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

NETL Annual Review Meeting, May 25th, 2021

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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

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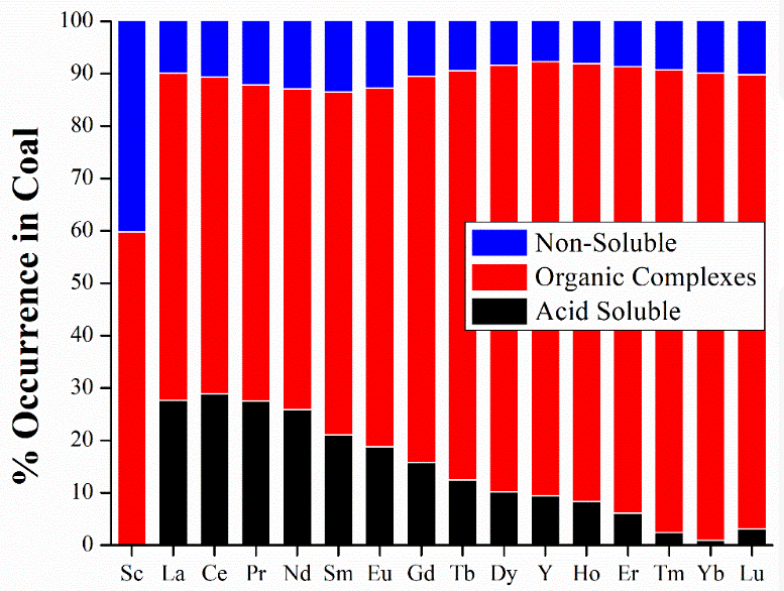
Presentation Overview

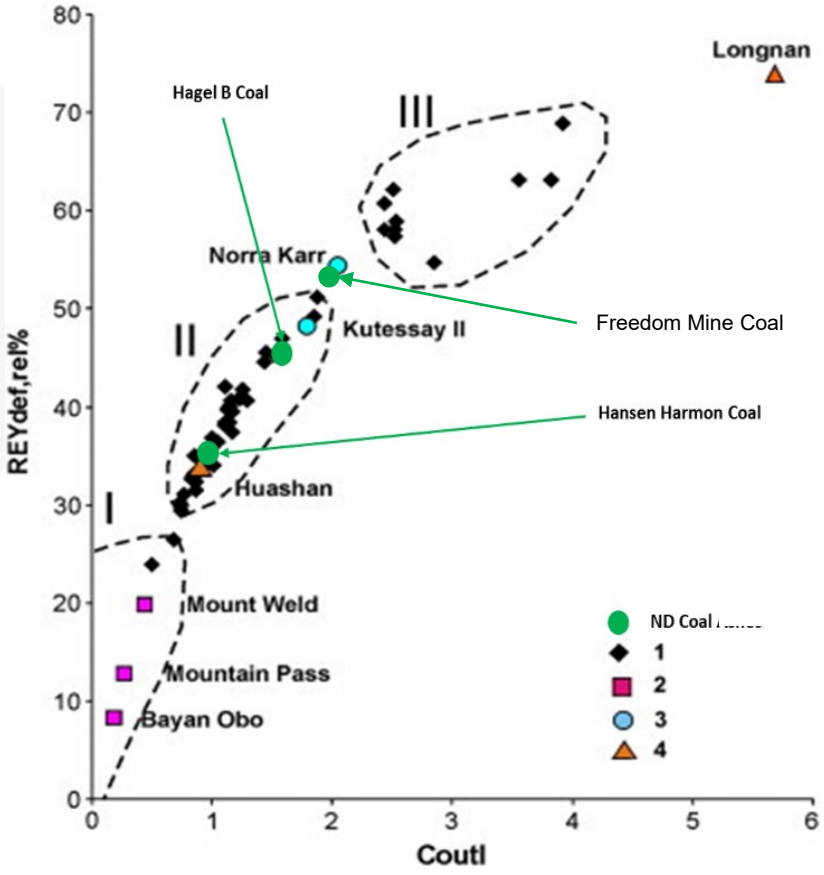
- Technology and Project Background
- Project Objectives and Scope
- Accomplishments to Date
- Project Next Steps
- Questions

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



Lignite Background - REE



Modified from Seredin and Dai, 2012

- Lignite often identified with high HREE/LREE ratios
  - Economically favorable distributions for usage
- Process developed produces other CM
  - High-value Ge and Ga concentrates

