Advanced Manufacturing of Alpha Double Prime Iron Nitride (ADPIN): An Innovative Rare Earth Element (REE) Free Ultra-High Performance Permanent Magnet for Clean Energy Applications

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FeNix Magnetics Inc.

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Overview

Timeline

- Funding Opportunity Announcement Number DE-FOA-0001465, Advanced Manufacturing Projects for Emerging Research Exploration, Topic Area 1: Advanced Materials; Subtopic 1.1: Innovative Advanced Materials Manufacturing for Clean Energy; Tier 2 proposal
- Award issued May 2018
- Projected End date April 2020
- Project 12.5% complete

Barriers

- FeNix's current laboratory scale process produces ~2g quantity at ~99% purity of the target γ-(Fe,M):N phase for this 1st step of our 3-step process. At this rate it takes weeks to produce enough material for a single 1cm^3 magnet.

Budget

	BP1 Costs	BP2 Costs	Total costs	Cost incurred through 06/30/2018
DOE Funded	365k	433k	799k	$13k
Project Cost Share	201k	-	201k	-

Partners

- FeNix Magnetics has a Service Agreement in place with Case Western Reserve University (Prof. M. Willard, Materials Science & Engineering)

Objectives

- Alpha double prime iron nitride (ADPIN) α"-$Fe_{16}N_2$ is a high performance rare earth element free (REE-free) permanent magnetic material with the highest ever reported magnetization (M_S~2.8T).
- ADPIN is ideally suited for applications in magnetic refrigeration and to challenge the price-performance dominance of rare-earth based magnets for other clean energy applications.
- The development of ADPIN at commercial scale will enable economically advantaged and energy efficient magnetic refrigeration and HVAC chillers, which has a total technical energy savings potential of 1.25 quads/year.
- It will also challenge the dominant permanent magnet material, $Nd_2Fe_{14}B$ with Dy additions (NEO), for other clean energy applications such as electric vehicle motors and wind turbine generators.
- The NEO market is estimated at 90,000 MT and has a 61% market share of the $20B permanent magnet market, which itself has an estimated 9.4% growth rate.

