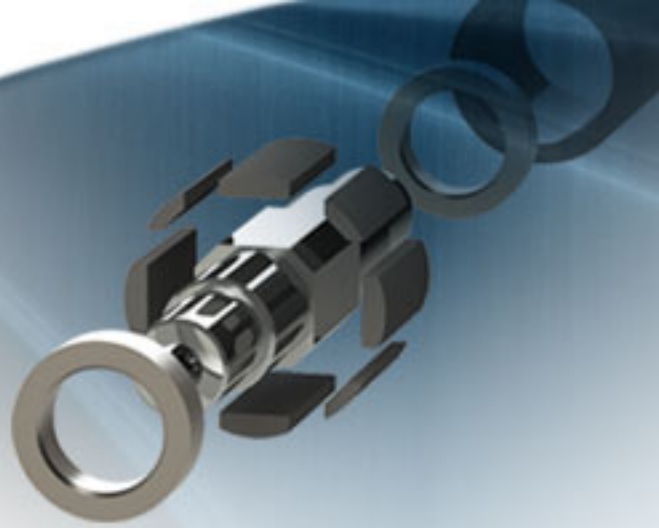
ARNOLD®
MAGNETIC TECHNOLOGIES



Arnold Magnetic Technologies

Advanced Materials for High Performance Electric Machines

Tim Wilson
Chief Executive Officer
Arnold Magnetic Technologies

engineexpo2014
★ NOVI ★ ★ MICHIGAN ★

Arnold Overview

- Our mission is to facilitate the more efficient electrification of systems for a greener environment
- We produce engineered components and systems that allow machines to run faster and hotter with higher efficiency and lower costs in smaller packages
- Products include RECOMA® SmCo, Arnon® Silicon Steel, shaped field magnets, Wraptite® composite sleeving and system integration of these materials

$130M in sales

Privately held

Facilities in the US, Europe & Asia Pacific

~ 750 Employees

2,000+ Customers

100+ Years in Business

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The Automotive Market Has Very Demanding Emissions and Fuel Efficiency Regulations

CO_2 Targets (grams CO_2/km)

