Development of Novel Sintered Carbon Ore Building Materials

DE-FE0032083

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U.S. Department of Energy

National Energy Technology Laboratory
Resource Sustainability Project Review Meeting
October 25 - 27, 2022

Outline

- Project Overview
- Technology Background
- Technical Approach and Project Scope
- Progress and Current Status of Project
- Plans for Future Testing, Development, and Commercialization
- Summary

Project Overview

- Total project cost: $649,407
- DOE: $517,702
  - Award No. DE-FE0032083
- Cost share: $131,705
  - MTI: $10,200
  - UND: $16,505
  - NACC: $42,500
  - NDIC: $62,500

Project Overview

- Period of Performance: 10/01/2021 through 09/30/2023
- Develop value-added products from carbon ore
- Carbon ore building materials will contain ≥70 wt.% carbon and ≥51 wt.% of carbon from carbon ore
- Demonstrate the ability to produce Sintered Carbon Ore Building Materials (SCBM)
- Ultimately to produce 5-10 bricks per day
- Complete a Technical and Economic Analysis (TEA), a Technology Gap Analysis, and a Life Cycle Analysis (LCA) on the SCBM process
- Create a conceptual design of a carbon-based building using LIG2 products

Technology Background

- The primary product of SCBM technology will be producing LIG2 standard bricks
  - With capability to brick veneer, CMU's, insulation, and others
  - Appearance of these materials can be modified to add aesthetic value
- Based on the sintering of lignite carbon-ore particles with additive at relatively low temperatures in an inert atmosphere
- During heating, the pyrolyzed carbon-ore and additive interact as a result of sintering with a reactive liquid phase
- Laboratory compressive strength measurements show this technology can produce carbon-ore composites with strengths exceeding the ASTM requirements for various types of brick[1]

[1] - "Specifications for and Classification of Brick," The Brick Industry Association, Oct-2007.

Technology Background

- Builds on past work conducted by Microbeam and UND (Gupta)
  - Showing carbonaceous foams can be designed using controlled pyrolysis
  - Tailorable properties
  - Addition of biofibers enhanced the mechanical strength
  - Properties of low ranked carbon-ore and waste carbon-ore
- UND and MTI have performed laboratory-scale testing and analysis on sintered carbon-ore and additive blends
- Scanning electron microscopy (SEM) analysis of samples show that the carbon-ore particles are well-bonded to the additive binder

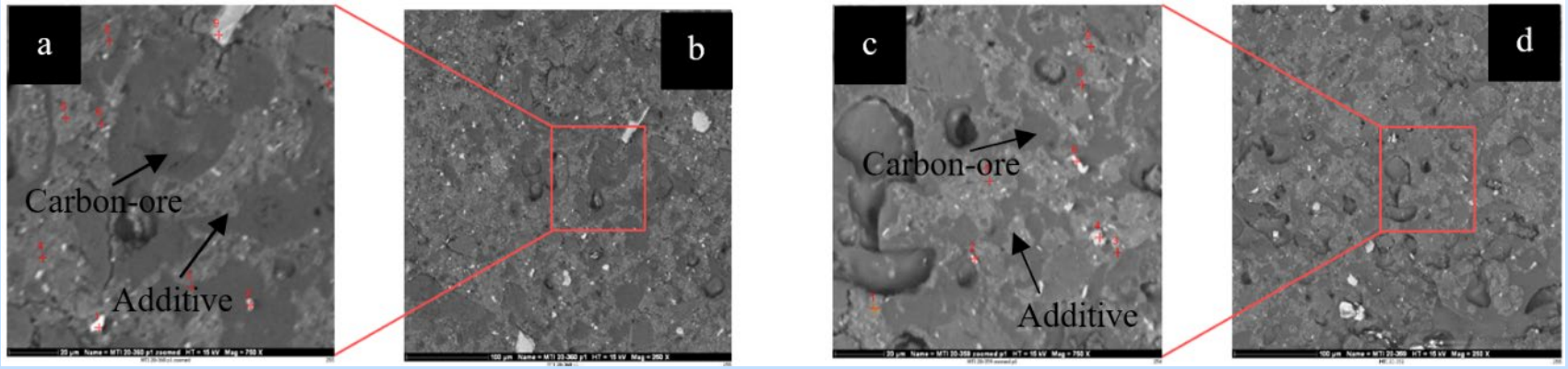


Figure 1: SEM micrographs of (a-b) Cleaned carbon-ore (50 wt.%)-additive (50 wt.%), (c-d) carbon-ore (75 wt.%)-additive (25 wt.%) after sintering in inert environment.

Technology Background

- Technical and/or economic advantages:
  - Low temperature production
  - Low environmental impact
  - Low-cost fabrication
  - Easily tailorable properties
  - Flexible manufacturing
  - High performance
  - Direct use of coal in product
  - Utilizes ND lignite
  - Can utilize REE extracted lignite or waste lignite
- Technical and/or economic challenges:
  - Initial bench scale development
  - Limited domestic sources of required additive
  - Feedstock prices and availabilities are highly dependent on global energy prices

Technical Approach/Project Scope

- Project Scope of Work
  - **Task 1:** Project Management and Reporting
  - **Task 2:** Feedstock Procurement
  - **Task 3:** Production of Building Materials
  - **Task 4:** Product Testing and Analysis
  - **Task 5:** Technical and Economic Assessment
- Success Criteria
  - Demonstrate the ability to successfully sinter carbon-ore to produce value-added carbon products and high strength building materials
  - Demonstrate the ability to produce 5-10 bricks/day
  - Complete a TEA, LCA, and conceptual design showing potential for technology to be profitable for the lignite industry

Technical Approach/Project Scope

Perceived Risk	Risk Rating (Low, Med, High)			Mitigation/Response Strategy
	Probability	Impact	Overall	
Financial Risks:				
Cost of Materials	Low	High	Low	Review cost of materials and identify alternatives as needed.
Underestimate level of effort required to complete the work	Low	High	Med	Continually track costs and schedule.
Cost Schedule Risks:				
Cost tracking	Low	High	Low	Assign responsibility for managing cost. Dedicated program resource manager for project management. Utilization of Project cost tracking system.
Technical Scope Risks:				
Availability of additive bonding materials	Low	High	Low	Project team has identified multiple sources of additive materials for additive bonding materials.
Operational consistency during testing	Medium	Medium	Medium	Work with plant operations and carbon ore delivery to maintain optimum test conditions to ensure quality data is obtained.
Management Planning and Oversight Risks:				
Equipment Availability	Medium	High	Medium	All equipment and sources of equipment to be purchased have been identified. Current supply chain delays will be monitored and may cause delays in receipt of equipment. Equipment will be purchased as soon as possible to mitigate any potential issues.
ES&H:				
Volatile organic compound release	Low	Low	Low	All gases and volatiles released during sintering will be released into a hood.

