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# 3-D Printing of NdFeB Nylon Polymer Bonded Magnets

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# 3D Printing or Additive Manufacturing (AM)

**Goal:** Fabricate near-net shape NdFeB magnets and to minimize waste associated with magnet manufacturing and reduce cost.
**Target:** Gap magnets with energy product, (BH)max: 15-20 MGOe

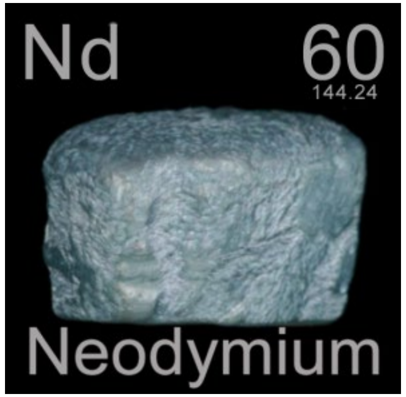
**Conventional Methods:** Sintered magnet manufacturing, Injection molding, and Compression molding

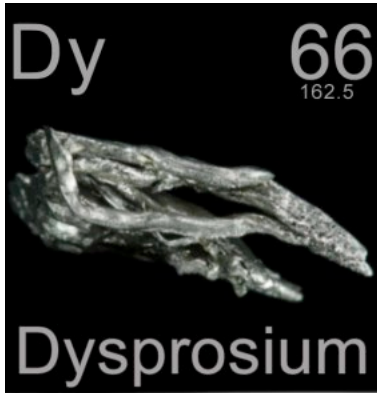
**Why AM?** No tooling required, Rapid prototyping at production scale, Minimum critical material (rare earth elements (Nd,Dy in Nd,DyFeB and Co in SmCo)) wastage, Cost effective, CAD software, Complex shapes and sizes

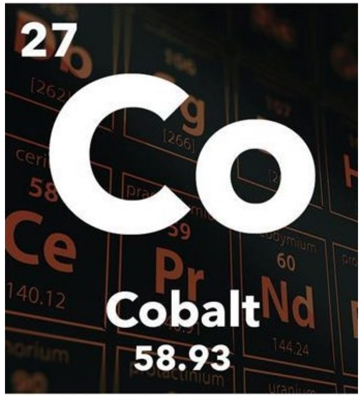
**Summary:** (i) Energy product of 13.0 MGOe has been achieved with 70 vol% anisotropic NdFeB in nylon with post-field annealing
(ii) Results outperformed conventional injection molding
(III) AM magnets Enable All 3D Printed Brushless Motor
(iv) Demonstrated 3-D Printing of High Performance Magnets Can Aid U.S. Manufacturing, Conserve Resources

# The Mission of Critical Materials Institute (CMI) – An Energy Innovation Hub

- To assure supply chains of materials critical to clean energy technologies,
- Enabling innovation in US manufacturing, and
- Enhancing US energy security.



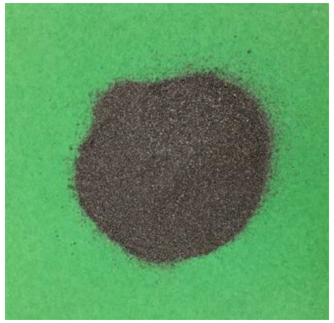




- **Rare Earth Permanent Magnets ($(Nd,Dy)_2Fe_{14}B$ and SmCo) are widely used in automobiles, hard disk drives, motors, sensors, wind power generators, transducers, loudspeakers, separations, etc.**
- **No NdFeB magnet manufacturing companies in US**
- **90% rare earth world supply in China**

https://cmi.ameslab.gov/

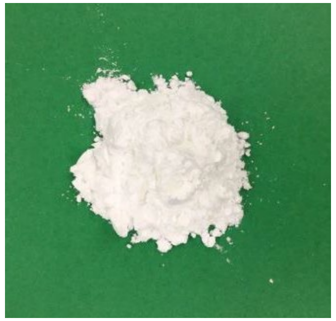
# Big Area Additive Manufacturing (BAAM) Process

