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

Contract Number: DE-EE0008306

FeNix Magnetics, Inc.

Project Period: 05/01/2018 – 10/31/2020

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Overview

Project Title: 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

Timeline:

Project Start Date: 05/01/2018

Budget Period End Date: 10/31/2019

Project End Date: 10/31/2020

Barriers and Challenges:

The goal of this proposed effort is to develop a fluidized bed reactor system to move beyond the current rate limiting step and produce large sample sizes (500 g) of nitrided powders for use in the subsequent steps that result in ADPIN powders for magnet fabrication.

BP1 on campus startup → BP2 transition to industrial space

Accelerated this timeline to BP1 and requested 6-month NCE between BP1 & BP2 to obtain required safety permits.

AMO MYPP Connection:

- Advanced Materials Manufacturing

Project Budget and Costs:

Budget	DOE Share	Cost Share	Total	Cost Share %
Overall Budget	$798,624	$201,488	$1,000,112	20.15%
Approved Budget (BP-1)	$365,469	$201,488	$566,957	35.54%
Costs as of 4/30/2019	$188,295	$169,770	$358,066	47.41%

Project Team and Roles:

- FeNix Magnetics, Inc.

Project Objective(s)

- 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 <u>total technical energy savings potential of 1.25 quads/year</u>.
- 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.

➢ *<u>AMO Strategic Goals:</u> Transition DOE supported innovative technologies and practices into U.S. manufacturing capabilities.*

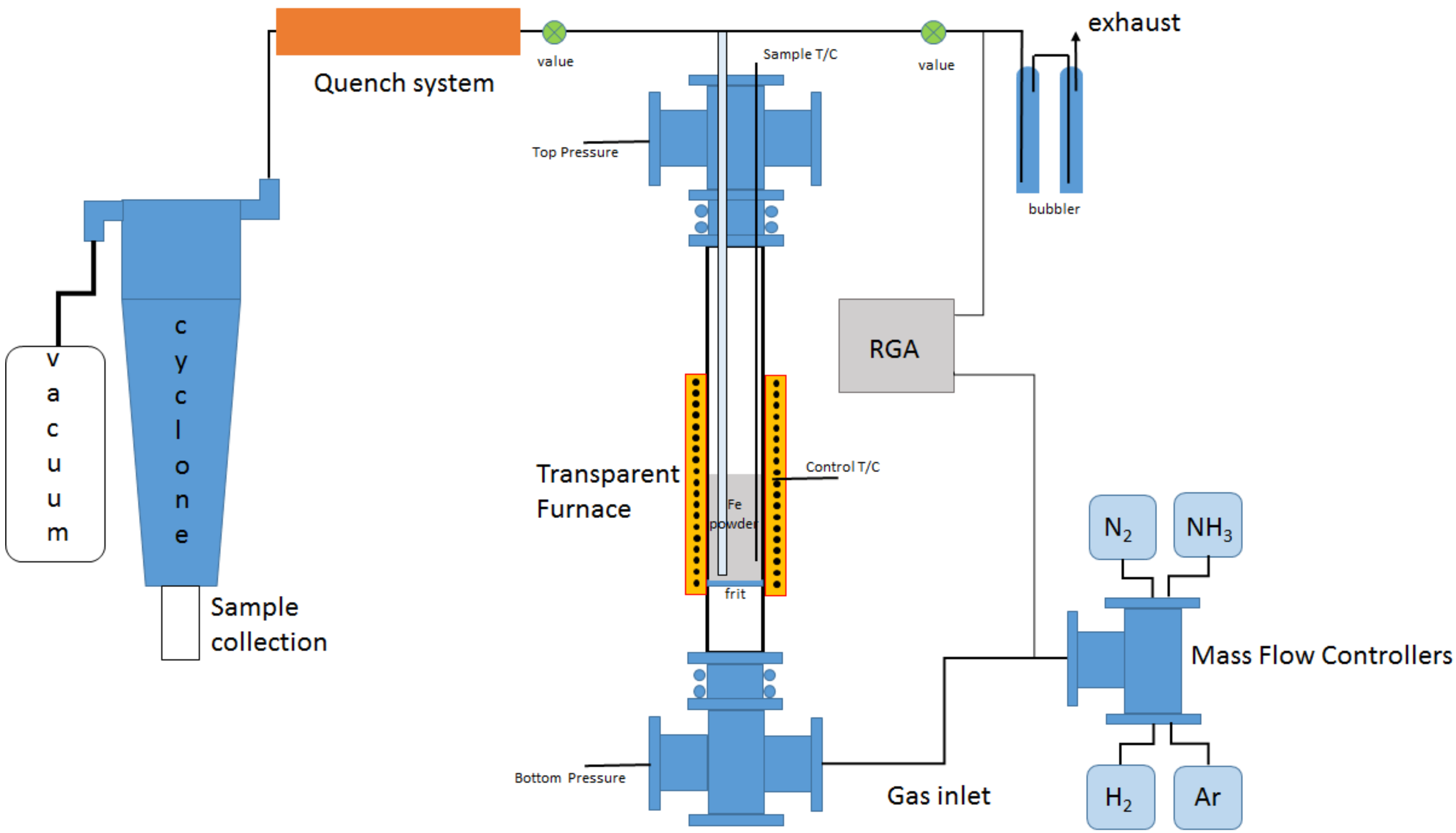
➢ *<u>AMO MYPP:</u> Advanced Materials Manufacturing: Advance technologies that accelerate the research, development, and demonstration of new materials, on a path towards integration of these materials into applications for cost effective, advanced clean energy technologies.*

