FluxDynamics

Maximizing Electric Motor Energy Savings Under Real-World Conditions and Constraints

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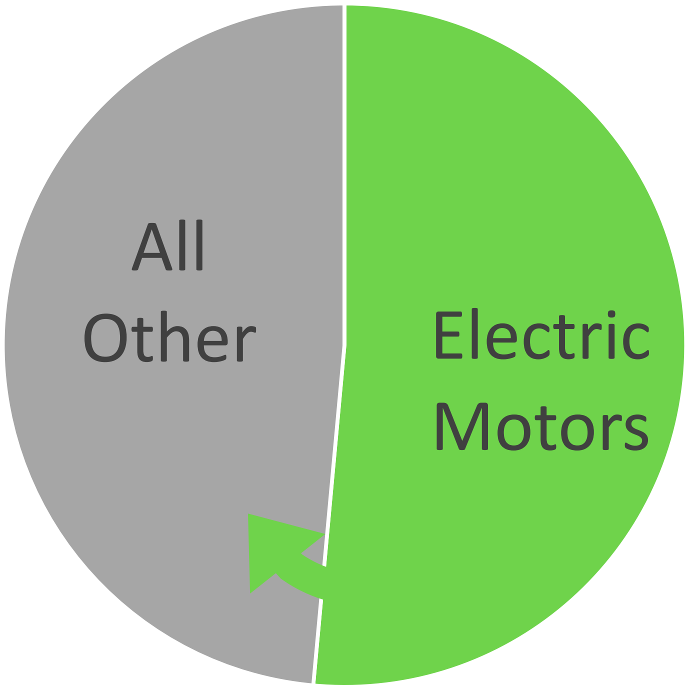
The Need

- Electric motor systems consume half of all electricity produced worldwide – and that share is increasing.

- The generation of that electricity produces 15% of ALL greenhouse gases.

- Reducing power consumption through improved motor system efficiency is the MOST IMMEDIATE and MOST COST-EFFECTIVE means of reducing greenhouse gas emissions today.



Use of Electricity

The Challenge

Factors Limiting Motor Efficiency

- Incorrectly sized motors
- Fixed speed operation
- Mechanical gearing
- Cost of motor, especially for higher efficiency units
- Complexity of VFD installation and operation
- Age of installed motors
- Responsible party for electric bill payments
- Difficulty in changing motors in the field

The Opportunity

Build a Motor that Alleviates These Issues

- Design a motor with efficiency per unit cost as the goal
  - A unique approach to motor design
  - This requires a multi-variable optimization
- Easy to use and apply to existing applications
- Integrate the drive with advanced software
- Low first cost is an essential element

Improving Motor Efficiency

There are only two major losses in motors

- **Conduction loss** in the windings
  - Reduce winding loss with more winding volume
  - Obtain high fill factor for the winding
- **Iron loss** in the stator and rotor
  - Coreless motor designs are one option
  - Use a better magnetic material with low losses
- All other motor loss sources are secondary

