Coal Core Composites for Low Cost, Light Weight Fire Resistant Panels and Roofing Materials

Project Review

Award #DE-SC0018794

October 19, 2020

Project Description and Objectives

Purpose of Project

- To utilize coal as a low-cost filler in low-cost polymer-derived ceramics to produce commercially viable high-volume products

Alignment with Fossil Energy Objectives

- Commercial applications would use large volumes of coal – products contain >70% coal
- Raw coal is used – little or no pre-processing is needed
- Production to be sited near or at coal source – will provide high-value jobs

Initial Question that was answered:

Can a successful laboratory process be scaled up to produce full size parts? – <u>confirmed</u>

Technology Benchmarking

Comparison of Semplastics Roof Tiles to Commercial Products

Property or Attribute	Semplastics X-tiles (pressed) (psi)	Semplastics X-tiles (extruded) (psi)	Clay Roof Tiles (high-end tiles) (psi)	Vermont Slate (high-end slate) (psi)
Flexure Strength	5715	3250	1460	3680
Density	1.65	1.45	2.08	2.51
Impact Resist (normalized)	1.80	1.40	1.00	3.50
Porosity (% by volume)	4.5	8.5	15.3	0.50
Cost/Square ($/100 sq ft)	$550-$700 (est.)	$425-$500 (est.)	$350-450	$900-1,200

Status of Project

- Have demonstrated ability to produce full size (16" x 12" x 0.5) pressed tiles with no cracks – targeted for slate replacement
- Full size tiles demonstrate comparable properties to baseline small pressed test plates
- Demonstrated scaled-up extrusion of larger plates for clay tile replacement

<u>Project goals have not changed</u>

Plan to produce full square of pressed X-tiles and full square of extruded X-tiles as prototype demonstration

Utilized input from roofing contractors, attended trade show exhibitions, and performed validation testing against product requirements for use in Miami Dade County, Florida – one of the most stringent specifications for clay tile