Technical Innovation

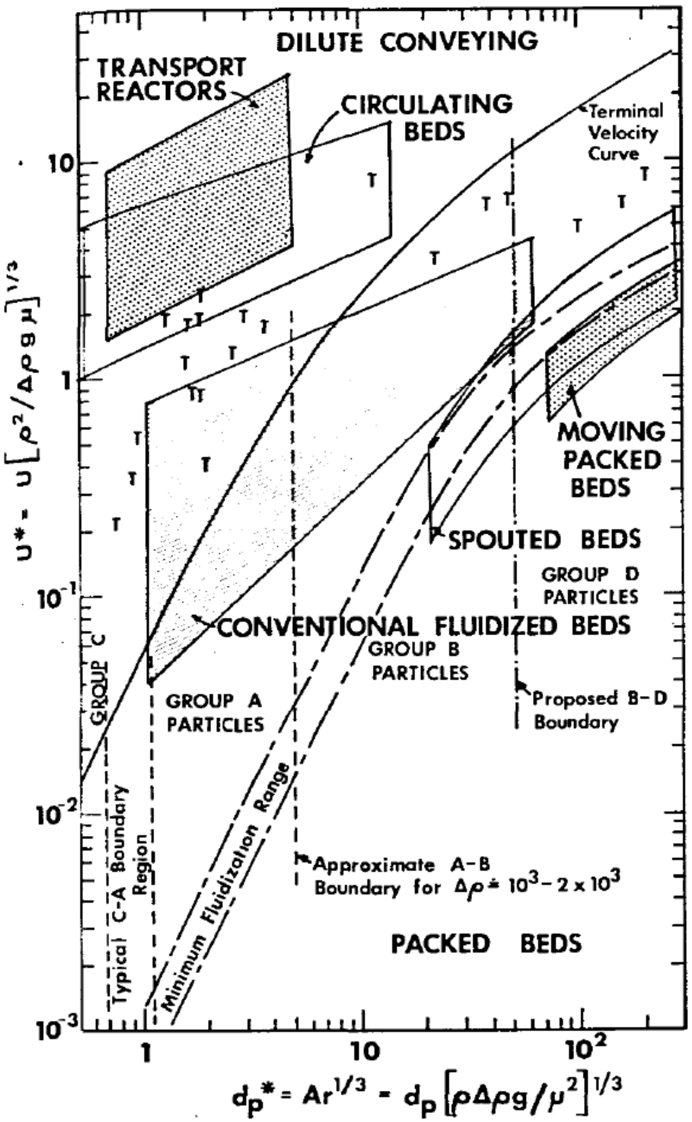
- The rate limiting step of the current process is large scale production of magnetic powders.
- FeNix Magnetics proposes to develop a fluidized bed reactor (FBR) technology for the prototype scale production of ADPIN magnetic powders.
- This is a three step process:
  - Step 1) nitriding & quench to 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