	2012	2015	2020	2025
	154	130	95	70
	240	181	152	137
	185	167	145	125

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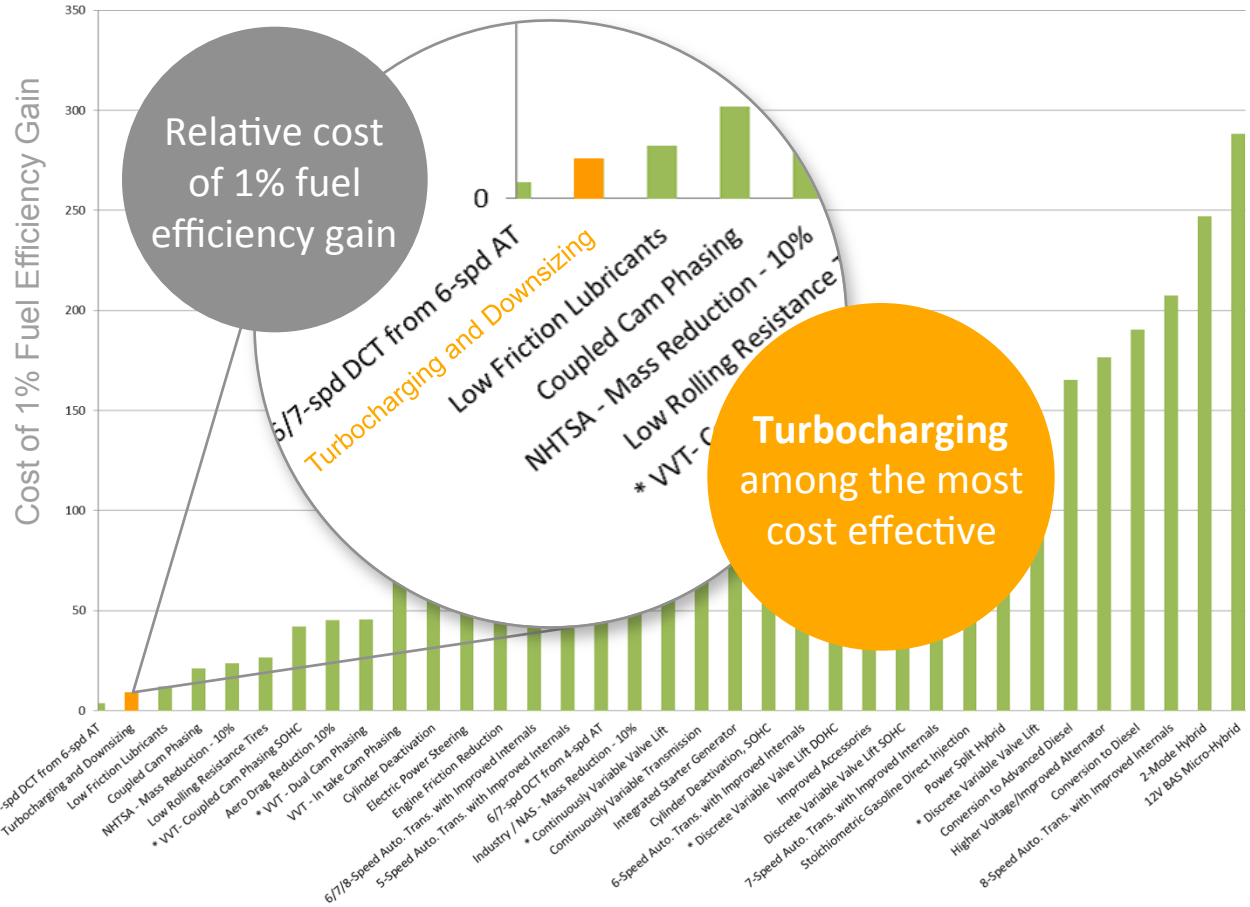
Potential Solutions to Meet the Regulations



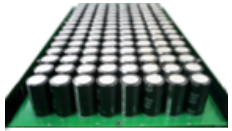
Source: NHTSA Study

Hybrid Supercharging / Turbocharging

Traditional turbocharging is an option . . .

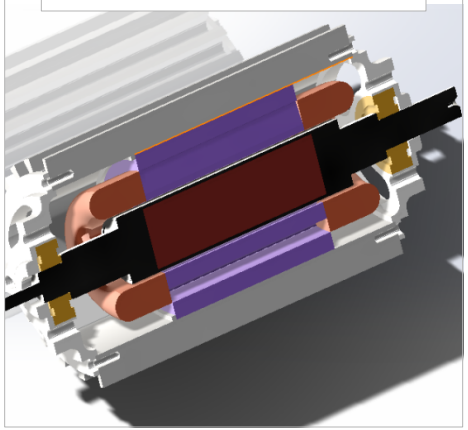
Power

Li-Ion Batteries



Ultra Capacitors

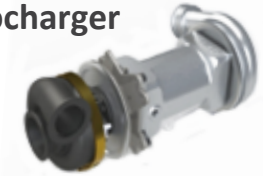
High Performance Electric Motors



Supercharger

Which Drive

Turbocharger



. . . but can result in "turbo lag" due to a lack of kinetic exhaust energy from downsized engines. Electric driven systems can alleviate this problem.

Source: "Case Study – Electric Supercharger (eSupercharger) for Range Extender Engine." *Case Studies*. N.p., n.d. Web. 24 July 2014.

