

Tusaar Corp

***Environmentally Friendly Economical Sequestration of
Rare Earth Metals from Geothermal Waters***

Project Officer: Holly Thomas

Total Project Funding: \$715K

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Dean P. Stull, Ph.D., PI & Presenter

Tusaar, Inc.

Low Temperature Track

The Problem

- Commercial extraction of lanthanide and other critical and valuable elements from geothermal process waters
 - REE are critically important in the US
 - REE demand is rising
 - US is dependent upon foreign sources
 - Few viable domestic supplies/options exist

The Project

- Environmentally Friendly Economical Sequestration of Rare Earth Metals from Geothermal Waters
 - Geothermal waters are an available and potential REE source
 - Geothermal waters offer a range of technical challenges

The Target

- Demonstrate that a novel media can effectively absorb REE from Geothermal Waters
- REE can be recovered and the media regenerated
- Model a commercial process

The Future

- Technical Advancement
 - Larger scale pilot demonstration plant
 - Commercial feasibility analysis
 - Commercial operation
- Commercial Success
 - Cost effective production of REE from existing and future geothermal power plants

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The Technical Strategy

- An iterative experimental design – a matrix format
 - Identify and prioritize operating variables
 - Identify and model geothermal brines
 - Screen media for metal removal
- Use a rapid through-put bench scale isotherm test
- Explore range of operating conditions
- Select materials/conditions for confirmatory column studies
- Optimize laboratory conditions
- Advance best case with authentic geothermal brines
- Use optimized data to complete process design at scale
- Complete techno-economic analysis

The Technical Approach - Challenges

– Media

- Application under high temperature and salt concentration
 - Absorptive and regenerative capacity
 - Process design constraints
- Selective absorption of REEs
 - Absolute and relative basis
 - Salt concentration - 1-20%
 - REE concentrations 10-200 ppb
 - Selectivity for individual REE

– Analytical

- Complex matrix
- Low concentrations

The Technical Approach - Unplanned challenges & solution

- Analytical throughput
 - Cross contamination – sporadic intra run variance - SOP changes
 - Equipment downtime – Improved maintenance
- Brine formulation
 - Quality of individual components –impurities determined, quantitated and formula adjustments
 - pH variability related to REE doping – little buffer capacity, adjust formulation and broaden target ranges
- Experimental design for high through put screening
 - Volume requirements related to media mass – adapt test model
 - Modeling column efficiency following screening – under investigation
 - Media impact on target brine pH – under investigation

Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
<p>1.2.1 Selection & formulation of two geothermal model brines with solution stability</p>	<p>Complete - Brine 1 & 2 defined, prepared and evaluated.</p>	<p>December 31, 2014</p>
<p>1.2.2 Establish sorption and recovery capacity goals (%wt. /wt.) for Tusaar proprietary absorptive media for removal of target REE/metals from model geothermal brines.</p>	<p>Capacity goals established for initial target media – 0.1 to 0.4% wt/wt initial goal for Media 1 & 2. Exploratory media will likely exceed these levels</p> <p>Recovery after sorption from model brines under investigation.</p>	<p>March 31, 2015</p>
<p>1.3.1 Completion of an initial experimental design focused on the top three variables/parameters</p>	<p>Complete – target parameters are pH, temperature, REE concentration</p>	<p>March 31, 2015</p>
<p>GO/NO-GO Decision Point Demonstration of metal recovery and stripping from media coupled with reasonable operating parameters and life cycle parameters.</p>	<p>Program mid point decision, in process – due July 31, 2015</p>	

Technical Accomplishments - overview

- Selected and formulated model brines
- Completed the foundational experiments to investigate media performance work
 - Manufactured, qualified and reserved large lots of media
 - Developed REE qualification method for media
 - Expanded media qualification to include REE capacity test
- REE absorption from a model brines experimentally confirmed
- Media metal recovery and media regeneration under investigation – early results positive

Technical Accomplishments

- Select Results
 - Test matrix designed

Master Matrix			
	REE Concentration ¹	Brine pH ²	Isotherm temperature ³
Media 1			
Media 2			

