

Rare Earth Metals Recycling by Hydrogen Processing

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Project Overview

- DOE SBIR Phase 2 Project Funding \$1.15million
- **Project Duration:** 04/03/2023 to 04/02/2025
- **Project Participants:** Dr. Junhua Jiang (Savannah River National Lab), Dr. Andrew Sexton (Trimeric Corporation), Prof. Maohong Fan (University of Wyoming), Prof. Sandeep Kumar (Old Dominion University).
- **Overall Project Objectives:**
 - ✓ 1) **Direct REM magnets recycling by hydrogen treatment in 50 kg/day scale;**
 - ✓ 2) **Non-REOs separation from REOs in 5 lbs/batch, 50 kg/day scale;**
 - ✓ 3) **REMs production from REOs/salts by hydrogen reduction in 10 kg/day scale.**

Technology Background

- Importance of critical minerals to U.S. economy and national security
- Rare earth metals (REMs) demand soaring
- China is dominating REMs supply chain - risk
- ✓ REMs mining challenge
- ✓ REMs recycling is a sustainable approach
- Conventional REOs to REMs by metal reduction or electrolysis has limitations
- Advantages of REOs to REMs by hydrogen reduction
- ✓ Clean process
- ✓ No side products

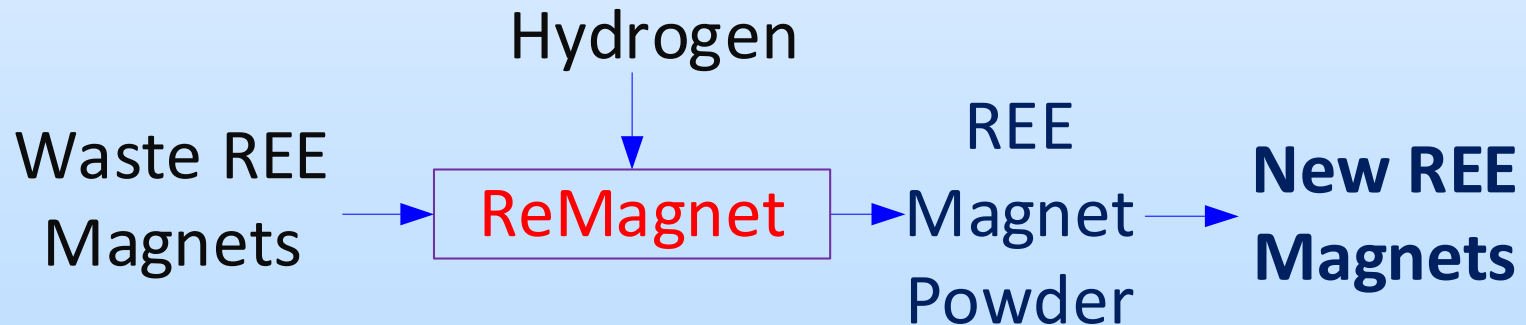
Technology Background

- Recycling of rare earth metals from post-consumer products
- Avoid liquid phase extraction
- Direct production of some REMs without electrolysis
- Phase 1 completed proof-of-concept for the approaches proposed



Technical Approach – Task 1

- REEs recycling – from magnets from magnets
- **ReMAGNET™** - treatment of waste REEs magnets by hydrogen, producing REE magnet powder used for manufacturing new magnets
- ✓ No grinding needed
- ✓ Easy coating separation



