Selection of Rotor Material for Industrial Induction Motors

The Case for Copper

Key Findings

- Copper's superior electrical conductivity makes it ideally suited for the rotor bars and end rings in induction motor rotors.
- Manufacturers of industrial motors can produce premium efficiency motors at a reduced cost using die cast copper rotors.
- The value of energy saved by super-premium efficiency motors incorporating die cast copper rotors pays back the initially higher manufacturing cost in less than 4 months. This enables motor manufacturers and end-users to share in the economic benefits.
- Super-premium motors based on copper rotors have a lower carbon footprint than motors using die cast aluminum rotors.

Introduction

This report describes the economic and environmental benefits for manufacturers and users of industrial motors incorporating die cast copper rotors (Figure 1).

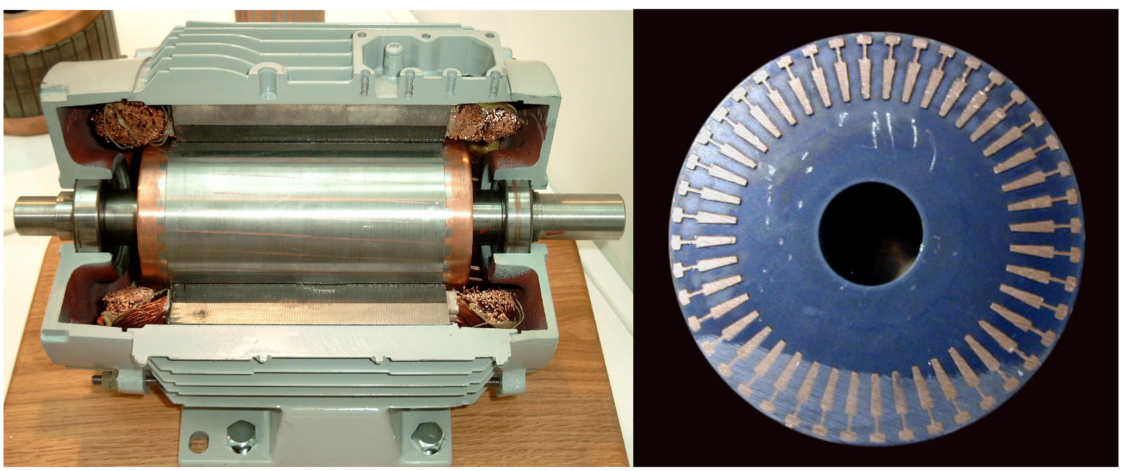

Figure 1. Source: IBIS/Siemens

Die casting copper is more challenging than die casting aluminum because of copper's much high melting temperature. However, the production technology necessary to die cast copper rotors has been developed and a number of manufacturers and rotor suppliers are producing such rotors on a routine basis. Technical information can be found at www.copper-motor-rotor.org.

Copper's high electrical conductivity provides motor designers and manufacturers with the ability to maintain Premium motor efficiency and reduce manufacturing cost, or attain Super-

Premium motor efficiency and lower the motor's lifecycle costs. The benchmarking analysis considers these two alternatives from a baseline of a 91.6% efficient NEMA Premium industrial motor.

Metal prices have experience volatility recently. Between 1980 and 2008, the average price ratio of copper to aluminum has been approximately 1.5. Over this analysis period, for more than 60% of the time, the ratio was less than or equal to 1.5. In recent years, the ratio has risen sharply. In 2006, the ratio reached 2.81, however, the level has since lowered to 1.9 in October 2008. This relative price volatility may have contributed to the reluctance of some motor manufacturers to proceed with die cast copper rotors.

However, the analysis indicates that even at a high cost for copper, manufacturers of premium electric motors will benefit from the use of die cast copper rotors and that end users can economically justify the selection of a copper-based super premium design.

Figure 2 depicts the comparative manufacturing cost of 7.5 kW industrial electric motors and shows the advantage of copper rotors even at a high metal price ratio.