Project Objectives

- 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
    - Utilizing at least 500 kg/hr coal input and producing 50-100 grams/hr of REO concentrate
  - Economic and environmentally-friendly extraction of REEs from coal

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

Accomplishments Completed

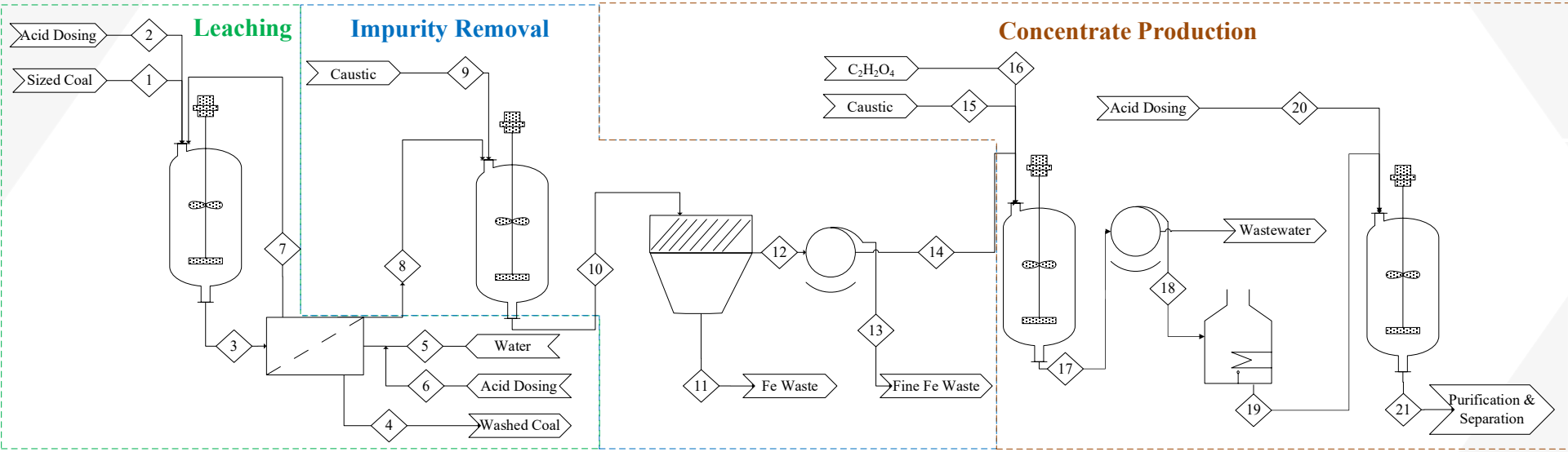
- Pilot Design Study
- Preliminary Feasibility Study
- Coal Acquisition
- Procurement of Pilot Components
- Development of Control Software
- Bench Testing Progress
- MREO Concentrate Purification

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

Pilot Design – PFD

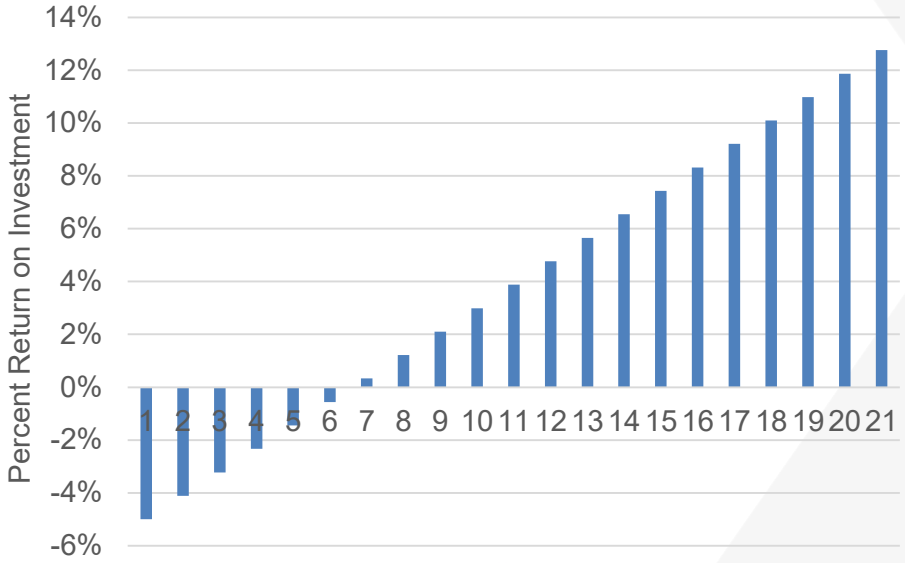
- Three major process steps (after coal handling)
  - Leaching of REE/CM
  - Removal of Impurities from liquid
  - Recovery of REE/CM into solids



