Rare Earth Element Extraction and Concentration at Pilot-Scale from North Dakota Coal-Related Feedstocks

2020 NETL Annual Crosscutting Technologies Meeting

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UNIVERSITY OF NORTH DAKOTA

LEADERS IN ACTION

Team Members

Project Team Members

- UND Institute for Energy Studies
- Microbeam Technologies Inc.
- Barr Engineering Co.
- Rare Earth Salts LLC
- MLJ Consulting LLC
- North Dakota Geological Survey

Project Sponsor Representatives/Executive Advisory Team

- U.S. Department of Energy NETL
- Lignite Research Program
- North American Coal
- Great River Energy
- Minnkota Power Cooperative
- BNI Energy
- Great Northern Properties
- Critical Materials Institute
- North Dakota University System
- Valley City State University

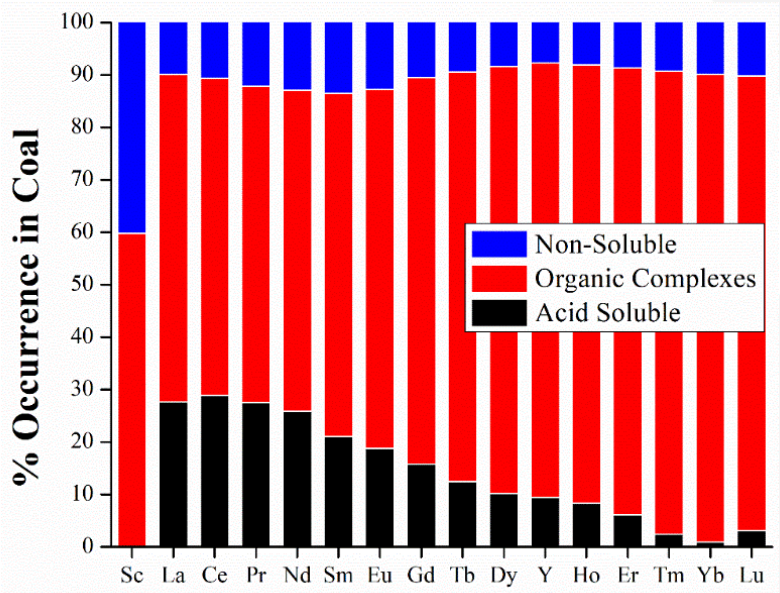
Presentation Overview

- Project Objectives and Scope
- Accomplishments to Date
- Project Next Steps
- Next Steps for Commercialization
- Applicability to Strategic Goals
- Questions

