ReFreeDrive

Rare earth-free motors for medium and high power electric vehicles

Fernando Nuño – Copper Alliance
Marco Villani – University of Aquila

18 November 2020

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

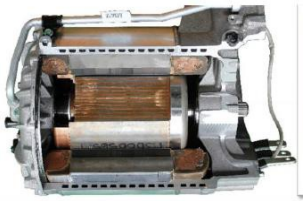
ReFreeDrive Project Overview

General Figures

Rare earth free e-drives featuring low cost manufacturing (2017-2021)

Project funded by the European Union's Horizon 2020 research and innovation programme with a budget of 6 M€

Benchmark Tesla S60



INCREASE SPECIFIC TORQUE BY 30%

REDUCE MOTOR ENERGY LOSSES BY 50%

15% COST REDUCTION AGAINST SIMILAR SOLUTIONS

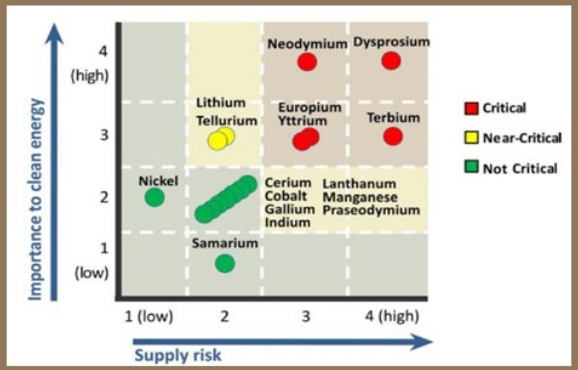
INCREASE POWER DENSITY IN POWER ELECTRONICS BY 50%

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

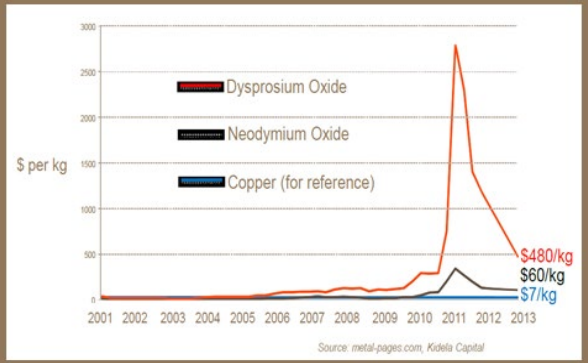
The rare earth issue

The use of rare earth-based magnets is challenging for multiple reasons

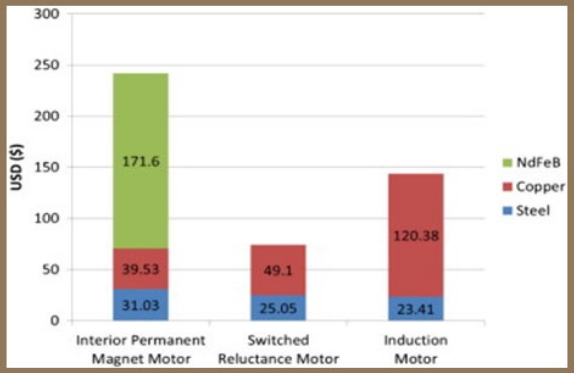
Supply risk



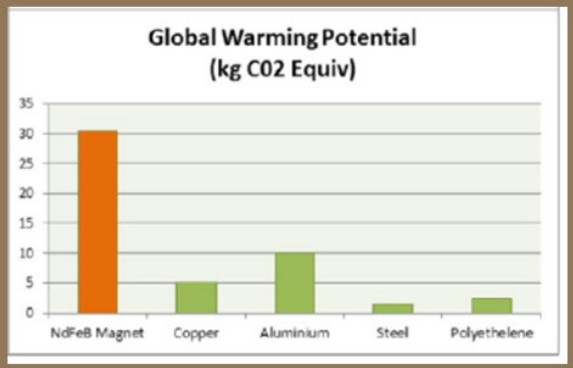
Market uncertainties



Cost



Environment & LCA

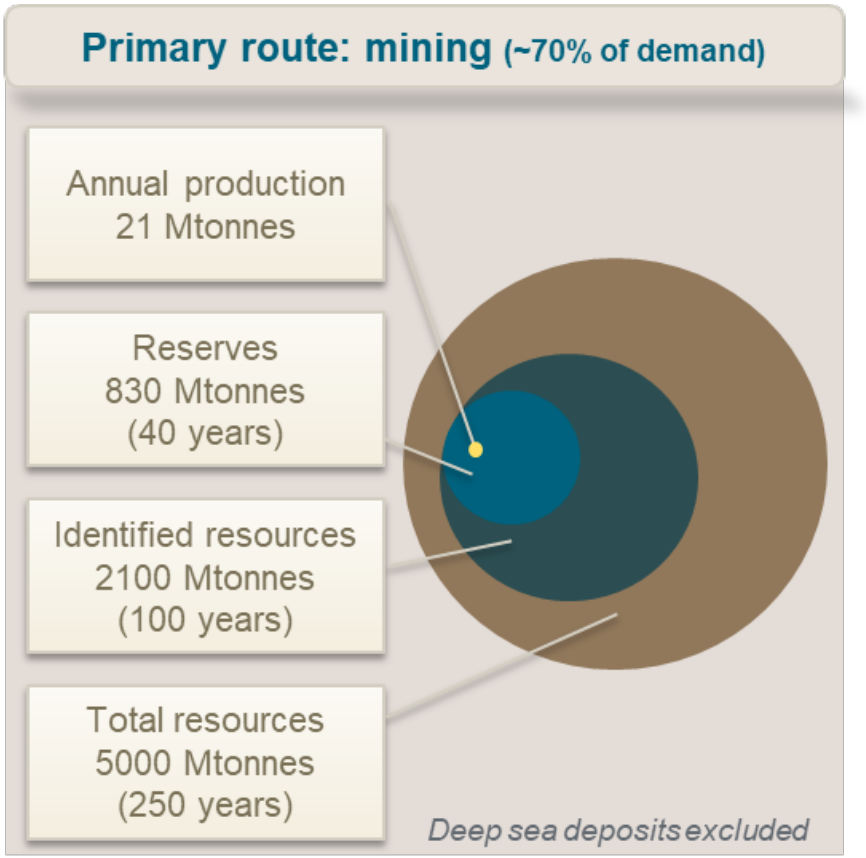


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

Copper is available

There are sufficient mining and recycling copper reserves & resources worldwide to cope with growth