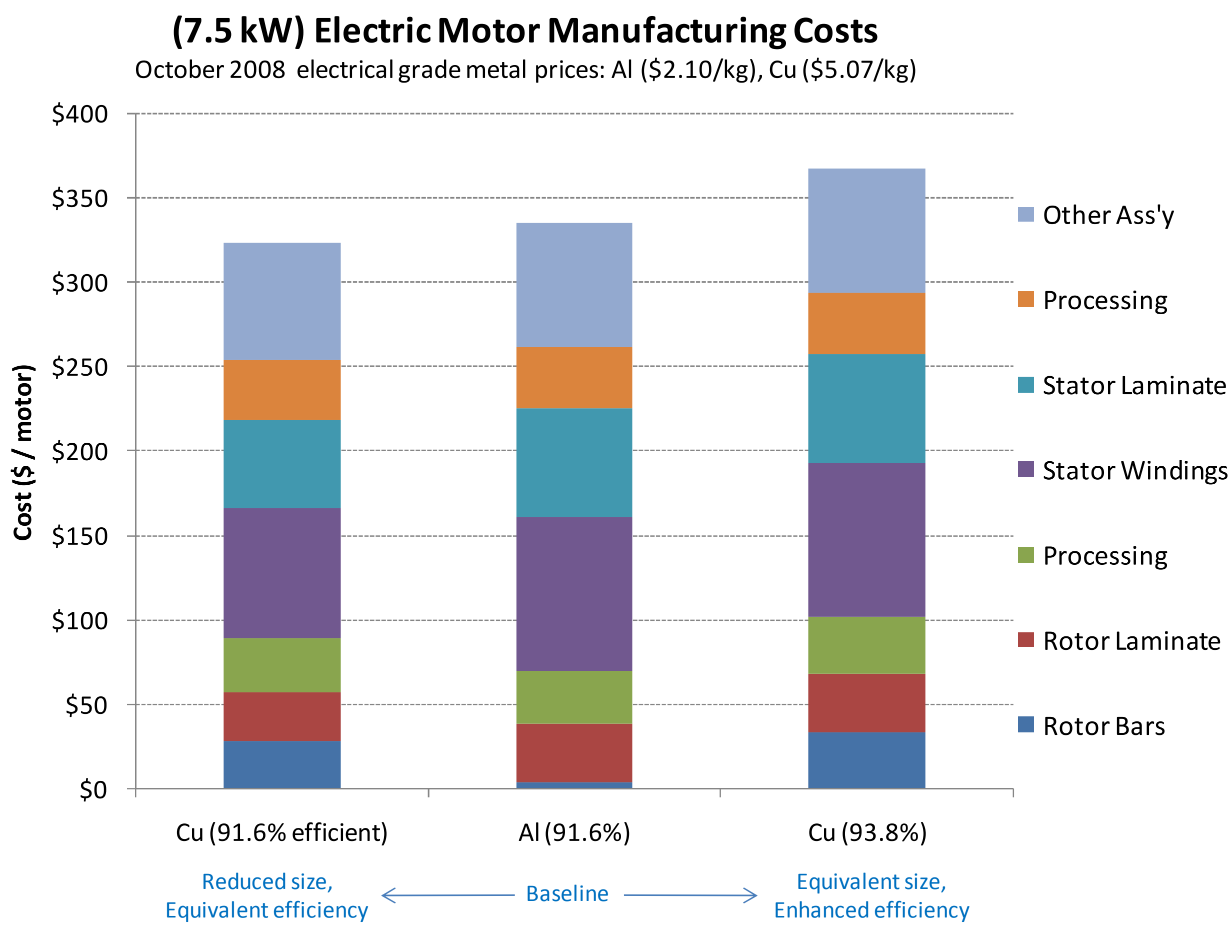

Figure 2. Source: IBIS/Kirtley, Brush, et al

1. Copper rotors for reduced size, equivalent efficiency motors

- To achieve performance (efficiency) that is equivalent to copper designs, the length of an aluminum rotor must be increased by an average of 20%. Some manufacturers have found aluminum motor length must be increased by as much as 50% relative to equivalent copper motors.
- Rotor length directly impacts the cost of many of the other motor components.
- Both the stator and rotor components contain stamped, stacked lamination steel. Increasing the length of the rotor increases the amount of electrical grade lamination steel that is required, and the number of stampings.
- The stators are comprised of copper wire which is wound in bundles around and through the stator "stacks". The size (length) of the stator directly impacts the copper wire content and processing time requirements.
- The cost of other components, including the shaft and housing are directly impacted by the size (length) of the rotor.
- For a premium (91.6%) efficiency 7.5 kW electric motor, the cost of copper is more than offset by the cost savings associated with shorter motor length. Relative to an equivalent 7.5 kW aluminum rotor design, copper saves the manufacturer approximately $12.21 or 3.6%.