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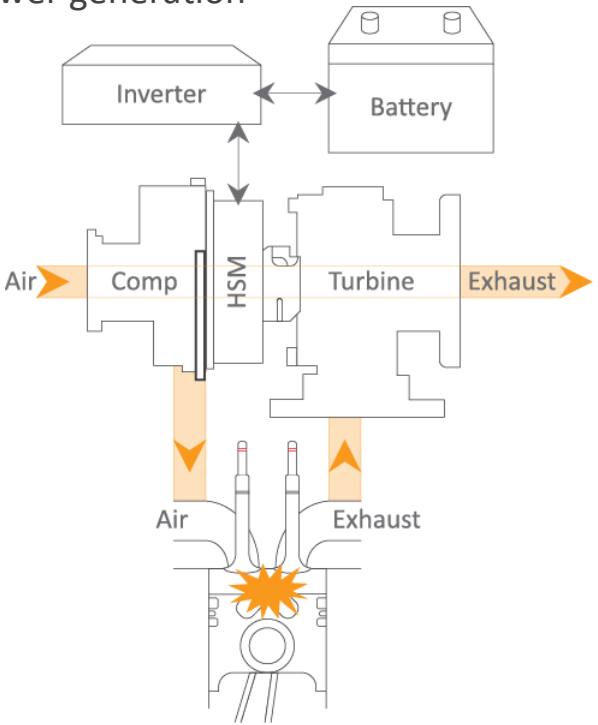
Application Configurations

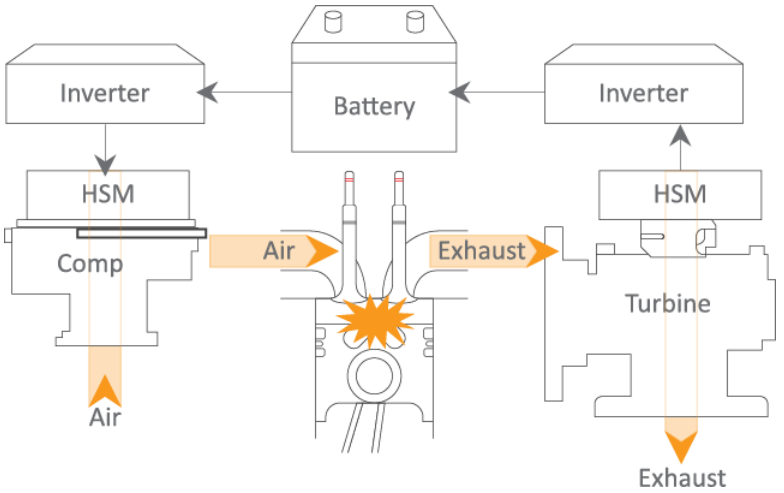
Coupled

Compressor-Motor-Turbine providing boost assist and power generation



De-Coupled

Compressor-Motor & Motor-Turbine separated allowing boost assist and power generation along with multiple engine layouts



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High Speed Electrification Design Challenges

- Energy Density at Elevated Temperatures
  - Demagnetization
- Eddy Currents
  - Iron Losses in the Stator
  - Excessive heat in the rotor
- High Speed Rotor Dynamics
  - Containment
  - Balancing
  - Deflection
- Voltage
  - 12 Volt, 42/48 Volt, 300+ High Voltage
- Energy Storage for Recuperative Systems
  - Li vs. Ultracapacitors