Primary route: mining (~70% of demand)



Secondary route: recycling (~30% of demand)

400 Mtonnes available in the "urban mine" (20 years)

Copper can be recycled repeatedly without downgrading

Most of copper alloying elements can be recovered

Landfills

150 Mtonnes available in landfills (7 years)

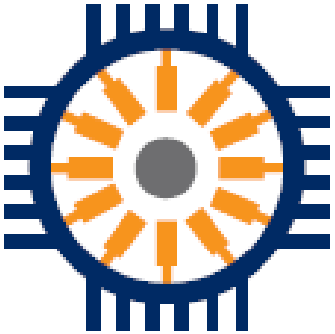
Estimated 110 to 330 megatonnes needed for the world energy transition

Meeting future copper demand: https://sustainablecopper.org/meeting-future-copper-demand/
The World Copper Factbook 2018: https://www.icsg.org/index.php/component/jdownloads/finish/170/2876
Dynamic Analysis of Global Copper Flows. https://pubs.acs.org/doi/10.1021/es400069b
US Geological Survey (USGS), 2019: https://prd-wret.s3-us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/atoms/files/mcs-2019-coppe.pdf

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

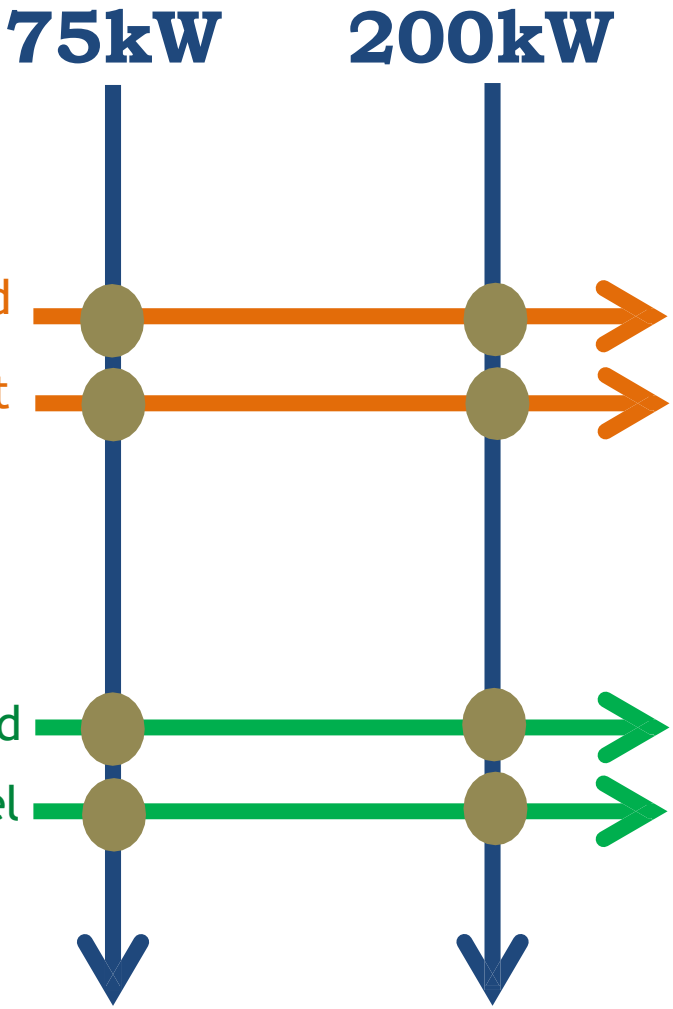
ReFreeDrive Project Overview

Project Technologies



Induction machines with copper rotor

Synchronous reluctance machines



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

ReFreeDrive Project Overview

ReFreeDrive KPIs, benchmark and achieved ratios

200 kW	ReFreeDrive KPI	Benchmark Tesla S60 200 kW	Induction 200 kW	SynRel PM 200 kW	SynRel 200 kW
Specific Peak Power (kW/kg)	4,3	3,31	4,3	4,3	4,3
Peak Power Density (kW/ liter)	8	7,89	8	8	8
Specific Peak Torque (Nm / kg)	8,2	6,32	8,2	8,2	8,2
Maximum speed (rpm)	21750	14500	20000	18000	18000
Peak efficiency (%)	96	92	>96	>96	>96

75 kW	ReFreeDrive KPI	Benchmark Nissan Leaf 75 kW*	Induction 75 kW	SynRel PM 75 kW	SynRel 75 kW
Specific Peak Power (kW/kg)	4,3	1,94	1,6	3,1	1,6
Peak Power Density (kW/liter)	8	8,75	5,4	5	3
Specific Peak Torque (Nm/kg)	8,2	6,30	2,5	5	3
Maximum speed (rpm)	22000	12000	18000	15000	15000
Peak efficiency (%)	96	95	>96	>96	>96

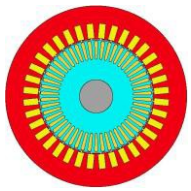
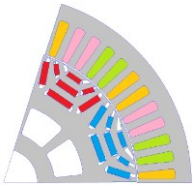
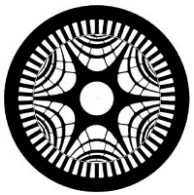
* Housing excluded

