NEXT-GEN
POWER MAGNETICS

Whitepaper

New Magnetic Material Technology for Electromagnetic Products

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Introduction

CleanMag™ is an advanced materials technology with high-performance magnetic solutions.

Products

- CleanMag™ Powder
- CleanMag™ Magnetic Core
- CleanMag™ SMC
- CleanLam™ Lamination



Applications

- Inductor
- Choke
- Filter
- Transformer
- DC-DC Converter
- Inverter
- Actuator
- Solenoid
- Axial Motor
- Traction Motor
- Transverse Flux Motor
- Radial Motor


Inductors and chokes in Inverter and DC-DC converter


Stator and Rotor in motors and generator

Markets

- Electric Vehicle: Power converter, Traction Motor, On-board charger, Charging station
- Datacenter: DC-DC converter, Inverter, Generator
- Industrial and Robotics: Servo motor, Actuator
- Consumer electronics: Inverter, Filter, DC-DC converter, Wireless charging, Solenoid
- Energy: Generator, Transformer
- HVAC: Pump, Sensor, Generator
- Automotive: DC-DC converter, Solenoid
- Electric bike: Axial motor, DC-DC converter, Inverter
- Aerospace and Defense: Inverter, DC-DC power converter, APU
- Drone: Motors, DC-DC power converter

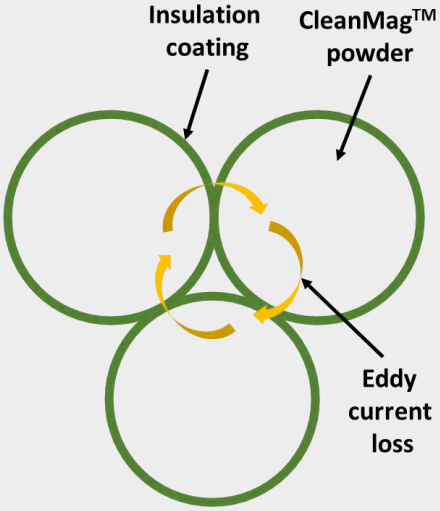
Physical Properties

Ideal Density	6.5-7.6 g/cm3
Apparent Density	2.5-3.5 g/cm3
Tap Density	3.2-4.5 g/cm3
Melting point	1350-1500° C
Electrical resistivity	200-350 microohm-cm

Physics of insulation coating on soft magnetic products

The thinning of the lamination helps in reducing eddy loss of the lamination stator and rotor stack. Based on the first principle, eddy loss, Pcl goes down with higher material resistivity, ρ, and goes down with lower lamination thickness, t.

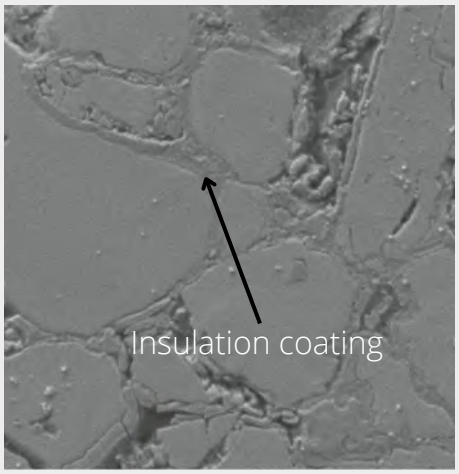
$$P_{\mathrm{cl}} = \frac{\pi^2 t^2 B_m^2 f^2}{6\rho}$$



Pcl is the eddy loss, t is the thickness of lamination, Bm is the magnetic induction, f is the frequency and ρ is the resistivity.

Insulation coating is made using oxides or other electrically insulating material. The thickness of the insulating material is between 50 and 200 nm. The coating thickness control and homogeneity of the coating are important factors.

Sometimes particles might agglomerate and create a larger particle. A great powder core needs to avoid any particle agglomeration and the particle boundaries need to be coated homogeneously with electrically insulating materials.



CleanMag™ Powder and Magnetic Cores

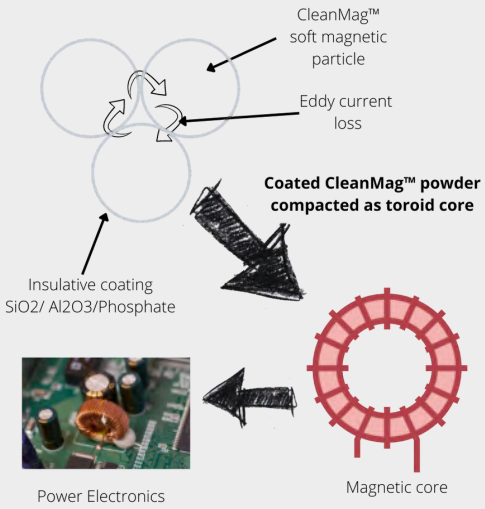
CleanMag™ has two powder variants. Smaller powders are for power electronics applications such as inductors and transformers. The larger particles are motor axial motor applications. It is to be noted that our technology is particle size and shape agnostic. We have the capability to produce CleanMag™ with any particle size or shape if that helps in customization for any customer.

	Particle Size (D50)	**Applications**
CleanMag™ X	5 µm	Inductor and Transformer
CleanMag™ Y	120 µm	Axial Motor

Physics of a great powder core

The physics of making a great powder core is multifaceted and dynamic. The ideal soft magnetic composite powder core should have a high magnetic induction, low core loss, and reasonable mechanical and thermal stability.