**MQA anisotropic powder**



➕

**Nylon-12**

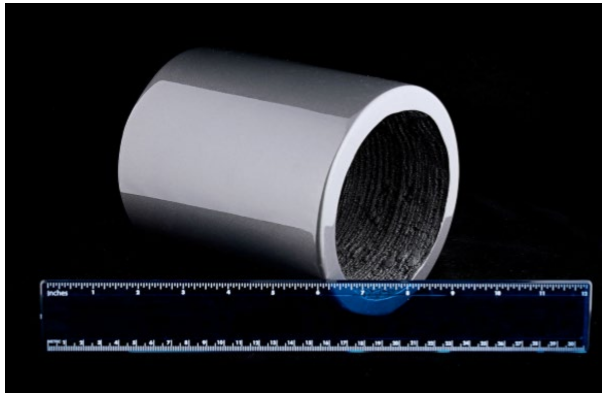


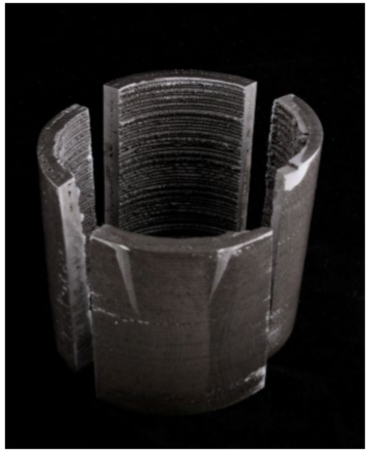
**Mix, melt and extrude**

**Composite pellets: 70 vol % MQA+ Nylon**

**BAAM printing**

**Additively printed NdFeB bonded magnets**





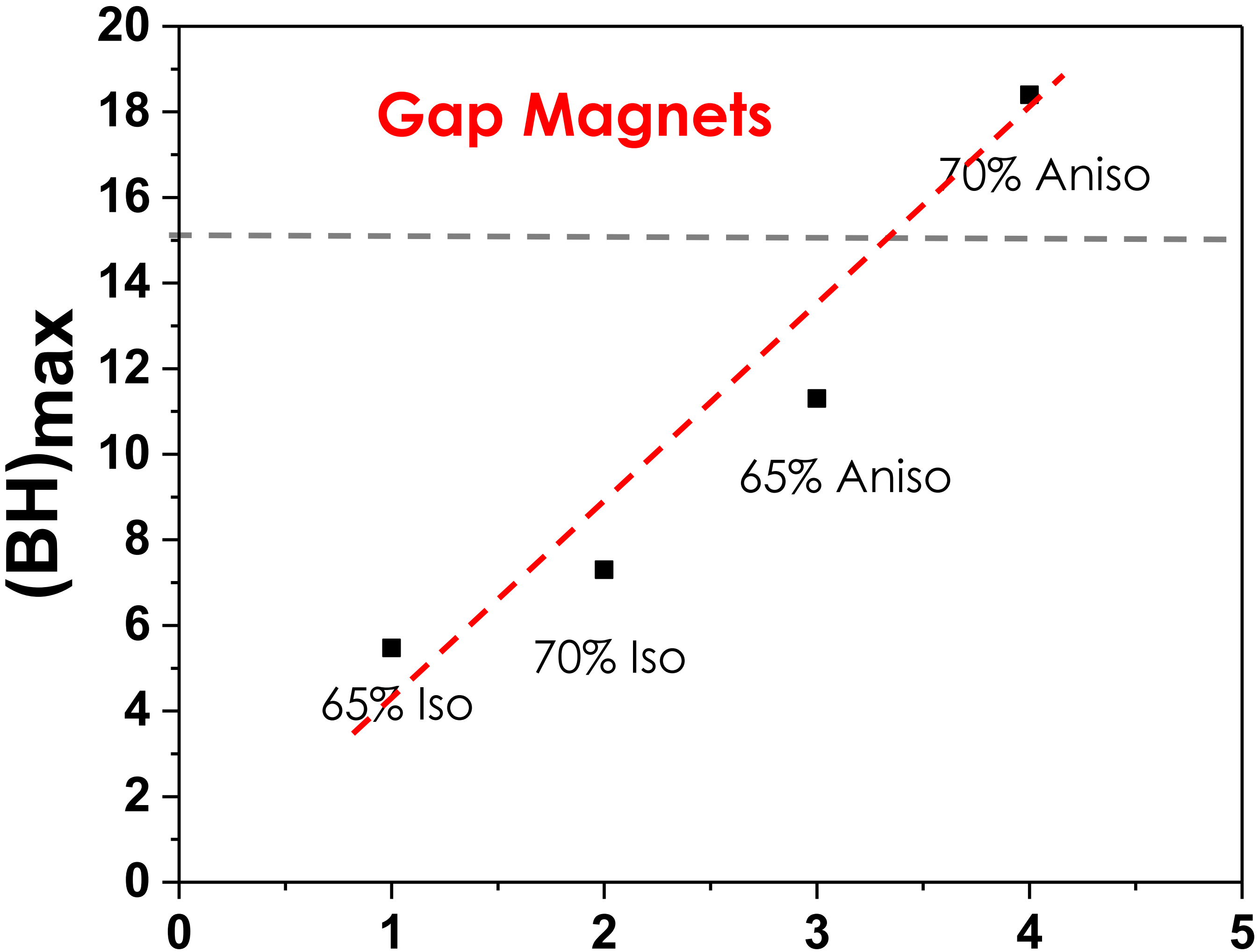
$(BH)_{max} \sim f^2$

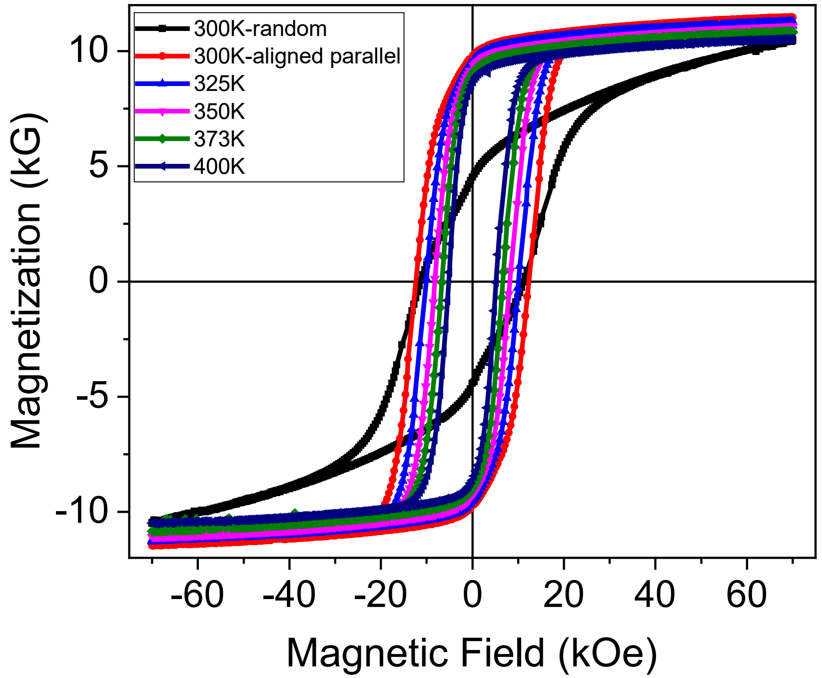
*f = magnet volume fraction*

https://web.ornl.gov/sci/manufacturing/mdf/

Li, L. *et al., Sci. Rep.* 6, 36212 (2016); *Additive Manuf.* 21, 495 (2018)
Magnetic Moments, The Economist, Nov. 19, 2016
Frontiers of Materials Research 2019 (National Academy of Sciences; p.2-26)

# Plans Going Forward: Magnets outperformed injection molded magnets with high energy product (Iso and Aniso with different loadings)

