High-Performance Coal-Based Façade Panels and Architectural Components

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PROJECT OVERVIEW

Overview

- Funding
  - Federal = $498,700
  - Non-Federal = $125,342
  - Total Project = $624,042
- Period of Performance: 1/1/21-9/30/22
- Team Members
  - University of North Dakota Energy and Environmental Research Center (EERC)
  - Center for Applied Research and Technology (CART)

Project Objectives

1. To develop a process to produce rigid-board building panels using at least 55% by mass of coal-derived material (71% by mass of carbon) as filler in a new family of moldable inorganic resins.
2. To produce prototype quantities of Composite Rigid Board Insulation Panels (CRBIP) with dimensions at least 16” × 32” × 1” and of Architectural Composite Wall Panels (ACWP) / facade panels with dimensions ranging from 9” × 14” × ½” to 8” × 12” × ¾” or larger.
3. To demonstrate that the panels have better mechanical strength (three to five times higher flexural strength), lower weight (30-50% lighter), and significantly improved insulation (two to three times the R-value) compared to commercially used and certified building panels.
4. To conduct target market analysis for the coal-based X-MAT® Panels, including adjacent market applications for the technology, the potential volume of coal used at scale, the associated selling price(s), and a comparison of the competitive commercial products.
5. To execute a technology gap analysis to determine work required to scale up panel production and compare the value per ton of coal in the new process compared to using the coal as fuel.

TECHNOLOGY OVERVIEW

What are X-MAT Composites?

- Plastic and ceramic composite materials formed from raw powders mixed with our proprietary polymer derived ceramic (PDC)-forming resins
- Capable of using a variety of powdered materials in an “as-is” state
  - Coal – from Lignite to Anthracite
  - Coal Combustion Residuals (CCR) or Fly Ash
  - Coal by-products – GOB, Shale-coal
- Quick, Simple Fabrication - Particles are coated with resin then bonded together to make bulk parts
- Low-Pressure Molding at room temperature

How are X-MAT Composites unique?

- Our Polymer Derived Ceramic resins are tuned at the Atomic Level to contain varying amounts of silicon, oxygen and carbon or other elements
- Liquid resins not hazardous, cured resins UL94 V-0
- Use Raw Coal - Resin fully coats and encapsulates the filler particles
- Resin acts as binder between particles - no sintering needed
- X-MAT "Mix and Mold" Process is simple, scalable, and cost-effective - Single Batch Composite
- X-MAT ceramic composites won't burn despite having high coal content
- Low-cost inorganic resins + Coal $0.02-0.05/lb

TECHNICAL APPROACH/PROJECT SCOPE

Processes to Produce X-PANELS

For All X-PANELS

- Raw powdered coal was mixed with a customized ceramic forming polymer designed to bond to the coal. The ratio ranges from 65% to 75% coal to produce a “clay-like or damp sand” material
- The mixture was tamped into large trays and cured to 160-200°C in air for 2 hours.
- The cured material was removed from the trays and pyrolyzed in inert gas at 1000°C for 2-4 hours
- The ceramic/carbon ore composite material was then chain milled and sieved to produce < 600 micron ceramic/carbon ore engineered aggregate

Processes to Produce X-PANELS (Cont.)

For Ceramic X-PANELS

- The ceramic aggregate was mixed at a 75-80% ratio of aggregate to 20-25% ceramic forming resin
- The mixture was pressed or tamped into a panel mold and cured for 2 hours at 160-200°C
- The cured panel was de-molded and pyrolyzed in inert gas at 1000°C for 2-4 hours

For Resin Based X-PANELS

- The ceramic aggregate was mixed at a 75-80% ratio of aggregate to 20-25% high temperature inorganic resin
- The mixture was pressed or tamped into a panel mold and cured for 4 hours at 200-250°C

Processes to Produce X-PANELS (Cont.)