The magnetic induction of a powder core is dependent on the inherent material composition and non-magnetic components in the core. The lower core loss is obtained via low hysteresis loss and low eddy current loss. Low hysteresis loss is the result of reduced internal stress and low coercivity. We can obtain low eddy loss via high resistivity material and insulation between particles.



CleanLam™ Laminations

CleanLam™ lamination is a unique product for motors and generators. The laminations are capable of producing more efficient motors and generators. The laminations are used in stators and rotors.

Physics of a great lamination product

Motor and generator lamination is generally made from thin electrical steel. The thin laminations are hot and cold rolled to thicknesses such as 0.35 mm, 0.25 mm, and 0.15 mm. Lamination stack/core is used as stator and rotor core.

The thinning of the lamination helps in reducing eddy loss of the lamination stator and rotor stack. The lamination layers have the insulative coating in between those to reduce or eliminate eddy current loss.

The thin lamination stack also needs to have low magnetostriction, low coercivity, and moderate permeability.

The performance of the lamination core determines the torque and power density of the motors and generators.

CleanMag™ X

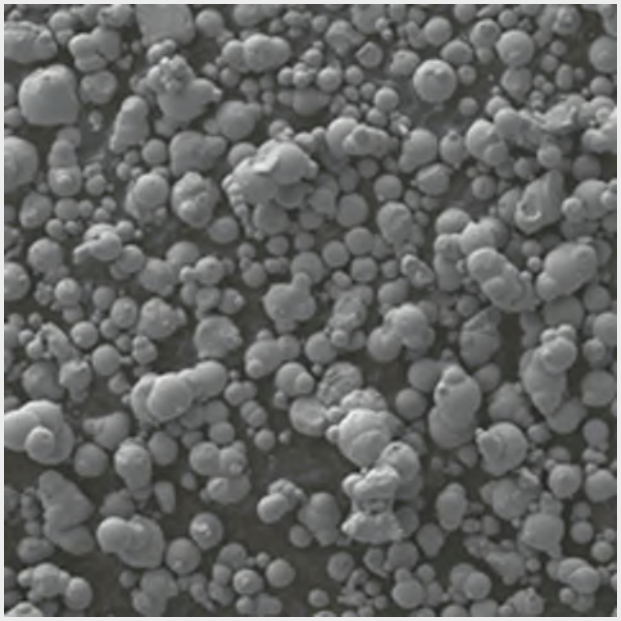
CleanMag™ X

CleanMag™ X is a proprietary powder for power magnetic applications in inverters, DC-DC converters, and transformers. The power inductors, chokes, filters, and transformer cores need a better magnetic core for a smaller, lighter, and more efficient solution.

Particle Size Distribution (PSD)

D10	1 µm
D50	5 µm
D90	11 µm

CleanMag™ X powder is based on Iron and a few other proprietary components.



Process Flow

CleanMag™ X magnetic cores are made in five stages. In the first stage, we toll manufacture our proprietary starting composition using a gas atomizer. In stage two, we manufacture the proprietary CleanMag™ composition. In the third stage, we insulate the powder with oxides or non-conductive materials. In the fourth stage, the coated powders are compacted and finally, the parts are heat-treated to make a mechanically sturdy core.