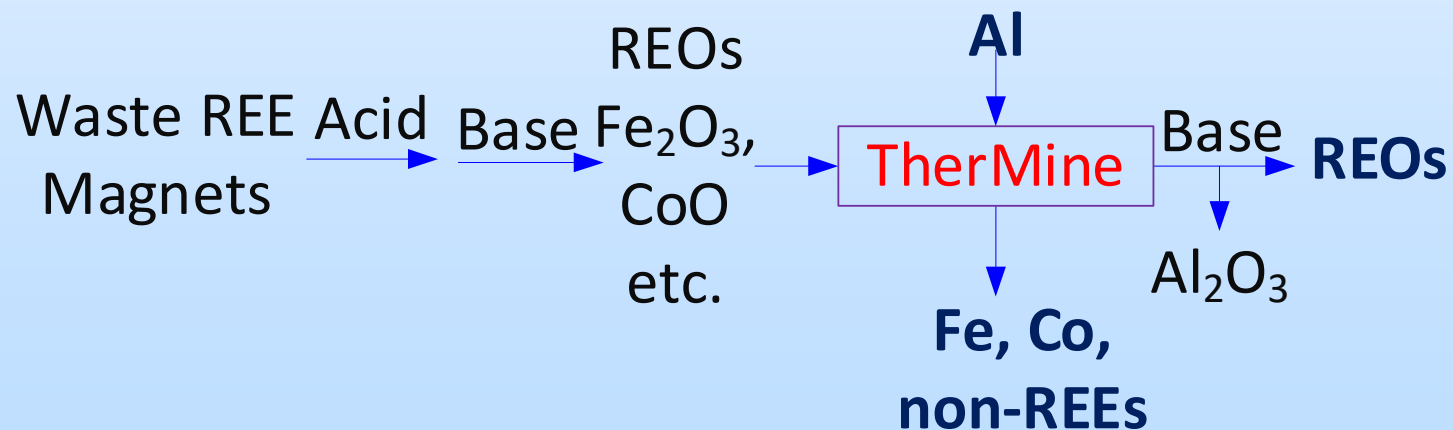
Technical Approach – Task 2

➤ *TherMine*TM - Ultra-fast separation of non-REOs from REOs by thermite reaction



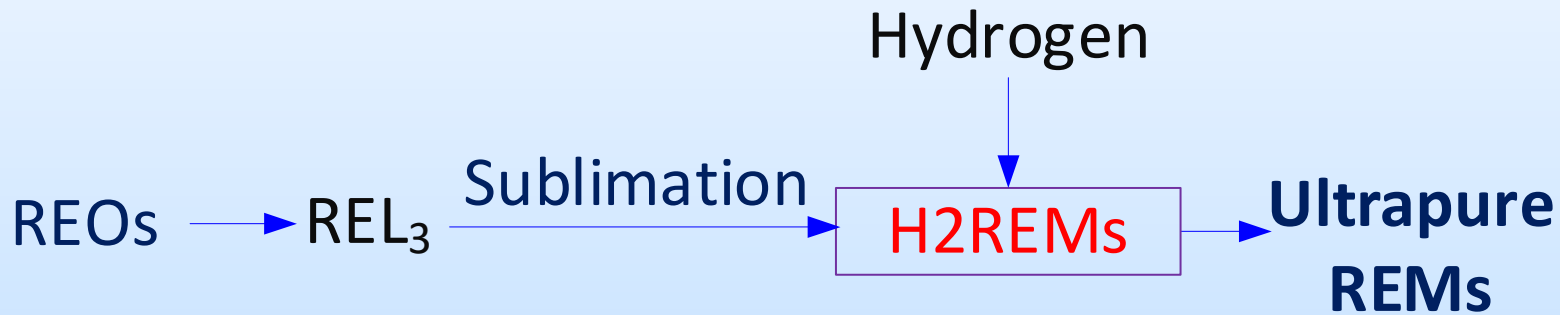
M = Fe, Co, Ni, etc. non-REMs

Extremely Exothermic



Technical Approach – Tasks 3 &4

- **H_2REMs ™** - Hydrogen reduction of REE volatile compounds (REL_3) to REMs in high yield; high purity REMs production
- Hydrogen plasma facilitated REMs production



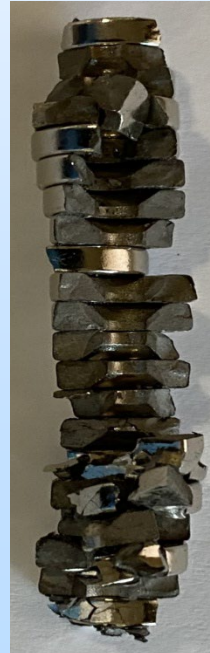
Project Progress – Task 1

- Acquired 3180 lbs crushed computer hard drives
- ✓ Separated and recovered parts with REMs: NdFeB magnets (364.2 lbs) and brushes (85.4 lbs)