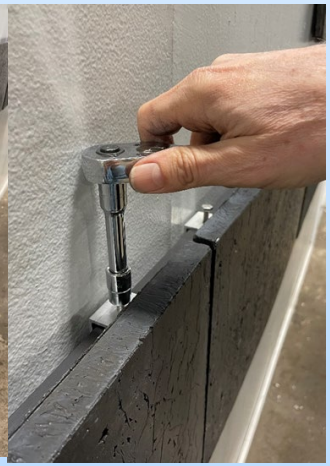
For X-MATRIX Based Panels

- The ceramic carbon ore aggregate was mixed with Portland Cement, water, and additives to make a coarse mortar
- The mixture was poured into a panel mold and placed on a vibrating table to settle the material and remove air bubbles
- The panel was allowed to stand for 3 days in the mold and was then de-molded prior to a full cure to form the X-MATRIX Panel.

PROGRESS & ACCOMPLISHMENTS

Panel Prototypes

16” x 32” Coal-Derived Ceramic X-PANEL™ Rail Clips Fastened by concealed undercut anchors



Dark Features are the Light-weight Coal-Based Ceramic Aggregate (X-MATRIX™) Aggregates are repurposed material from cracked ceramic panels.

16” x 32” Polished X-MATRIX™ X-PANEL™ Rail Clips Fastened by concealed undercut anchors

Comparison of X-PANEL Prototypes to Commercial Panels

Resin	Resin Cost/lb	Avg. Flexure Strength (psi)	Plate Cost per sq. foot	Cost of panel
B183	$$$	5324	$$$	$$$
B214	$$	4386	$$	$$
B212	$	4901	$	$
B218	$	TBD	$	$
Commercial High Price		4263	$25.00	$88.75
Commercial Med Price		2031	$16.00	$53.25
Cement fiber Shingle		not measured	$6.00	$21.30

Resin Content (%)	Porosity (%)	Areal Weight (lb/sq. ft)	R-Value (1 inch)
18%	11	4	Est. 1.3
22%	3.5	4.1	Est. 1.2
25%	0.8	4.15	Est. 1.1
Comm High	23	4	1.24
Comm Med	38	3.8	2.24
Insulated X-P	3.2	2.25	Est 4.5

- Panels are 20-25% resin and 75-80% Ceramic Aggregate
- Commercial panels are fiber reinforced; current X-PANEL are not fiber reinforced
- We would be cost competitive with commercial counterparts

- Commercial fiber reinforced cement panels have high porosity
- R-Value estimates for X-PANELS are based on comparison with commercial organic resin panels

Façade Market Size by Application

MARKET SIZE

Facade Panels Market Volume (bn sq. ft.)	2021	2022	2026	CAGR (2022-2026)
Residential Construction	1.86	1.88	2.00	1.5%
Non-residential Construction	18.26	18.62	21.12	3.2%
Hotel Construction	3.19	3.21	3.52	2.3%
Total	**23.32**	**23.71**	**26.64**	**3.0%**

MARKET VALUE

Facade Panels Market Volume ($Bn)	2021	2022	2026	CAGR (2022-2026)
Residential Construction	2.34	2.64	2.84	1.8%
Non-residential Construction	52.85	63.07	84.21	7.5%
Hotel Construction	5.31	6.21	7.57	5.1%
Total	**60.50**	**71.93**	**94.61**	**7.1%**

Market size and value were determined by looking at facade panels, composite wall panels, insulation boards, fiber cement, metal, and glass facade panels. Additionally, the Hotel Construction subset was separated out due to it's high growth within the non-residential construction application.

Coal Utilization & Price Comparisons

Project Coal Utilization at Scale

Metric	Year 1	Year 2	Year 3	Year 4	Year 5
Panel Production	78K	104K	130K	130K	130K
Coal Utilization (lbs)	686K	915K	1,144K	1,144K	1,144K

Full Scale in this case was assumed to be a production level of 500 panels per day over 260 working days a year. We also assumed that in the Year 1 of Commercialization we would reach 60% capacity, followed by 80% capacity in Year 2.

Price Comparisons

Composite Panel Type	Average Price
Aluminum Composite	$25.00
Concrete	$25.00
Fiber cement	$16.00
Average Price	$22.00

We expect we would be able to sell in the range of $16-$22 to remain competitive. Higher-performance panels we could compete in the $25-$30 range.

Cost Drivers

Component	Cost Makeup
Resin	65%
Coal	25%
Other	10%

We expect our margins based on our materials costs at volume could range from 40%-75% which allows room to sell into distribution.