Technical Approach/Project Scope

Task / Subtask Number	Milestone Description	Planned Completion Date	Verification Method
✓ 1.1	Project Management Plan	10/31/2021	PMP File
✓ 1.1	Project Kick-off meeting	12/30/2021	Kick-off slides
1.1	Final Report	9/30/2023	Final Report File
✓ 1.2	Technology Maturation Plan (TMP)	12/30/2021	Initial TMP File
1.3	Workforce Readiness Plan (WRP)	9/30/2023	WRP File
✓ 1.4	Summary of Environmental Justice Considerations	12/30/2021	Initial Summary File
✓ 1.5	Summary of Economic Revitalization and Job Creation Outcomes	12/30/2021	Initial Summary File
✓ 1.6	Environmental, Safety, and Health Analysis	12/30/2021	Initial Summary File
✓ 1.7	Safety Management Plan (SMP)	10/31/2021	SMP File
✓ 2.0	Feedstock Procurement Report	12/31/2021	Quarterly Report
✓ 3.0	Identification of Optimum Processing Conditions	4/30/2022	Quarterly Report
4.0	SCBM Testing and Analysis Report	9/30/2023	Attachment to Final Report
5.1	Technical and Economic Assessment	9/30/2023	Attachment to Final Report
5.2	Technology Gap Analysis	9/30/2023	Attachment to Final Report
5.3	Conceptual Design	9/30/2023	Attachment to Final Report
5.4	Life Cycle Analysis	9/30/2023	Attachment to Final Report

Progress and Current Status of Project

- Equipment utilized in this project include:
  - Custom LIG2 brick die
  - Baker electric furnace
  - 100 Ton Redline hydraulic press
  - SWECO Vibro-energy grinding mill
  - Gilson jar mill and mixing accessories
  - Gilson vibratory sieve shaker
  - Laboratory supplies

