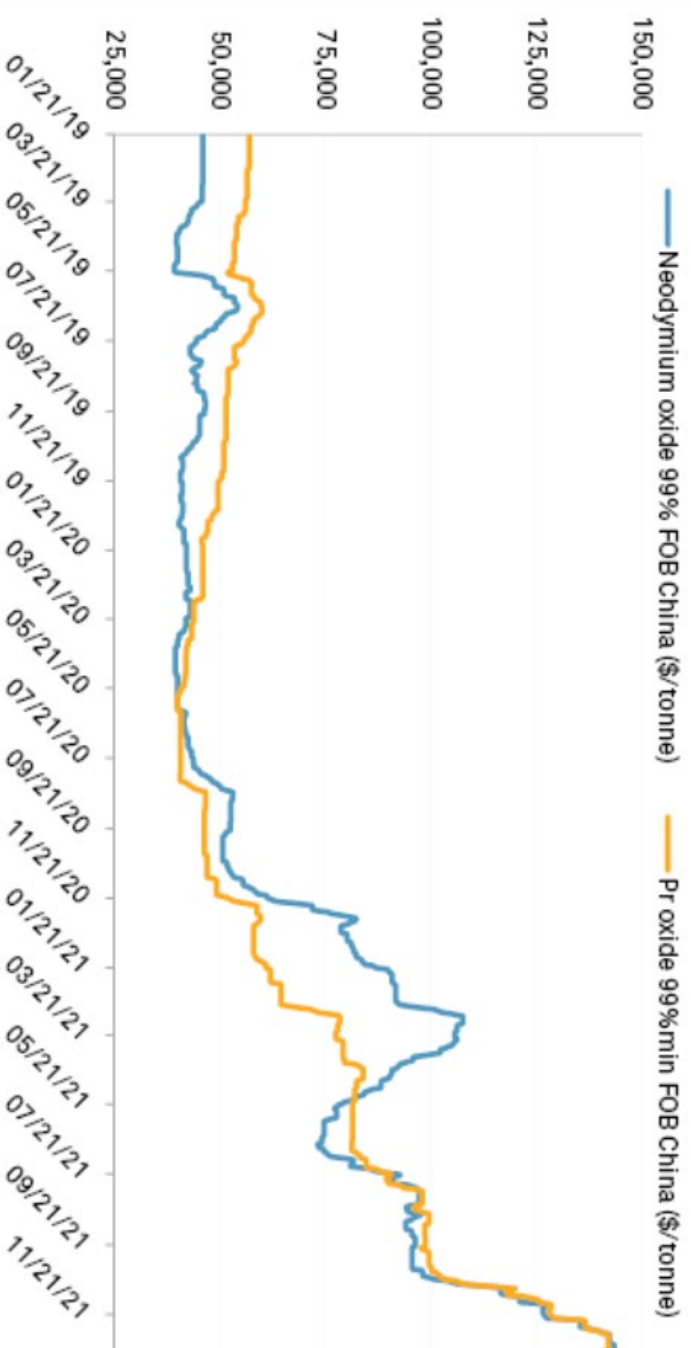
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Figure 116. Global supply-demand conclusions by decade

# Why rare earth elements free solutions?

## Market uncertainty

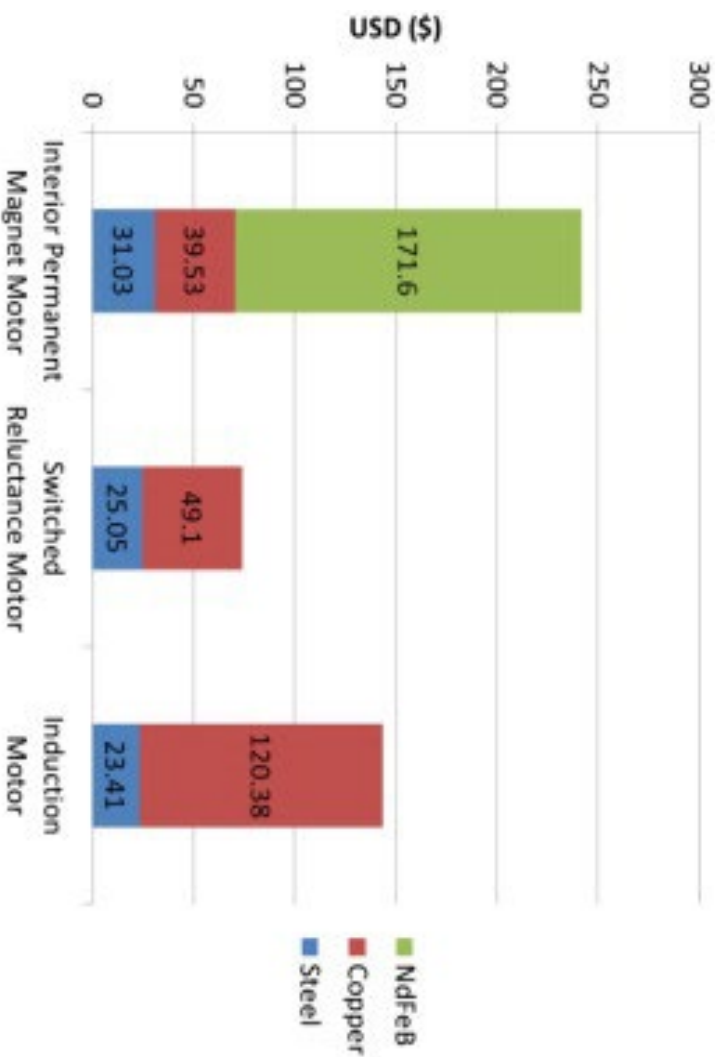
### Neodymium and praseodymium prices since 2019