The Motor Design Approach

Axial vs. Radial Motor Design

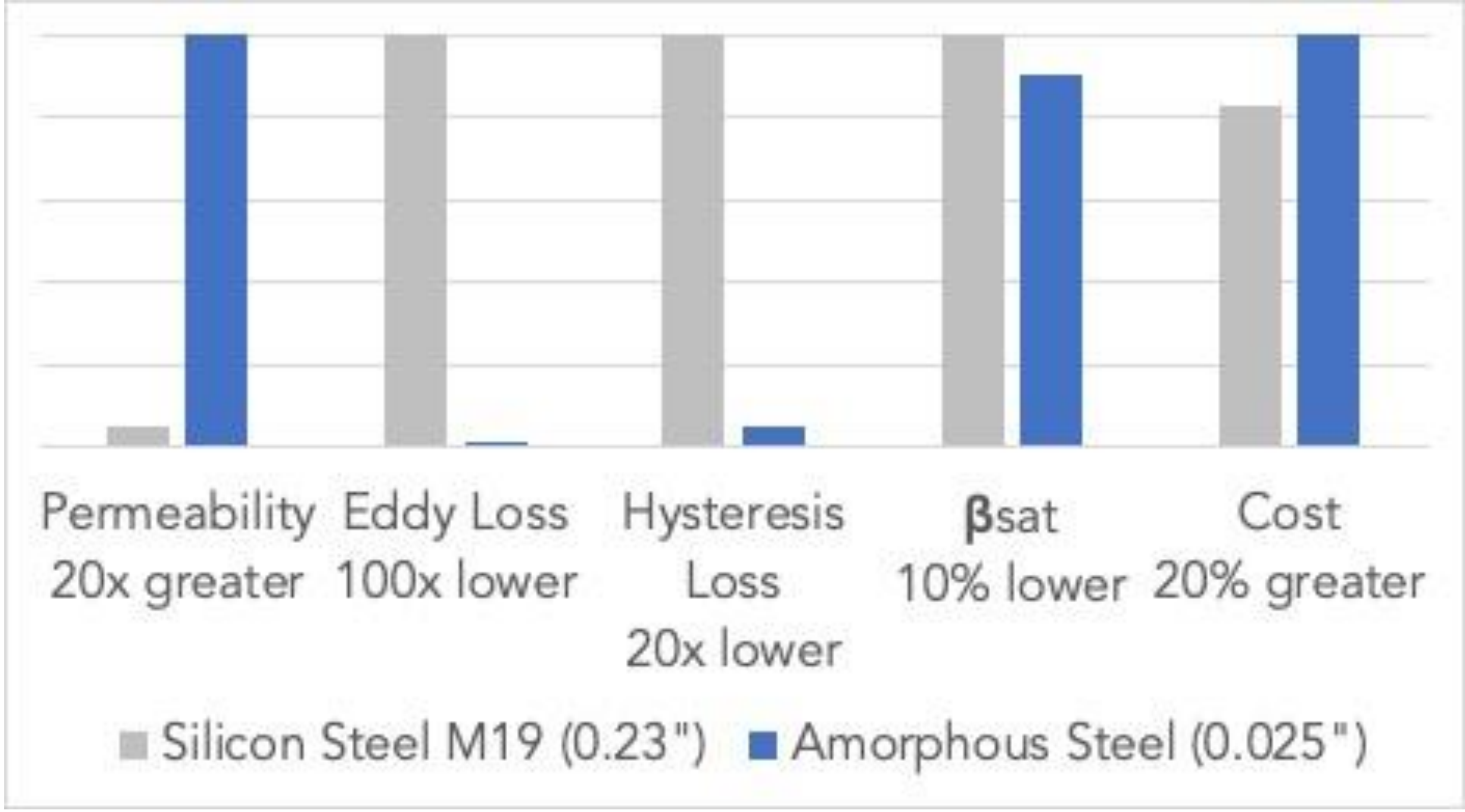
- Nearly all motors today use a radial design
- Axial motor designs are gaining attention recently
  - Higher torque per unit diameter
  - Can have extended winding area
    - Good conductor packing factor
  - Magnetic core or coreless designs
  - Low iron losses possible with optimized material

Magnetic Material Selection

Reducing iron losses with amorphous iron

- Amorphous iron has excellent magnetic properties
- However, it is very hard, very thin, and very brittle
  - Stamping it is extremely difficult
- No commercially available motors with amorphous iron
  - Hitachi has units that they use internally
  - No other supplier exists at a commercial scale
- FluxDynamics is developing a manufacturing process for commercial scale amorphous iron motors