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
  - Produces up to 25 tons/yr of REE concentrate

- Utilizes data from bench-scale data (DE-FE0027006)
  - REE Recovery
  - Consumable Usage



Coal Acquisition

- Blended, cleaned coal basis utilized for process feed
  - Blend of TREE-rich coal and HREE-rich coal seams
  - Coal spiraling utilized as coal cleaning process to remove mineral-rich tailings
- Up to 150 tons of >300 ppm material gathered to date on cleaned-coal basis

Procurement of Pilot Components

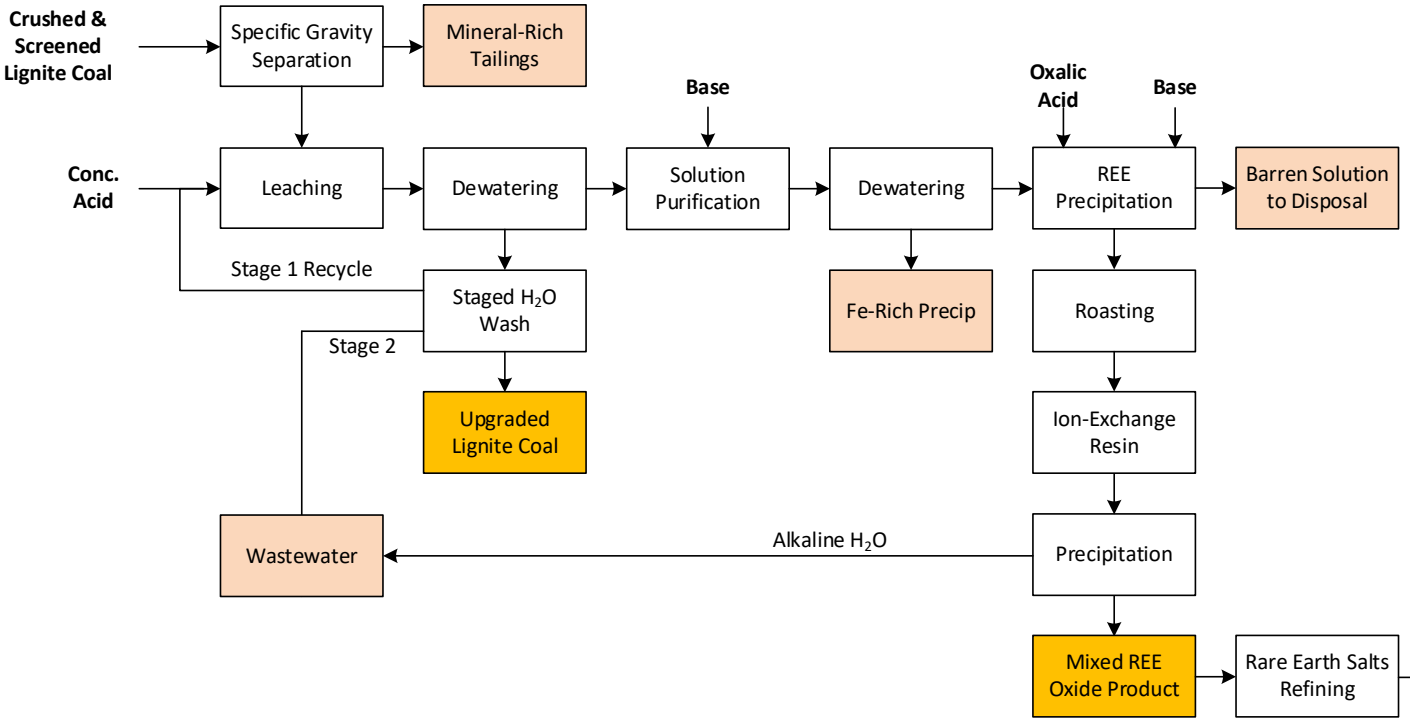
- All major pilot components purchased, some components awaiting delivery
  - Received:
    - Tanks, Mixers, and VFDs
    - Pumps, VFDs, and Piping and Valving
    - Conveyors, air blowers, and cyclones
    - Coal handling system (completed)
    - Coal spiral
    - Control system, sensors, and wiring components
  - Waiting on delivery
    - Leached coal filter presses (May 2021)
    - Filter bag housings for polishing (May 2021)