Data compiled Jan. 27, 2022.  
Source: S&P Global Market Intelligence

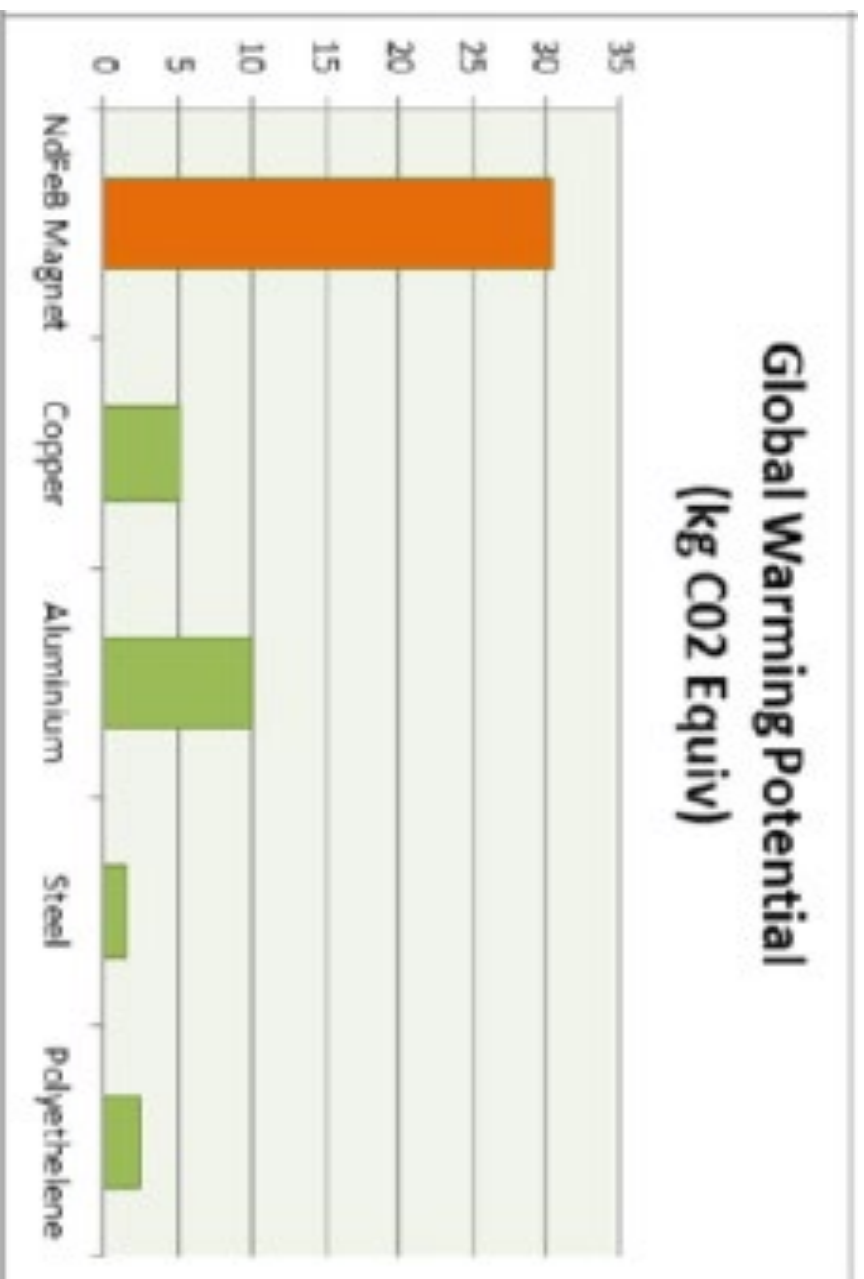
# Why rare earth elements free solutions?

## Cost



# Why rare earth elements free solutions?

Life cycle environmental impact



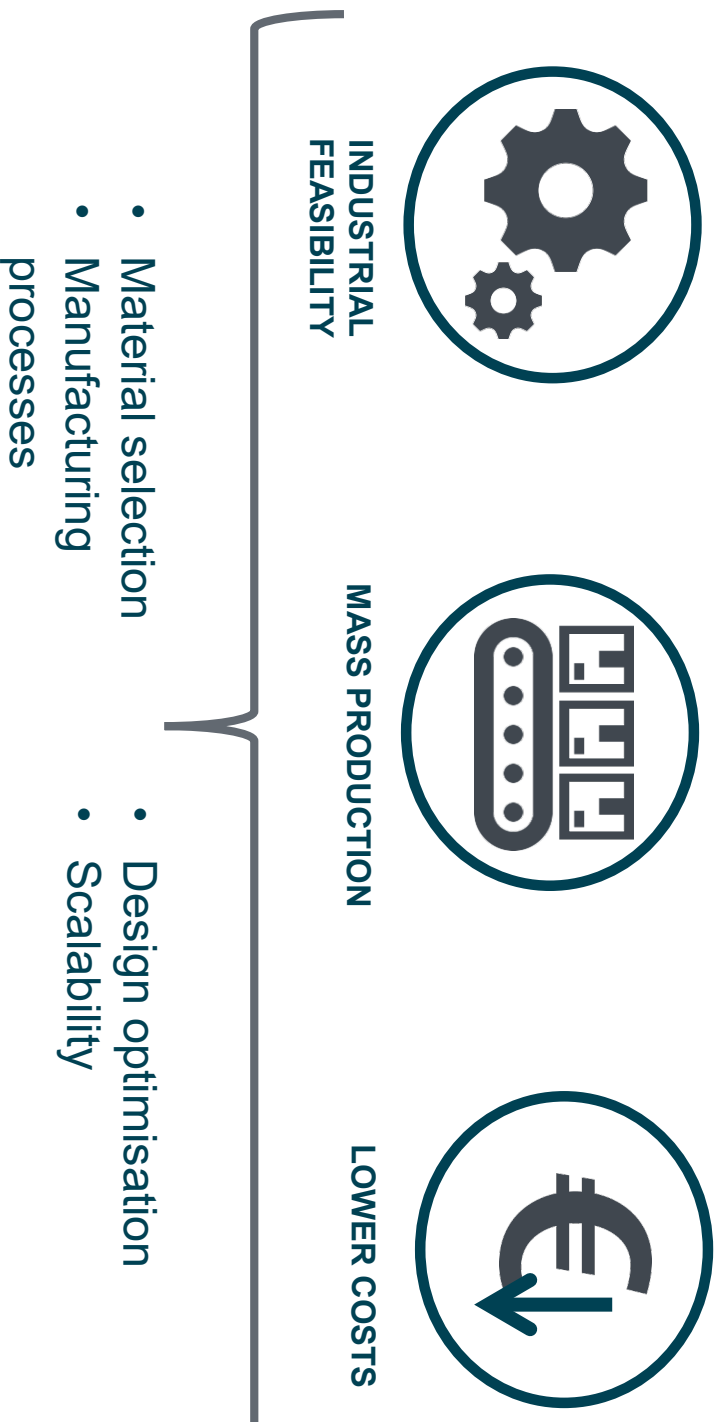
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# ReFreeDrive Project Overview