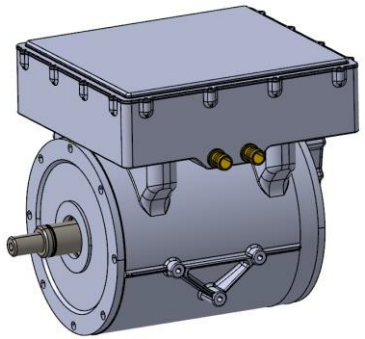
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

ReFreeDrive Project Overview

Comparison of the three technologies on drive cycle

Three rare-earth free motor variants were developed within ReFreeDrive to allow integration within a Jaguar Land Rover high performance vehicle: an induction motor, a ferrite-assisted synchronous reluctance motor and a pure synchronous reluctance motor

Motor variant	Induction	Ferrite SynRel	Pure SynRel
DC-link voltage	720 V	720 V	720 V
Max. modulation	0.98	0.98	0.98
Max. current	500 Arms	636 Arms	636 Arms
Required inv. kVA	430 kVA	550 kVA	550 kVA
Peak torque	380 Nm	470 Nm	415 Nm
Maximum speed	20,000 rpm	18,000 rpm	18,000 rpm
Gear ratio	13.55	12.19	12.19
Peak overall power	300 kW	250 kW	290 kW
Peak power @nmax	150 kW	90 kW	80 kW
			



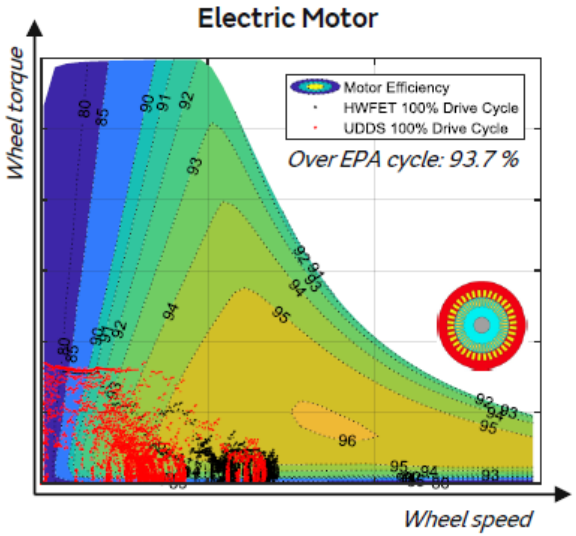
Motor and inverter of the high performance EDU

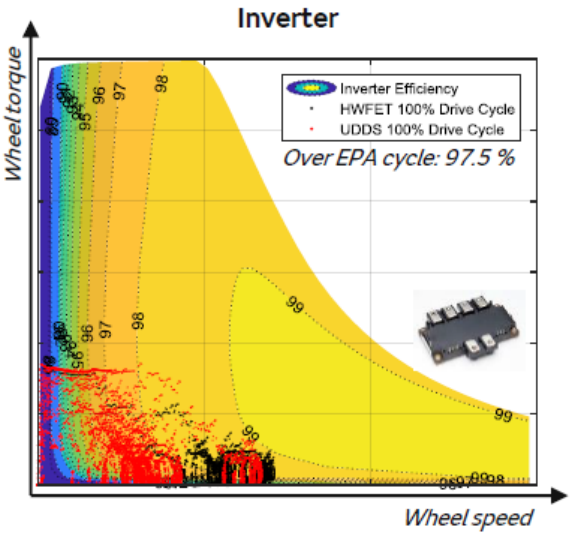
Mitsubishi FMF800DX-24A SiC module

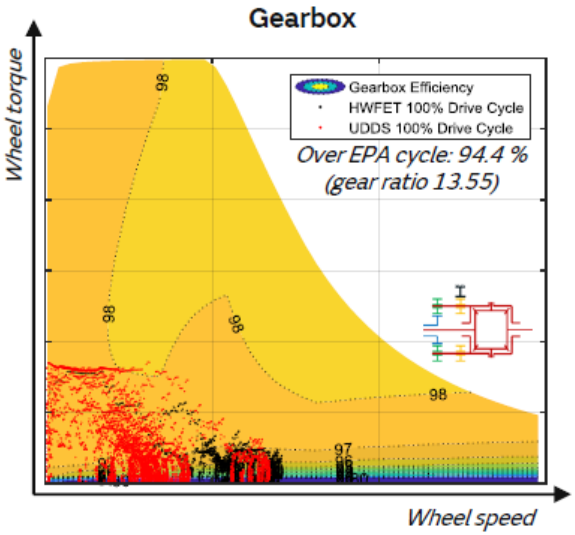
Source: Jaguar Land Rover, Coiltech Expo 2019 - http://www.refreedrive.eu/downloads