01 Buy atomized powder from powder manufacturers

02 Proprietary **CleanMag powder synthesis**

03 Insulation **coating** on CleanMag particles

04 **Compaction** of coated CleanMag™ **powder to cores**

05 Post annealing and QA Testing

Scalability

Fluidized bed process (batch), easily scalable to 300t/year with one machine

Double cone or V-blending or Blade mixing, scalable with off-the-shelf equipment

Compaction at 800-2000 MPa, scalable with equipment vendor partnership

Annealing between 250C and 700C and QA testing, scalable process in-house

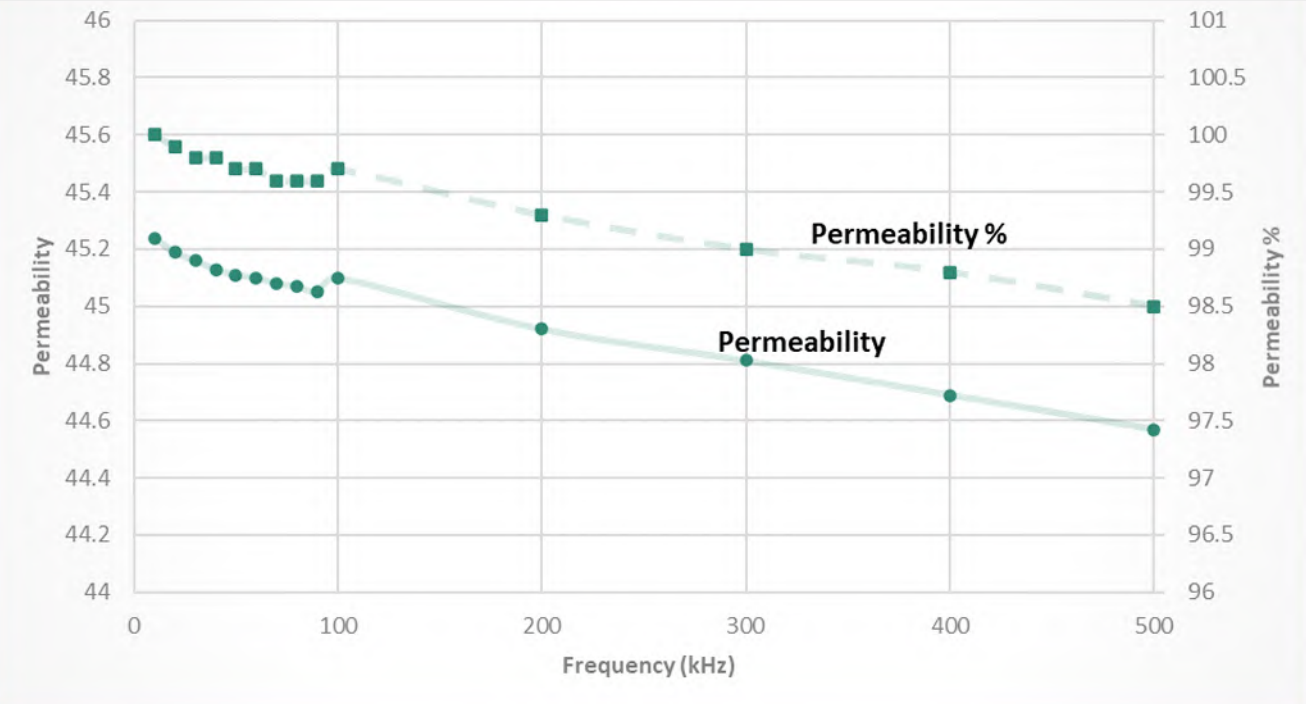
Magnetic properties

Magnetic induction	1.7-1.9T
Coercivity	10-13 Oe
Permeability	30-60

Permeability

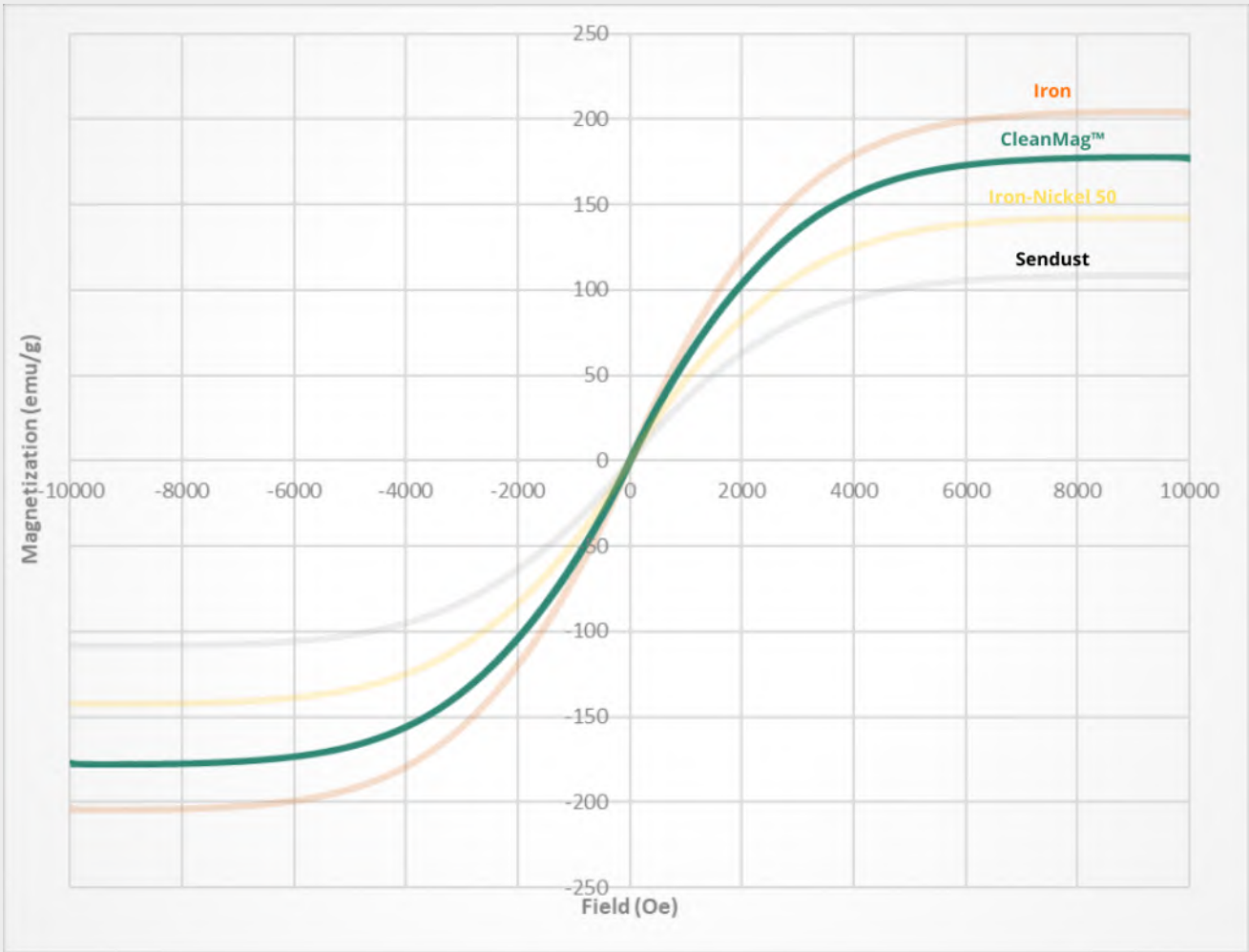
CleanMag™ X demonstrates a stable permeability at 500 kHz. The stability of the permeability at 500 kHz is over 98.5% at 500 kHz. Our in-house tester is limited to 500 kHz measurement. We expect the permeability to be stable in the MHz range.