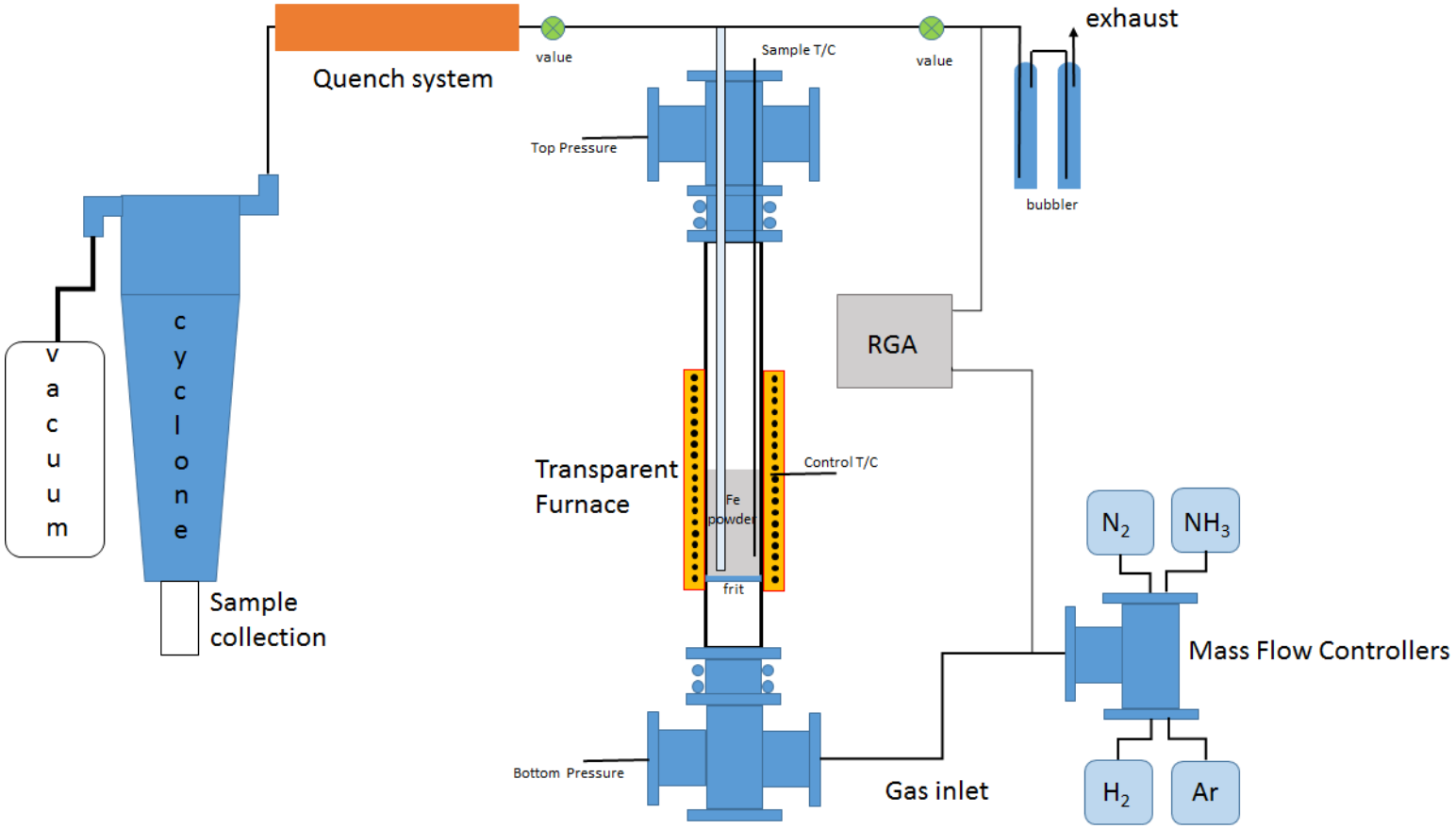
- *AMO Strategic Goals: Transition DOE supported innovative technologies and practices into U.S. manufacturing capabilities.*
- *AMO MYPP: Advanced Materials Manufacturing: Advance technologies that accelerate the research, development, and demonstration of new materials, on a path towards integration of these materials into applications for cost effective, advanced clean energy technologies.*

Technical Innovation

- The rate limiting step of the current process is large scale production of magnetic powders.
- FeNix Magnetics proposes to develop a fluidized bed reactor (FBR) technology for the prototype scale production of ADPIN magnetic powders.
- Patented technology (FeNix Magnetics is a spinout from CWRU)
  - US 9,997,285 B2 (June 12, 2018)
  - JP 6051456 (December 12, 2016)
  - Pending in China, South Korea, India and Europe.
- This is a three step process:
  - Step 1) nitriding & quench to achieve γ-(Fe,M):N phase;
  - Step 2) cryo-deformation to transform the γ-(Fe,M):N phase to α'-(Fe,M)N martensite phase;
  - Step 3) annealing to transform the α'-(Fe,M)N martensite phase to α"-$(Fe,M)_{16}N_2$ phase.