ReFreeDrive Project Overview

System level efficiency analysis – EPA cycle



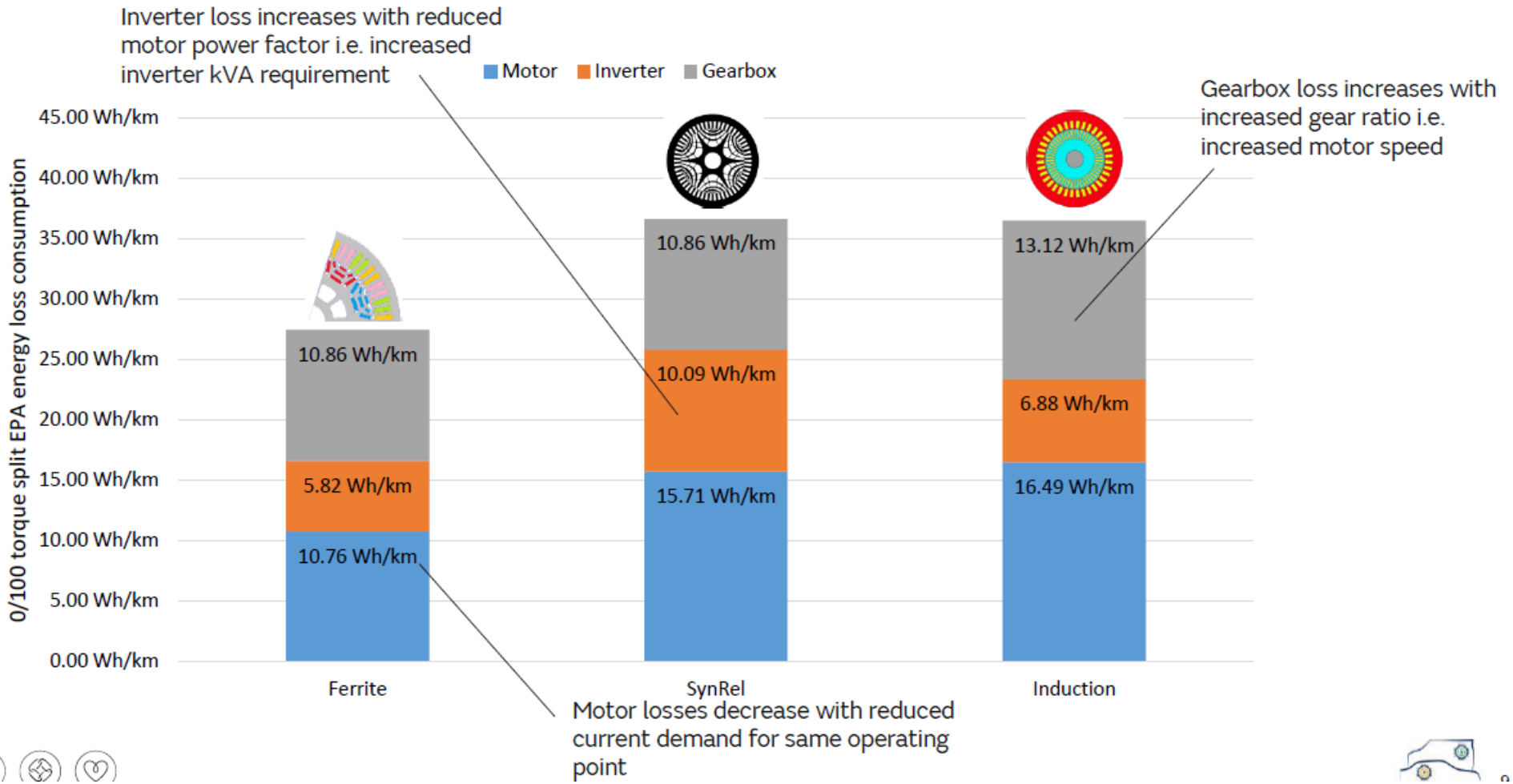




Source: Jaguar Land Rover, Coiltech Expo 2019 - http://www.refreedrive.eu/downloads

ReFreeDrive Project Overview

System level efficiency analysis – Energy loss splitdown



Source: Jaguar Land Rover, Coiltech Expo 2019 - http://www.refreedrive.eu/downloads

ReFreeDrive Project Overview

System level efficiency analysis – Energy loss splitdown

	Ferrite SynRel	Pure SynRel	Induction
Overall EPA efficiency	88.9%	85.8%	86.2%
Machine speed	18,000	18,000	20,000
Best overall efficiency	UDDS	Around HWFET drive cycle	At highway cruising speeds and beyond

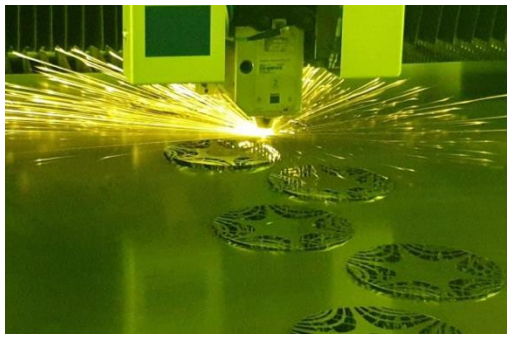
HWFET: Highway Fuel Economy Test cycle
UDDS: Urban Dynometeter Driving Schedule

Source: Jaguar Land Rover, Coiltech Expo 2019 - http://www.refreedrive.eu/downloads

ReFreeDrive Project Overview

Next steps

3Q 2020	4Q 2020	4Q 2020 1Q 2021
Prototypes manufacturing	Integrated powertrain testing	In-vehicle integration