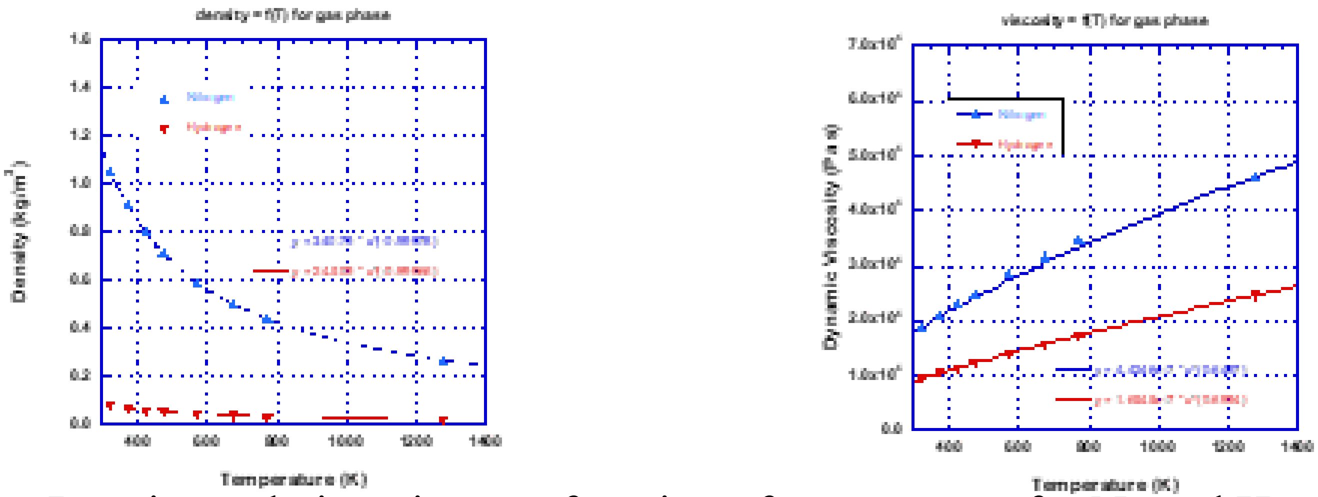


Grace developed a fluidization map based on non-dimensional flow velocity vs. non- dimensional particle size.

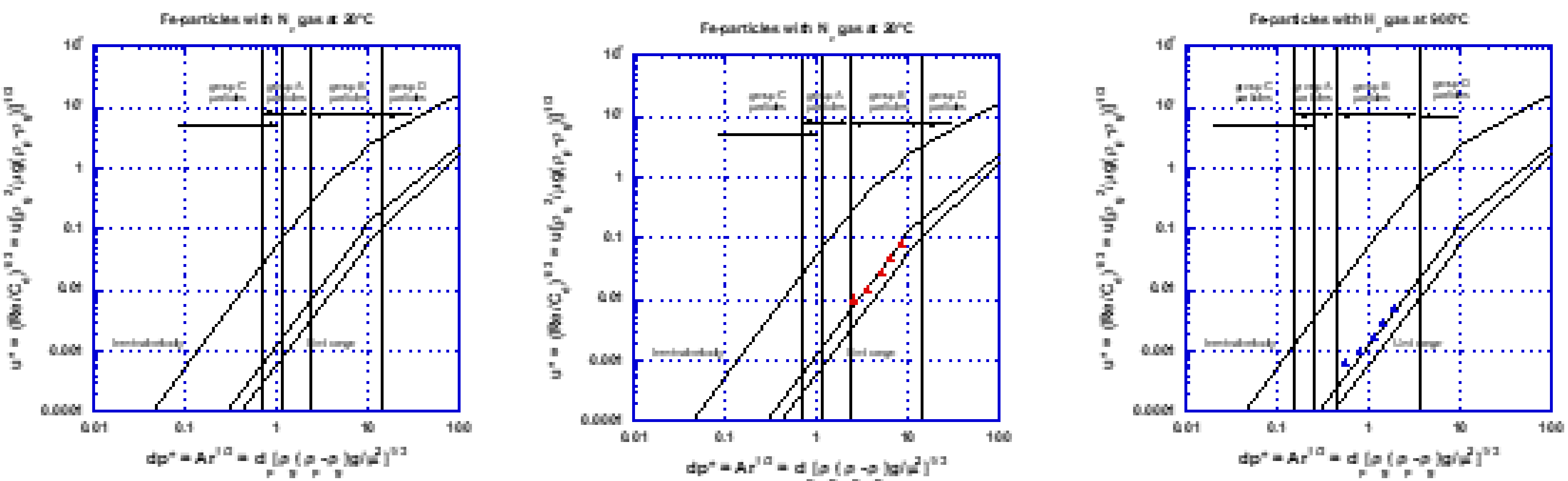
This type of mapping allows for changes in particle material, gas composition, and temperature to be analyzed.

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 placement of a particular set of experimental conditions (i.e. iron vs. alumina material, N_2 vs. H_2 gas, and temperature) does change.