Gilson vibratory sieve shaker

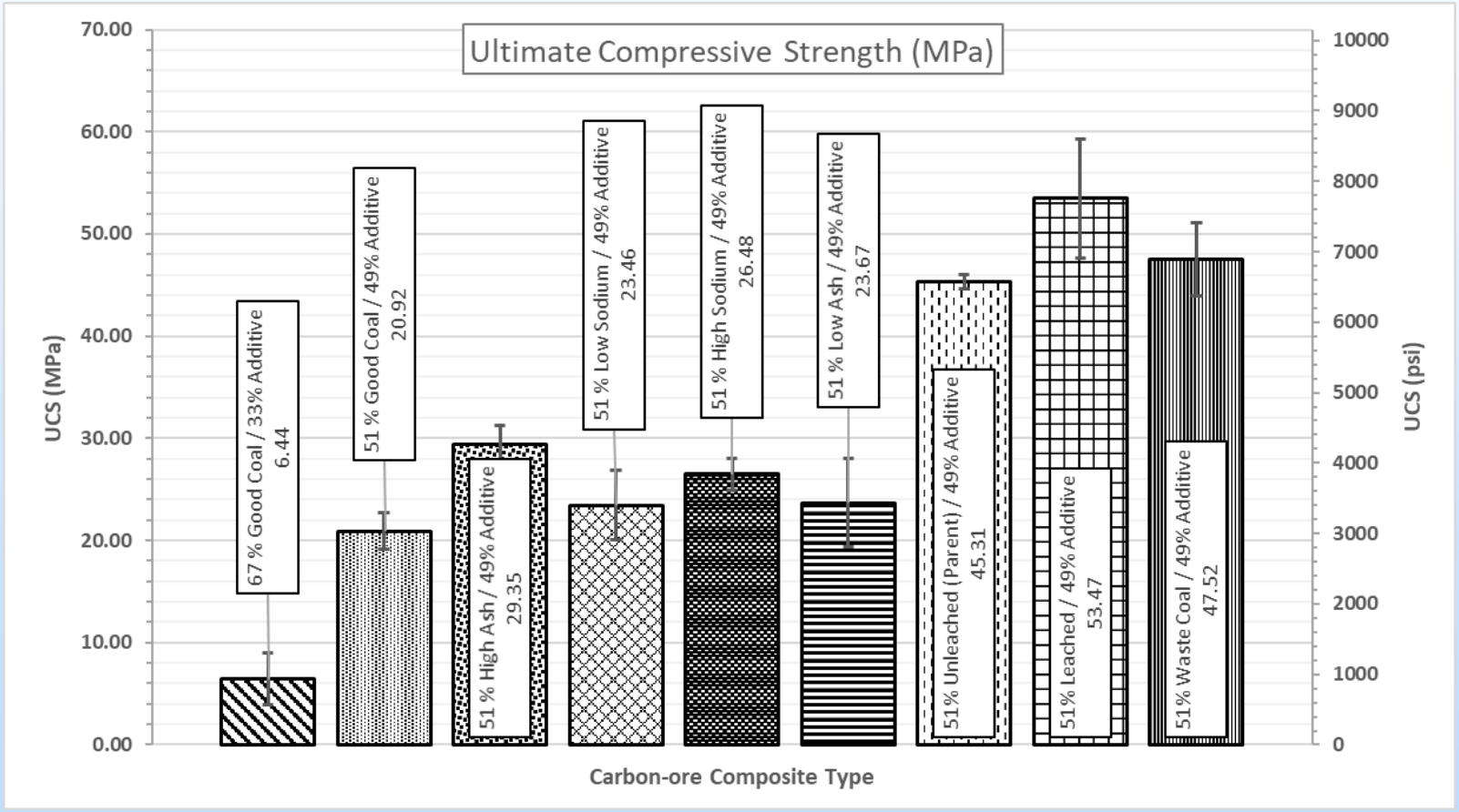
Gilson jar mill and mixing accessories

Gilson jar mill and mixing accessories

Baker electric furnace

Progress and Current Status of Project

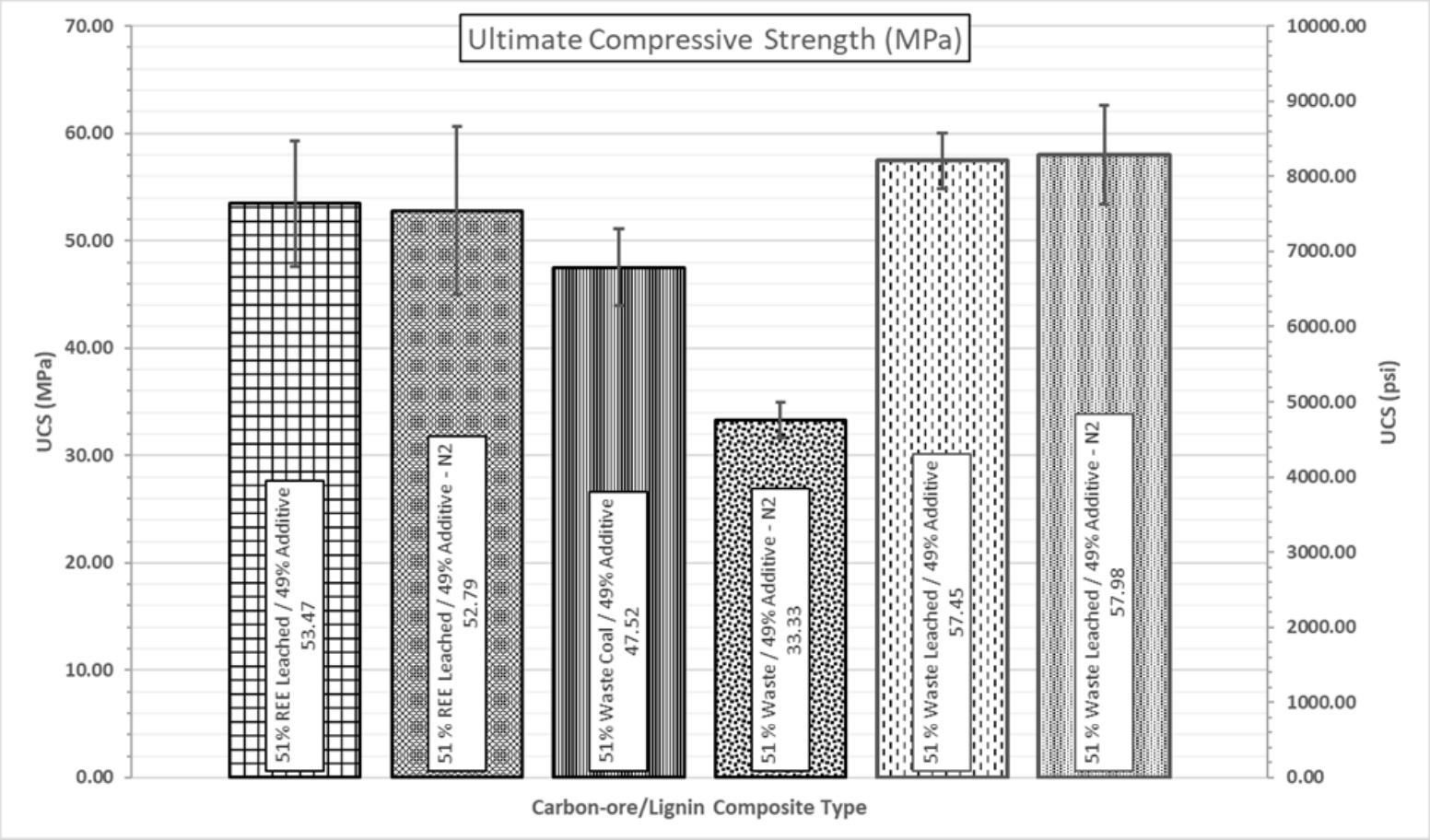
- Ultimate Compressive Strength



***ASTM C 62 SW compressive strength requirement for building brick = 20.7 MPa**

Progress and Current Status of Project

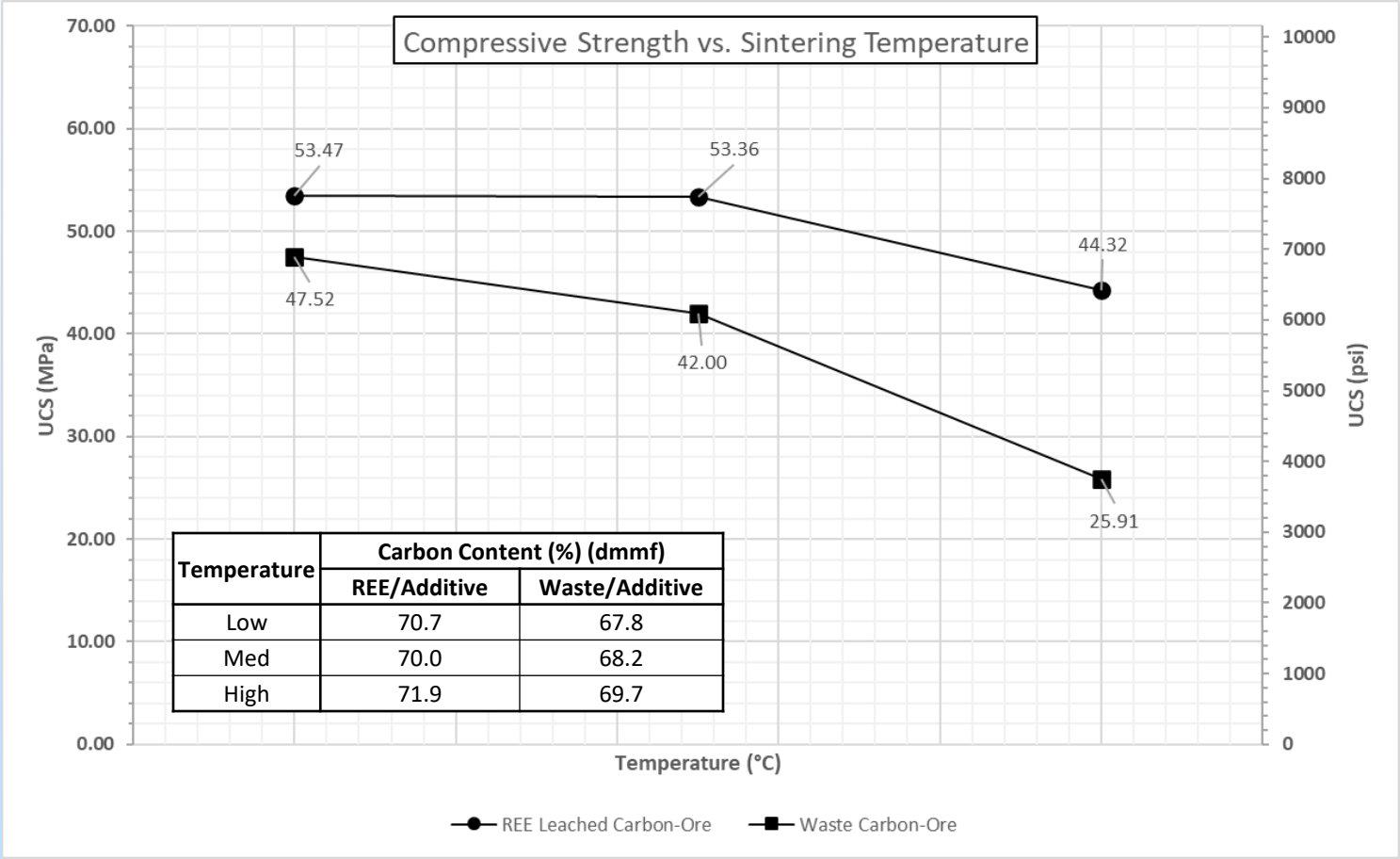
- Ultimate Compressive Strength and Atmosphere