Control Software for Pilot

- Utilizing National Instruments LabVIEW™ software
  - Contains >20 PID control loops
    - To be tuned during commissioning
  - Utilizes over 200 independent variables
  - Developed with process area emergency shutdowns
    - Includes plant-wide shutdown
  - Able to successfully manage all programming with less than 100 ms delay

Bench Testing – Parametric

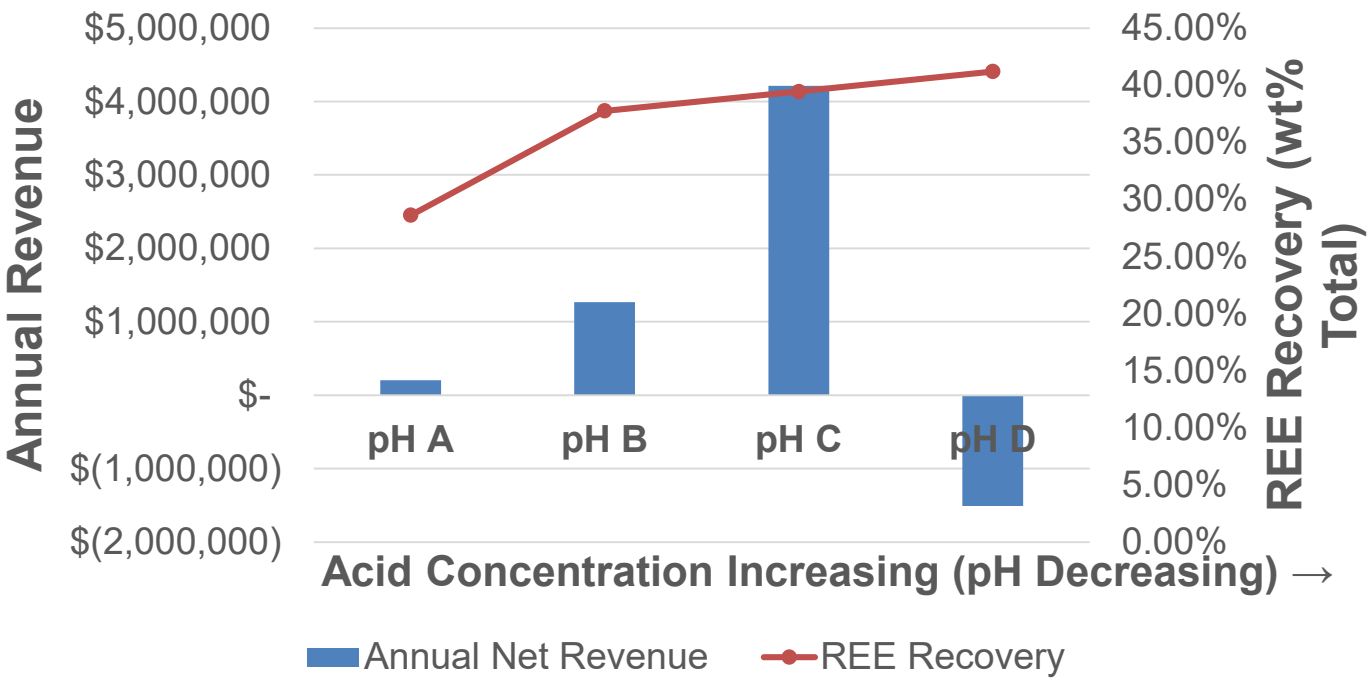
- Testing:
  - Chemical and physical operating parameters
    - Coal size
    - Leaching pH
    - Base type and concentration targets
    - Oxalic acid dosage
    - Use of seed crystals