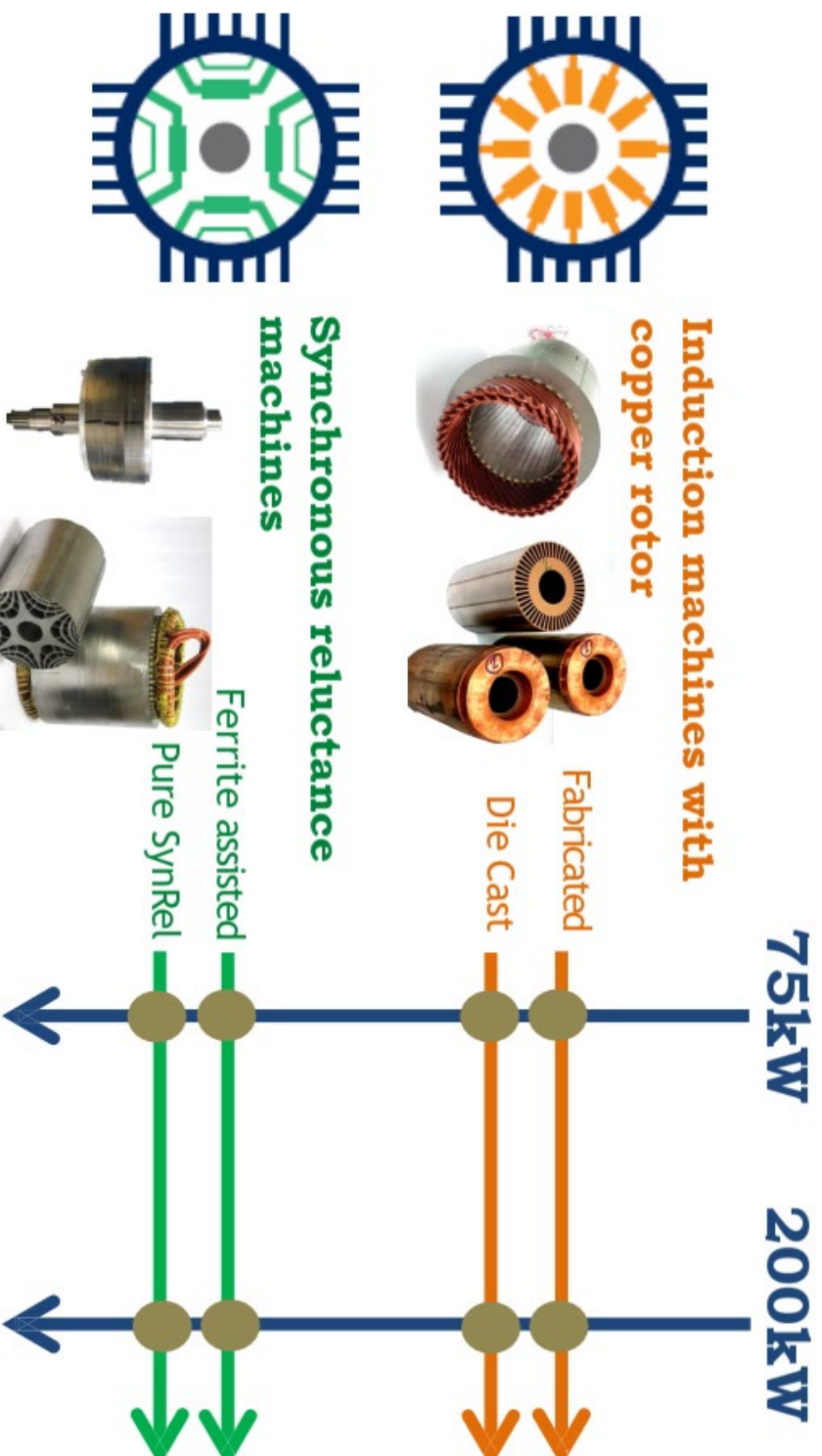
## Project Objectives

- The main aim of this project is to develop **rare earth-free traction technologies**



# ReFreeDrive Project Overview

Design & manufacture 8 different e-motors for electrical powertrains



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# ReFreeDrive Project Objectives

Target figures



**30%** INCREASE  
SPECIFIC TORQUE



**50%** MOTOR  
LOSSES REDUCTION



**15%** COST  
REDUCTION



**50%** INCREASE OF  
POWER DENSITY IN  
POWER ELECTRONICS

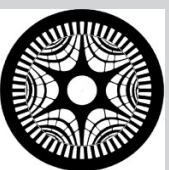
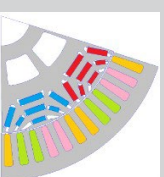
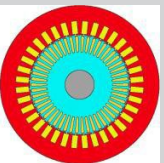
# ReFreeDrive Project Objectives