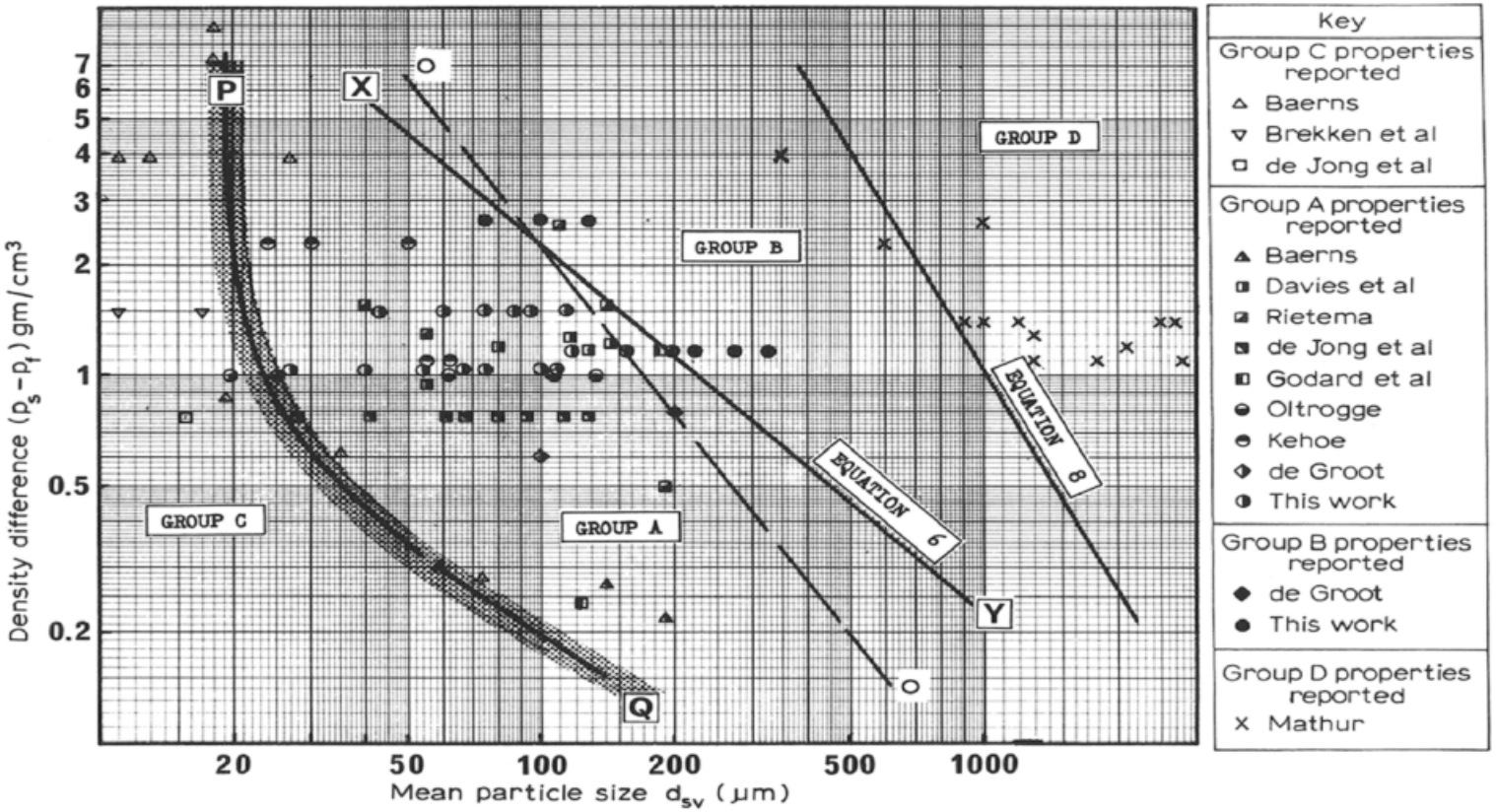
Technical Approach

Schematic of proposed fluidized bed reactor using a transparent fused quartz process tube and a transparent furnace system that will allow direct observation of the fluidized bed at operating temperatures and pressures.

