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

Annual Project Review

Award #DE-SC0018794

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Purpose of Project and Fossil Energy Objectives

Purpose of Project

- To utilize coal as a low-cost filler in low-cost polymer-derived ceramics to produce commercially viable high-volume use of coal for roof tiles

Alignment with Fossil Energy Objectives

- Commercial applications would use large volumes of coal – roof tiles contain more than 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

Driving Question that was answered:

Can a laboratory process be scaled up to produce full-size roof tiles with two different form-factors and target markets? – confirmed

Technology Benchmarking

Comparison of Semplastics Roof Tiles to Commercial Products

Property or Attribute	Semplastics X-tiles (pressed) (psi)	Semplastics X-tiles (molded) (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)	$250-$550 (est.)	$200-$400 (est.)	$350-$450	$900-$1,200

Current Status of Project

SEMPLASTICS

- Beginning the first round of new coal-clay barrel tiles (clay tile replacement) – have demonstrated ability to produce full size (16" × 12" × 0.5") tiles
- Have installed mixer, press, curing oven and larger kiln/retort to process up to 32 tiles per run
- Initial runs have demonstrated the heating cycle does not induce cracks in the tiles
- Full-size tiles demonstrate comparable properties to baseline small pressed test plates

CART

(Center for Advanced Research and Technology, Bluefield, WV)

- CART has begun producing the first flat tiles made with their new mold design and press
- CART will mix the resin with coal, press the tiles, and cure the tiles
- Due to issues with their kiln, CART will ship the cured tiles to Semplastics for pyrolysis at least for the next few months

Current Status of Project (cont.)

COVID-19 has caused delays

- Kiln ordered by Semplastics delayed more than 6 weeks then came in damaged, adding another 2 weeks to setup; finally installed and tested in February
- Kiln retort delayed 6 weeks due to metal supply delays and the welder himself contracting COVID-19
- The first firing of the kiln and retort with parts was completed March 29, 2021
- CART attempted to order a kiln in early January and found there was a 12-16 week lead time for a new kiln; sourced a used kiln but it arrived severely damaged and would need to be completely rebuilt
- CART will rely on Semplastics to fire their flat roof tiles for the next few months
- Semplastics re-activated the furnace used to make the Phase I and early Phase II pressed tiles – capable of firing 4 tiles per run (as for the kiln, a run takes 5 days)

CART has begun Prototype Flat, Pressed Tile Production

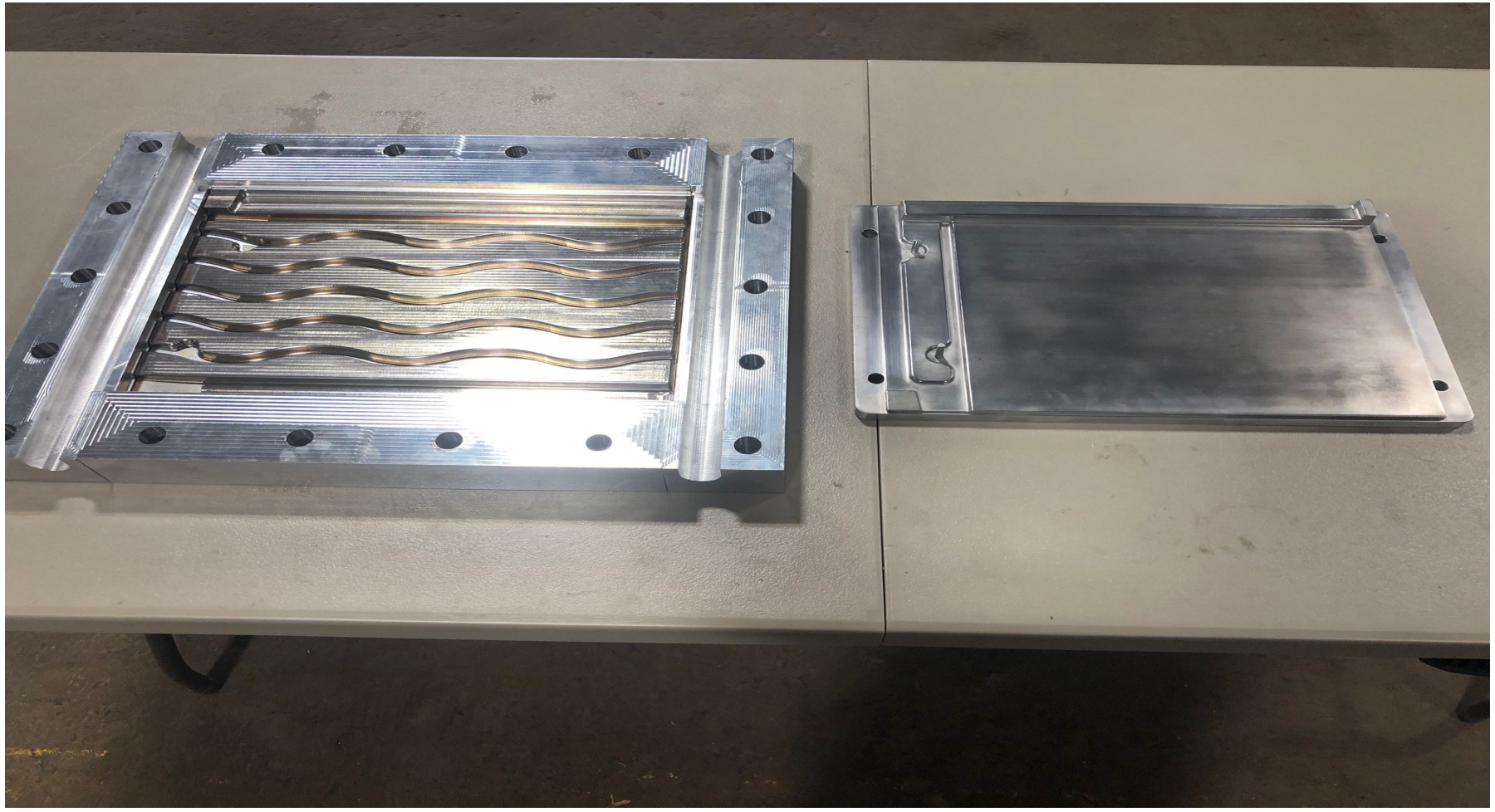
- CART has installed a 100-ton hydraulic press for prototype production (shown on left)
- Set up a prototype line to use 25 lbs of coal per batch
- Can make 5-6 cured roof tiles per batch
- Approximately 18 batches per square
- New design will minimize tile overlap
- **CART will do the prototype scale-up of pressed tiles demonstrating feasibility of producing a 10 ft × 10 ft square of cured 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