KPI	unit	Ref TESLA 60S	ReFreeDrive Goals		Comments
Specific power	kW/kg	3.31	> 4.3		Peak value, active parts only
Power density	kW/l	-	> 8.0		
Specific torque	Nm/kg	6.3	> 8.2		
Torque density	Nm/l	-	> 15.4		active parts only
Weight	kg	68	< 44.6		
Efficiency	%	<b>92%</b>	<b>96%</b>		Peak value

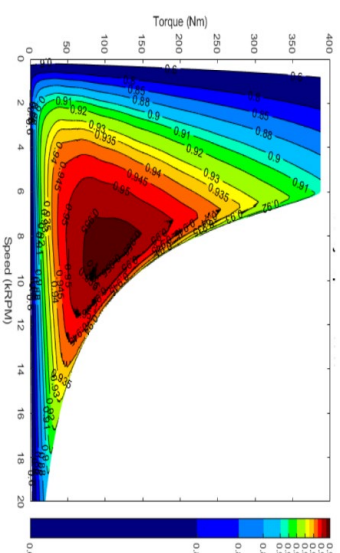
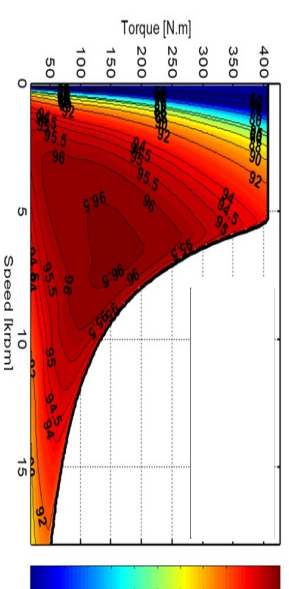
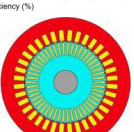
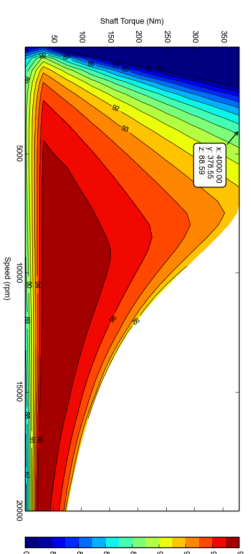
# ReFreeDrive Motor Achievements

## Simulated Performance Data

Motor variant	Induction	Ferrite SynRel	Pure SynRel
DC-link voltage	720 V	720 V	720 V
Max. current	500 Arms	416 Arms	500 Arms
Peak torque	378 Nm	405 Nm	385 Nm
Maximum speed	20,000 rpm	17,500 rpm	18,000 rpm
Gear ratio	13.55	12.19	12.19
Peak power	300 kW	226 kW	246 kW
Peak power @nmax	150 kW	95 kW	60 kW
Peak Efficiency	96%	97%	96%



Torque vs Speed efficiency map of 200kW



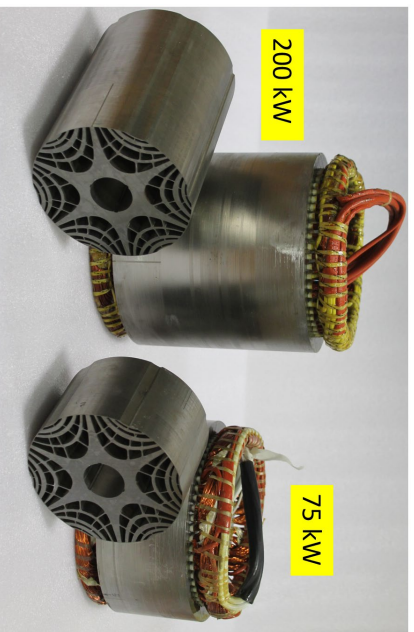
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# Prototypes Manufacturing

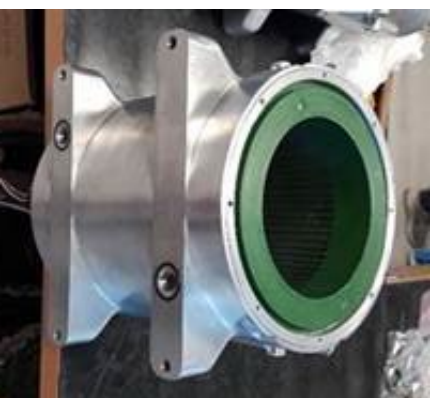
Two variants of Synchronous Reluctance Motors



Pure Synchronous  
Reluctance Motor



Ferrite assisted Synchronous  
Reluctance Motor

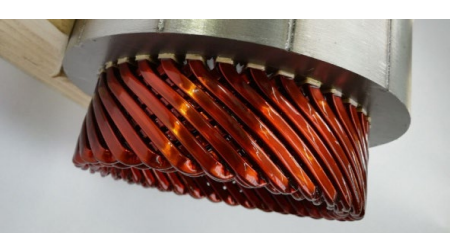
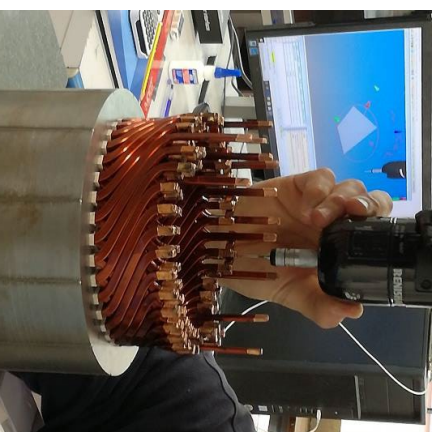
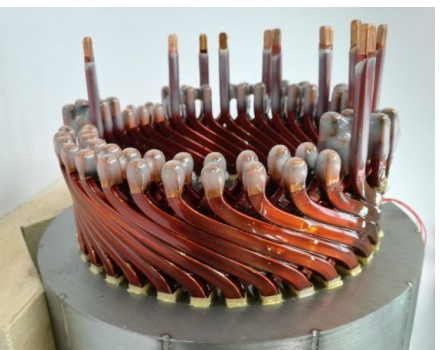