Results and Accomplishments



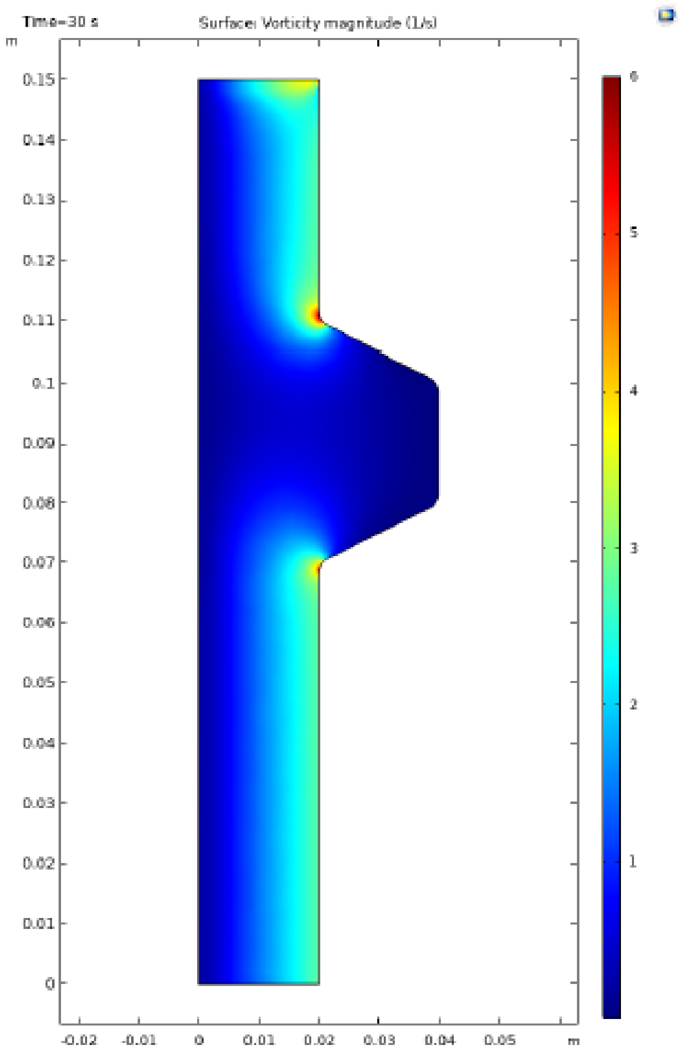
Density and viscosity as a function of temperature for N_2 and H_2 gas.



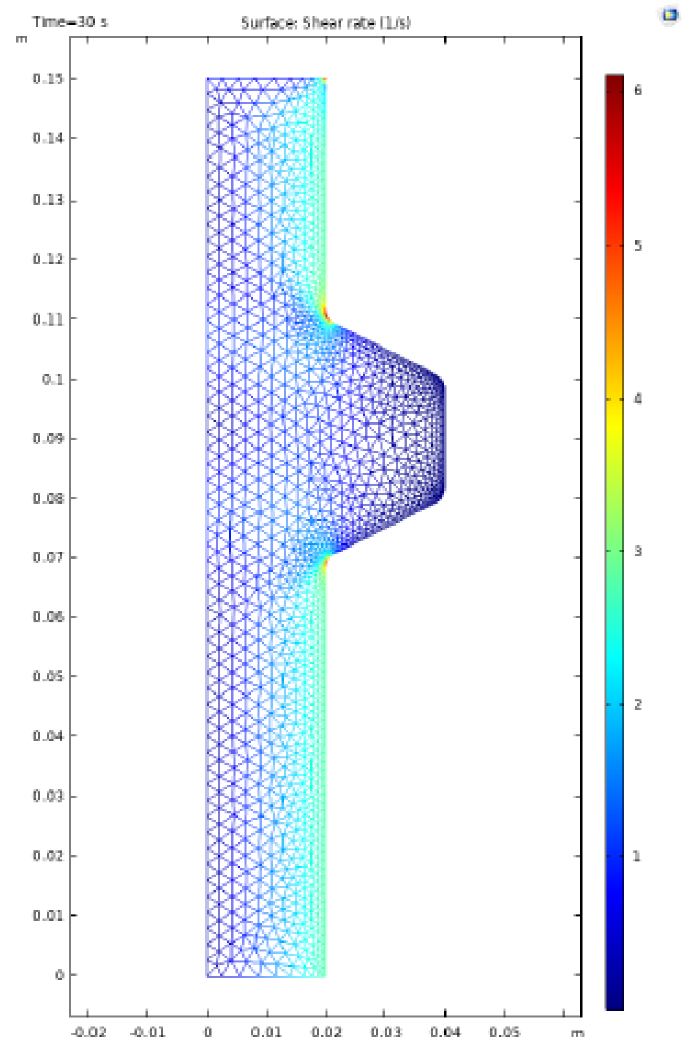
Fluidization map for iron powder. In b) experimental results from are placed on the map with N_2 gas at 20°C and are in excellent agreement (< 10%) with the predicted fluidization behavior. In c) predictions are made for iron powders with H_2 gas at 900°C.

Results and Accomplishments

Initial Numerical Modeling Results (recommended at last years review)



Vorticity = curl of velocity vector field



Shear rate showing finite element mesh

Transition (beyond DOE assistance)

- Manufacture magnetic powder at pilot scale →
- Manufacture demonstration bonded magnet →
- Incorporate demonstration magnet in magnetic refrigeration application.
- FeNix Magnetics has raised an additional $500,000 in private funding.