***ASTM C 62 SW compressive strength requirement for building brick = 20.7 MPa**

Progress and Current Status of Project

- Compressive Strength vs. Sintering Temperature

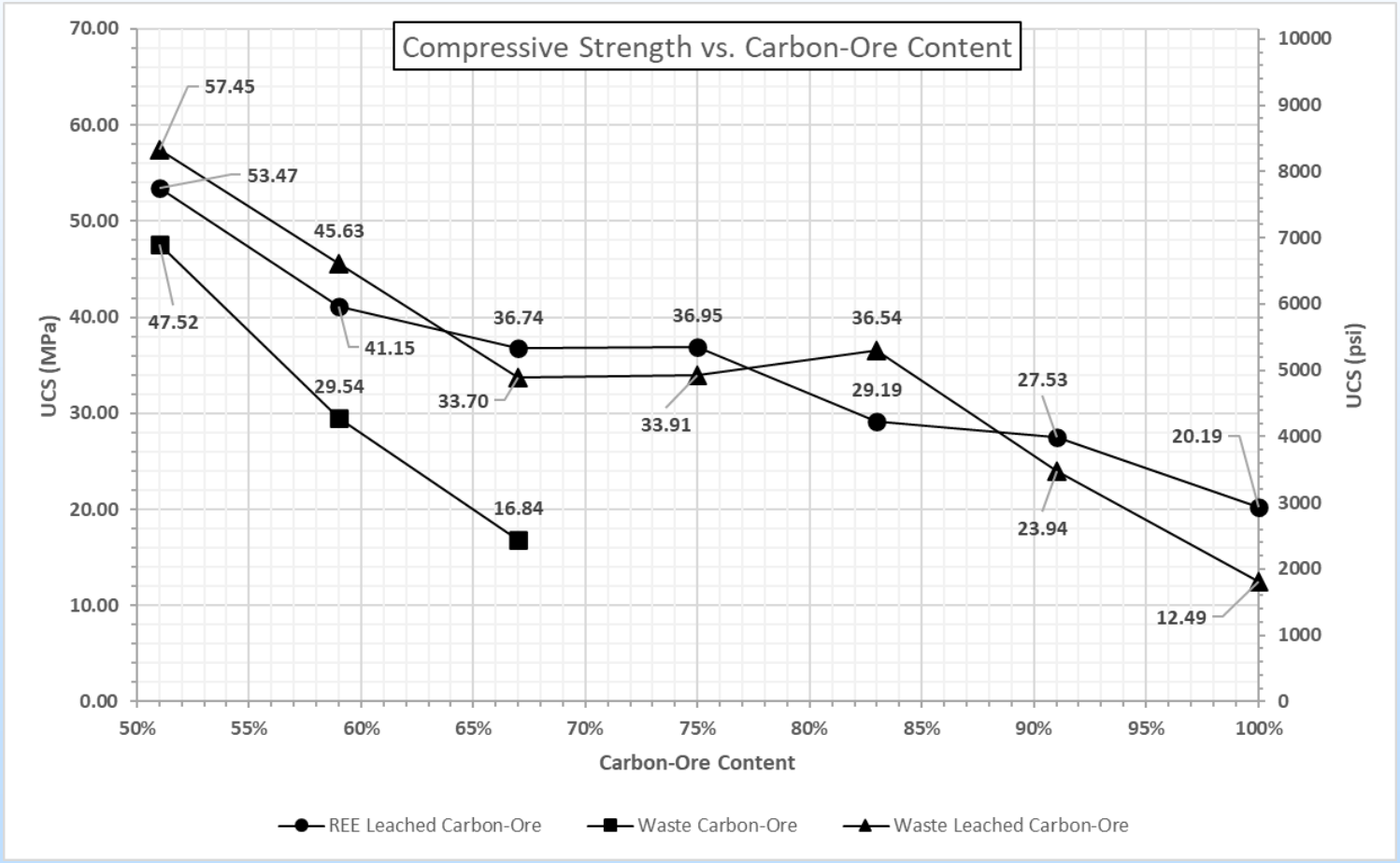


Temperature	Carbon Content (%) (dmmf)	
	REE/Additive	Waste/Additive
Low	70.7	67.8
Med	70.0	68.2
High	71.9	69.7