# Prototypes Manufacturing

## Induction Motor using Hairpin Stator Winding



The two ReFreeDrive induction motor prototypes are using innovative Hairpin Winding in the Stator



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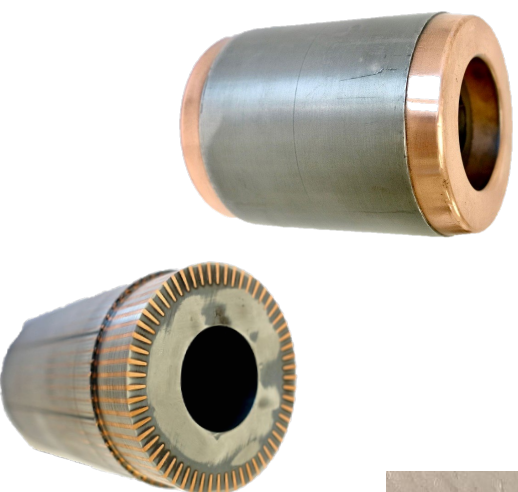


# Prototypes Manufacturing

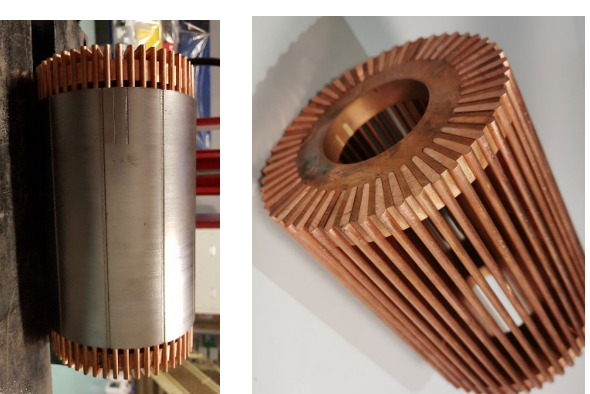
Two variants of Copper Rotor for the Induction Motor



Die-Cast Copper Rotor



Fabricated Copper Rotor





# ReFreeDrive Motor Achievements

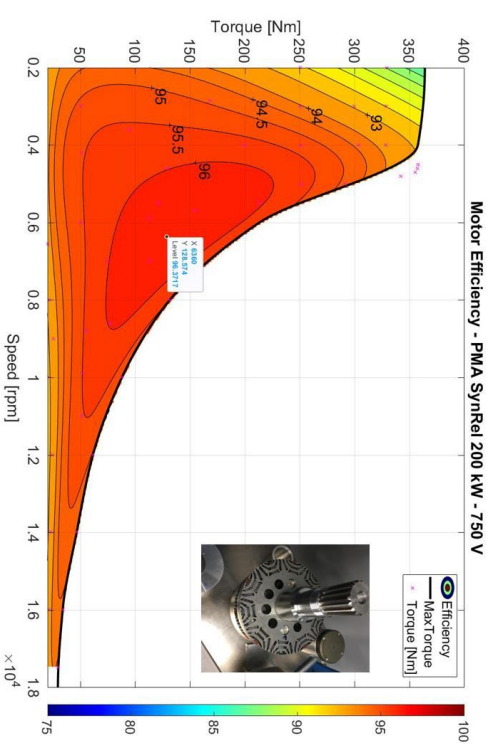
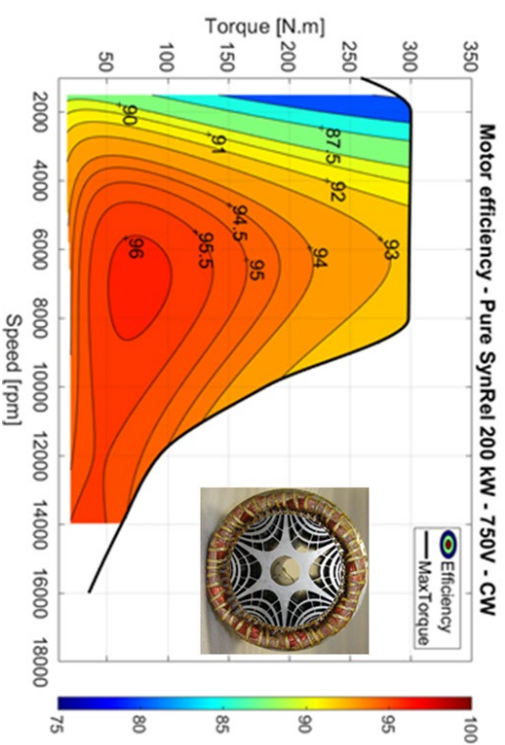
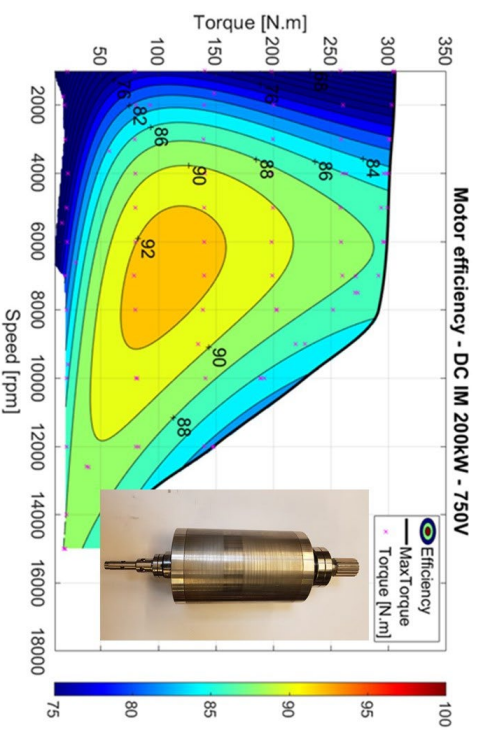
## Test Performance Data – 200 kW motors