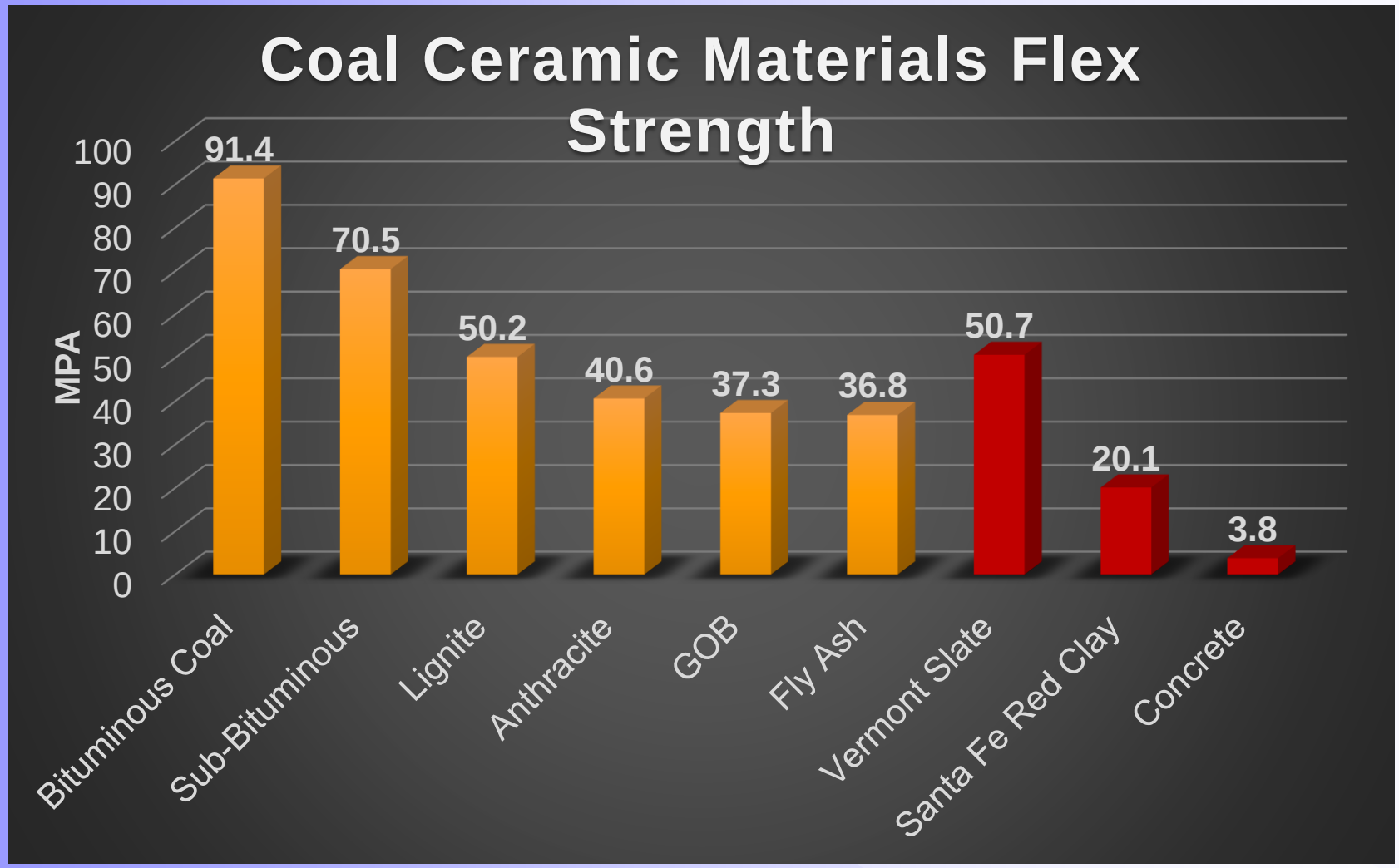
Project Update

Brief Background

What are Coal Core Composites?

- Mix raw coal powder with specially formulated ceramic-forming polymer (the polymer coats each coal particle)
- Mold like standard clay tiles or press at low pressure in a low-cost mold
- Remove from mold and cure to 150°C to harden the resin
- Pyrolyze in inert gas to 700-1000°C to convert the polymer to a ceramic
- Evaluated multiple types of coal – low-volatile bituminous was the strongest (used for roof tiles)

Tested Flexure Strength of Various Materials

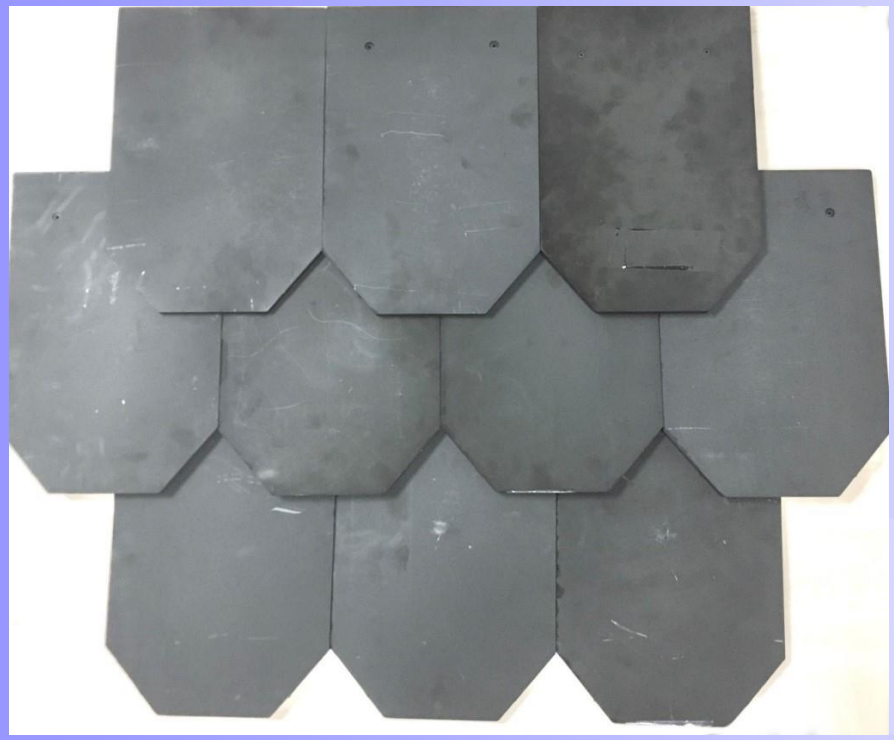


Produced 300 Plates-Varying Thicknesses and Design- Over 95% Yield

- Roughly 300 plates of dimensions 5” × 5” and of varying thicknesses (0.25” to 0.85”) have been produced so far
- Samples of the plates we have produced are shown below
- Flat, corrugated, and waffle-patterned plates are depicted

Samples of 5” × 5” plates (all are 0.5” thick).