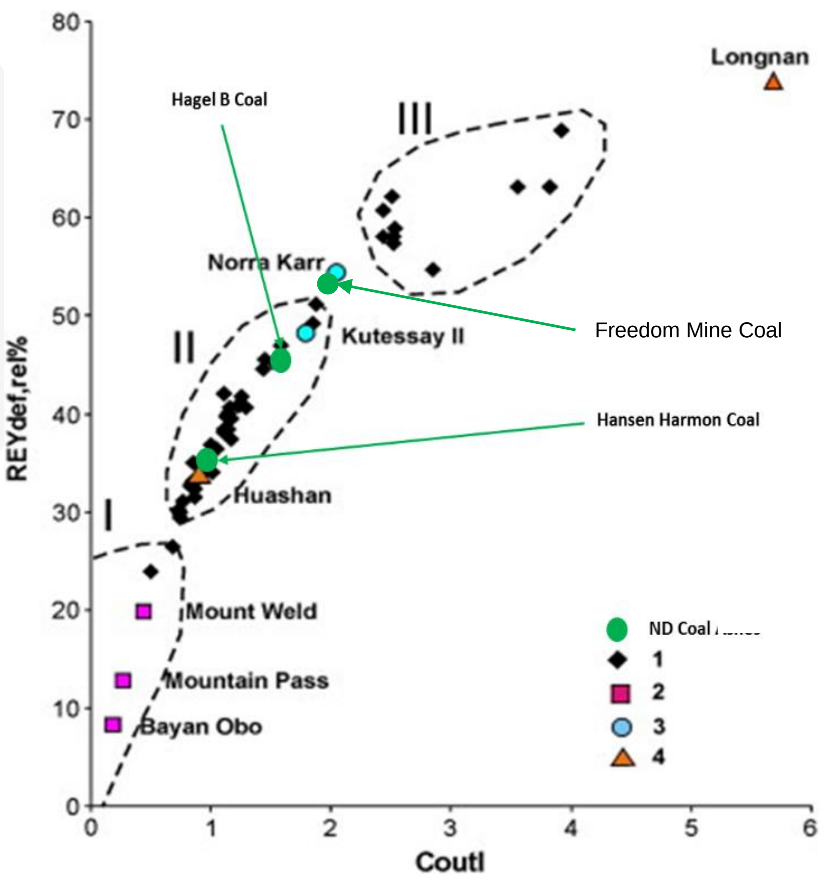
Technology Background

- Extracts REE from low rank coals (LRCs) utilizing weak acids
  - Weak organic associations, rather than mineralized forms (carboxylic acid)

- Utilizes the *pre-combustion* coal for the feedstock
  - Generates a reduced-ash unique byproduct
    - Usable for AC, humic acid
    - Low fouling ash for boilers



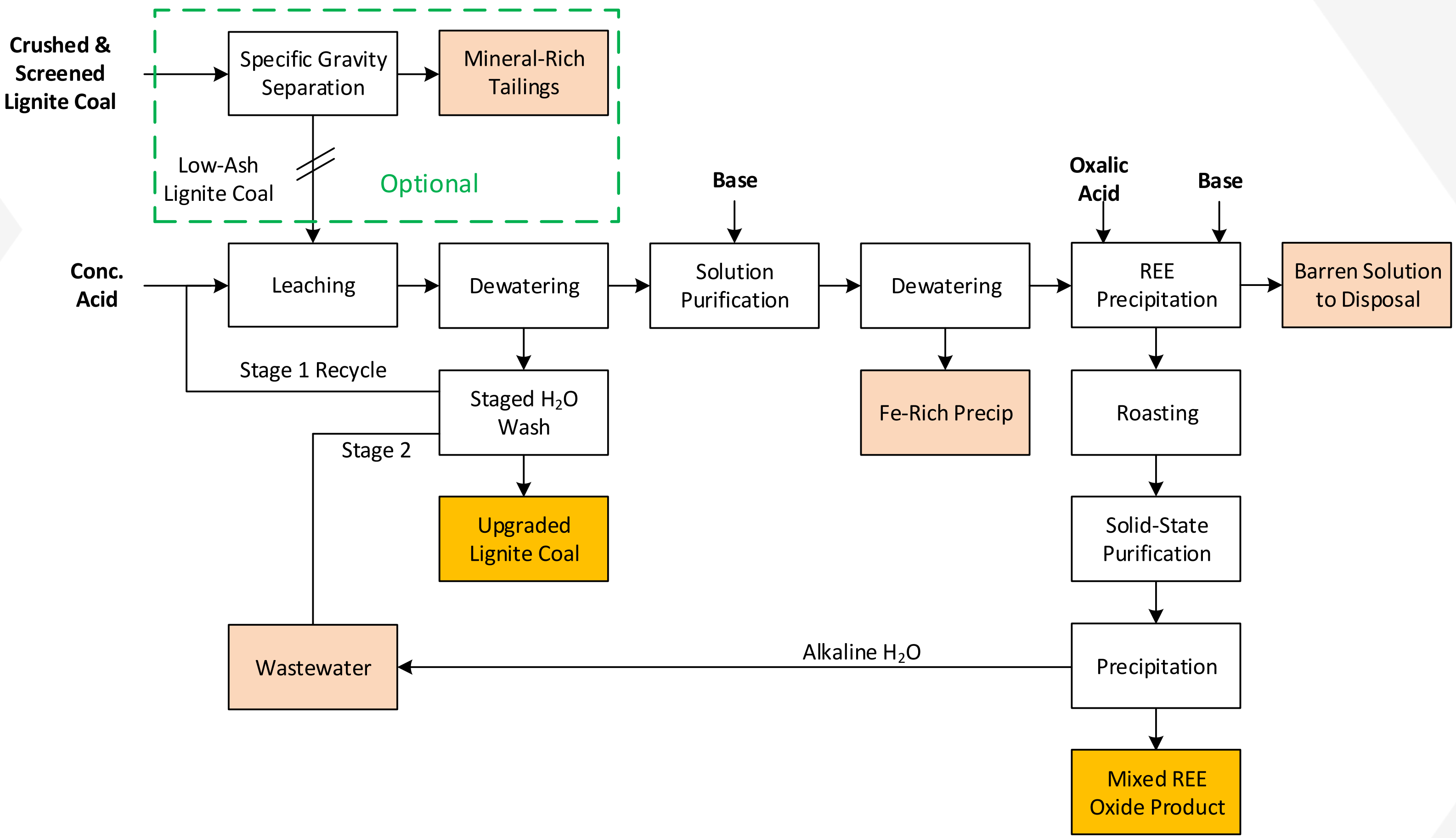
Technology Background (cont)