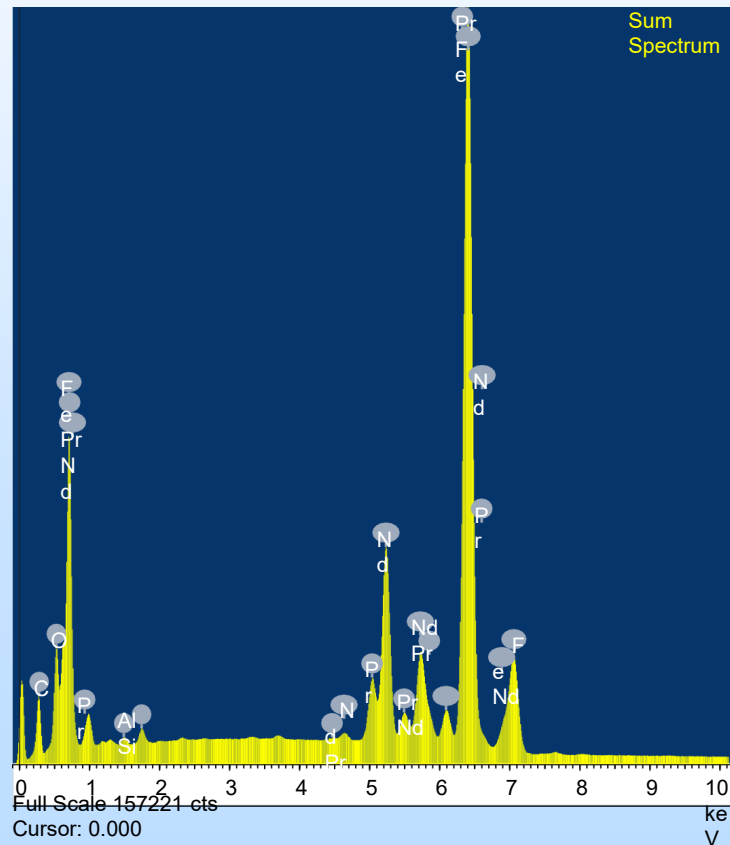
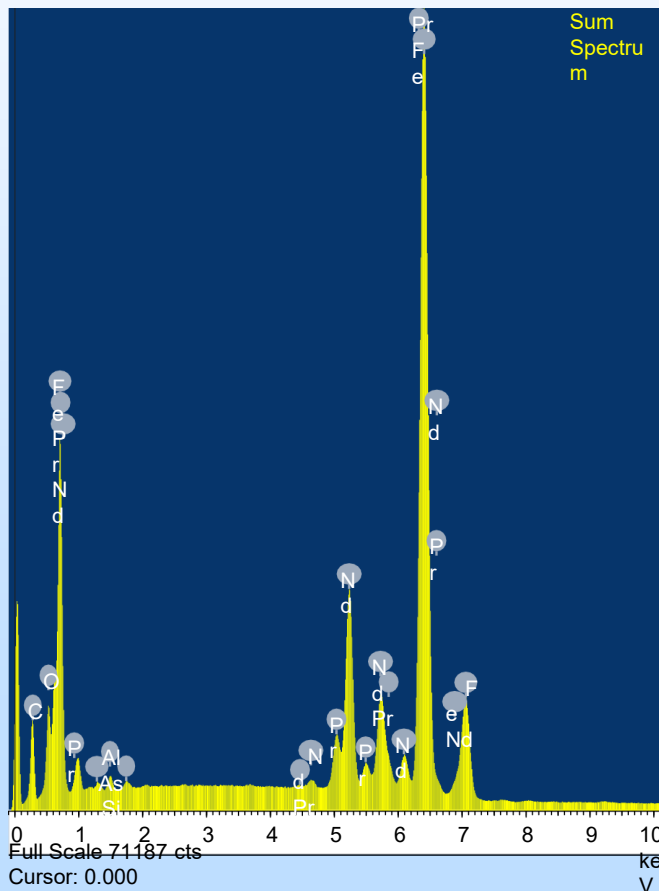
Project Progress – Task 1