We found a permeability up to 45 with our generation 1 product. Our future generation products will also have a permeability of 30 and 60.



Magnetic Induction

CleanMag™ X is a particle that demonstrates higher magnetic induction relative to other magnetic powders such as Sendust (FeSiAl), Iron-Nickel (FeNi50 and FeNi80), and has a little lower induction than pure Iron powder. CleanMag X has approximately 70% higher magnetic induction relative to Sendust, the most used Iron-based powder core in power electronics applications.

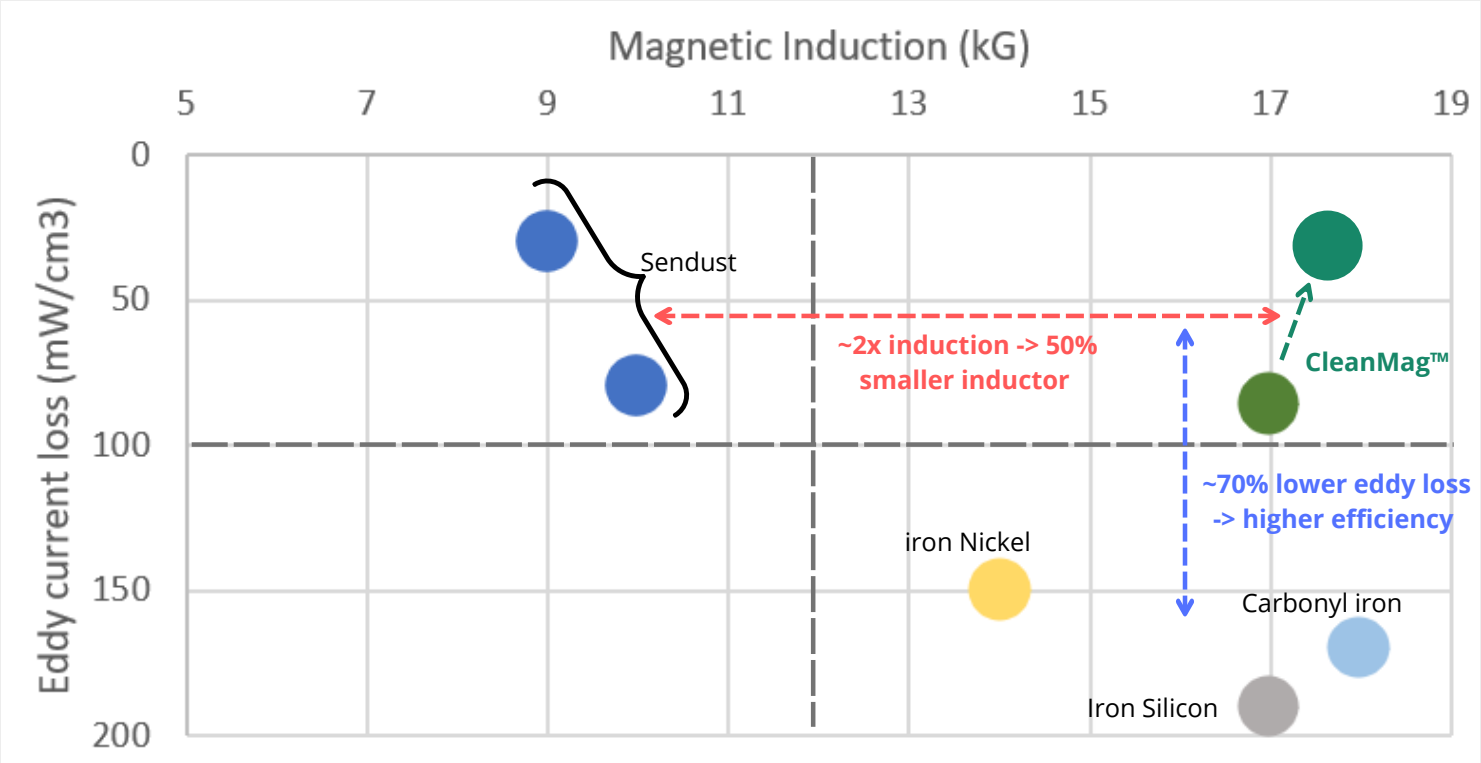


CleanMag™ X has a saturation induction of ~180 emu/g or ~1.7T. It is higher relative to other competing products.

Iron Nickel (FeNi50)	1.4T
Sendust (FeSiAl)	1.1T
Amorphous	1.5T
CleanMag™ X	1.7-1.9T

Core Loss

CleanMag™ X has lower core loss relative to other magnetic powders available in the market. We compared the performance of the CleanMag™ X powders without any insulation coating. The insulation coating is essential for reducing eddy current losses, however, without an insulation layer, we can find a head-to-head comparison between powders.