***ASTM C 62 SW compressive strength requirement for building brick = 20.7 MPa**

Progress and Current Status of Project

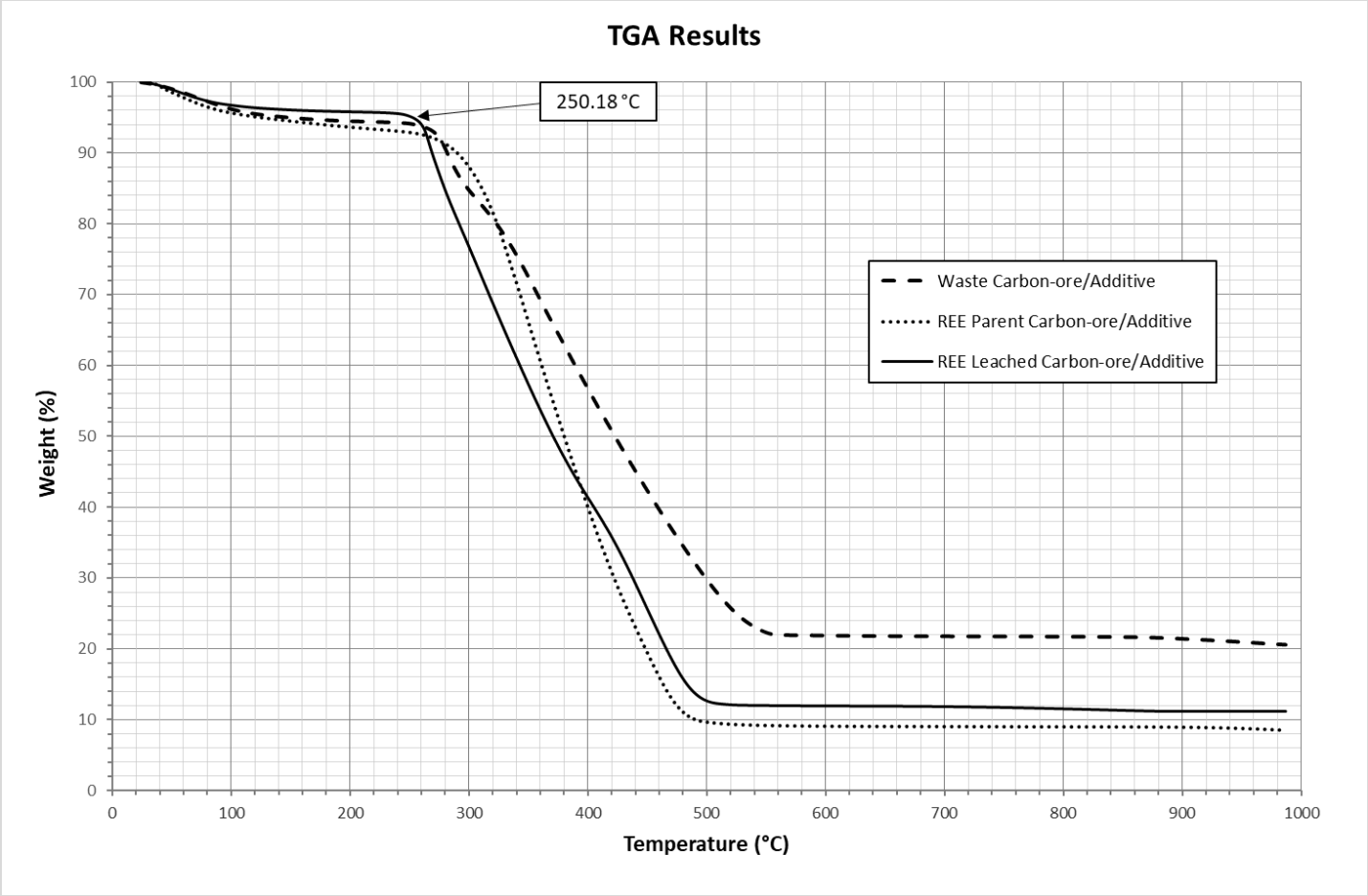
- Compressive Strength vs. Carbon-Ore Content