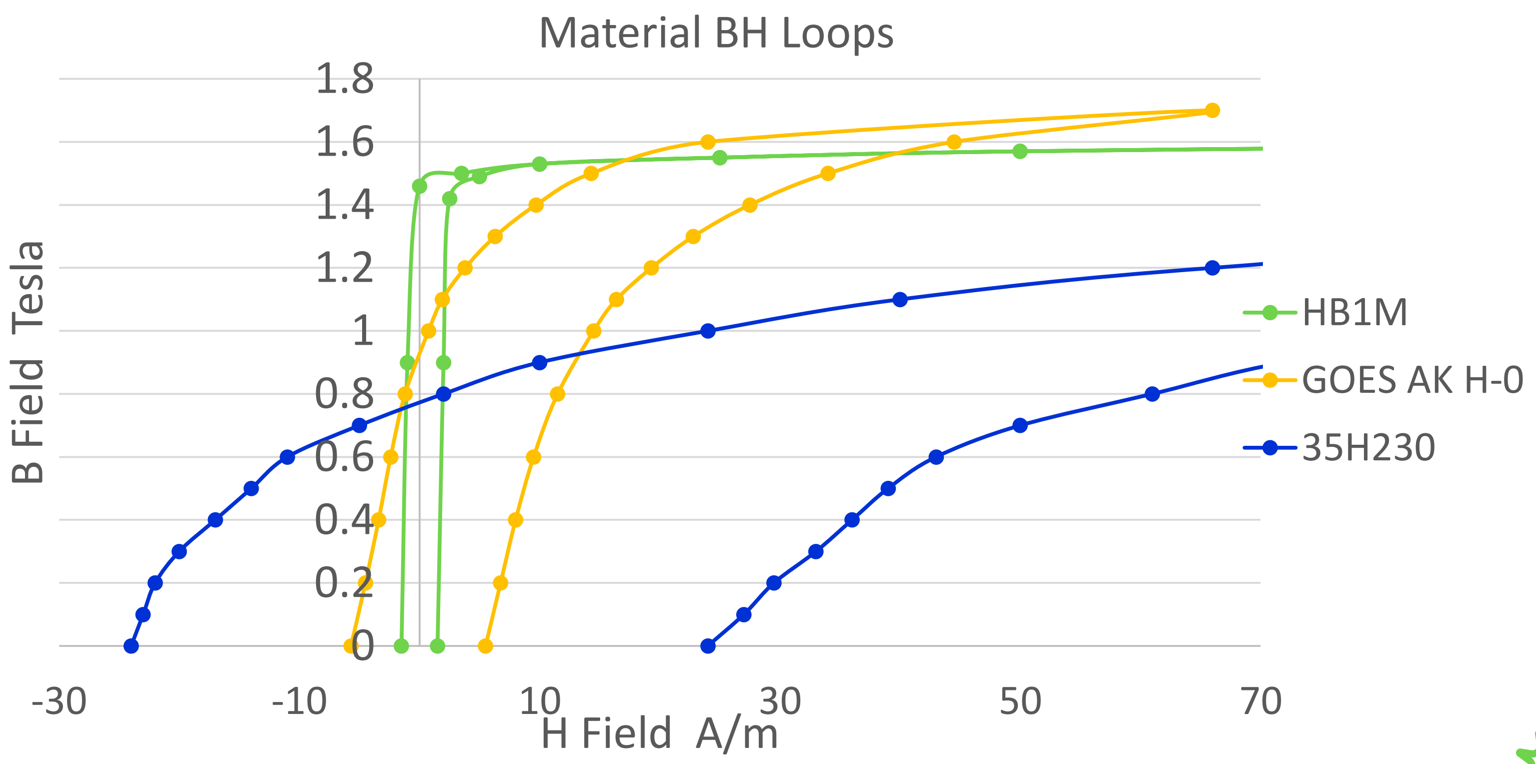
Use of Amorphous Iron vs. Silicon Steel



Amorphous Iron's properties make it ideal for use in Permanent Magnet motors.