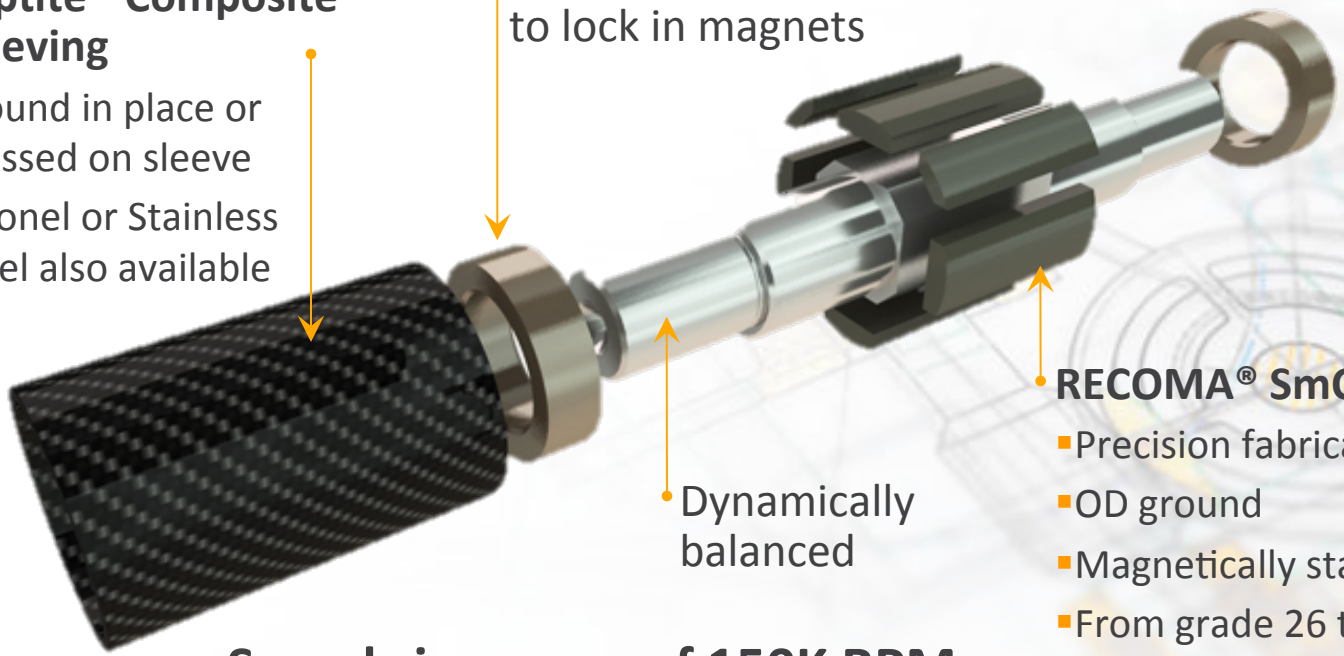
ARNOLD® MAGNETIC TECHNOLOGIES

Improving High Speed Rotor Performance

Wraptite™ Composite Sleeving

- Wound in place or pressed on sleeve
- Inconel or Stainless Steel also available

Precision fit end ring to lock in magnets



Dynamically balanced

RECOMA® SmCo Magnets

- Precision fabricated
- OD ground
- Magnetically stabilized
- From grade 26 to 33

Speeds in excess of 150K RPM
225°C + Operating Temperatures

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Stator Optimization

- Arnon® ultra thin (0.005” - 0.007”) non-oriented 3% silicon steel
  - Reduces eddy current losses and heat rise in the stator
  - C5 insulation coating

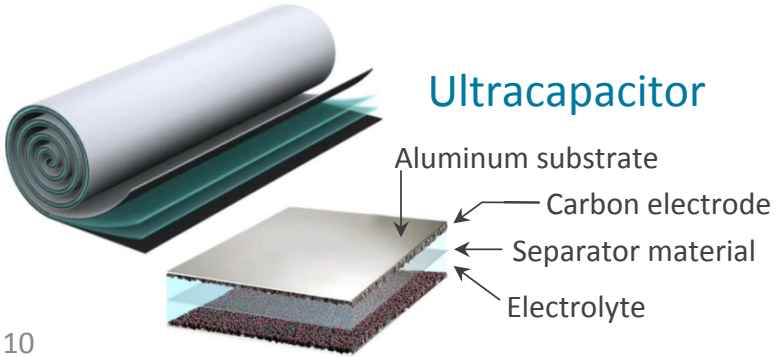
Thinner laminations for reduced eddy currents

ARNOLD® MAGNETIC TECHNOLOGIES

Energy Storage: BESThin™ Materials

Our materials enable energy density through thinner substrates

General Capabilities for Energy Storage Applications				
Material	***Industry Std. Thickness***	***PTM Thickness***	***Material Widths***	
Nickel (Ni)	10+ microns	2+ microns	1.25 – 300 mm	Anode Current Collector, Separator
Aluminum (Al)	5+ microns	2.5+ microns	1.25 – 430 mm	
Copper (Cu)	5+ microns	2+ microns	1.25 – 292 mm	
Titanium (Ti)	10+ microns	2+ microns	1.25 – 393 mm	Emerging
Stainless (SS)	10+ microns	2+ microns	1.25 – 430 mm	