2. Copper rotors for equivalent size, enhanced efficiency motors

- Motors account for more than 70% of the electrical energy use in the US industrial sector. Incremental improvements to electric motor efficiency can provide the end user with a significant economic benefit.
- The use of variable speed drives increases the efficiency of motor-driven systems at all operational speeds and also increases the starting torque of motors with copper rotors.
- In developing nations, the impact of improved motor efficiencies can dramatically affect the availability of electricity to all users who rely on inadequate power infrastructure. For instance, India faces chronic electricity shortage (of about 10%) and up to 20% during peak periods. At the same time, the actual per capita consumption has grown from 140 kWh in 1980 to 500 kWh in 2003 and expected to grow to around 800 kWh by 2012. Of the total electricity consumption in India, motors consume almost 70%.
- Further, the global environmental benefits of reduced power consumption and resulting carbon emissions that accompany incremental motor efficiency enhancements are significant and economically justified.
- If copper is directly substituted into an existing aluminum motor design (equivalent rotor, motor size), the efficiency of the motor will increase. Manufacturers who substitute copper into a 7.5 kW aluminum design, for instance, will incur a cost of $32.29 per motor, but increase the unit's efficiency by almost 2.5%.

- Super premium efficiency electric motors are more than justified from an end user's perspective (lifecycle costs).

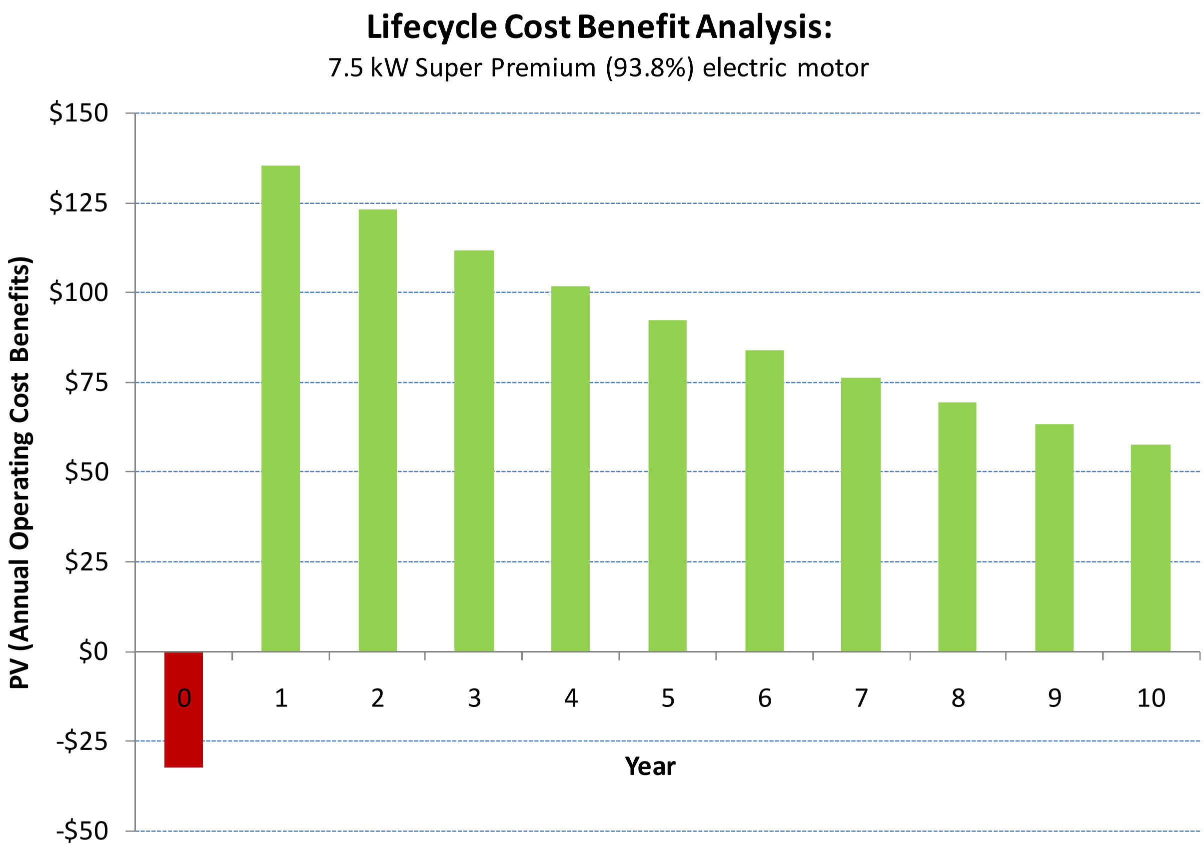

Figure 3, Source: IBIS, Energy Information Association (EIA)

- This analysis assumes that the additional price an end user pays for a super premium motor is equal to the manufacturing cost premium ($44.51 per motor) incurred by the manufacturer.