Amorphous Iron Magnetic Properties

Properties of Magnetically Permeable Materials



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Permanent Magnet Selection

Permanent Magnet Performance

Magnet type	Flux available	Cost $/Kilogram	Performance Ratio in KGauss/$
Ferrite (FB6)	4 K Gauss	$10 USD	0.4
Neodymium (N45)	12 K Gauss	$80 USD	0.15

Motor Conductor Selection

Conductor Performance

Conductor	Conductivity Siemens/m	Density kg/m^3	LME Pricing $/Kilogram	Performance Ratio Siemens-m^2/$
Aluminum	36.9×10^6	2700	$2.34 USD	5.84×10^3
Copper	58.7×10^6	8960	$8.55 USD	0.77×10^3

Motor Design Optimization

Use of Km as optimizing parameter

If one minimizes iron losses and ignores friction losses,
this leaves conduction loss (I^2R) as the dominant motor loss.
Then, the maximum possible motor efficiency can be defined as:

$$\boldsymbol{MPEff = \frac{PO}{PO + I^2R}}$$

Where PO = The motor power output
I = The root mean square (rms) value of the motor current
R = The effective motor winding resistance

Electronic Drive (VFD) Integration

Higher motor efficiency simplifies drive integration

- Lower heat generation by the motor
- Drive integration reduces overall motor cost
- Shorter axial design allows length for the drive
- Larger axial diameter provides area for cooling
- Good form factor for clean axial packaging of drive

Integrated Variable Frequency Drive (VFD)

- Provides all the energy-saving advantages of matching speed to application needs
- Integration with motor eliminates costs of separate packaging, cabling and assembly
- Simplifies installation – eliminating potential issues related to programming, compatibility, and mounting
- Provides real-time feedback on various performance data such as energy use, torque, etc.

Ease of Use with Software Enhancements

- **Real-time cost savings data**
  - Measure input and output power
  - Input characteristics of motor being replaced
  - Compute actual and predicted efficiencies
  - Provide cost savings to the user
- **Induction motor emulation**
  - Set motor type and characteristics
  - Measure torque and adjust to induction operation

Limitations of this Motor Design

No motor is ideal in all aspects

- Larger diameter than other PM motors
- Lower power density
- Much lower peak torque capability
  - 1.2 to 1.5 of rated
- Limited sources of amorphous iron