Performed Initial Scale-Up Demonstration for Pressed Tiles



Worked with Center for Advanced Research and Technology (CART) in Bluefield, WV

- Produced over 10 full size pressed roof tiles of baseline design
- Size is 16” × 12” × 0.6”
- New design will minimize needed overlap
- **CART will do the prototype scale up of the pressed tiles in West Virginia and produce a 10 ft × 10 ft square**

Extruded Tile Processing Progress

- Developed resin emulsification process to allow creating “black clay” or coal coated with a water resin emulsion
  - Material behaves just like regular clay used for roof tiles but is 72% coal when dried
- Demonstrated laboratory-scale extrusion of the coal clay
- Purchased a “pug mill” – a mixer/extruder to be used for prototype extrusions
- Successfully used the pug mill to produce larger size plates
- Purchased a 50 lb. per hour clay mixer to feed the pug mill

Semplastics will develop the prototype process for the extruded tiles in-house and produce the 10 ft × 10 ft square of tiles

- Semplastics has leased another facility adjacent to its current location for the scale-up work

Scale-Up Challenges

- Need to optimize scaled-up process for pre-ceramic polymer production
  - Produced 30-gallon scale at toll producer so far
  - Will refine the synthesis procedure for the next batches
- CART is optimizing the design of the mold for the pressed tiles and purchasing the prototype scale-up equipment
- Semplastics needs to optimize the end effector for the pug mill to produce the extruded tile form-factor
- Semplastics needs to develop methods to impart shapes to the extruded material

Next Steps at Semplastics

Semplastics has begun setting up prototype production equipment in the new facility

- The new facility, along with the current facility, will contain the scale up equipment including:
  - The coal/emulsified resin mixer
  - The pug mill
  - The curing oven
  - The pyrolysis furnace or kiln
- Both facilities together will produce the square of extruded tiles after the preliminary scale-up challenges are solved
  - Need to minimize edge tearing on the extruded bar/shape
  - Need to develop a process to produce barrel tiles
  - Will optimize the curing and pyrolysis heat cycle to accommodate large numbers of tiles

Next Steps at CART

- CART has begun setting up the prototype production line in Bluefield, WV, which will contain:
  - A large mixer to catalyze the pre-ceramic polymer
  - A planetary mixer to mix the coal powder with the polymer
  - A CNC milling system and a CNC router to produce tile molds
  - A hydraulic platen press to produce the pressed tiles
  - A large curing oven to cure the pressed tiles
  - An inert gas furnace or kiln to pyrolyze the plates into the ceramic tiles
- CART will use this equipment to:
  - Optimize the mold designs
  - Develop the curing and pyrolysis heating schedules
  - Produce the square of pressed tiles