- Lignite often identified with high HREE/LREE ratios
  – Economically favorable distributions for usage

- Process developed produces other CM
  – High-value Ge and Ga concentrates

Process Flowsheet



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Project Objectives and Scope

- As outlined by DOE – NETL in FOA 2003:
  - Development of pilot scale near 5-25% of commercial capacity of >2% REO concentrates utilizing coal-based resources of >300 ppm concentration TREE
  - Economic and environmentally-friendly extraction of REEs from coal

- Goal is to validate the REE extraction from LRC technology at a relevant scale for commercial deployment

Project Objective - Scale

- Previous economic analysis → 5 ton/hr coal output with activated carbon usage
  - Defined as commercial demonstration – able to operate profitably without external financing

- Pilot scoped for 10% capacity of this – 0.5 ton/hr coal output
  - REO Concentrate production of ~100 grams/hr
  - Coal output utilization not included within pilot scope

Project Objective - Coal

- Blended, cleaned coal basis utilized for process feed
  - Lower-REE coal from active mine blended with high-REE coal collected from outcrop seam
  - Coal spiraling utilized as coal cleaning process to remove mineral-rich tailings

- Up to 300 tons of >300 ppm material gathered to date on cleaned-coal basis

Project Objective – REO Purity

- Bench-scale testing resulted in >50% concentrate production as primary product
  - Poor controls on oxalate feed rate resulted in <85% produced in laboratory testing
- Pilot-scale testing and additional sensors/controls expected to keep concentration of primary concentrate >65%
  - Additional research in solid-state REE purification has identified path to >95% concentration

Project Objective - Commercialization

- Identify requirements and knowledge needed for effective commercialization of the technology
  – Including technology and non-technology needs

- Technology Needs:
  – Technology robustness to variable feedstocks (mining variability)
  – Impact of water quality on process streams’
  – Long-term steady-state data
  – Cost improvements as a plus

Project Updates

- Coal acquired from two locations
  - <300 ppm, high HREE/LREE ratio from active mine
    - Substantial improvements by coal cleaning expected due to high clay content within mined sample – UND choice
  - >300 ppm coal from outcrop sample – H-Bed
    - Collected with assistance from NDGS and with state permits
- Pilot design completed with process sizing and control loop development
- Feasibility Study complete with recommendations (to DOE)

Coal Acquisition – Freedom Mine

- 450 tons of 160-200 ppm coal extracted from the Freedom Mine (Buelah, ND) courtesy of NACC
  - Gathered from two distinct fields of coal, with one separated into two variable size fraction piles