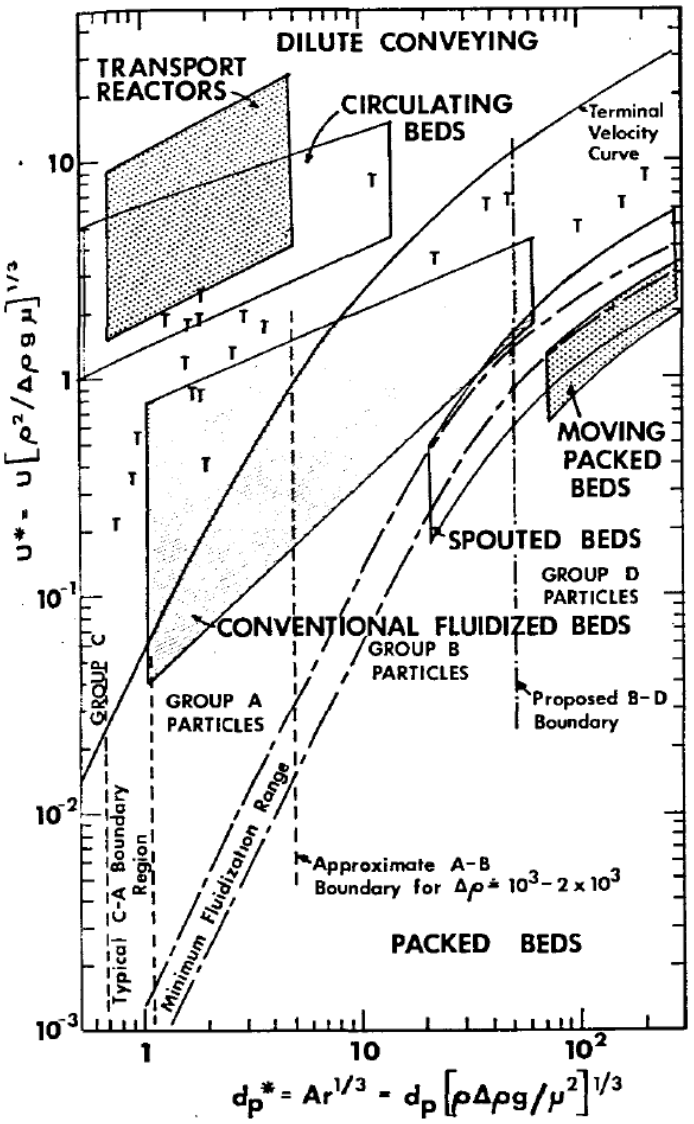


Technical Approach

There are many ways to map fluidization behavior with perhaps the most famous being that of Geldart shown below. His C-A-B-D classification was developed using air as the gas at room temperature. In his classification A and B powders can be fluidized while C and D powders generally cannot.



Technical Approach



However, the Geldart classification ONLY applies to air at room temperature. Grace developed a fluidization map based on non-dimensional flow velocity vs. non-dimensional particle size. This type of mapping DOES allow for changes in particle material, gas composition, and temperature. With these maps, the terminal velocity and the minimum fluidization range (U_{mf} range) do not change from map to map since their placement is determined by u* and dp*, but the relative boundaries between the Geldart classifications (C-A-B-D) do change as well as the placement of a particular set of experimental conditions (i.e. iron vs. alumina material, N_2 vs. H_2 gas, and temperature).

Results and Accomplishments

Project Status / Accomplishments

- Successful negotiated award cooperative agreement
- Held kick-off meeting with DOE team
- Successfully implemented Service Agreement with CWRU

Required Future Work

- Determine correct alloying element (Q2)
- Develop non-dimensional model (based on Grace) for system (Q3)
- Develop ‘bench-top’ fluidized bed test system (Q3)
- Develop Gen 1 (fused quartz) fluidized bed reactor (Q3 & Q4)

Transition

- Fenix Magnetics, Inc. was incorporated in 2016.
- IP licensing negotiations with CWRU currently underway.
- Magnetics industry is only interested in demonstrating permanent magnet.
- Powder scale-up is necessary first step that leads to ADPIN magnet demonstration.
- FeNix will be a manufacturer and seller of ADPIN powders and magnets, through a combination of in-house and tolled processing capabilities.
- However, the process technologies being developed by FeNix are highly specialized and specific to FeNix, even as they leverage decades of process know-how in other fields. Implementing these process technologies in-house and monitoring and optimizing them on a day-to-day basis is essential for maximizing the technology-process separation from the competition.
- Sales channels will, at least initially, occur through a set of 3-5 strategic partners. While this could limit margins it is extremely desirable to manage the Company's sales and marketing expense line and focus the product development on a few well-defined and specified targets.

Questions?