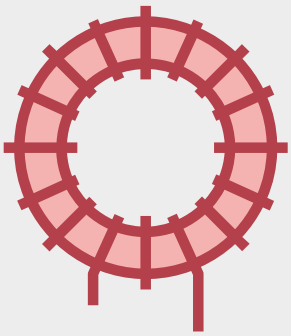


Value in an inductor

More efficient
20% lower inductor loss (50% lower core loss)

Smaller inductor
Up to 50% smaller

Cheaper
30% cheaper



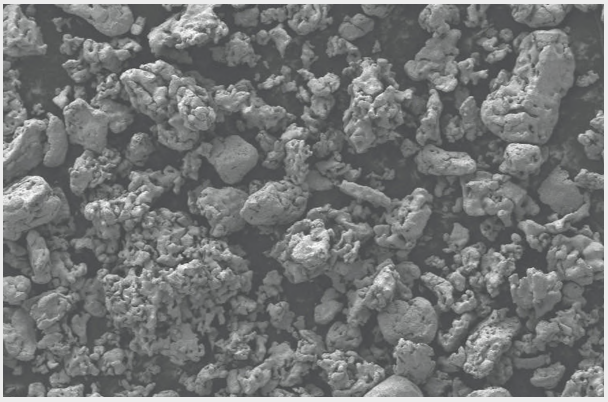
CleanMag™ Y

CleanMag™ Y SMC

CleanMag™ Y is a powder solution for soft magnetic composite (SMC) based axial motor. Axial motors are essential for power-dense motors used in niche applications.

Particle Size Distribution (PSD)

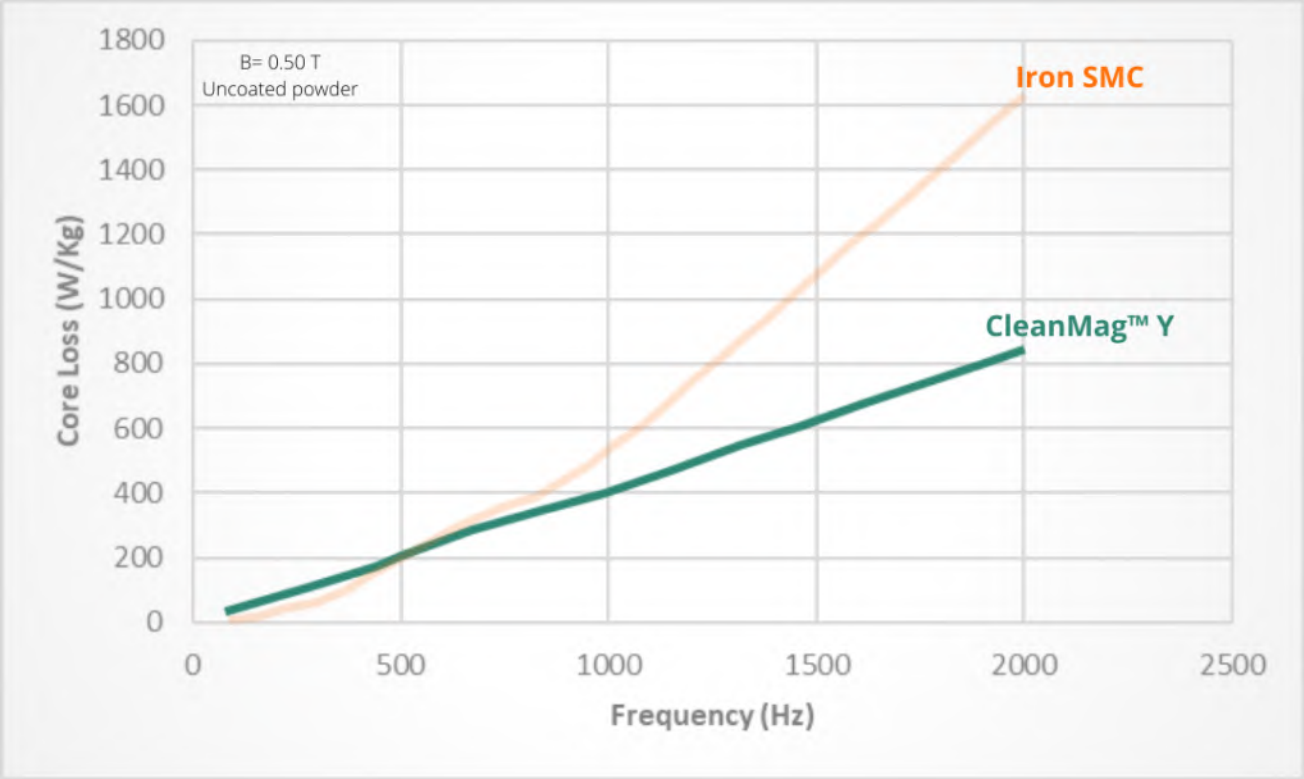
D10	45 µm
D50	130 µm
D90	215 µm



CleanMag™ Y powders are irregular-shaped

Core Loss

The core loss of CleanMag™ Y magnetic core is approximately 50% smaller than the currently available Iron SMC. We compared the core loss of the compacted core made from uncoated powders. For best performance, the powder particles need insulation coating. However, our comparison demonstrates the raw material's head-to-head performance and CleanMag particles are better than the incumbent technology.