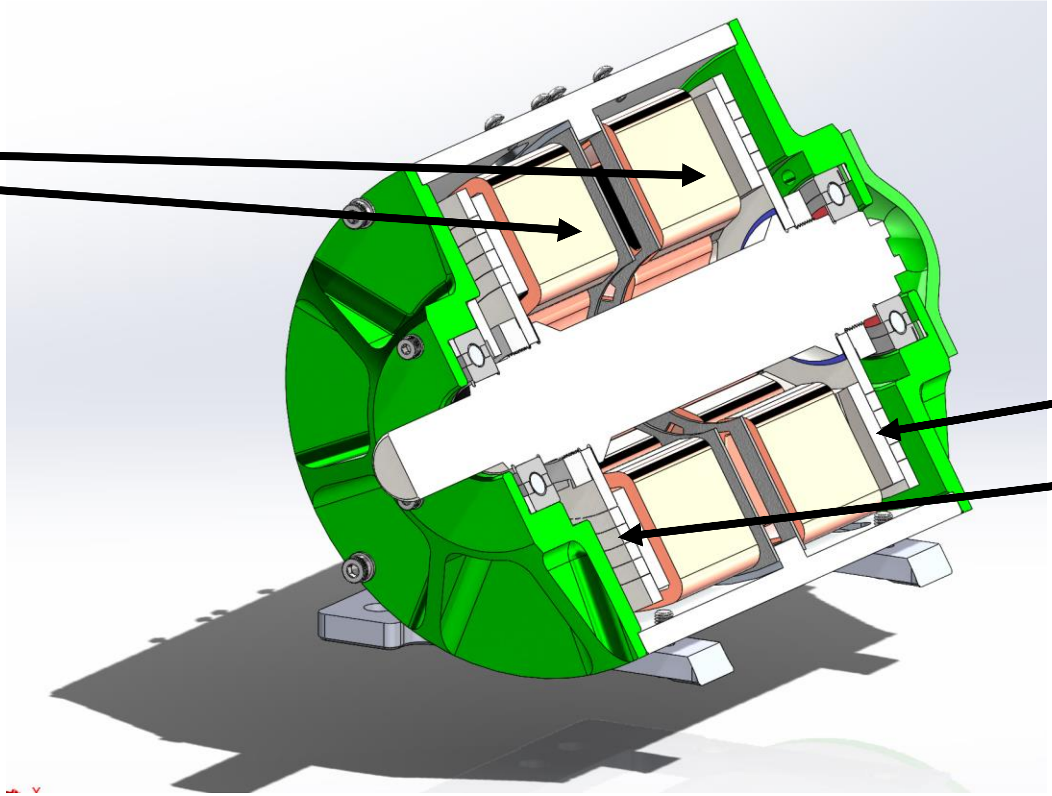
AxialPM Motor Specifics

Basic Axial Design

- Dual rotor design
- Single center-mounted stator
- Bobbin-style windings for high packing factor
- Magnetic encoder at end of shaft
- Electrically isolated bearings