Parametric Results – Leaching pH

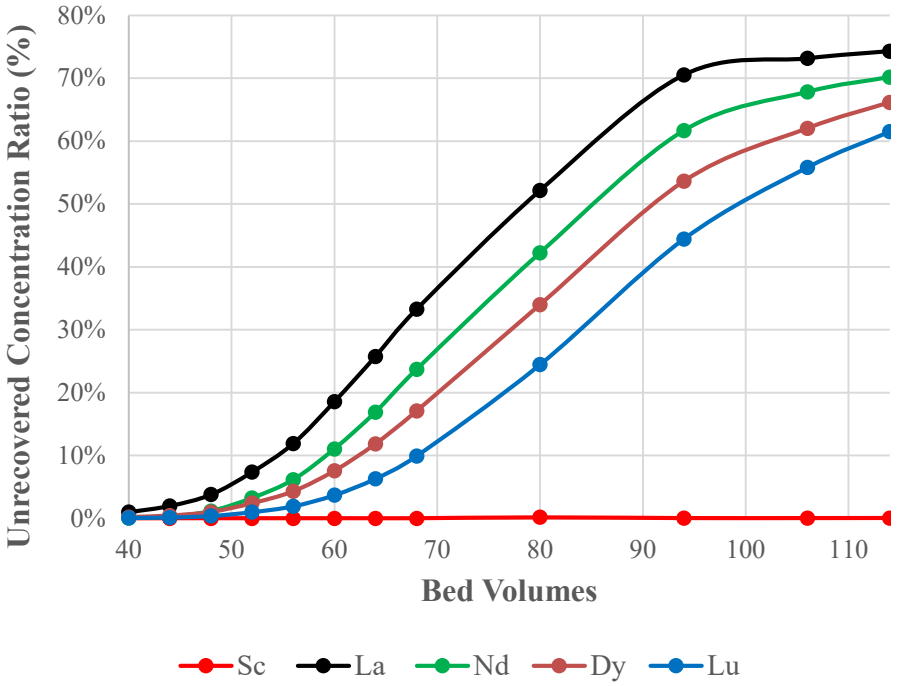
- Moderate pH (not lowest nor highest, identified as optimal point
  - Includes significant Sc leaching from B to C
  - Further REE recovery at expense of acid, base consumption

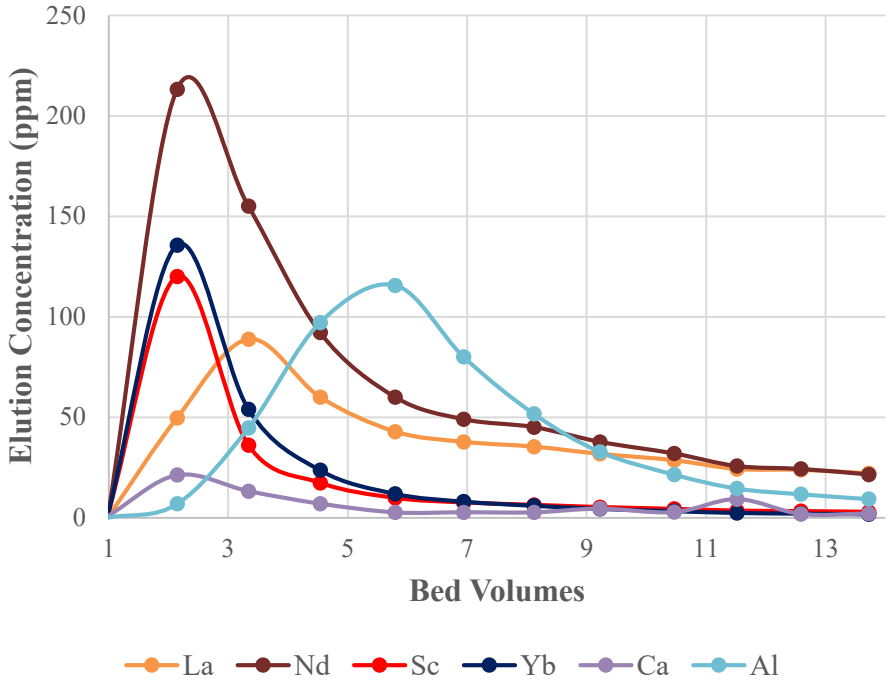
Note – Ce removal process added, limiting recovery



MREO Concentrate Purification

- Firing, dissolving, and separating impurities from ~65% pure concentrate using ion exchange resins
  - IDA and AMP resins chosen from ~10 options
  - Selective stripping using Na_2CO_3 for REE
  - Can produce ~85% pure (cation basis) REO concentrate
  - Ce excluded by firing to tetravalent form, insoluble in dissolution step





Project Next Steps

- Bench-Scale parametric and production testing
- Pilot Construction, Commissioning, and Testing
- MREO Concentrate Separation at RES
- Feasibility Study Update