- **Direct hydrogen treatment**
 - ✓ By heating to 250°C for an hour at 300 psig
 - ✓ Worked with and without demagnetization
 - ✓ Over 96% of NdFeB and SmCo powder recovered
 - ✓ Achieved 5 lbs per batch, 50 kg per day scale



Project Progress – Task 1

- Metallic Nd, Fe, and Sm, Co obtained
- Can be directly used for making magnets



Project Progress – Task 2

- Achieved 5 lbs per batch, 100 lbs per day scale
- Each reaction was completed under 15 minutes
- Cake make with 12-ton hydraulic press
- Separate non-REOs from REOs



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IMG_2368.MOV

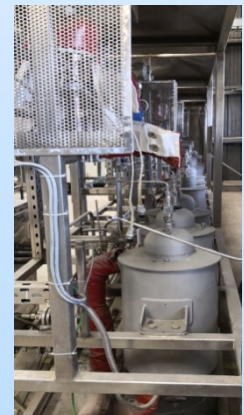
Project Progress – Task 2

- Fe and Co were reduced to metals; separated out by magnet
- Worked well under CO_2
- Direct Ce metal production from CeO_2
- Successful precious metal (Ru) recovery from waste catalyst



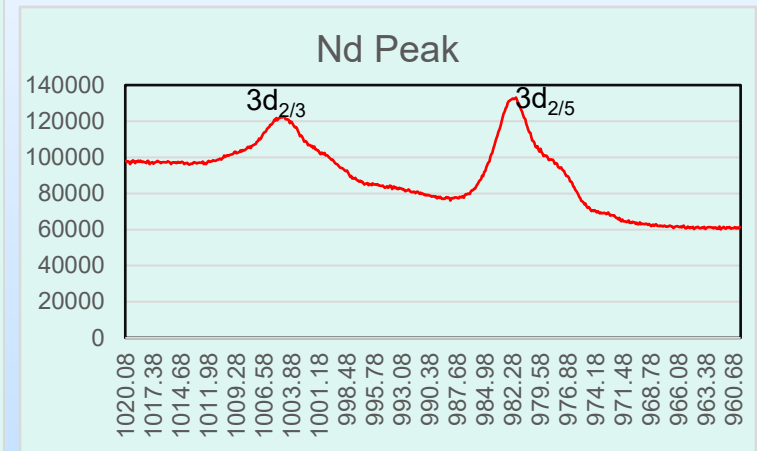
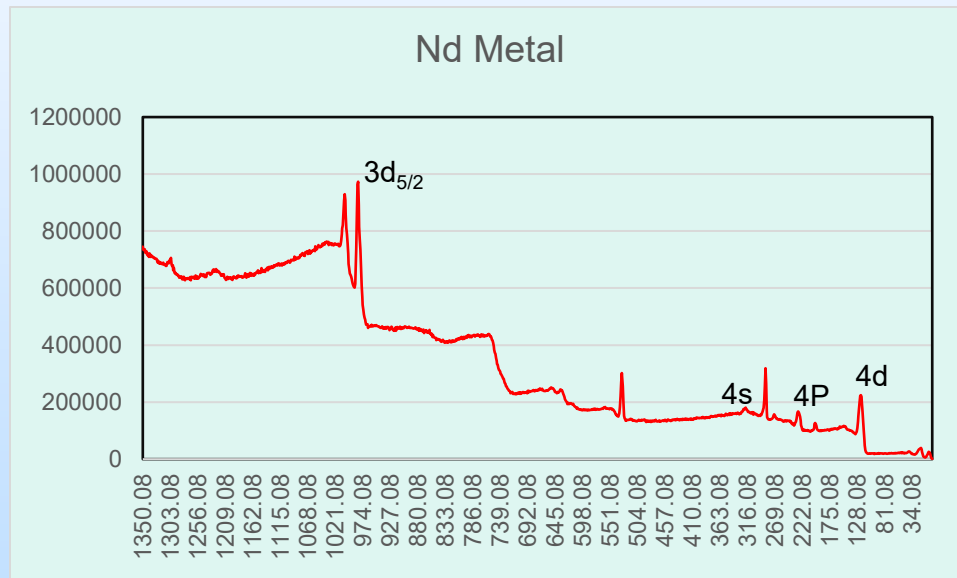
Project Progress – Task 3