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

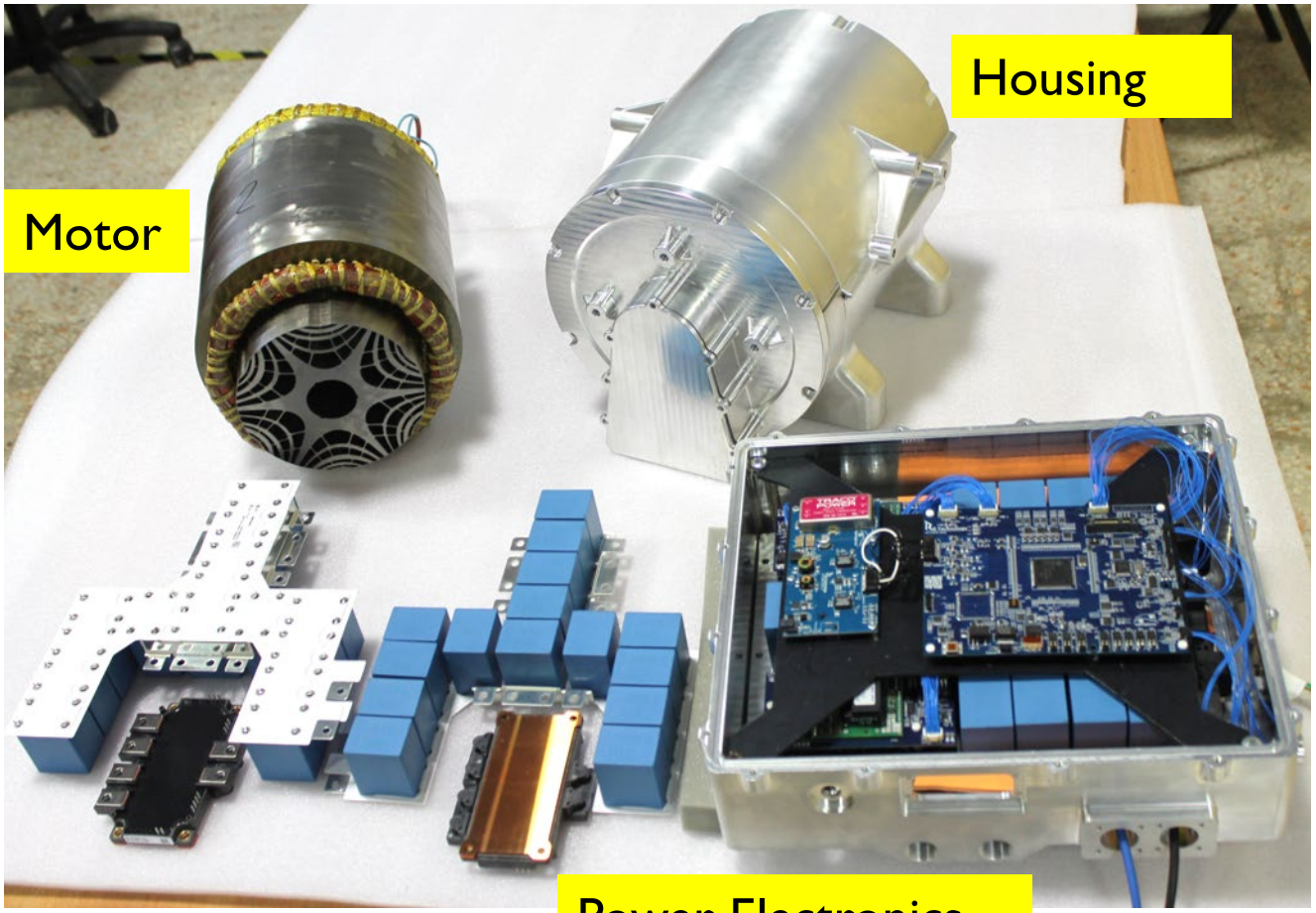
ReFreeDrive Project Overview

Two power level prototypes

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

ReFreeDrive Project Overview

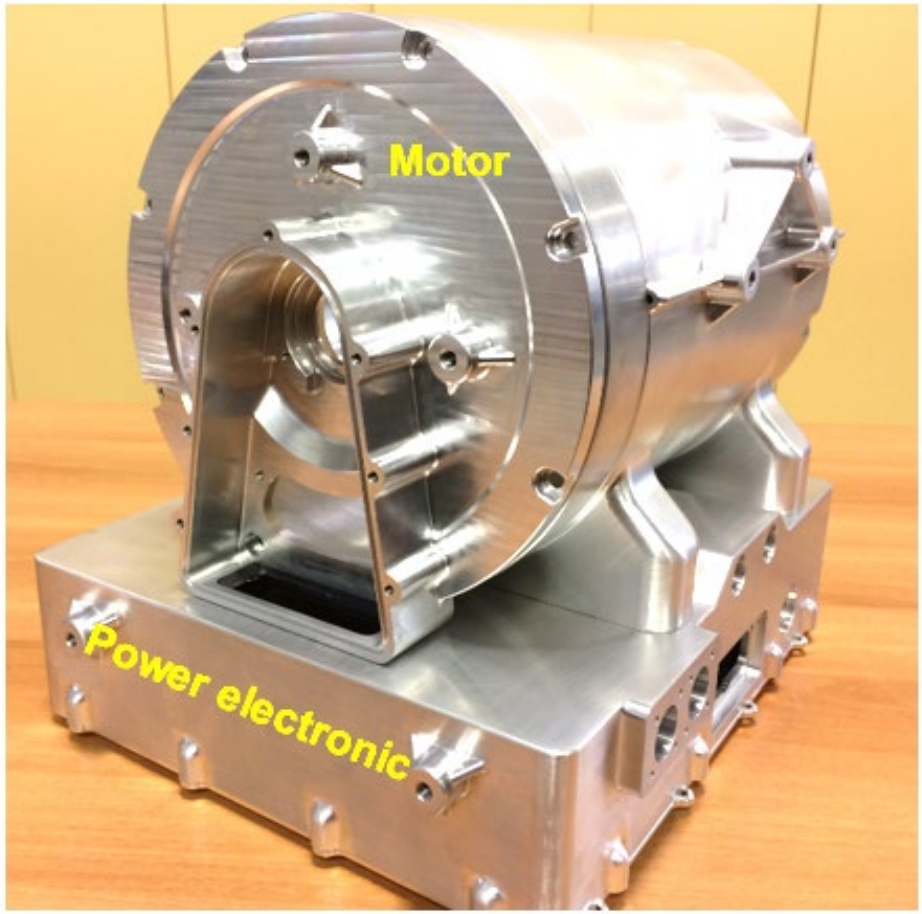
Prototyping the motor, housing and power electronics