200 kW KPIs	Benchmark Tesla S 60	ReFreeDrive target	PMa-SynRel	Pure SynRel	IM DCR
Specific peak power (kW/kg)	3.31	4.3	3.8	5	5.4
Peak power density (kW/liter)	7.89	8	17.7	22.1	30.6
Specific peak torque (Nm/kg)	6.32	8.2	7.9	6.9	7.7
Maximum speed (rpm)	14,500	15,000 - 22,000	17,500	16,000	15,000
Peak efficiency (%)	92	96	96.4	96	92.7*

\* lower than theoretical results due to software issues during testing

# ReFreeDrive Motor Achievements

## Test Performance Data – 200 kW motors



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# ReFreeDrive Motor Achievements

Drive unit efficiency for standard driving cycles

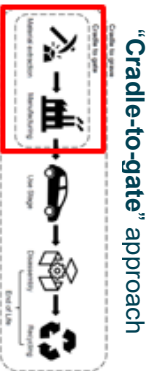
Including motor, inverter and gearbox

	PMa-SynRel	Pure SynRel	IM DCR
<b>Efficiency</b>			
<b>Highway Fuel Economy Test (HWFET) driving cycle</b>	88.7%	86.5%	86.1%
<b>Urban Dynamometer Driving Schedule (UDDS) driving cycle</b>	89.0%	85.3%	86.3%
<b>Environmental Protection Agency (EPA) driving cycle</b>	88.9%	85.8%	86.2%

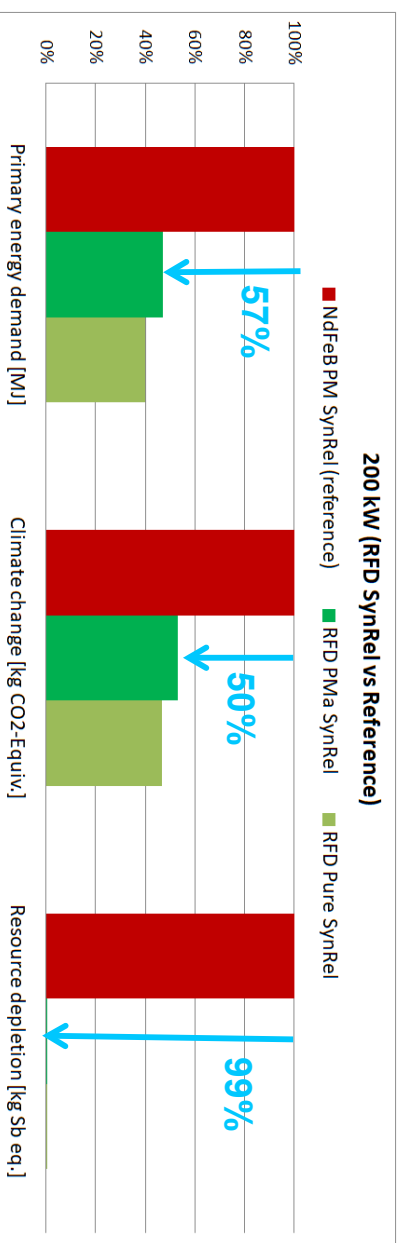
# ReFreeDrive Motor Achievements

## Life Cycle Assessment (LCA)

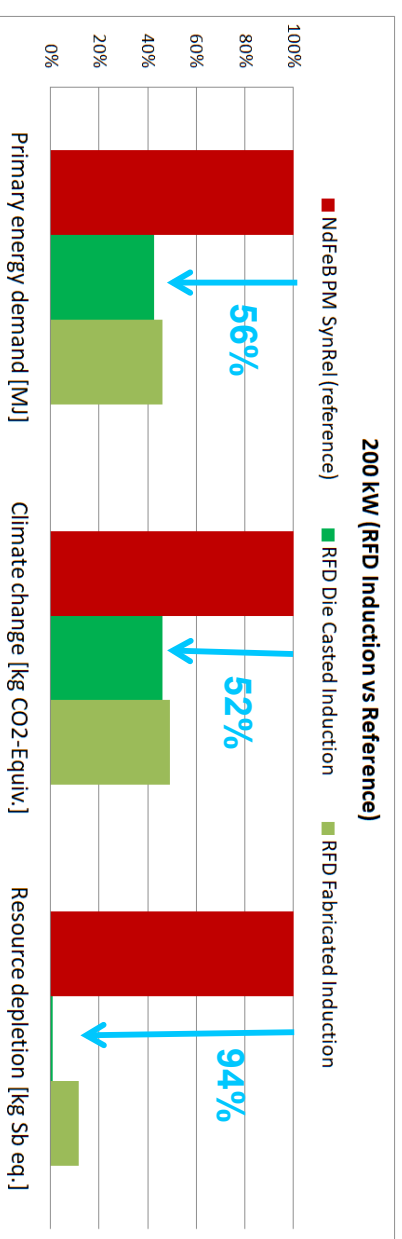
Environmental Impact comparison of **REFREEDRIVE** motors against current automotive electric motor (**NdFeB permanent magnets**)