FUTURE DEVELOPMENT, TESTING, COMMERCIALIZATION

Technology Gaps

Primary gaps to close for true commercialization:

1. Development of processes to support production of larger quantities utilizing different equipment
2. Optimization of formulations and processes to reduce costs at scale
3. Optimizing fabrication techniques to decrease areal weight and increase R-Values
4. Adapt color and texture technologies developed in other programs

Also, based on learning from our market analysis we would also introduce the production of 2” x 4” and 3” X 5” subway sized tiles which have many architectural and decorative applications and represent a sizeable market.

Future Work if Additional Funding is Secured

- Originally planned as part of the Phase II Effort, we have already identified an optimal location for the engineering scale up of the technology
- Testing and meeting standard industry requirements for fire-rated acoustical, structural and surface panels that include but not limited to the following:
  - NFPA 251: Standard Methods of Tests of Fire Resistance of Building Construction and materials
  - NFPA 285: Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Wall Assemblies Containing Combustible Components
  - ASTM E1803-14: Standard Test Methods for Determining Strength Capacities of Structural Insulated Panels.
- Additional process development to add fiber reinforcement, decrease areal weight, and improve insulating capabilities, and further reducing cost of resin formulations

Scale Up Plan

- Level 0 – Single-Unit Manual Ceramic Panel Equipment
- **Level 1 – Single-Unit Manual Fiber-Reinforced X-MATRIX Panel Equipment**
- Level 2 – Dual Production X-MATRIX / X-PANEL Products Equipment System
- Level 3 – High-Performance Composite Concrete Architectural Panel Production
- Level 4 – X-PANEL Prefabricated Architectural Wall Assembly Manufacturing Facility

Costs to Scale

Scale Up Level	Costs
Level 0	<$10,000
Level 1	$122,500
Level 2	$200K-$500K
Level 3	$500K-$5M
Level 4	$5M++

Coal Utilization for Facades

- Our Coal + PDC Technology substantially increases the value of coal compared with other applications
- Allows for diversification of coal utilization into a ‘green’ technology since the PDC encapsulates coal’s impurities
- Is also an avenue for repurposing coal waste products
- Our products are domestically manufactured, locally sourced

SUMMARY

A commercially viable process has been proven to produce a range of façade panels utilizing a minimum of 50% Carbon Ore and/or other Carbon Ore waste products

- X-MATRIX Panels that are 30-40% lighter than cement panels
- Ceramic X-PANELS that are 30-40% lighter and 2-3X stronger in flexure than concrete panels
- Inorganic resin bonded X-PANELS that are tougher and 2-3X stronger than commercial siding panels
- Insulating X-PANELS that range from 2 lbs/sq ft to 3 lbs/sq. ft
- X-PANELS with various colors and textures have been demonstrated

Due to the **obvious commercial viability of these products,** Semplastics will continue to advance and scale production, *but at a low level due to resource constraints.*

Acknowledgments

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- CART
  - CEO - Bruce Mutter
- EERC
  - Senior Research Engineer – Dr. Bruce Folkedahl
  - Senior Analytical Chemist – Carolyn Nyberg

APPENDIX

Organization Chart

Semplastics (Prime)

PI leading a team of Engineers & Techs

Primary Technology & Prototype Development
Project Management

CART (SubK)

Prototype Development
Product Design
Assist in Scale-Up Design

EERC (SubK)

Characterization and Analysis including Leach Testing, Particle Size Analysis, etc.

Gantt Chart

Task	Description	Year 1				Year 2	
		Q1	Q2	Q3	Q4	Q1	Q2
1.0	Project Management & Planning						
2.0	Fabrication Process Development and Test Specimen Manufacturing						
M1	Test Samples produced with desired mechanical properties						
3.0	Production and Testing of Prototype Thickness Plates						
M2	Prototype Plates produced with desired properties						
4.0	Production of Prototype Panels						
M3	Prototype Panels Produced						
5.0	Target Market Analysis, Cost Projections, and Competitive Analysis of target market						
M4	Market Analysis Completed						
6.0	Scale-Up Plan, Cost Model and Plan Cost Estimations						
M5	Scale Up Plan Completed						