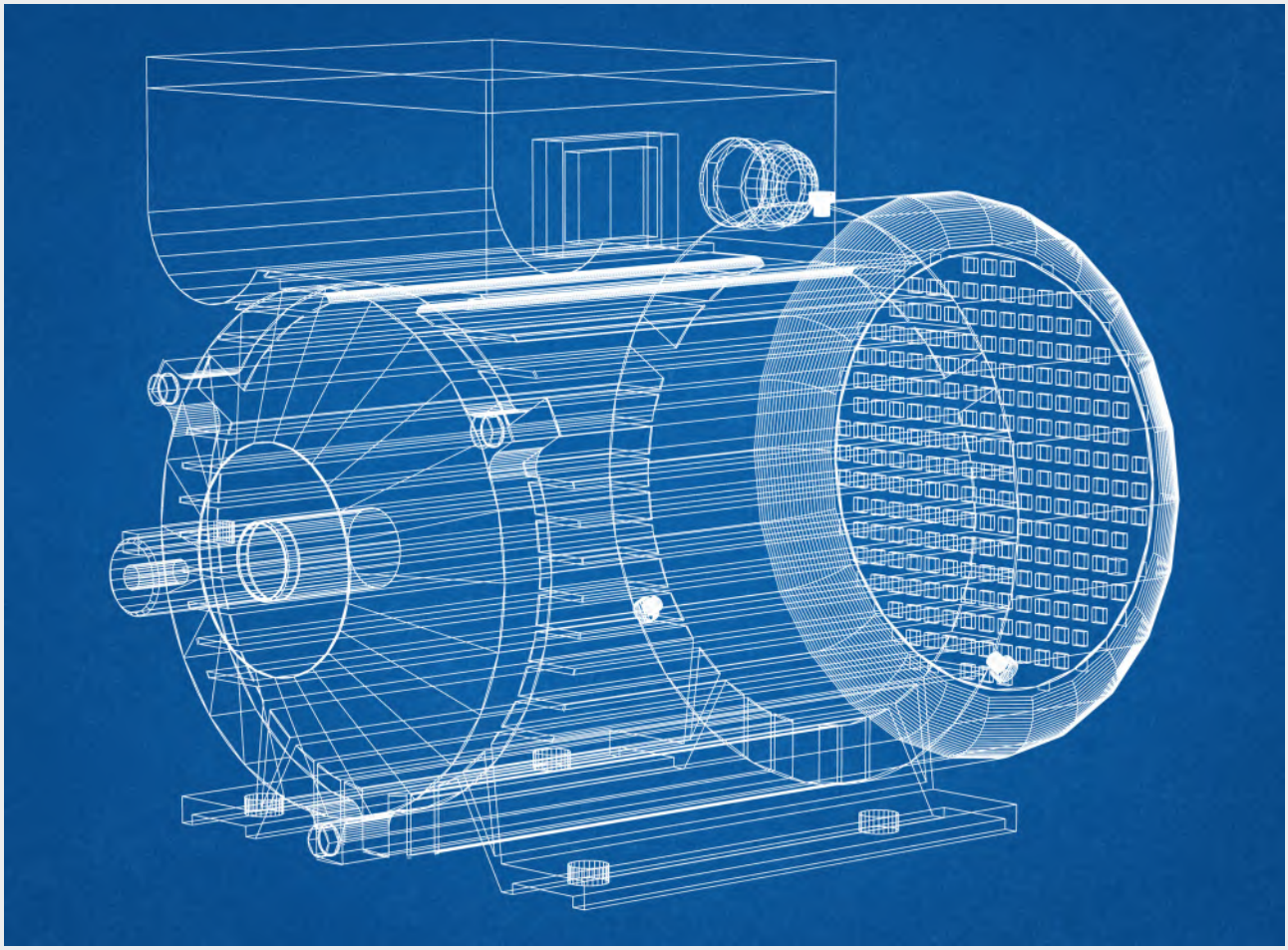


Magnetic induction

The CleanMag™ Y powder has magnetic induction of 1.9T which is 5% lower than Iron particles. This is a little disadvantageous for motor applications. However, the lower loss would enable higher efficiency in motors and that would help in obtaining even higher power density and torque density with CleanMag™ Y stators and rotors in axial motors (AFM) and transverse flux motors (TFM).

Applications

- Axial Flux Motors
- Transverse Flux Motors



CleanLam™

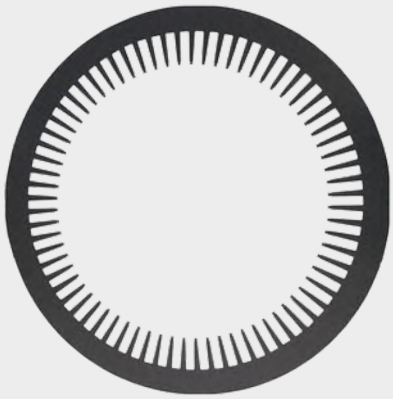
CleanLam™ Lamination

CleanLam™ is a proprietary metal alloy lamination for stators and rotors of motors, generators, and pumps.

CleanLam™ is available in any available size and shape depending on the customer's design.