- Ash content near 45%, expected strong benefit of spiraling
  - High due to the inclusion of clay layers near the margin of the seam – UND choice

Coal Acquisition – H-Bed

- High-REE content H-Bed sampled in southwestern ND
  - 40 super sacks collected, approximately 44 tons
  - Average of ~480 ppm, with average ash near 35%

Sample ID	Dry Ash (wt%)	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Total REE (ppm)
H Bed - Bags 1-3	36.49	23.0	47.0	70.5	171	21.4	87.2	19.0	4.24	16.6	2.38	12.8	2.30	6.12	0.82	5.14	0.71	490.2
H Bed - Bags 4-6	36.80	23.9	40.4	51.8	127	16.5	69.7	15.9	3.59	14.1	2.01	11.2	2.09	5.85	0.81	5.41	0.76	391.0
H Bed - Bags 7-9	21.58	21.9	60.3	78.1	172	21.3	86.0	18.3	4.25	17.8	2.61	14.8	2.81	7.66	1.03	6.47	0.88	516.2
H Bed - Bags 10-12	30.00	21.3	56.0	101	222	26.2	104	21.8	4.94	19.7	2.82	14.8	2.63	6.88	0.90	5.47	0.75	611.2
H Bed - Bags 13-15	28.24	16.0	47.5	63.6	144	16.9	66.9	13.7	3.13	13.1	1.93	10.9	2.12	5.92	0.80	5.06	0.70	412.3
H Bed - Bags 16-18	24.03	13.2	50.2	60.5	124	13.7	52.1	10.2	2.36	10.6	1.62	9.5	1.92	5.43	0.72	4.46	0.63	361.1
H Bed - Bags 19-21	26.65	19.2	43.7	47.2	111	13.3	55.1	11.8	2.69	11.3	1.71	10.0	1.98	5.67	0.79	5.06	0.70	341.2
H Bed - Bags 22-24	31.13	22.5	54.0	65.9	157	19.4	81.3	17.8	4.09	17.0	2.49	13.9	2.59	7.13	0.98	6.22	0.85	473.2
H Bed - Bags 25-27	51.54	19.1	46.5	59.3	141	18.1	76.2	16.7	3.79	15.3	2.20	12.1	2.26	6.19	0.83	5.42	0.73	425.7
H Bed - Bags 28-30	41.55	23.7	56.6	65.2	155	19.5	81.6	18.0	4.15	16.9	2.45	13.7	2.57	7.15	0.98	6.17	0.85	474.5
H Bed - Bags 31-33	33.58	23.6	58.4	68.7	167	20.9	87.8	19.3	4.42	18.1	2.62	14.5	2.71	7.55	1.02	6.50	0.89	504.0
H Bed - Bags 34-36	31.03	26.6	53.9	83.6	211	27.3	115	25.8	5.80	22.1	3.04	15.6	2.72	7.11	0.94	5.98	0.80	607.3
H Bed - Bags 37-39	32.63	24.8	45.5	77.8	199	25.5	106	23.3	5.09	18.9	2.62	13.3	2.29	6.14	0.82	5.25	0.71	557.0
H Bed - Bag 40	17.68	23.8	52.5	81.0	202	26.2	110	24.3	5.41	20.8	2.97	15.9	2.87	7.95	1.09	7.21	0.98	585.0