- In an industrial setting (electricity price: $0.09/kWh), a super premium motor that is used 360 days per year and 24 hours per day will have an economic payback period of 0.30 years.

- The present value associated with a super premium 7.5 kW motor's manufacturing cost premium, and decade of lifecycle economic benefits is: $945. In other words, under these assumptions, a premium of up to $945 for a 93.8% rather than a 91.6% efficient motor paid by a user would be recovered in less than 10 years.

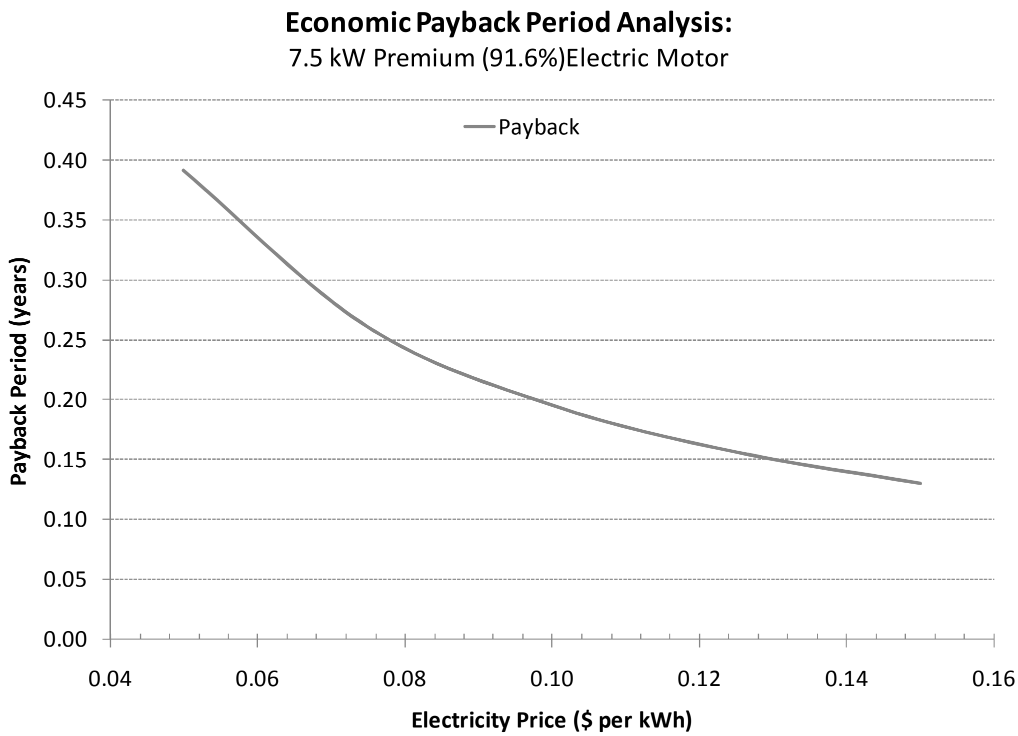

Figure 4. Source: IBIS, EIA

3. Motors with copper rotors have a lower carbon footprint

- Technology strategy decisions are increasingly scrutinized for their environmental impact. The growing environmental consciousness of businesses, governments, and consumers; and high global energy costs and carbon taxes drive the need to continuously seek more energy-efficient materials and processes. This includes reducing the energy content of materials used in products, and the product's use of energy during its operational life.