Thickness available:

- 0.25 mm
- 0.35 mm
- 0.50 mm

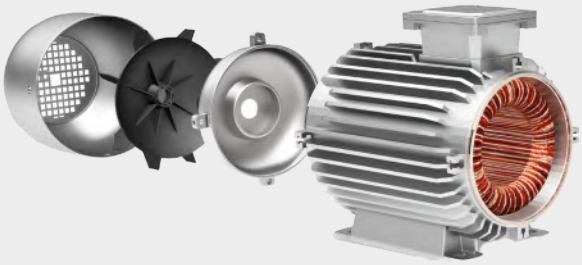


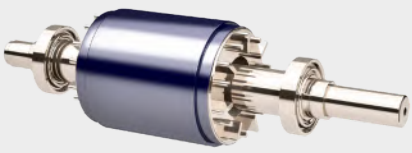
Applications

- Motors
- Generators
- Pumps

Magnetic Induction

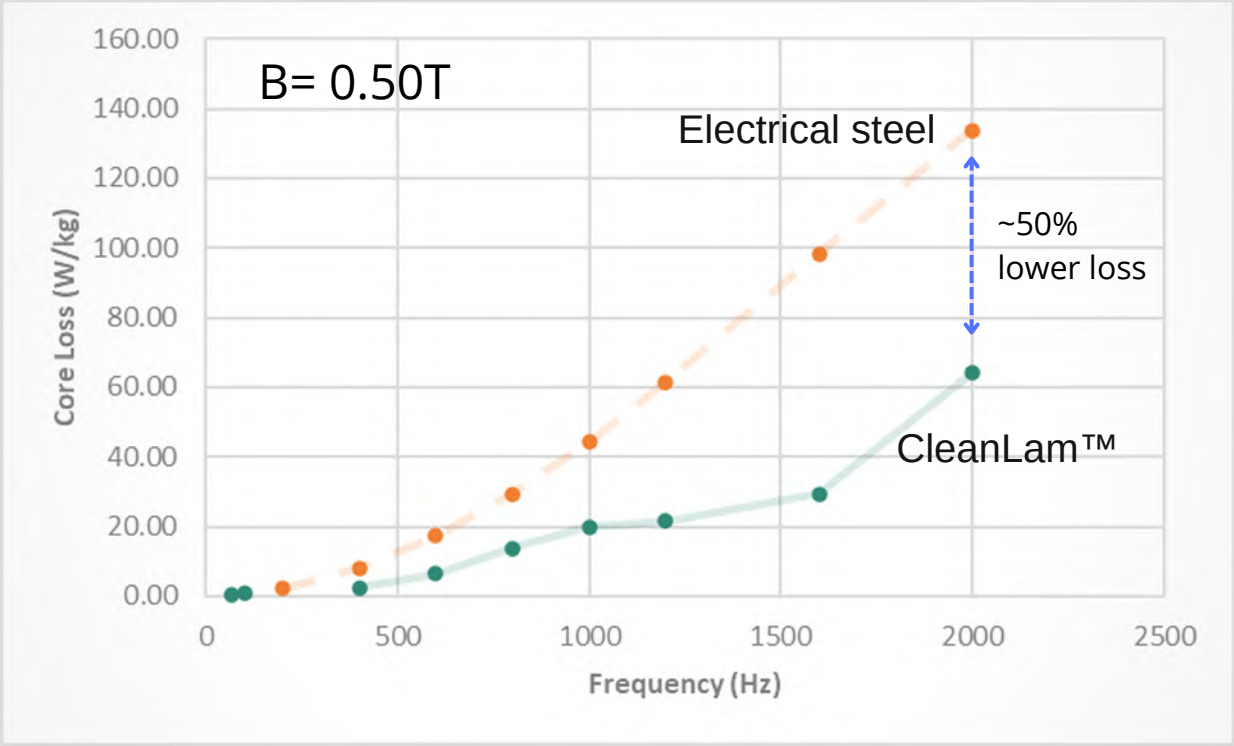
		Cost
CleanLam™	1.85-2.05 T	$
Silicon Steel	1.9-2.0 T	$
Iron Nickel	1.5 T	$$
Amorphous and Nanocrystalline	1.2-1.5 T	$$$
Iron Cobalt	2.3 T	$$$





Core Loss

CleanLam™ demonstrates lower core loss relative to the Silicon steel cores. We used 0.45mm thickness to benchmark the performance of our technology. The core loss of CleanLam™ products is approximately 50% lower relative to Silicon steel. The lower core loss enables a higher efficiency motor.



Value in a motor

More efficient
20% lower motor loss (50% lower core loss)