Expected Outcome by End of Phase II

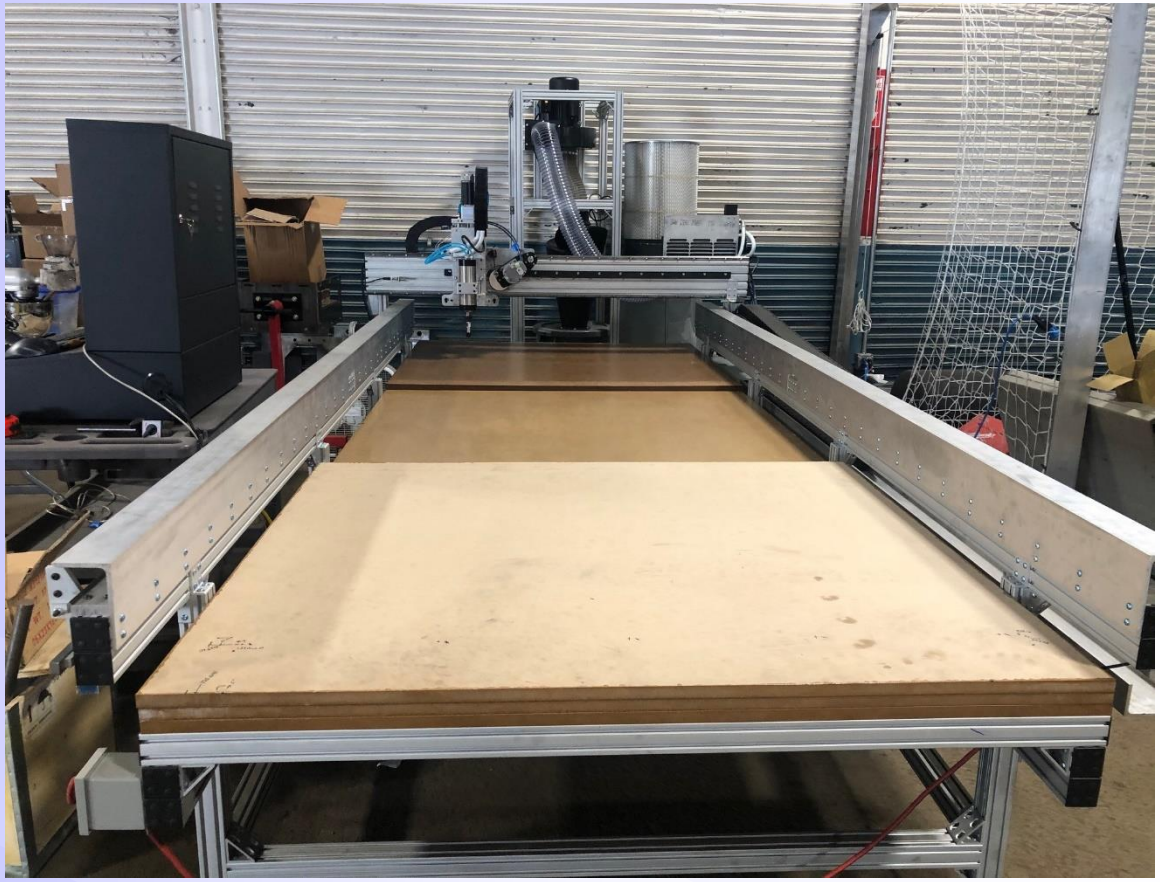
- CART will produce a full “square” (10’ × 10’) of full-size flat tiles
- CART will produce up to 30 flat tiles to support testing at an accredited roof tile testing laboratory to confirm the tiles meet commercial performance specifications
- Semplastics will produce a full “square” of extruded tiles – ideally barrel shaped
- Semplastics will produce up to 30 full-size barrel-shaped tiles to support testing at an accredited testing laboratory
- Both CART and Semplastics will provide suggested improvements based on the Phase II work including:
  - Techniques to streamline production processes
  - Cost reduction routes
  - Further improvements in design for both tile types

New Technologies and Process Improvements

- Recently developed an “Aggregate Process” that is a significant improvement over the pressed tile and extrusion technique
  - Decreased pressing pressure from current 1000 psi to as low as 75 psi
  - Decreased part shrinkage so lower stresses during pyrolysis – allows larger parts
  - Control over % porosity and pore size
  - Pore size and % porosity independent of pressing pressure
  - Parts up to 3” thick can be produced with no cracks after pyrolysis
  - Expected to increase production tile yield by more than 15% over the current process
  - Expected to decrease tile production costs
  - Being developed to produce other coal-filled ceramic parts such as coal bricks