Continuous Pilot Design Summary

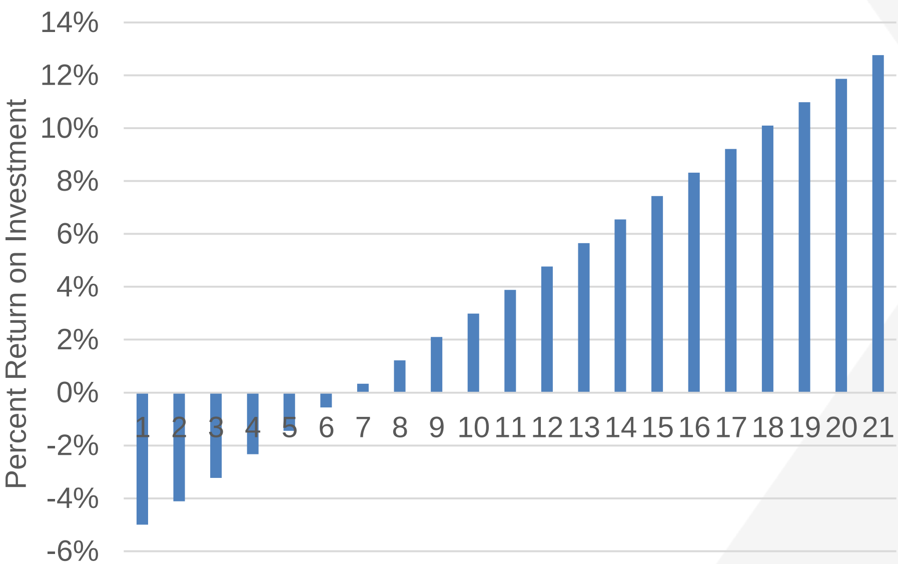
- Included within the continuous scope of the pilot:
  - Coal crushing and preparation (to topsize of -4 mesh)
  - Coal spiraling and mineral-rich tailings disposal
  - Leaching of REE and filtration/washing of coal
  - Solution purification and REE precipitation
  - Wastewater treatment of spend waste

- REE concentrates will be fired to oxides batch-wise as produced (kg/day)

- All processing permits (industrial safety, air, water) have been issued

Feasibility Study - Economics

- Plant Scope: 5.5 ton/hr AC feed for REE extraction
  - Includes CAPEX and OPEX of AC plant
    - Salables: AC, REE Concentrates, Ge, Ga
    - Consumables: Acid, Base, Oxalic Acid, Coal Feed, Labor, Electrical/Heat, Maintenance, and REE/CM refining costs
  - Discounted payback at 6.2 years
- Utilizes data from bench-scale data (DE-FE0027006)
  - REE Recovery
  - Consumable Usage



Project Next Steps

- Following Go/No-Go Decision (September 30th)
  - Bench-scale testing of blended coal feed to evaluate parametrics critical for pilot-scale operability
  - Procure, construct, and shakedown pilot facility at host site identified
  - Operate pilot facility to process at least 100 tons of >300 ppm material
  - Utilize bench-scale REO separations technology at Rare Earth Salts to evaluate refining costs/viability
  - Update Feasibility Study to reflect pilot recoveries and extrapolated costs

Bench-Scale Testing

- Testing to include:
  - Effect of water quality on REE processing (purity, recovery, etc.)
    - Testing tap, RO, and DI planned
  - REE concentrate purity enhancement
    - Sensors added to bench-scale system to mimic pilot planning
    - Solid-state post-calcining concentrate improvement
  - Parametrics for pilot scale coal blend and steady-state information
    - Acid concentration/pH, base usage, precipitant concentration, seed crystal usage