- REOs reduction by hydrogen at 700°C failed
- RECl_3 reduction by H_2 at 500-700°C yielded RECl_2
- Successful REMs production using higher vapor pressure REL_3 (L=organic ligand) reduced by hydrogen at 600°C with catalyst
- ✓ Scaling up in progress



Project Progress – Task 3

➤ Nd metal product analytical result



Project Progress – Task 4

- Hydrogen plasma facilitated reduction for REMs production
- ✓ Cost-effective custom plasma equipment developed
- ✓ Scaling up in progress



Plans for future development/ commercialization

- **REE Magnets (NdFeB and SmCo) Production from Waste Magnets**
- **Nd, Sm, Dy, Pr Recycling from Magnets**
- **La, Ce Recycling from Refining Catalysts**
- **Ce Recycling from Polishing Sand**
- **Noble Metals Recover from Waste Catalyst**
- **High Purity REMs Production**

Outreach and Workforce Development Efforts or Achievements

➤ Outreach activities

- ✓ Established a used electronics collection center for local community**
- ✓ Gave talks on urban mining in local colleges and professional meetings**
- ✓ Show and tell of critical materials in local science events**
- ✓ worked and promoted technology with other companies**

➤ Workforce Development

- ✓ Hiring 3 summer interns from colleges**
- ✓ Hiring and training new professional**

Summary Slide

- **The *ReMagnet*[™] process provides a straight forward way for REMs magnets recycling**
- ✓ **No necessary to separate REMs from the magnets**
- **A very efficient method for separating of non-REOs from REOs was developed**
- ✓ **Cost-effective chemicals used**
- **Rare earth metals production by hydrogen reduction successful**
- ✓ **Though REOs and chlorides didn't work out**
- ✓ **Plasma could facilitate the process**