Prototype Production Equipment at CART

CNC Machining Center
for machining molds



12 ft long × 4 ft wide CNC Router
for adding features to tiles

More Prototype Production Equipment at CART

Hobart 50-quart Planetary Mixer for mixing resin and polymer

Mechanical Convection Oven for curing pressed tiles

Tile Mold at CART

New Tile Mold for pressed tiles

Prototype Production Equipment at Semplastics

Chain Mill for milling coal down to size

Clay Mixer for mixing coal and polymer

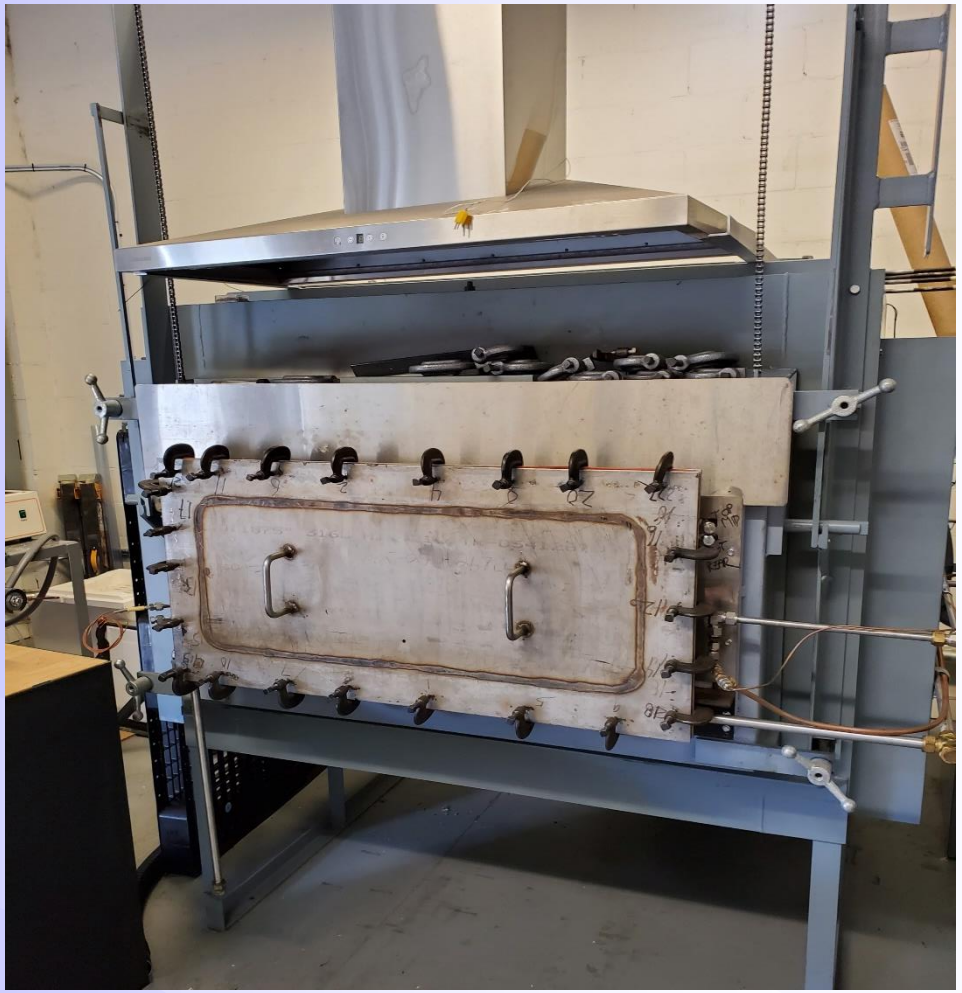
More Prototype Production Equipment at Semplastics