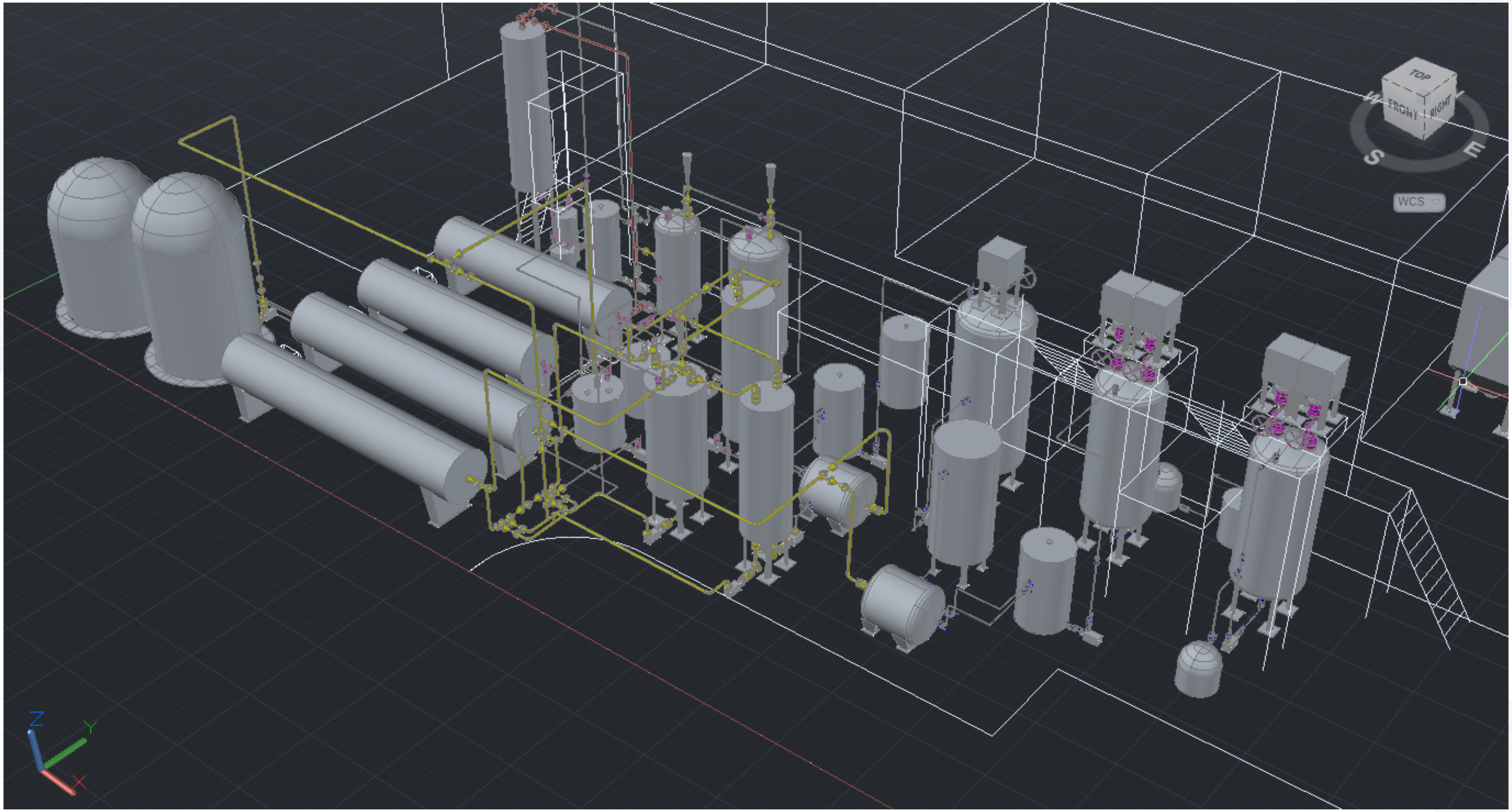
Pilot Procurement & Construction

- All major and ancillary equipment specified during pilot design to vendor-level specifications
  - Vendors have been contacted and quotes available

- 6-Month period of procurement/construction of plant starting October 1
  - With commissioning, anticipate pilot start near June/July 2021