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

ReFreeDrive Project Overview

Integrated motor + power electronics
Shared liquid cooling

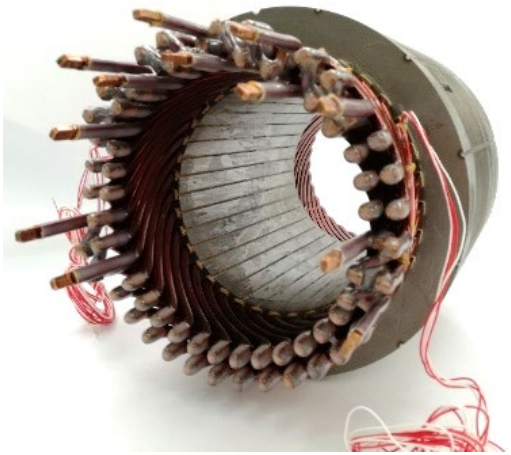


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

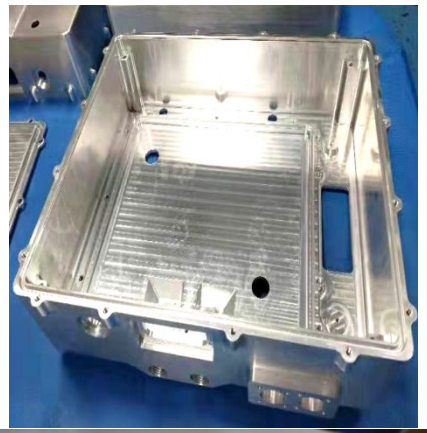
ReFreeDrive Project Overview

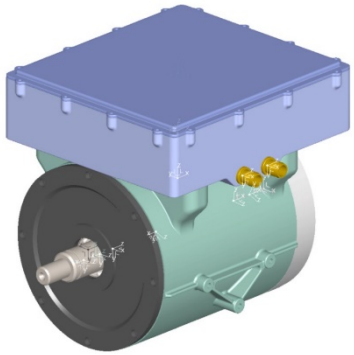
Induction motor prototype manufacturing

Stator Assembly with Hairpin Winding