Pug Mill for Extruding Sheets of Coal-Clay for tiles

End effector or extrusion nozzle for tiles

Additional Equipment at Semplastics

Grieve convection oven for curing tiles



Furnace for pyrolysis of cured tiles

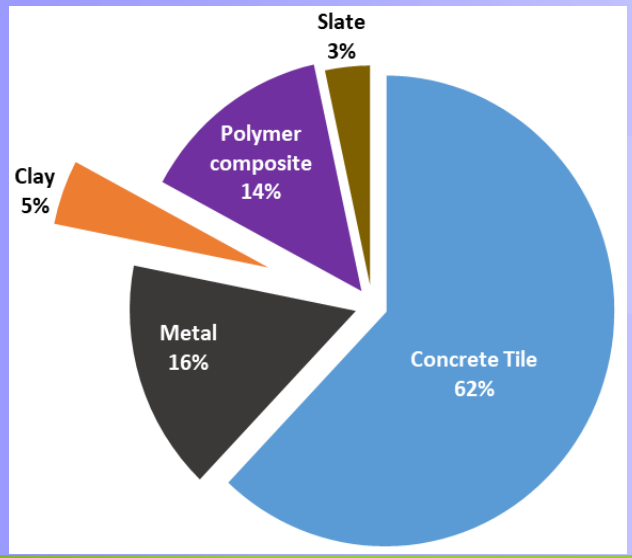
Total Available Market and Targets

High End Roof Tiles: $7.2 Billion in 2020

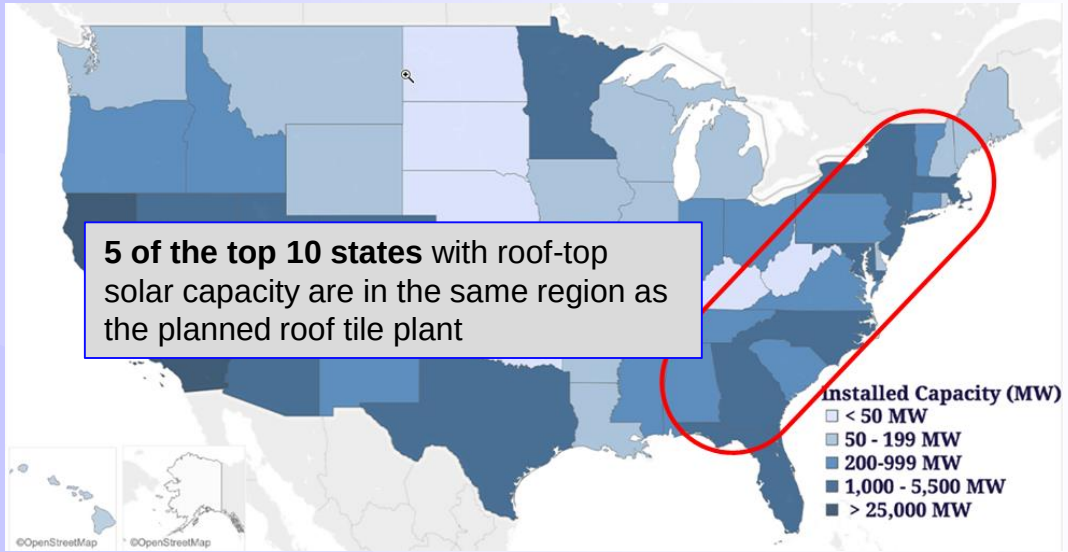
Product Type	2018	2019	2020	CAGR % 2018–2020
Concrete Tile	$ 3,793.6	$ 3,947.1	$ 4,100.5	4.0%
Metal	$ 1,043.0	$ 1,122.0	$ 1,201.0	7.3%
Clay	$ 248.0	$ 327.0	$ 406.0	27.9%
Polymer composite	$ 590.2	$ 657.6	$ 724.9	10.8%
Slate	$ 379.2	$ 568.8	$ 758.4	41.4%
Total Available Market	**$ 6,054.1**	**$ 6,622.4**	**$ 7,190.8**	9.0%

Initial Product Replacement Target!

Distribution by Volume in 2018

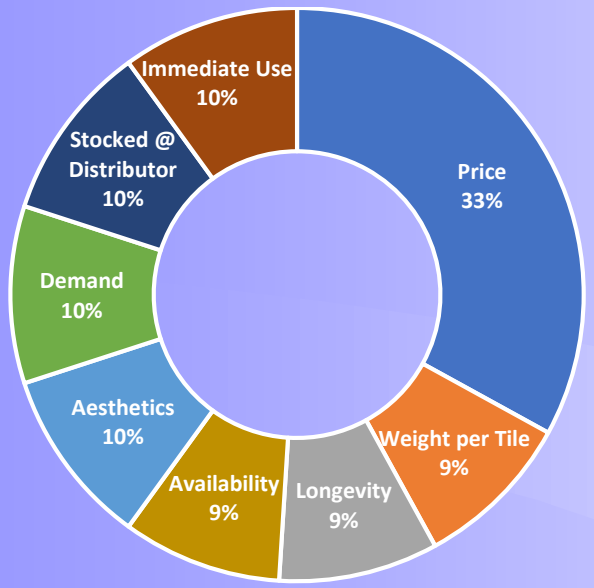


Target Distribution Region



Commercial Products

Design Drivers



Stage 1

Slate style
(pressed)

Target price:
$700/sq.

Stage 2

Villa style
(extruded)

Target price:
$500/sq.