Appendix

➤ Demagnetization



➤ Techno-economic Analysis

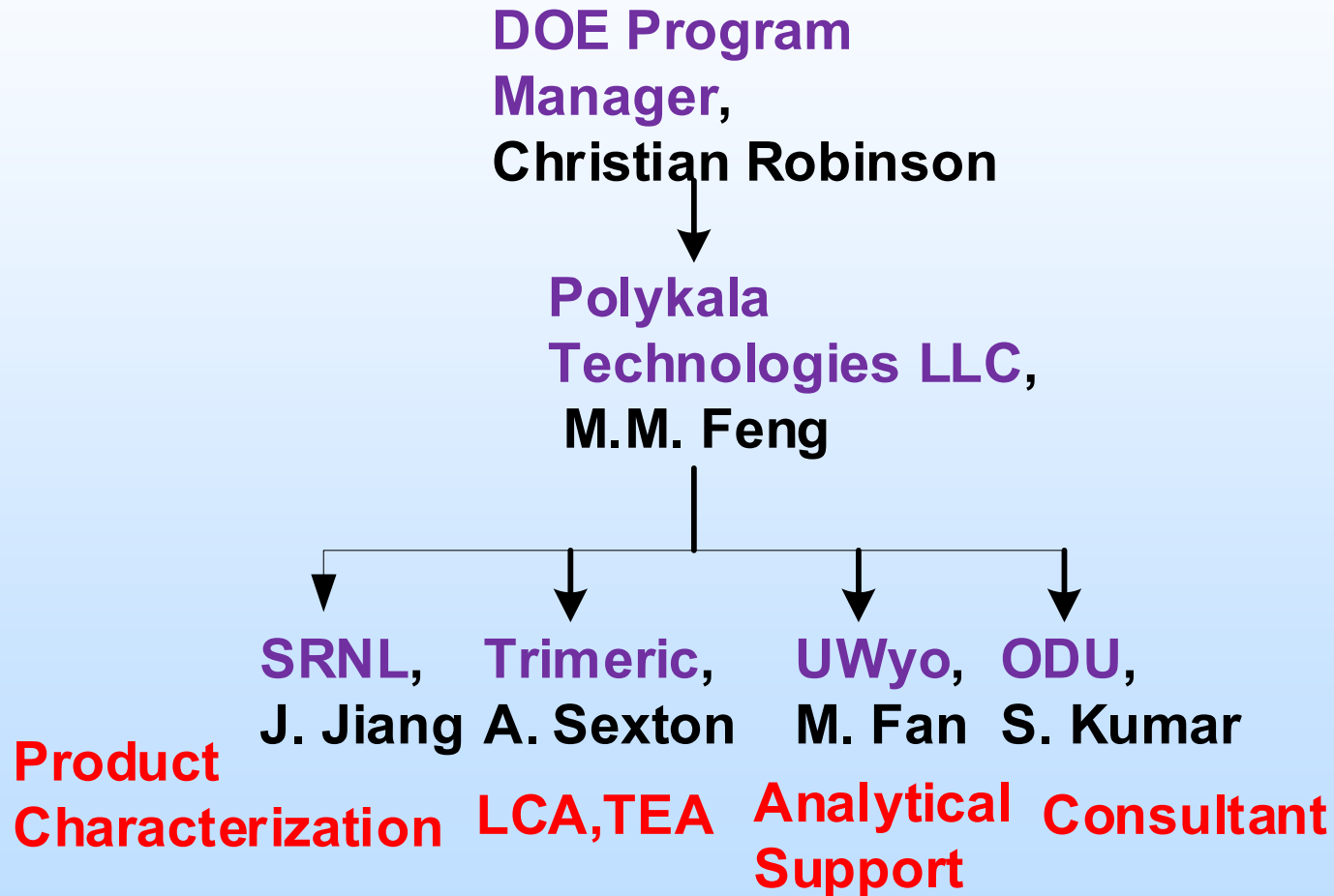
Year	0	1	2	3	4	5	6	7	8	9	10
CAPEX	(\$5,317,900)										
Max Net Revenue	\$1,466,400	\$1,466,400	\$1,466,400	\$1,466,400	\$1,466,400	\$1,466,400	\$1,466,400	\$1,466,400	\$1,466,400	\$1,466,400	\$1,466,400
NPV of Max Net Revenue	\$151,400	\$904,100	\$709,900	\$557,400	\$437,700	\$343,700	\$269,800	\$211,900	\$166,400	\$130,600	

Appendix

Revenue per batch	Base Case	Free Feed
Nd Metal Value	\$21,400	\$21,400
Non-REE metals	\$400	\$400
Total Gross Revenue/Batch	\$21,800	\$21,800
MAX Net Revenue/Batch	\$6,400	\$16,300

Operating Expenses per Batch	Base Case	Free Feed
Recycled NdFeB Magnet (Feed Material)	\$9,900	\$0
Chemicals	\$1,700	\$1,700
Base (NaOH)	\$1,500	\$1,500
Acid (HCl)	\$300	\$300
Gases	\$1,000	\$1,000
Heating for Drier	\$300	\$300
Wastewater Treatment	\$800	\$800
Solid Waste Disposal	\$20	\$20
Scrubber for Vent Gases	\$30	\$30
Electricity	\$50	\$50
MIN Total Expenses/Batch	\$15,600	\$5,700

Organization Chart



Gantt Chart

Tasks/Months (Year 1)	1	2	3	4	5	6	7	8	9	10	11	12
Task 1 <i>REMAGNET</i> process scale up	█	█	█†									
Task 2 <i>THERMINE</i> process scale up				█	█	█†						
Task 3 REMs production by hydrogen processing							█	█	█†			
Task 4 REMs production under plasma										█	█	█†

Tasks/Months (Year 2)	13	14	15	16	17	18	19	20	21	22	23	24
Task 5 Ultrapure REMs production by cascade separation	█	█	█	█†								
Task 6 Pilot scale REMs production by hydrogen processing					█	█	█	█	█	█†		
Task 7 Techno-economic analysis											█	█†

Acknowledgement

- **DOE SBIR Phase 2 grant support –
Contract No. DE-SC0021544**
- **Christian Robinson, DOE SBIR project manager**
- **Project partners**