- Equipment sized for nameplate of 500 kg/hr coal output

Pilot Layout Plans



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Pilot Testing Plans

1. Test variable equipment and control setups for operability/reduced chemical or residence time requirements

2. Confirm parameters specified by bench-scale data for optimal economic point

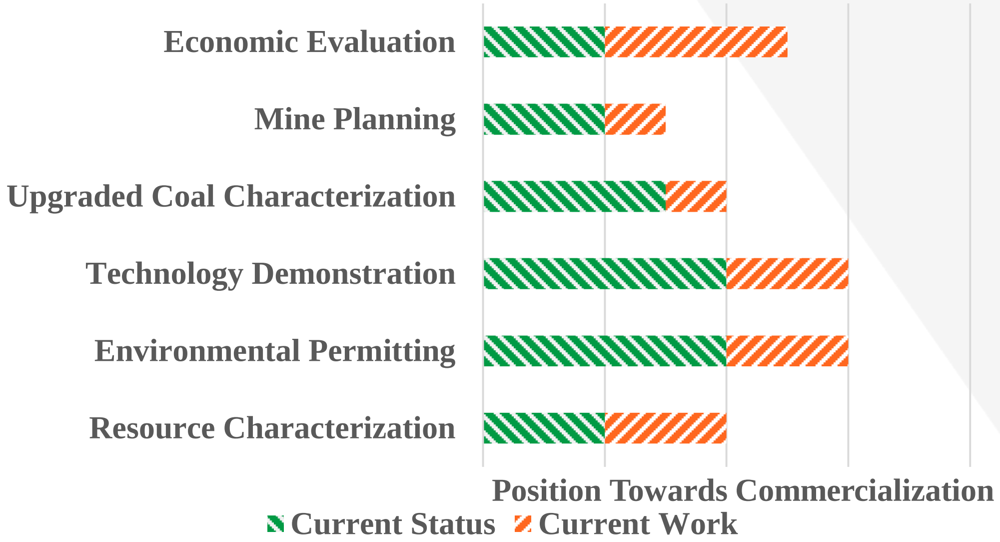
3. Establish long-term steady state (>100 hours in total) and evaluate feedstock variance effects

Bench-Scale REO Separation

- Preliminary separation at lab scale based upon bench-scale concentrates produced
  - Evaluate potential of reducing processing time/costs for lignite-based REE concentrates
- Bench scale processing of pilot products generated (kgs)
  - Using the chosen optimal processing from lab-scale

Technology to Market Path

- Upon successful pilot testing:
  - Commercial demonstration scale viewed as next step for technology
  - Validation of REO concentrate separation valuable for commercialization



- All flows necessary for commercial environmental evaluation will be analyzed during pilot operation
  - Solid, liquid, and gas outputs and required control mechanisms to suit
  - Economic analysis at higher accuracy based on steady-state pilot data

Challenges Remaining for Comm.

- Detailed resource characterization of REE within lignite reserves
  - At bankable level of detail over geographic and stratigraphic layers of seams
  - Development of mine plants to suit these reserves

- Commercial demonstration viability and long-term economic picture
  - Required for significant investment in larger plants to match coal-fired utilities

Potential Commercial Partners

- Lignite owners/miners/users
  - On the project, have two owners, two miners, two users
  - Also have letters of support/interest from two additional owners/users

- Project partners include:
  - Most (>50%) of lignite holders and users within ND
  - All major (>1,000,000 tons/yr) mines with ND
  - Major support from the ND state government

Summary

- Developed technology has been demonstrated to be economic, even at small scales
  - Combined with high-value carbon utilization
- Pilot designs are complete for 500 kg/hr coal output system
  - 10% scale of planned commercial demonstration
  - Construction/operation to continue after Go/No-Go decision September 30th
- Strong industrial and governmental support from ND for project success
- Additional resource characterization/development, particularly of high-REE potential sites in southwestern ND needed

Summary

- Discovered high REE concentrations in ND lignite
- REE weakly bound – primarily as organic complexes
- Pre-combustion extraction permits sale of upgraded coal products
  - REE concentration through selective precipitations
- Preliminary parametric testing complete
  - Finalizing operating parameters and equipment for semi-continuous testing
- Commercialization pathways
  - Multiple products for synergistic economic approach
  - VCSU/GRE Spiritwood for pilot/commercial demo opportunities

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Questions?

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