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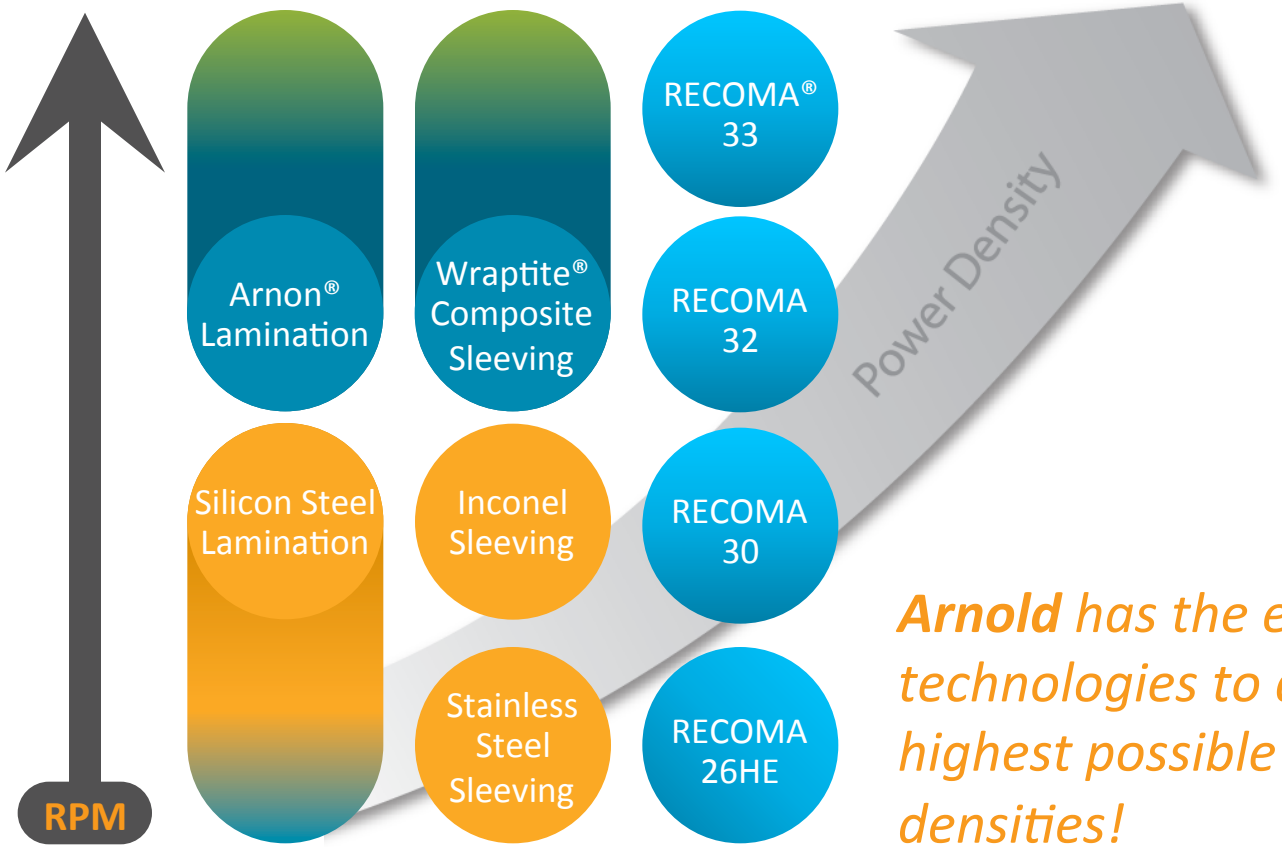
Higher Power Densities Benefit from Arnold's Technologies



***Arnold** has the enabling technologies to achieve the highest possible power densities!*

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www.arnoldmagnetics.com