***ASTM C 62 SW compressive strength requirement for building brick = 20.7 MPa**

Progress and Current Status of Project

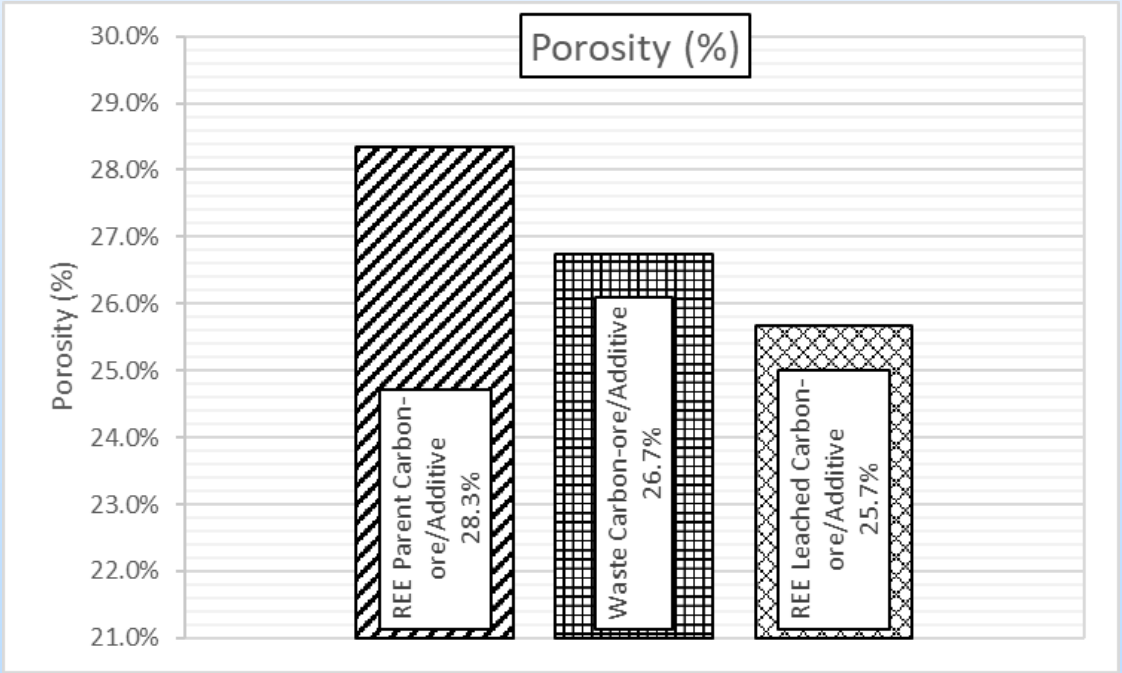
- Thermogravimetric Analysis



Progress and Current Status of Project

- Density and Porosity Analysis

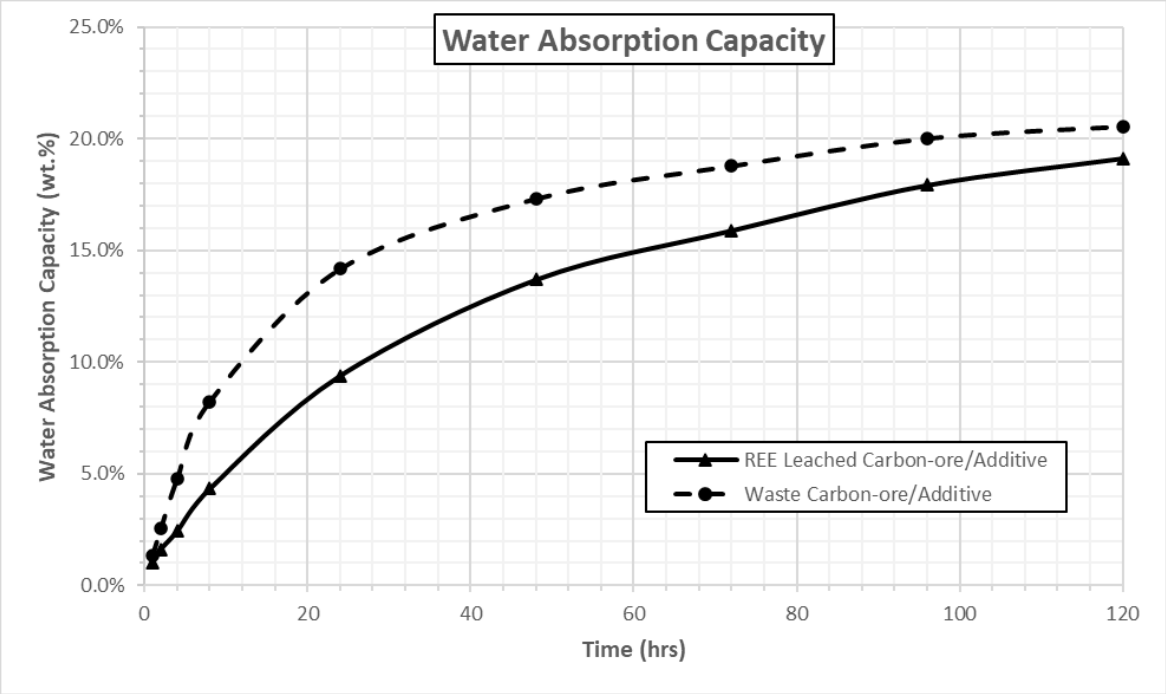
Sample Type	Pycnometry Density (g/cc)	Apparent Density (g/cc)	Porosity (%)
REE Parent Carbon-ore/Additive	1.563	1.120	28.3%
Waste Carbon-ore/Additive	1.635	1.198	26.7%
REE Leached Carbon-ore/Additive	1.543	1.147	25.7%