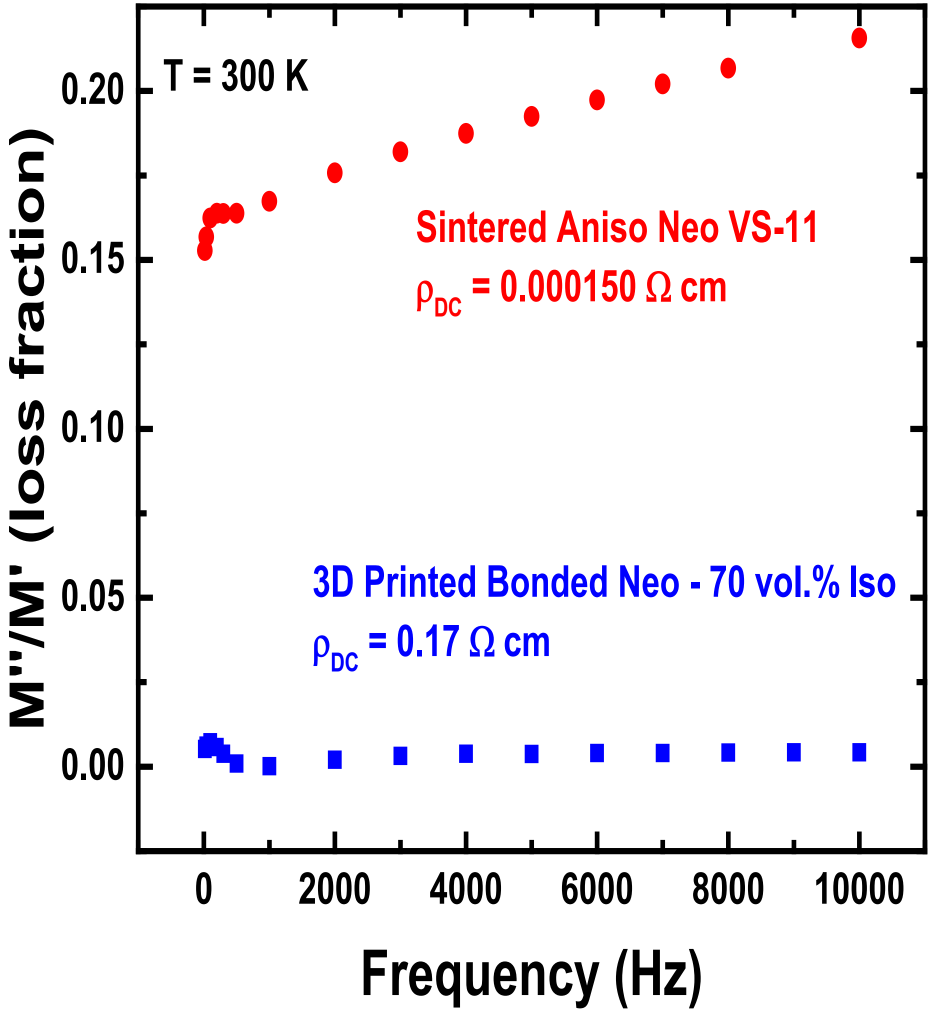



**Post-annealing conditions: 550 K; 0.75 T**

| Hc (kOe) | Ms (kG) | Br(kG) | (BH) max (MGOe) |
|---|---|---|---|
| 11.2 | 11.5 | 4.5 | 3.6 |
| 12.3 | 10.5 | 9.7 | 18.4 |

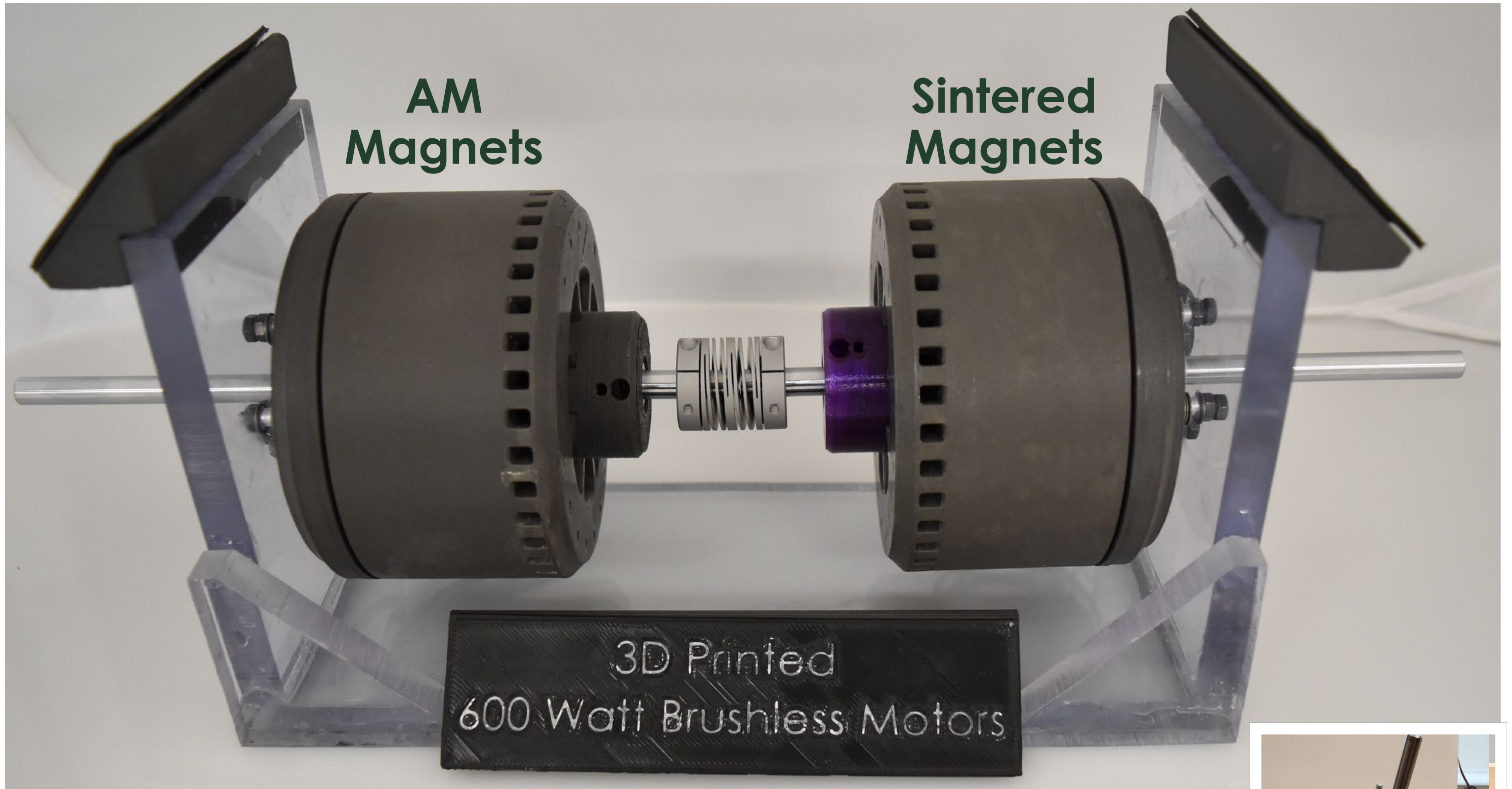
# AM magnets Outperformed Sintered NdFeB magnets with Reduced Eddy Current Loss and Improved High Resistivity