Inverter Box and Motor Assembly



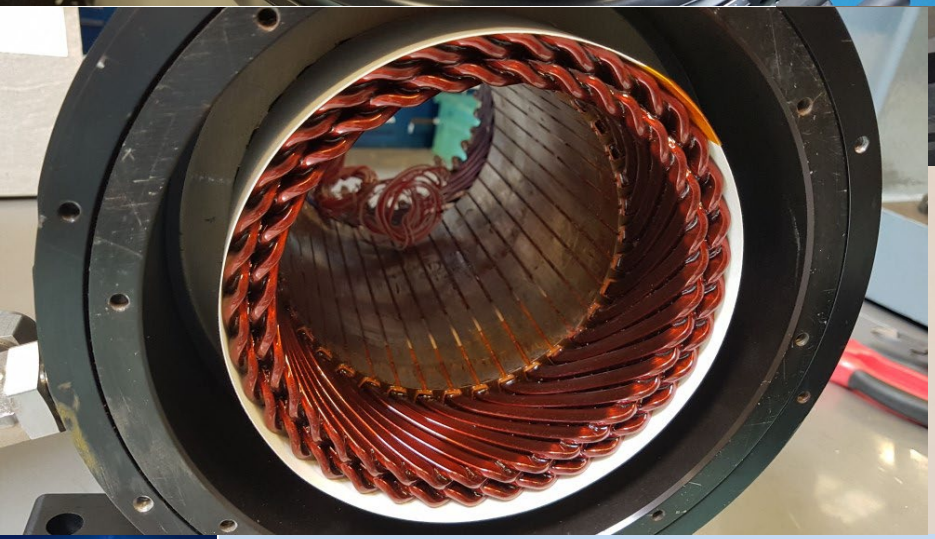


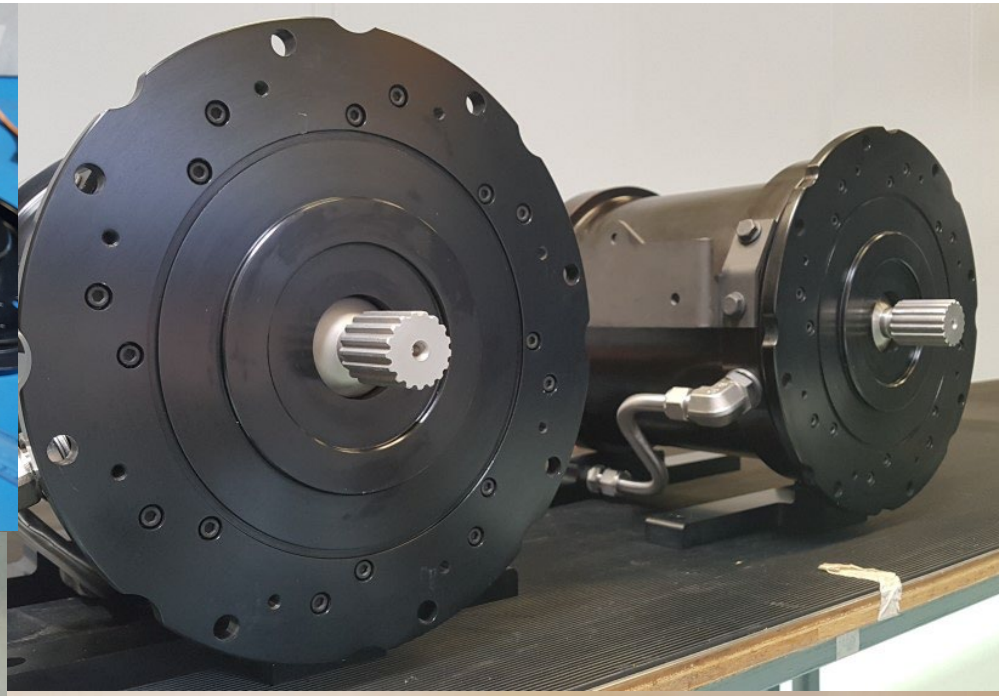
Die-cast and fabricated Copper Rotor

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

ReFreeDrive Project Overview

Induction motor prototype manufacturing

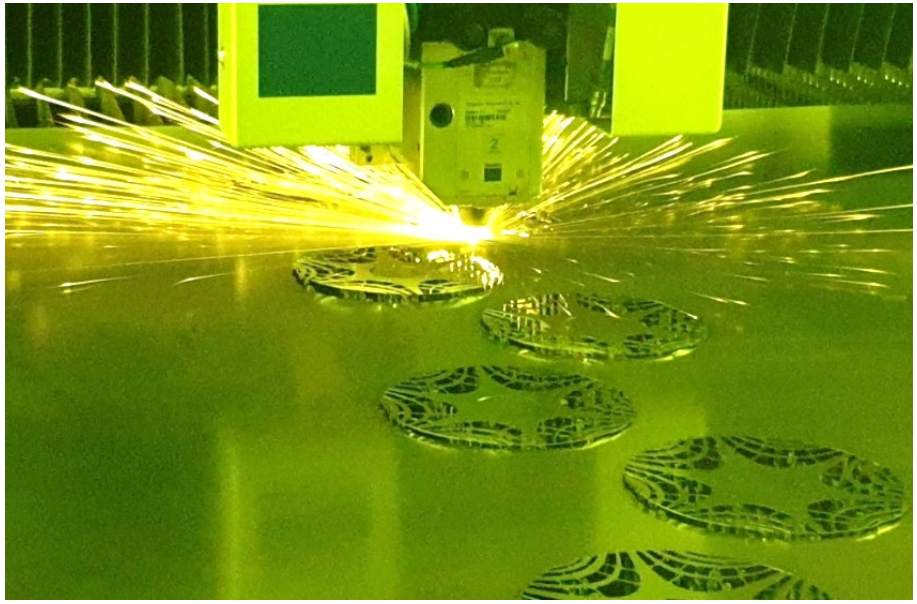


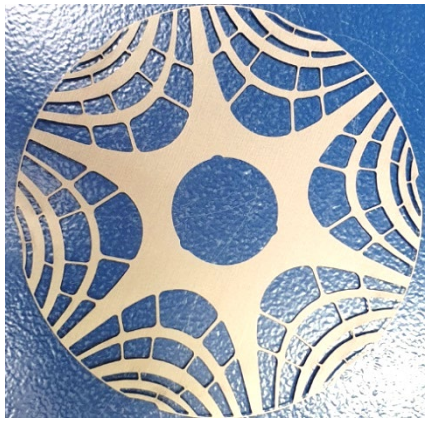


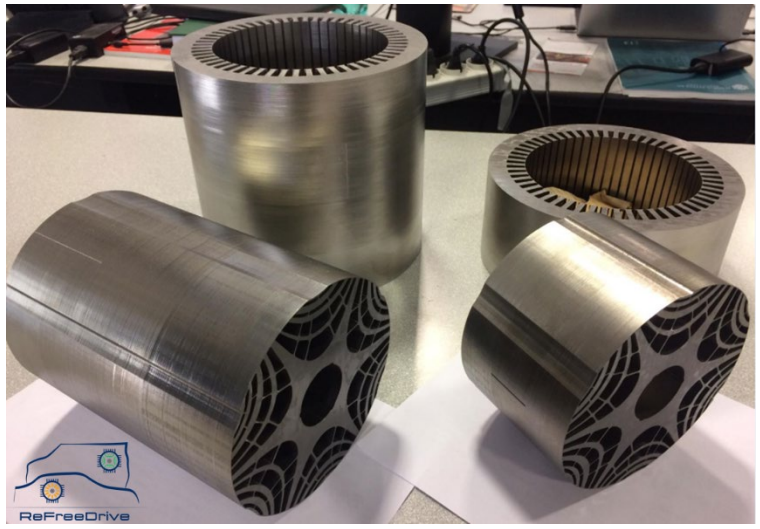
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