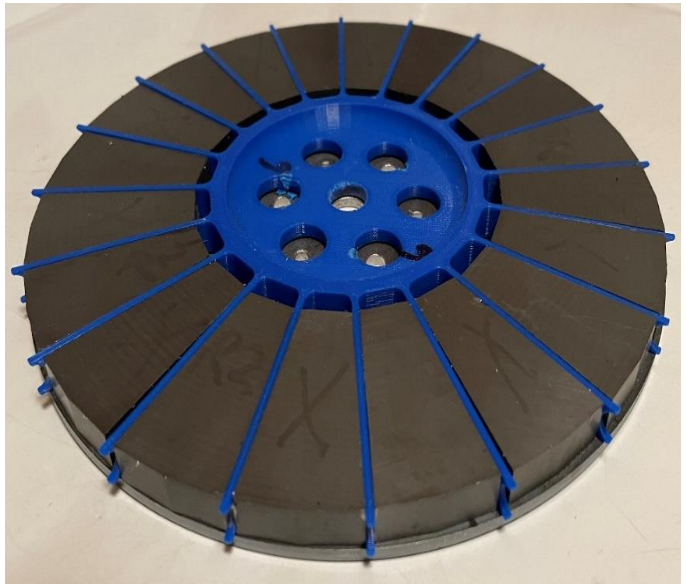
Cut-a-Way of AxialPM Motor

Stators made with Amorphous Iron with bobbin windings

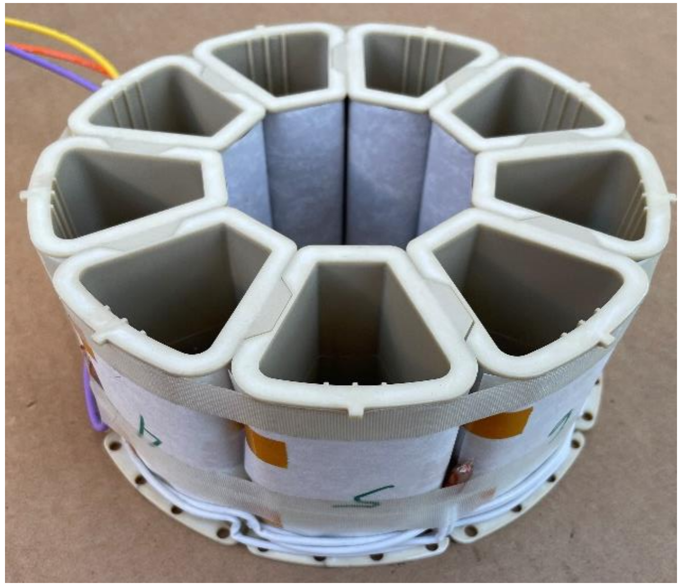


Rotors made with Ferrite Magnets

Motor Components

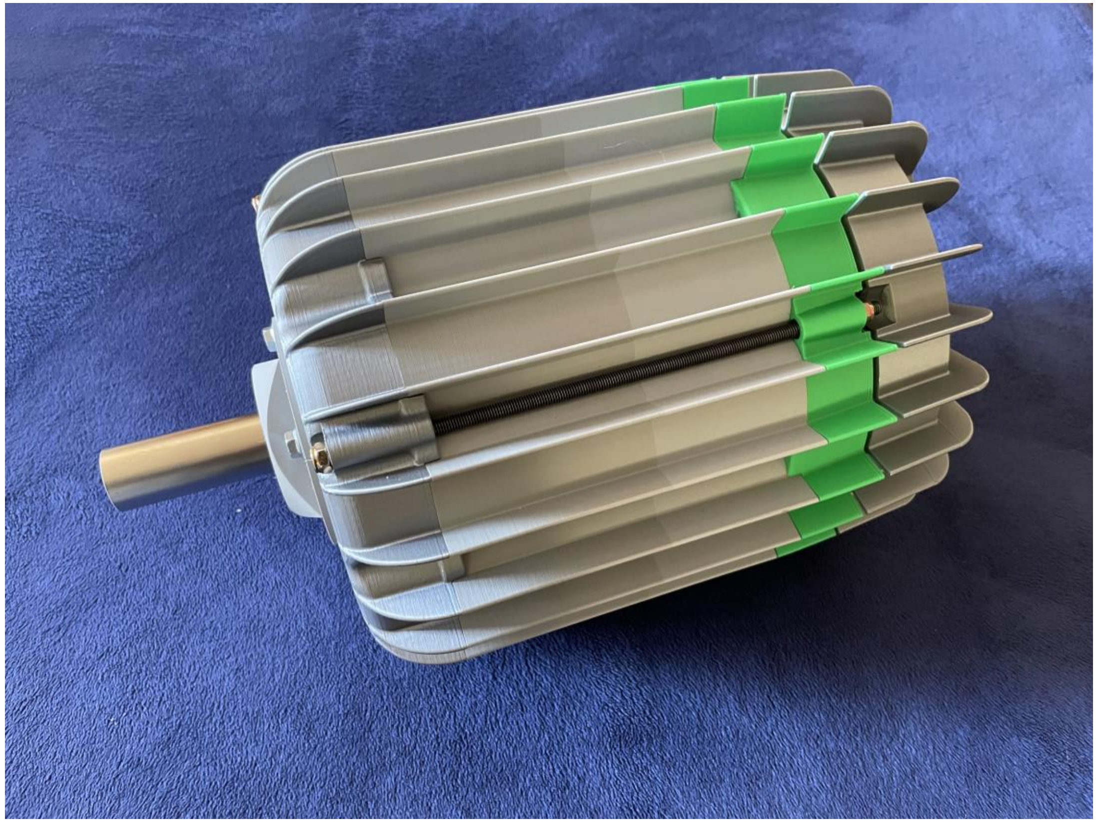


Rotor with Ferrite Magnets



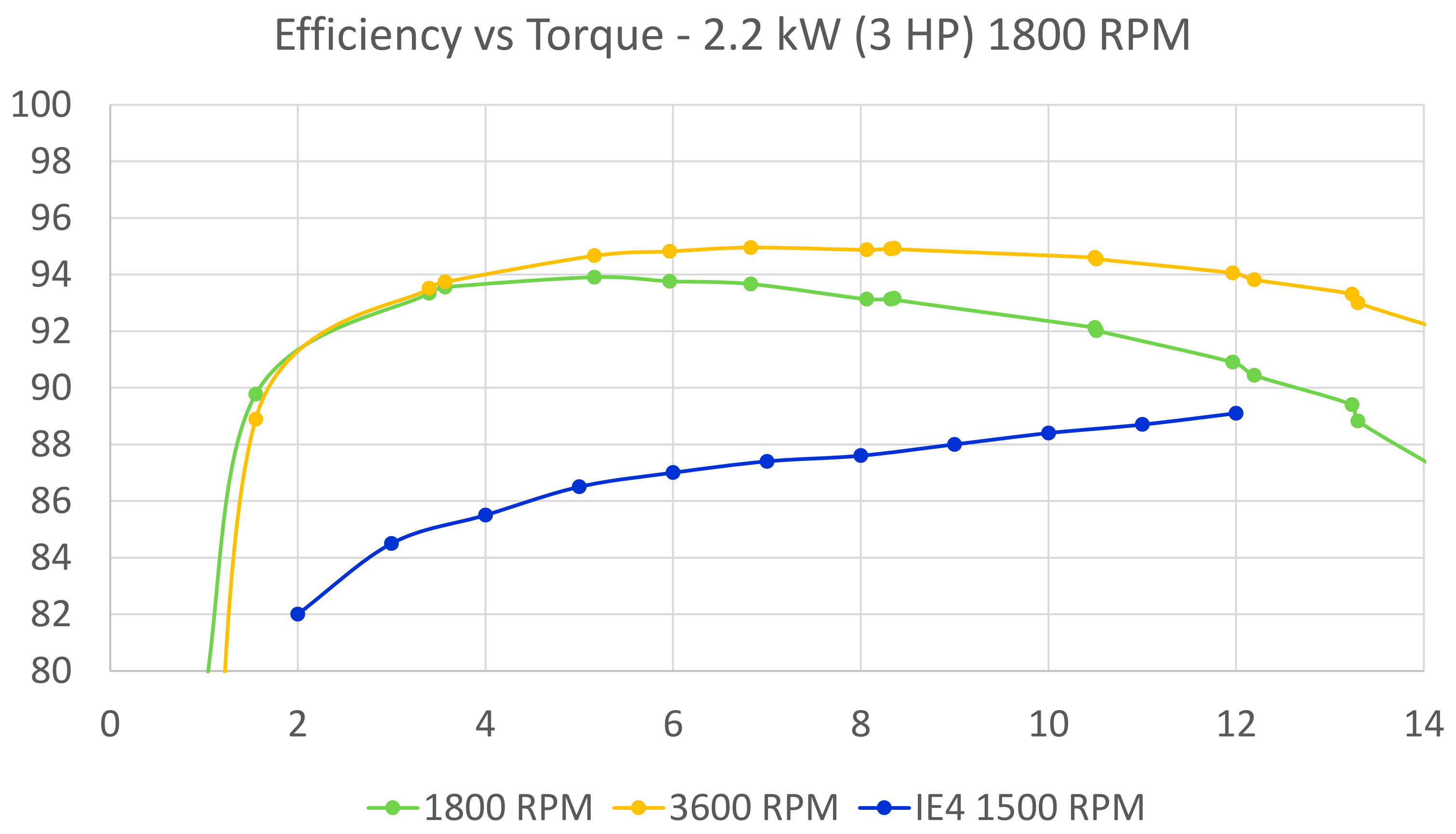
Bobbin-Style Coil Assembly

Motor Assembly



Prototype Motor Casing with Integrated Drive Module Mounted on Rear

Motor Performance