REE Concentration		
REE Conc.	Media 1	Media 2
100 ppb		
1 ppm		
10 ppm		

Brine pH		
pH ¹	Media 1	Media 2
2.5		
3		
3.5		
4		
4.5		
5		
5.5		
6		
6.5		
7		

Isotherm Temperature		
	Media 1	Media 2
Ambient		
40 °C		
50 °C		
60 °C		

Technical Accomplishments - Select Results

- Proprietary media selected
 - Wide pH working range, >200 regenerations, good REE capacity
 - Analytical requirements established and implemented
- Two geothermal brines modeled from available data
 - Brine 1 - pH 5.5, TDS >100,000
 - Brine 2 - pH 3.2, TDS <5000
- Experimental plan uses model brines at native pH doped with REE standard mix at 38ppm total
 - ~1000 times native levels to speed development work
- pH and temperature were selected as initial critical variables
 - Plant operating parameters and brine compositions

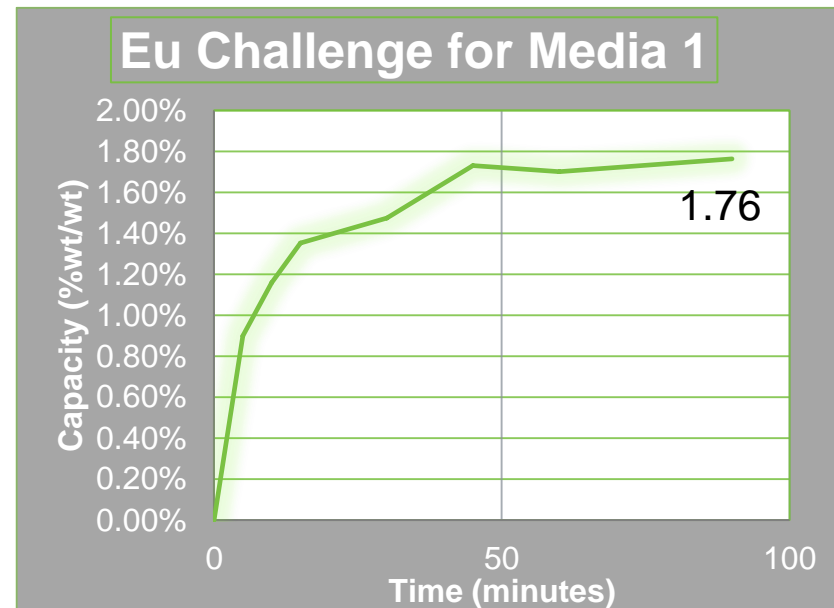
Technical Accomplishments - Select results

– Analytical qualification

- Matrix issues over dynamic range of salt & REE concentration
- Solution using ICP MS instrument
 - Dilute samples for analysis with synthetic matching brines
 - MDL for REE 0.02 µg/L – minor inter element variation
 - Working solution range 1-10ppb
 - REE concentration for native brines with REE below 10ppb

Technical Accomplishments - Select results

- Media 1 & 2 Europium Challenge Qualification
 - Test solution @ 500ppm Eu
 - ~1.76% wt/wt isotherm capacity
 - >4% wt/wt column capacity (estimated)
- Media performance in brine
 - 36ppm total mixed REE, 21°C, 90 minute mix time
 - Best case sequestration 98% of available REE
 - Media capacity 0.1 to 0.4 % wt/wt
 - Brine 1 & 2 produced similar results



Milestone or Go/No-Go	Status & Expected Completion Date
<p>GO/NO-GO Decision Point Successful demonstration of metal recovery derived from the combined experimental determinations of media capacity and recovery efficiency for at least one metal of value in the model brine.</p>	<p>July 31, 2015 Work is in process</p>
<p>Milestone for Task 3: Complete evaluation of results and a preliminary economic analysis</p>	<p>October 31, 2015 Under review as work proceeds</p>
<p>Milestone for Task 4: Completion of the Techno-Economic Analysis</p>	<p>February 28, 2016 Conceptual</p>
<p>Milestone for Task 5: Final Report and Complete Data Upload</p>	<p>March 31, 2016</p>

Next 9 months Focus on:

- Perfect the laboratory model for media evaluation
- Confirm column absorption performance
- Obtain and examine authentic geothermal brines
- Preliminary economic model development
 - Review world prices and trends for REE elements
 - Review capital requirements for critical elements
 - Identify critical operating parameters - unit operation integration into existing geothermal energy extraction plant
- *Broaden our view* - experimental media for absorption
- *Reduce our risk* - Identify secondary variables for impact on future commercial application
 - Contact time, flow rates, process aids used in geothermal operations

Future Direction

- Successful completion of program
 - Partnering with industry participant(s)
 - Design and construction of pilot operation
 - Commercial feasibility from Pilot operation
 - Design and installation of commercial operation
 - Commercial operation