ReFreeDrive Project Overview

Pure Synrel motor prototype manufacturing





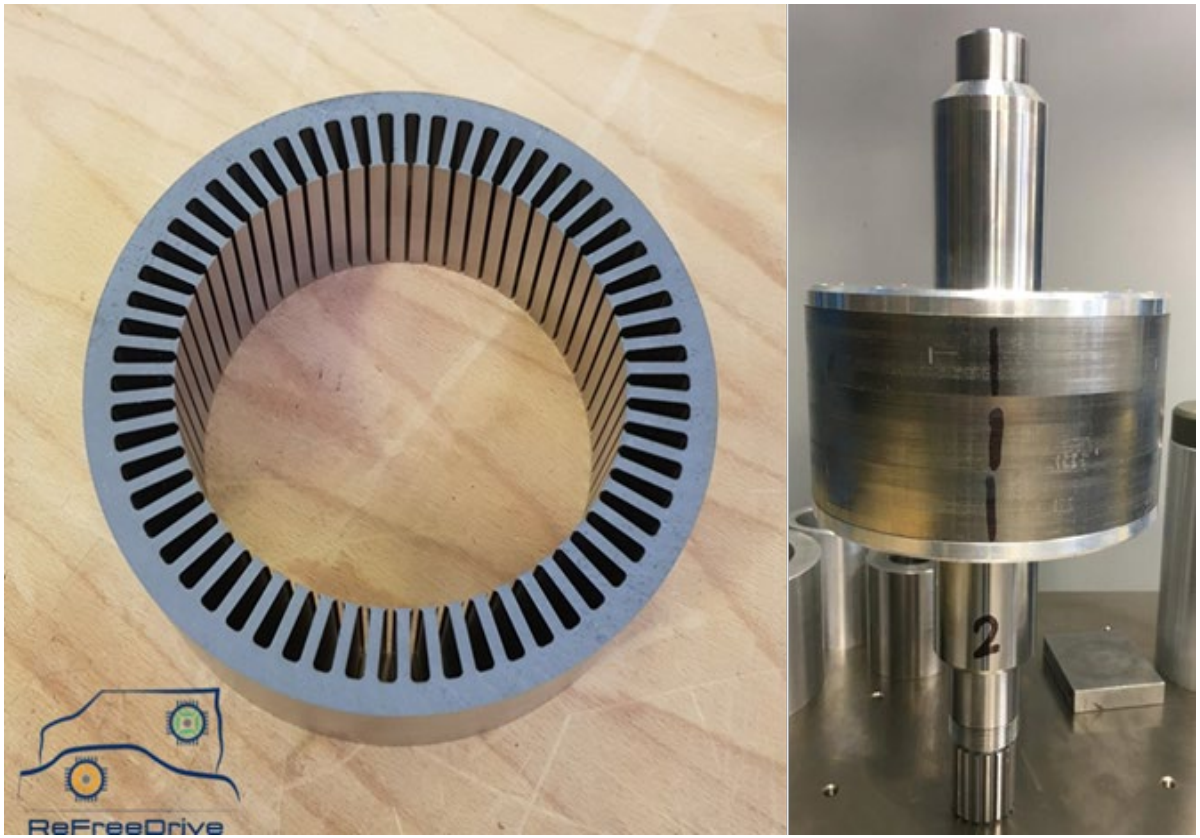


Laser cut of the electrical steel (courtesy of LCD)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

ReFreeDrive Project Overview

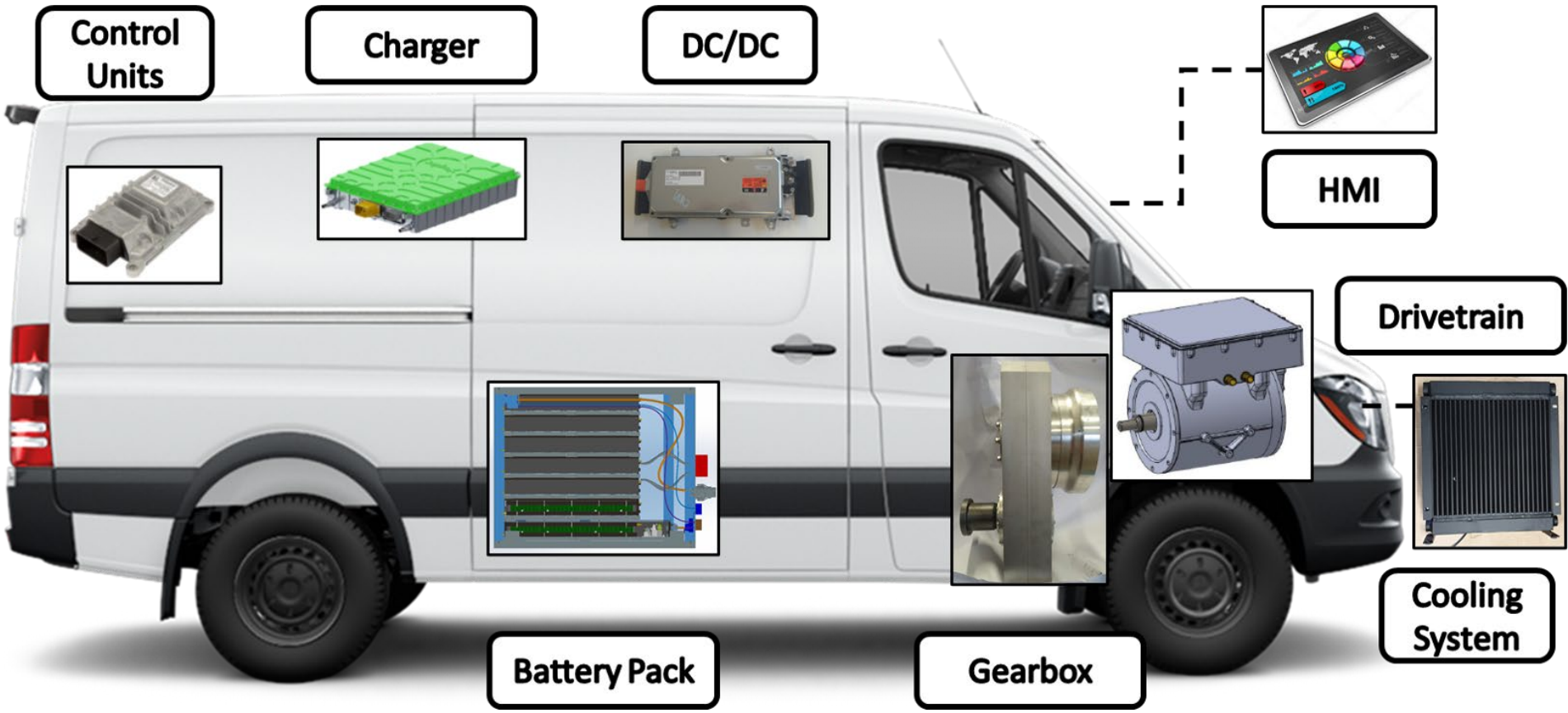
PM Synrel motor prototype manufacturing



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

ReFreeDrive Project Overview

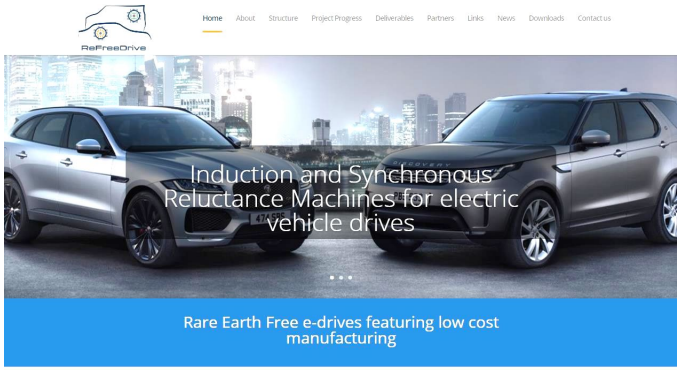
In-vehicle integration



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143

ReFreeDrive Project

www.refreedrive.eu



www.copperalliance.org

fernando.nuno@copperalliance.eu

https://univaq.it/

UNIVERSITÀ DEGLI STUDI DELL'AQUILA

marco.villani@univaq.it

https://www.linkedin.com/company/electric-drivetrain-innovation-cluster/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 770143