Progress and Current Status of Project

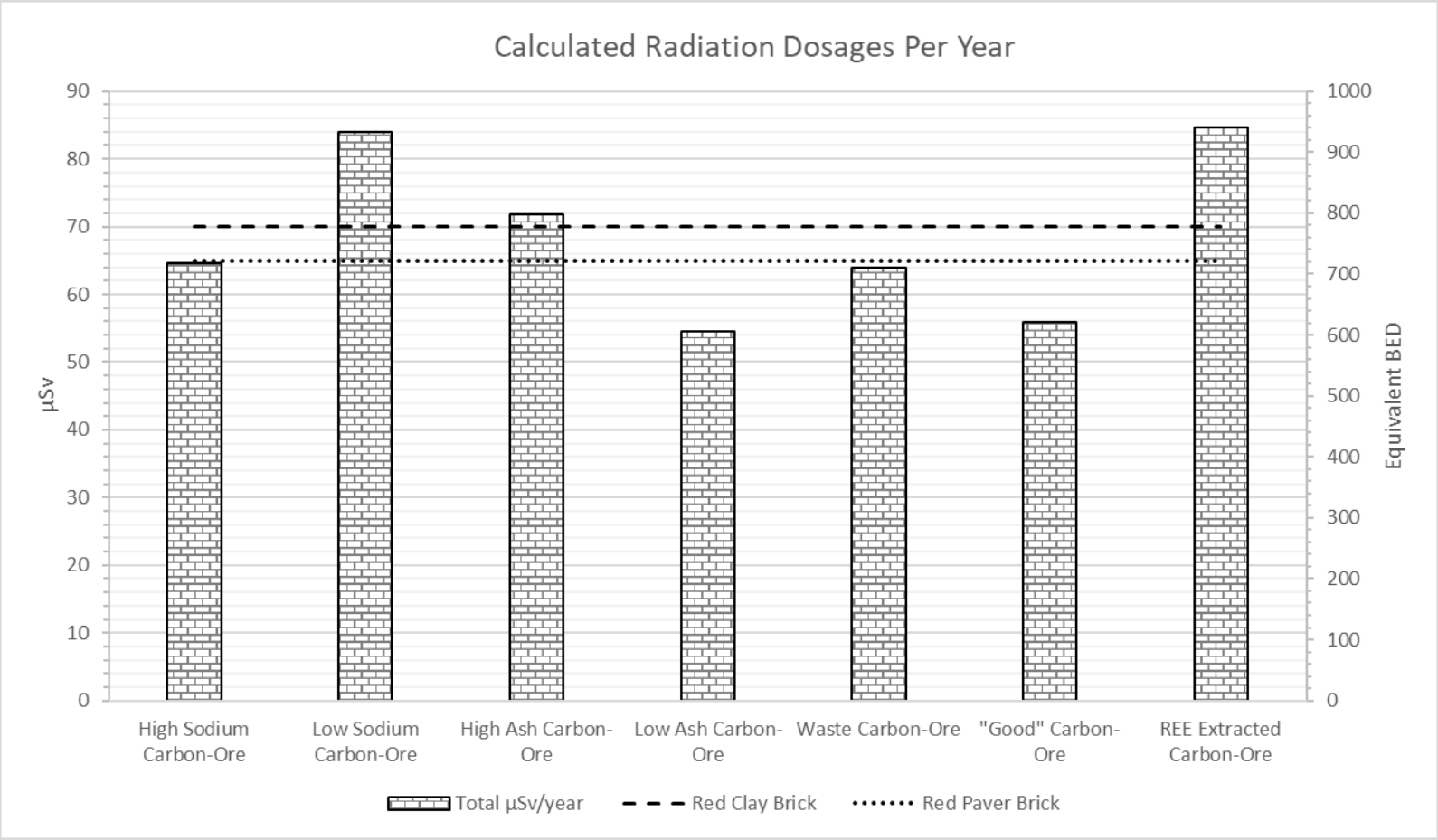
- Water Absorption Analysis

Time (hrs)	REE Leached Carbon-ore/Additive	Waste Carbon-ore/Additive
1	1.03%	1.37%
2	1.63%	2.53%
4	2.43%	4.77%
8	4.33%	8.23%
24	9.40%	14.17%
48	13.70%	17.30%
72	15.90%	18.77%
96	17.93%	20.00%
120	19.13%	20.53%



Progress and Current Status of Project

- Health and safety testing and analysis



Progress and Current Status of Project

- Preliminary LIG2 brick manufacturing

Preliminary pre-sintered LIG2 brick (left), and post-sintered LIG2 brick (right). Second attempt of LIG2 brick fabrication.

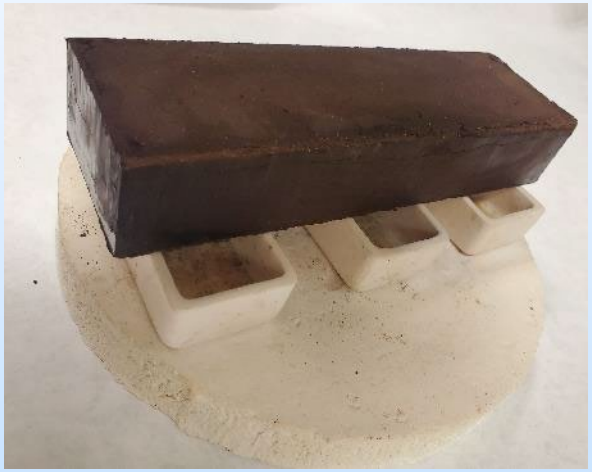
Progress and Current Status of Project

- Preliminary LIG2 brick manufacturing

Preliminary pre-sintered and post-machined LIG2 brick (left), and post-sintered LIG2 brick (right). Third attempt of LIG2 brick fabrication.

Progress and Current Status of Project

- Preliminary LIG2 brick manufacturing
  - 10 total attempts thus far



Preliminary pre-sintered LIG2 brick (left), post-drying (middle), and post-sintered LIG2 brick (right). 9th attempt of LIG2 brick fabrication.

Progress and Current Status of Project

- Performance levels achieved thus far include:
  - Develop value-added products from carbon ore
  - Carbon ore building materials will contain ≥70 wt.% carbon and ≥51 wt.% of carbon from carbon ore ✔
  - Demonstrate the ability to produce Sintered Carbon Ore Building Materials (SCBM) ✔
  - Ultimately to produce 5-10 bricks per day
  - Complete a Technical and Economic Analysis (TEA), a Technology Gap Analysis, and a Life Cycle Analysis (LCA) on the SCBM process
  - Create a conceptual design of a carbon-based building used LIG2 products ✔
- Economic and technical advantages of project performance:
  - Environmentally friendly
  - Economically affordable
  - High Performance

Progress and Current Status of Project

- Synergy opportunities of this project include:
  - "Rare Earth Element Extraction and Concentration at Pilot-Scale from North Dakota Coal-Related Feedstocks" DE-FE0031835
  - "Production of Germanium and Gallium concentrates for Industrial Processes" DE-FE0032124

Plans for Future Testing/Development/ Commercialization

- In this project:
  - Tribology
  - Thermal conductivity and expansion
  - Flexural strength
  - Full-scale compressive strength
- After this project:
  - Pilot scale production
  - Building code compliance evaluation and certification
  - Design and construction of LIG2 brick building
- Commercial scale-up potential:
  - Scale-up and identification of mass-production pathways
  - Identification of target markets and fit-for-use production
  - Marketing and securement of preliminary contracts
  - Design, construction, and operation of commercial facility

Outreach and Workforce Development Efforts/Achievements

- Outreach
  - Public news release[2]
- Workforce Development
  - Provided training to produce sintered carbon-ore building materials (SCBM) samples for employees at MTI and postdoc, graduate, and undergraduate students at UND
  - Provided opportunities for individual study in materials science, carbon-ore and biomass processing, manufacturing, and characterization techniques

[2] "Grand Forks-based company awarded $499K from U.S. energy department to use coal as building materials", Grand Forks Herald, https://www.grandforksherald.com/business/grand-forks-based-company-awarded-499k-from-u-s-energy-department-to-use-coal-as-building-materials, June 2021.

Summary Slide

- The SCBM technology is a groundbreaking technology that demonstrates that lignite coal particles can be successfully sintered at relatively low temperatures to produce a high-strength building material
  - Laboratory findings have shown SCBM's to exceed ASTM brick requirements for compressive strength
  - Capable of producing products that meet or exceed building materials requirements while maintaining ≥70 wt.% carbon and ≥51 wt.% carbon coming from carbon-ore
  - Demonstrate the technical and economic flexibility of the SCBM technology
- Will continue development and refinement of scale-up LIG2 brick production
- SCBM technology can valorize waste and REE extracted carbon-ores providing value-added opportunities for the carbon-ore industry

Acknowledgements

- DOE/NETL
  - Project Manager: Mark Render
- University of North Dakota
  - Dr. Surojit Gupta
  - Dr. Jin Zhang, Mackenzie Geigle, Tim Fah, Caleb Matzke
  - Nolan Theaker
- North American Coal Corporation
  - Gerard Goven
- North Dakota Industrial Commission/Lignite Energy Council
  - Mike Holmes