- The energy required to produce copper is far less than many competing materials. Both aluminum and copper materials used in motor rotor production must come from high purity virgin sources (recycled copper can be used for electrical applications but requires significant refining). Figure 5 shows global average energy requirements and resulting carbon footprint for copper production. Aluminum production requires up to 6.3 times more energy than copper and can result in nearly seven times more CO_2 emissions.

	kWh/ton	kg CO_2/ton
Copper (primary)	11,137	8,744
Aluminum (primary)	70,044	55,185
Mild steel (primary)	9,378	7,380

Figure 5. Source: Deutsches Kupferinstitut e.V./IBIS/International Energy Agency Data Services

- As shown in Figure 6a, there is a significant difference in the energy embodied in the metals used in the production of electric motor rotors. The embedded energy in a premium (91.6% efficient) aluminum rotor is equivalent to 95 kg of CO_2 and a comparable copper rotor has the equivalent of 47 kg of CO_2. At a CO_2 tax of $20/ton, an aluminum design would have a tax of $1.90, while the copper design would have a tax of $1.00 per motor.

- The embedded energy in a super premium (93.8% efficient) copper rotor is equivalent to 57 kg of CO_2. The carbon tax (at $20/ton of CO_2) incurred for this design is $1.10 per motor.

- But embodied energy presents only a fraction of total a CO_2 produced over the life cycle of an electric motor. Figure 6b shows the total and incremental CO_2 produced by…

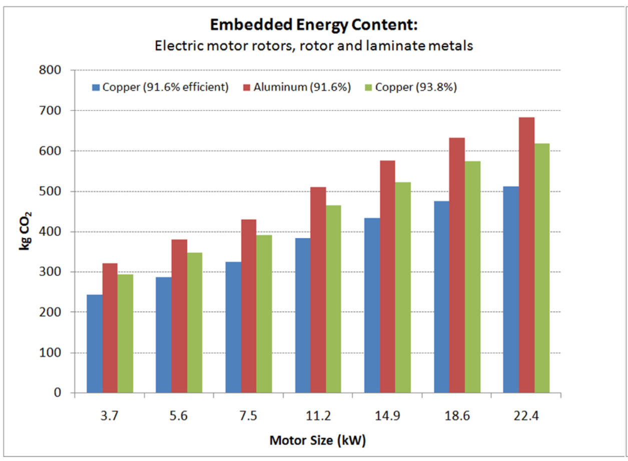

Figure 6a. Source: IBIS

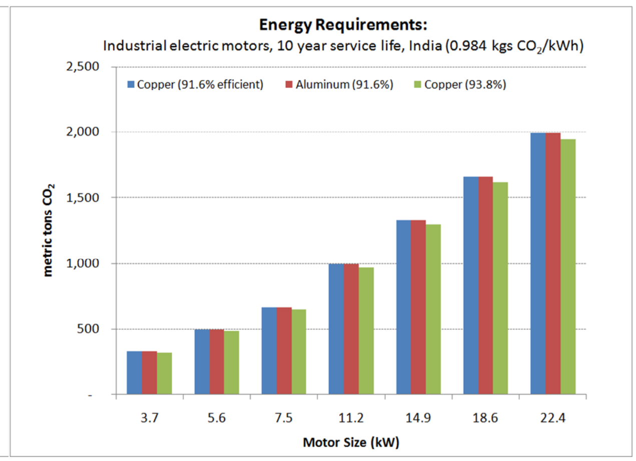

Figure 6b. Source: IBIS

- Super premium electric motors, such as the copper rotor-based products depicted in Figure 6b consume 2.5% less energy. The result, for example, is that over the course of a 10 year service life, a 7.5 kW super premium motor will generate 23.3 metric tons less CO_2. This emissions reduction has the potential to save the end user $467 ($20 per ton carbon tax), in addition to any direct energy cost savings.