200kW  
SynRel



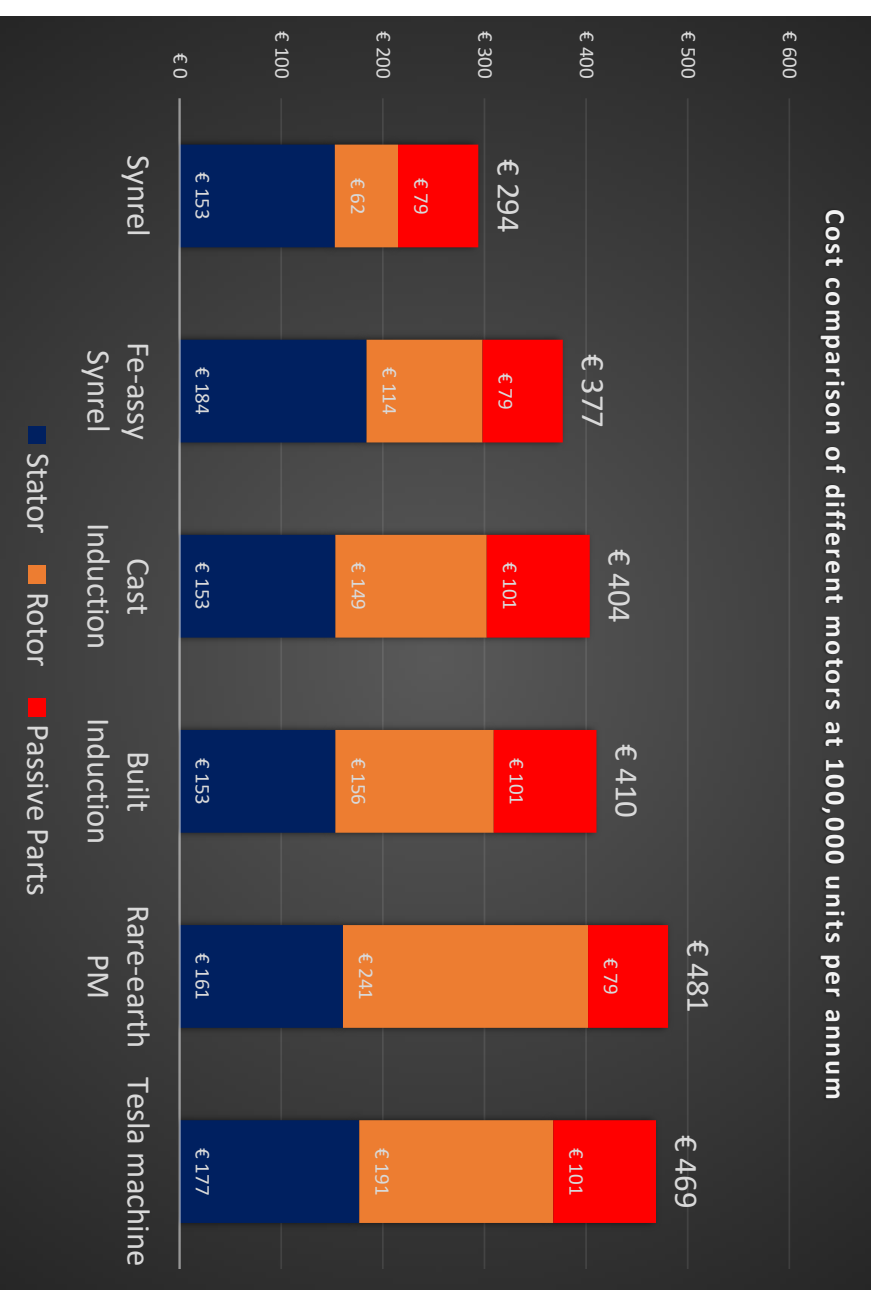
200kW  
Induction



# ReFreeDrive Motor Achievements

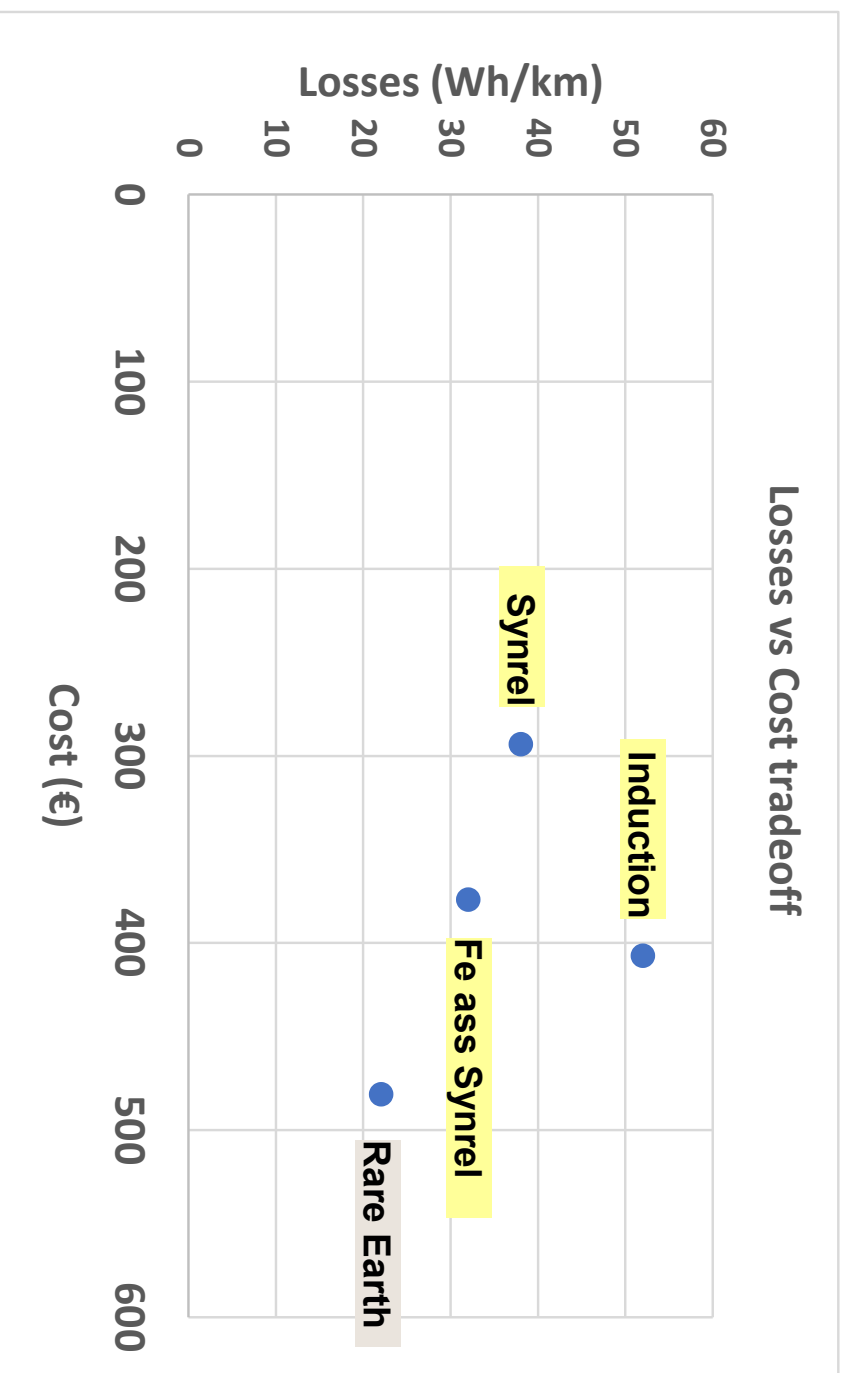
## Techno-Economic Assessment

All ReFreeDrive motors show **significant lower production costs** compared to benchmark Tesla Model S induction motor, and to rare-earth PM



# ReFreeDrive Motor Achievements

## Techno-Economic Assessment



Obvious that our ReFreeDrive motor alternatives will never surpass the rare-earth PM motor total driving efficiency for a given powertrain configuration.

But, as the battery price will decrease in some years, our cheaper motor solutions will become viable economically, when the efficiency lost by a cheaper motor technology can be offset through higher battery capacity.

# ReFreeDrive Project

Technologies well adapted to various applications

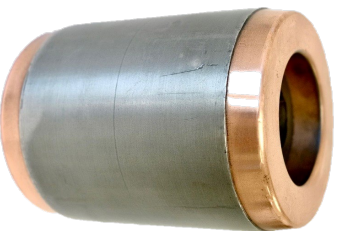
**The induction motor** with die cast or fabricated copper rotor can provide high torque for **SUV** applications. The technology can also be used as a low-cost solution for **secondary traction units** not intended to operate for the full driving cycle.

**The synchronous reluctance motor with ferrite permanent magnets** achieves high torque and competitive efficiency, and the low cost of ferrites reduces series production costs. This would be a suitable option for **midsize cars**.