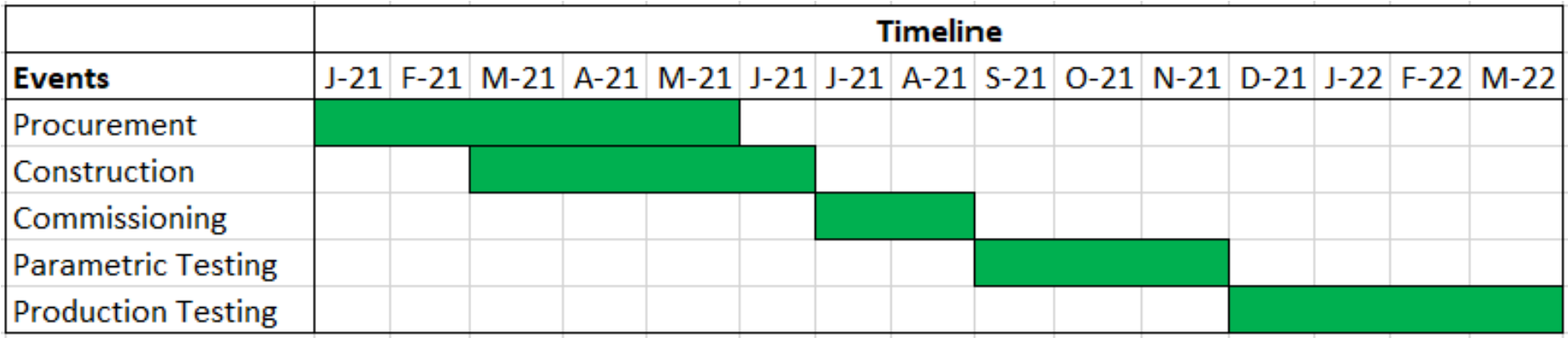
Bench-Scale – Testing

- Complete testing of parameters for remainng process steps
  - Impurity Removal
    - Base Type
    - pH
  - REO Concentrate Production
    - Oxalic Acid Concentration
    - Seed Crystal Dosage

- Bench-Scale Production Testing – 0.5 tons of coal blend
  - Anticipated completion – August 1st, 2021

Pilot Schedule

- Pilot system anticipated to be complete for testing by September, 2021
  - Will include PID loop tuning, safety checks, and personnel training
  - 24-hr testing, with week-on/week-off scheduling planned
    - Parametrics to use 2-3 day-weeks, production of 5 day-weeks



Pilot Construction

- Coal handling systems have been constructed for the plant, including staged crushing
  - Topsize of 1/8”, with fines rejection (by cyclone) of -150 US Mesh
  - Able to crush up to 5 tons/hr
- Other construction to begin upon final equipment delivery

Pilot Commissioning

- Upon construction, “cold” commissioning to start
  - Without chemical additions (acids/bases)
  - Needed to tune flow PID loops for tank level control, estimate filter times
  - Leak-check all pipelines and determine flowability problems (using slurries)

- “Hot” commissioning
  - Addition of acids/bases to tune respective PID controls
  - Gather preliminary data on processing and effective residence times of the system

Pilot Parametric Testing

- Utilizing >300 ppm blended lignite feed
  - Brief parametric testing based on results of bench-scale testing
    - Only choose optimal point and one other (closest economic point) for each process area
    - Focus on unit ops of greatest impact (largest economic difference per unit change)
  - Further trains personnel on pilot operation and handling
    - Reduces personnel risks with production testing, where majority of >300 ppm coal will be utilized

Pilot Production Testing

- Production testing aimed at producing at least 15 kg of MREO concentrate at a purity of >85-90%
  - Can produce as much as 6-8 kg of REE's per 24-5 week, assuming stable operation
  - Determination of data required for AACE Class 4-3 study for future economic preparation
    - Including pilot-scale ZLD wastewater treatment plant to evaluate for scale-up

MREO Separation

- At least 10-15 kg of MREO concentrate to be delivered to partner RES for inter-lanthanide separation
  - Major element targets of Sc, Pr, Nd, Dy, and Tb
  - Goals to produce 99+% pure individual oxides of all target elements by end of project (July 2022)
    - Bench-scale processing of UND-based concentrates underway with ~25 grams of concentrate delivered

Feasibility Study Update

- Complete project with TEA and Feasibility Study update based upon pilot data and estimate refining costs
  - Include sections on potential lignite resources identified over the course of the project
  - Include environmental costs and impacts of the plant/project based upon pilot data
  - Furnish in NI-43-101 Preliminary Economic Assessment (PEA) format for industrial release
    - May not meet exact legal requirements of NI-43-101 PEA

Summary

- Pilot design and preliminary HMB/economic modeling complete for testing purposes
- Pilot procurement near-complete, with testing start aimed for September 1st, 2021
- MREO Separation to pure lanthanides underway at RES with bench-materials
  - To be combined with bench and pilot production testing products

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Questions?

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