- ➢ **Eddy current heating in large motors with permanent magnets can be significant**
- ➢ **Often eddy current heating is reduced by slicing the permanent magnets into smaller pieces**
- ➢ **AM magnets have 1000 times less eddy current loss and three orders of higher resistivity compared to sintered magnets**
- ➢ **Demonstrated the potential of using additively printed NdFeB magnets in motors**

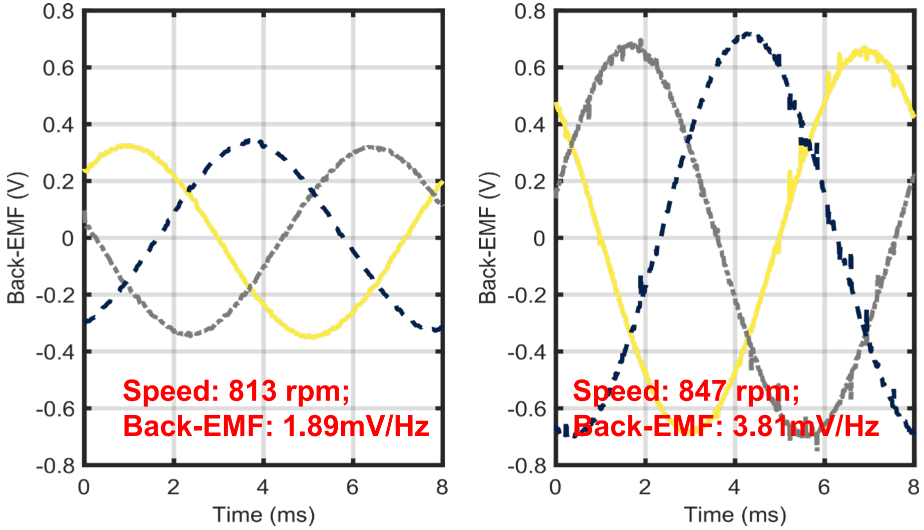
Li, L. *et al., Additive Manufacturing 21, 495-500 (2018)*

# AM NdFeB Bonded Magnets Enable All 3D Printed Brushless Motor




Rotor

Stator




**Comparison of line-to-line open circuit voltage of all 3D printed motor (image shown below) with bonded magnets (left) and sintered NdFeB magnets (right)**

- ***Based on our success with 600-W motor, we are trying to fabricate a 1000-W motor in a Halbach array configuration***

Christoph Laimer **(http://www.laimer.ch/)**

Oak Ridge National Laboratory

Magnet Applications — A Bunting Magnetics Company

CMI Critical Materials Institute — An Energy Innovation Hub

# Successfully developed AM methods to achieve nearly 98% dense Fe6Si magnet laminates – coupled with BAAM magnets (motor prototype in progress)


**BAAM NdFeB Magnets** **2017 R&D 100 Award**

- **Big Area Additive Manufacturing has been successfully used to fabricate near-net-shape NdFeB bonded magnets.**
- **Efforts are being made to print anisotropic gap magnets in the presence of magnetic fields.**
- **Successful demonstration of additively printed magnets with reduced manufacturing waste and potentially offset some REE demand through more targeted use of gap magnets.**

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