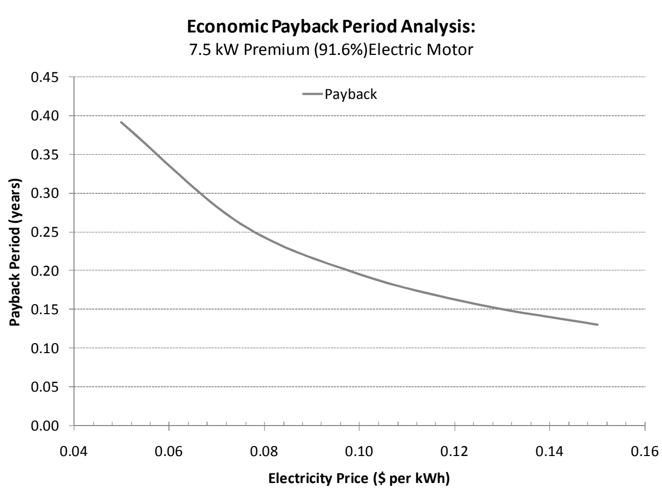

Figure 7. Source: IBIS

4. Implications for motor manufacturers

- Technology for producing die cast copper rotors has been established, and industry continues to advance the state of the art.
- Motor manufacturers should select die cast copper rotors to produce premium efficiency motors at reduced manufacturing costs. While the cast rotor itself is more expensive to produce, significant cost savings are associated with the reduction in motor length.
- Through the substitution of copper for aluminum rotors (with conductor bar redesign but no change in rotor size), copper provides a cost effective means of achieving higher motor efficiencies.
- Based on reduced energy consumption, end users of super premium motors can realize significant cost savings (utility costs and carbon tax). This provides a strong marketing message to support new motor sales. For example, many mining companies have specified motors with copper rotors to reduce energy use and achieve CO_2 reduction.
- The demand for higher motor efficiencies is expected to rise along with a growing global environmental consciousness, and fluctuating energy costs. Some end users are willing to pay a premium for super premium electric motors. Siemens reports that within two years, super premium motors have grown to account for approximately 25% of their new motor sales in the US.
- Manufacturers whose product line includes variable speed drives can deliver motor driven systems with the highest efficiency when the drive is used in combination with a motor with a copper rotor.
- Copper enables manufacturers to achieve up to 2.5% efficiency gains in current aluminum based products without increasing the size of the motor. This means that the investment incurred by manufacturers seeking to produce higher efficiency motors will be minimized.

In Summary

Rotor manufacturing costs are important to material selection decision, but not the only factor for motor manufacturers and end users to consider. Copper rotors are more expensive to cast than aluminum. However, manufacturers of equivalent performance motors can save costs due to the significant and beneficial impact on laminate steel, stator material, and assembly costs.

- Higher efficiency motors can be produced while incurring minimal additional cost.
- The energy savings associated with super premium copper rotor motors has a significant impact on reducing the life cycle costs for end users.
- Carbon emissions are reduced through the use of higher efficiency motors; saving the end user, if a carbon tax applies and providing a more sustainable motor technology.

- The combined economic benefits end users realize through the implementation of high efficiency motors (power costs, carbon tax reduction) translates to a high value proposition for these motor products.

- In developing countries, the impact of broadly adopted high efficiency motors has the potential to ease the burden on developing power infrastructure, and increase the availability of electricity to more consumers.

Figure 8 illustrates the cost differences for motors with copper or aluminum rotors at material costs $2.10/kg for aluminum and $5.07/kg for copper. A complete parametric technical cost model developed by IBIS Associates permits evaluation of motor manufacturing costs based on materials prices, labor rates, energy costs, and motor design tradeoffs.

Electric Motor Manufacturing Costs: by rotor material (efficiency)

	7.5 kW			14.9 kW			22.4 kW		
	Cu (91.6%)	Al (91.6%)	Cu (93.8%)	Cu (91.6%)	Al (91.6%)	Cu (93.8%)	Cu (91.6%)	Al (91.6%)	Cu (93.8%)
Rotor Bars	$27.57	$3.61	$33.08	$38.42	$5.03	$46.10	$46.65	$6.11	$55.98
Rotor Laminate	$28.76	$34.80	$34.80	$37.92	$45.88	$45.88	$44.59	$53.95	$53.95
Processing	$32.86	$30.61	$33.43	$33.39	$30.96	$34.06	$38.08	$31.22	$38.82
Stator Windings	$76.57	$91.88	$91.88	$129.90	$155.87	$155.87	$176.95	$212.35	$212.35
Stator Laminate	$52.74	$63.82	$63.82	$69.33	$83.89	$83.89	$81.40	$98.49	$98.49
Processing	$35.54	$36.27	$36.27	$37.81	$38.80	$38.80	$40.92	$42.13	$42.13
Other Ass'y	$68.65	$73.91	$73.91	$75.68	$84.65	$84.65	$86.52	$98.79	$98.79
Total	$322.69	$334.91	$367.20	$422.45	$445.09	$489.26	$515.10	$543.04	$600.50

Figure 8. Source: IBIS

Alan Goodrich of IBIS Associates is available to support market promotion efforts related to the use of die cast rotors in industrial motors. He can be reached at:

Alan@ibisassociates.com

Tel +1.781.290.5387