**The pure synchronous reluctance motor** represents a very cost-effective solution. The absence of permanent magnets and copper windings in the rotor makes it highly material efficient and, because of optimized rotor geometry, it can achieve reasonable power densities. This type of motor is suitable for **smaller city cars** for which cost, not power density, is the most important factor

# ReFreeDrive Project

Technologies well adapted to various applications



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# ReFreeDrive Project

## Outlook

### Market Demand

>25 Mio BEVs per year produced globally in 2030 - Need to substitute critical rare earths to assure supply base in EU

### Technology Comparison

ReFreeDrive investigated 3 different drivetrain solutions as alternatives to rare earth PM machines.

### Cost effective

ReFreeDrive drivetrain solutions show acceptable performance at lower cost ratio for mass production.

### Green & Sustainable

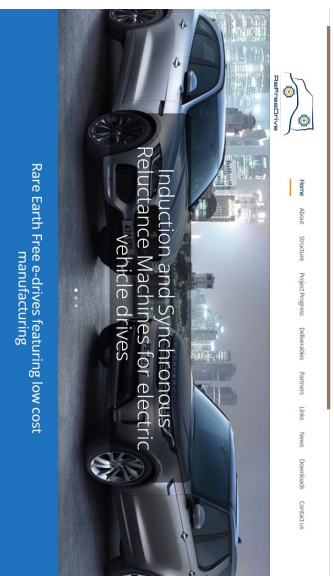
ReFreeDrive solutions show a significant lower environmental impact compared to NdFeB PM motors.

### Know-How

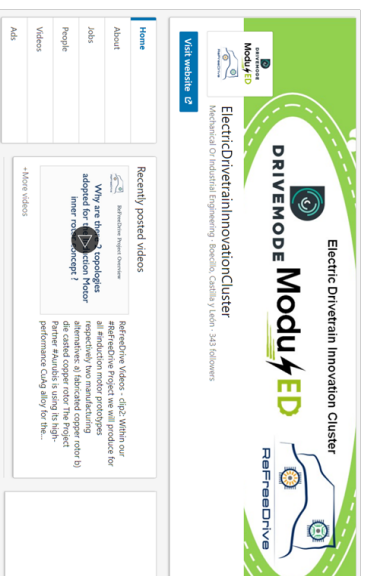
Know-how generated in project developments for follow-up on academic and commercial level

# ReFreeDrive Project Overview

[www.refreedrive.eu](http://www.refreedrive.eu)



ElectricDrivetrainInnovationCluster in LinkedIn  
<https://www.linkedin.com/company/11805543>



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CRMAEV Task 40 - ReFreeDrive / ICA

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