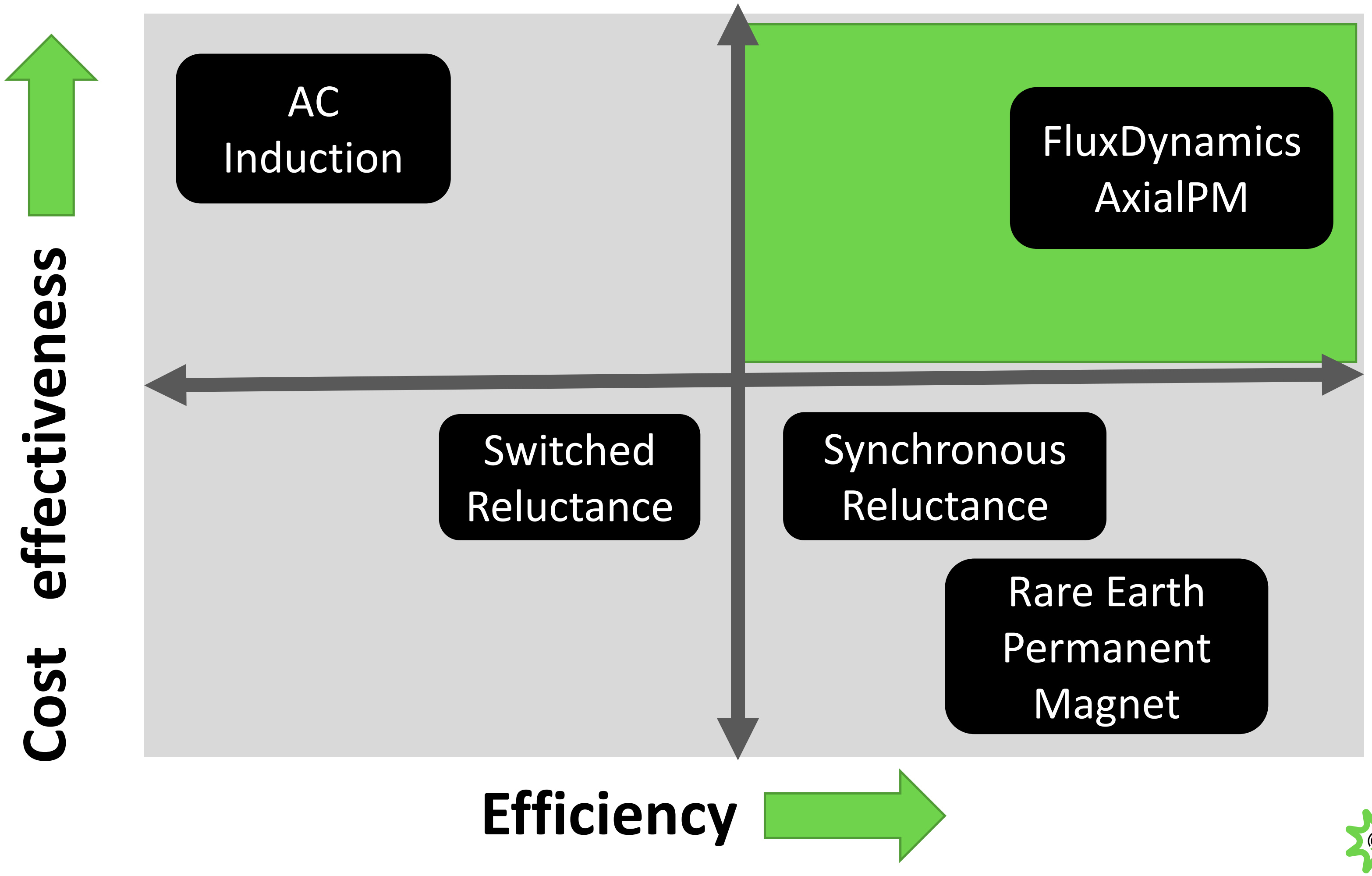


The Solution: Unprecedented energy efficiency at a first cost that can compete with today’s ubiquitous AC induction motors

2hp/1800rpm Motor Industry Efficiency Classes	Efficiency Standards
IE1 AC Induction Standard Efficiency	81.50%
IE2 AC Induction High Efficiency	84.00%
IE3 AC Induction Premium Efficiency*	86.50%
IE4 Super-Premium Efficiency (Largely Rare Earth Magnets)	89.50%
IE5 Ultra-Premium Efficiency (Always Rare Earth Magnets)	90.00%
FluxDynamics AxialPM (Ferrite-Based Magnets)	93.00%

*Current standard for new applications in the U.S.
FluxDynamics reduces motor losses (wasted energy) by over 50% vs. current standard IE3 m

Competitive Motor Landscape



Thank You and Questions

Conclusion: FluxDynamics has developed a motor that eliminates or addresses all of the factors limiting motor efficiency shown on the first slide of this presentation.

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