Thank You

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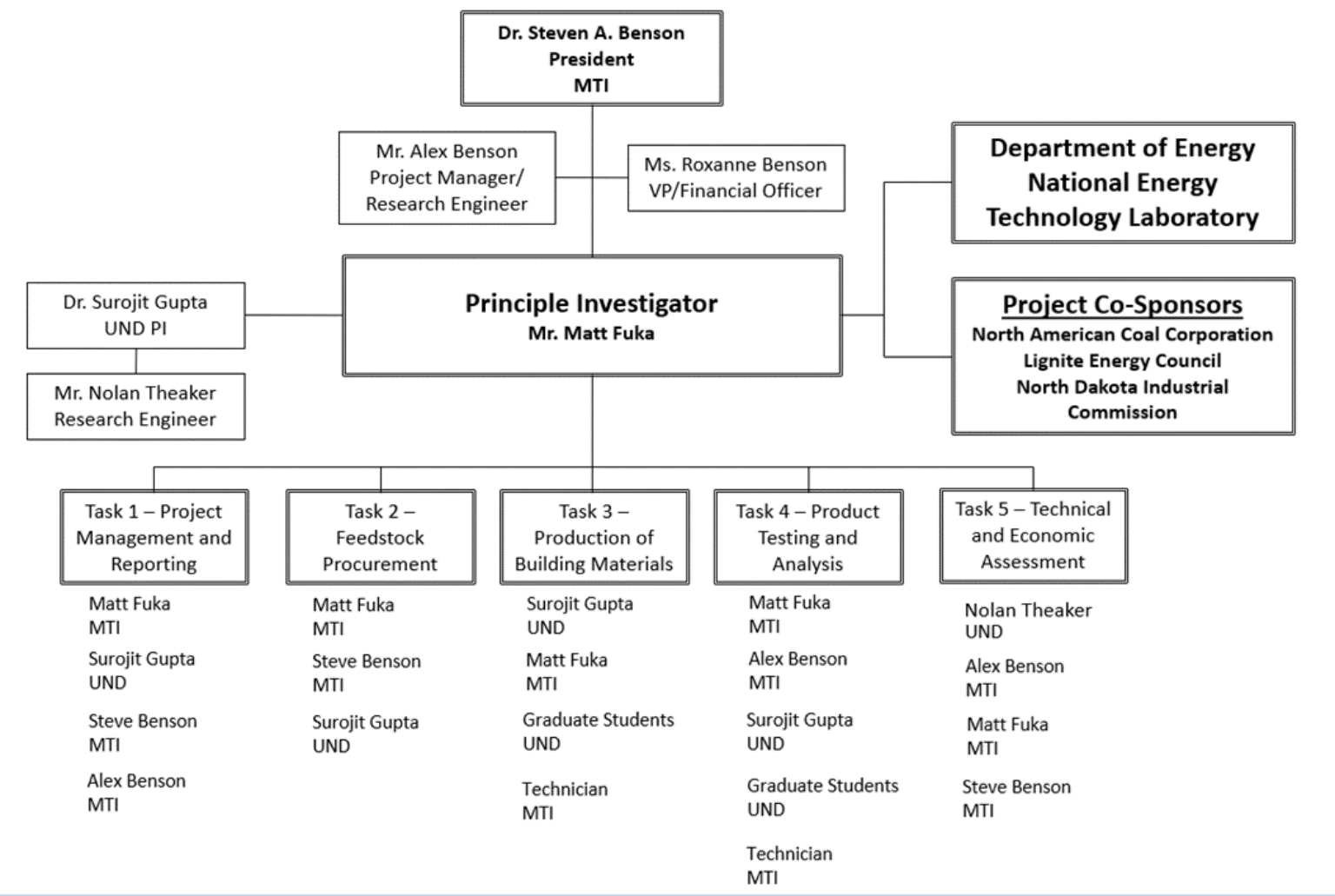
Appendix

Organization Chart

- Project Team:
  - Microbeam Technologies Inc. (Lead)
  - University of North Dakota
- Support From:
  - U.S. DOE/NETL
  - North American Coal Corporation
  - North Dakota Industrial Commission/Lignite Energy Council

Organization Chart



Gantt Chart

Task/Subtask Name	Start Date	End Date
Task 1 – Project Management and Reporting	10/1/2021	9/30/2023
Milestones		
Project Management Plan (PMP)		10/31/2021
Project Kickoff Meeting		12/30/2021
Technology Maturation Plan (TMP)		12/30/2021
Workforce Readiness Plan (WRP)		9/30/2023
Summary of Environmental Justice Considerations		12/30/2021
Summary of Economic Revitalization and Job Creation Outcomes		12/30/2021
Environmental, Safety, and Health Analysis		12/30/2021
Safety Management Plan (SMP)		10/31/2021
Final Report		9/30/2023
Task 2 – Feedstock Procurement	10/1/2021	12/31/2021
Milestones		
Feedstock Procurement Report		12/31/2021
Task 3 – Production of Building Materials	11/1/2021	7/31/2023
Subtask 3.1 – Equipment Set-up	11/1/2021	12/1/2022
Subtask 3.2 – Optimization of Processing Conditions	12/1/2021	4/30/2022
Subtask 3.3 – Production of Testing Quantities	5/1/2022	7/31/2023
Subtask 3.4 – Identification of Commercializable LIG2 Products	4/1/2022	4/30/2022
Milestones		
Identification of Optimum Processing Conditions		4/30/2022
Task 4 – Product Testing and Analysis	12/1/2021	7/31/2023
Subtask 4.1 – Phase Analysis and Mechanical Testing	1/1/2022	4/30/2023
Subtask 4.2 – Scanning Electron Microscopy (SEM) Analysis	2/1/2022	5/31/2023
Subtask 4.3 – Durability Analysis	4/1/2022	7/31/2023
Subtask 3.4 – Identification of Candidate LIG2 Products	7/1/2022	7/31/2023
Milestones		
LIG2 Testing and Analysis Report		9/30/2023
Task 5 – Technical and Economic Assessment	4/1/2022	9/30/2023
Subtask 5.1 – Techno-Economic Assessment	4/1/2022	5/31/2023
Subtask 5.2 – Technology Gap Analysis	6/1/2022	7/31/2023
Subtask 5.3 – Conceptual Design	7/1/2022	8/31/2023
Subtask 5.4 – Life Cycle Analysis of Products	8/1/2022	9/30/2023
Milestones		
Technical and Economic Assessment		9/30/2023
Technology Gap Analysis		9/30/2023
Conceptual Design		9/30/2023
Life-Cycle Analysis		9/30/2023