Commercial Value Proposition

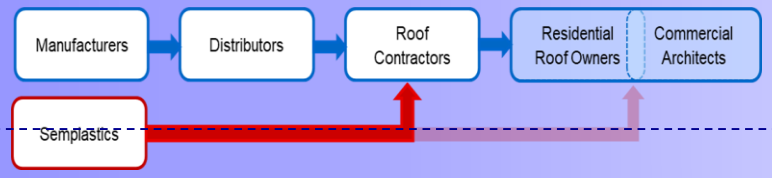
- **Domestic option** for manufacturing ceramic roof tiles
- **Supports jobs** in the coal sector
- **Beneficial use application** for coal with technology that can move into new sectors (such as new building materials, batteries, proppants)

	Features	Value	Benefits
End-users (Resident Roof Owners)	Fireproof and non-combustible	Greater safety	Lower insurance costs
	High tensile and flexural strength	Low maintenance	Lower ownership costs
	Great impact resistance	Good load distribution	Minimally affected by addition of solar panels
	Low porosity	Low water absorption rate	Low maintenance
	High wind resistance	Low damage from extreme weather	Can overcome "chatter" during high wind or hurricane events
	High sound dampening	Greater environmental buffer	
Roof Contractors	Light weight	Ergonomic	Easy to install
	Coal-based composition	Classification as "Environmental Product Declaration"	LEED credits can be used for new construction projects
	Direct from manufacturer	Lower price for comparable product	Greater product margins
Distributors	Light weight	Lower shipping costs	Greater amount per shipment load
	Coal-based composition	Potential for earning CO_2 credits	Opportunity for greater product margins

Commercial Strategy and Revenues

Manufacturing and direct distribution to end-customers in the roofing industry

Value Chain Position



Channels

Manufacturing Representatives

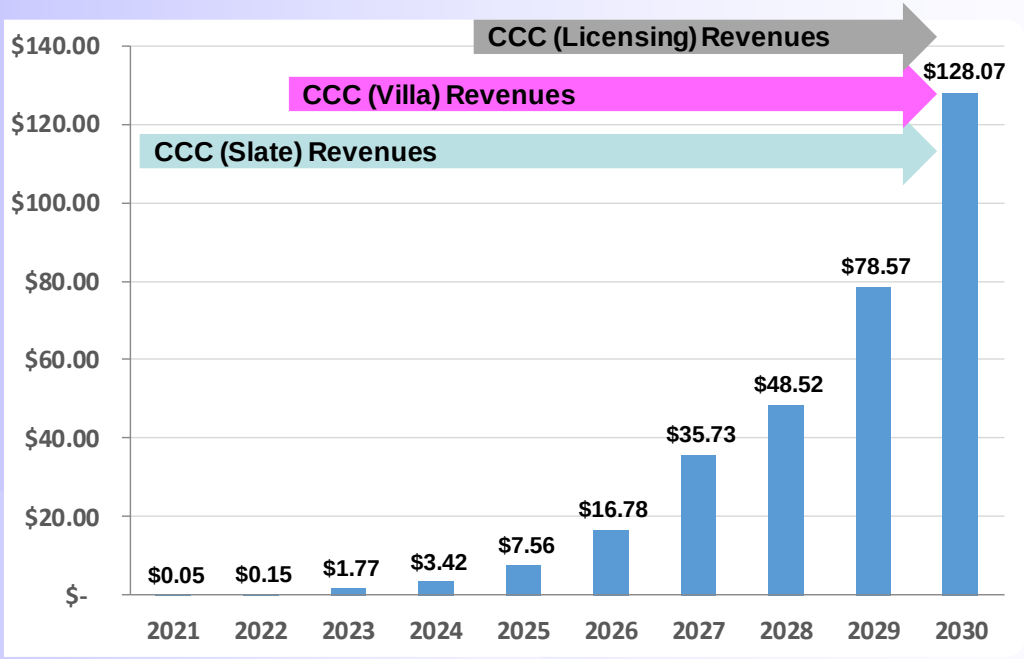
- Joe Hall Roofing
- Mad Sky

Online Contractor Applications

- iRoofing "app"
- Acculynx

Online Web and Digital Marketing

- http://www.x-tiles.com
- Other online building retailer websites (e.g., https://www.buildzit.com/)



- Cumulative revenues up to 2030 reach **$320 Million**
- Expected first commercial sales in **2022**

Questions / Discussion