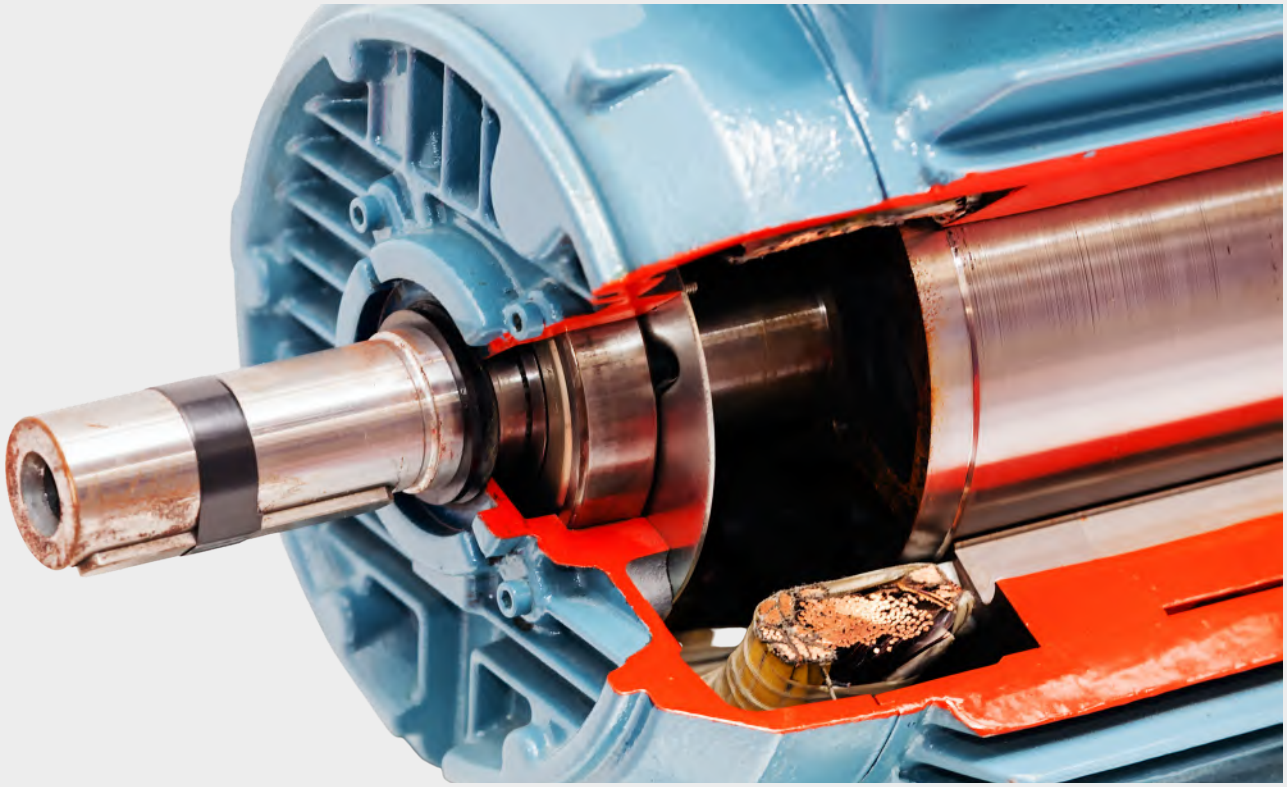
Cheaper
Save up to $50 per motor

Cooler machine
15% lower temperature rise

More reliable machine
~2x more machine life

Process Flow and Scalability

		Scalability
1	Toll manufacture proprietary composition of Iron-alloy	Toll Mfg. by steel mills
2	Laminate coil via high-speed stamping	Partnership with machine shop with capability to process millions of laminations
3	Build CleanLam™ material system in the laminations	In-house processing reactor. Custom reactor designed for processing laminations for 500k motors.
4	CleanLam™ laminations are stacked as stator and rotor cores	Partnership with machine shop with capability to process millions of laminations
5	Assemble motor parts and build motor	Mfg. by Tier-1s/OEMs



Sustainability Impacts

2021-2050
CLIMATE IMPACT

Our technology will enable the saving of 2.6 Billion Metric Tons of CO2e by 2050. Motors, transformers, generators, and pumps are responsible for over 70% of the total energy losses in the world. CM Materials technology will enable higher efficiency, lower cooling requirements, and smaller components in electromagnetics. Approx., 97% of total energy-saving and CO2e emission reduction would happen with CM Materials technology in those applications.

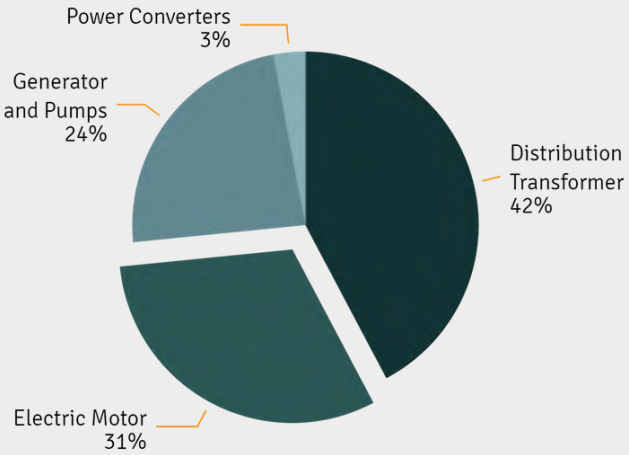
Power converters in different applications such as EVs, solar, consumer electronics, etc. would reduce 3% of Co2e emission by using CM Materials technology.

over the top advantage
MADE IN USA

CM Materials' technology is developed and manufactured in the USA. We will lead the technology leadership of the USA and promote local manufacturing ecosystem.

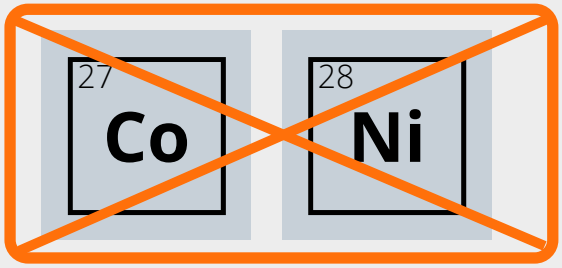
Climate impact by applications

Total CO2e
2.6 billion Metric Tons by 2050



over the top advantage
SUPPLY CHAIN

CM Materials Technology doesn't use any Nickel, Cobalt, or Rare-earths. High-performance soft magnetic or electromagnetic technologies use critical elements such as Cobalt, Nickel, or Niobium. CM Materials' technology is based on cheaper and sustainable raw materials. Additionally, the more available raw material makes CM Materials' technology supply chain more attractive.



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