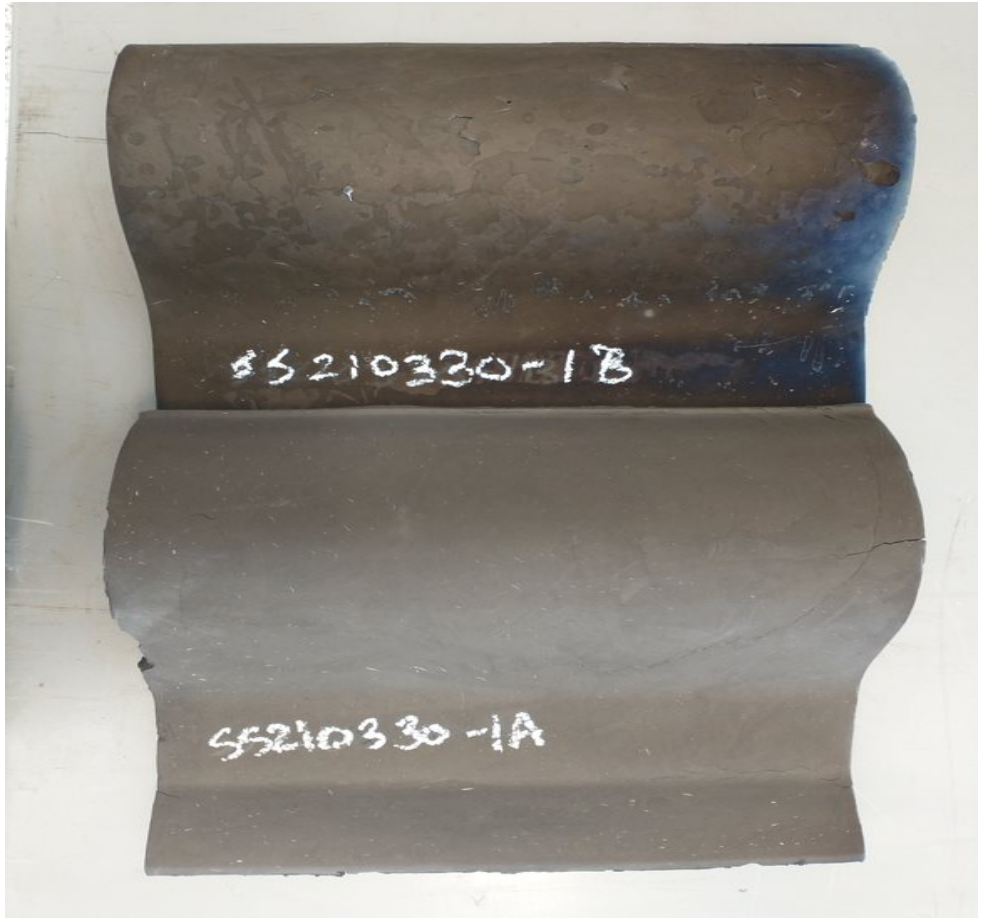
New Tile Mold for pressed tiles

Semplastics Coal-Clay Tile Program

- Developed resin emulsification process to create “black clay” or coal coated with a water resin emulsion
  - Material behaves just like regular clay used for roof tiles but is 68-70% coal when dried
  - Demonstrated a baseline formulation to make coal-clay for either extrusion or low-pressure molding
- Designed and built a barrel tile mold
- Used 50 lb. per hour clay mixer to mix the emulsified polymer with the raw coal powder to make the coal-clay
- Used our “pug mill” – a mixer/extruder – to extrude short 4” diameter rods that are then pressed in a low-pressure mold
- Demonstrated that coal-clay can be molded into full-size barrel tiles using a 30-ton hydraulic press with the mold

Barrel Tiles

As-molded Barrel Tile



2 Tiles after Pyrolysis/firing

Coal-Clay Tile Processing

50 lb. per hour Clay Mixer

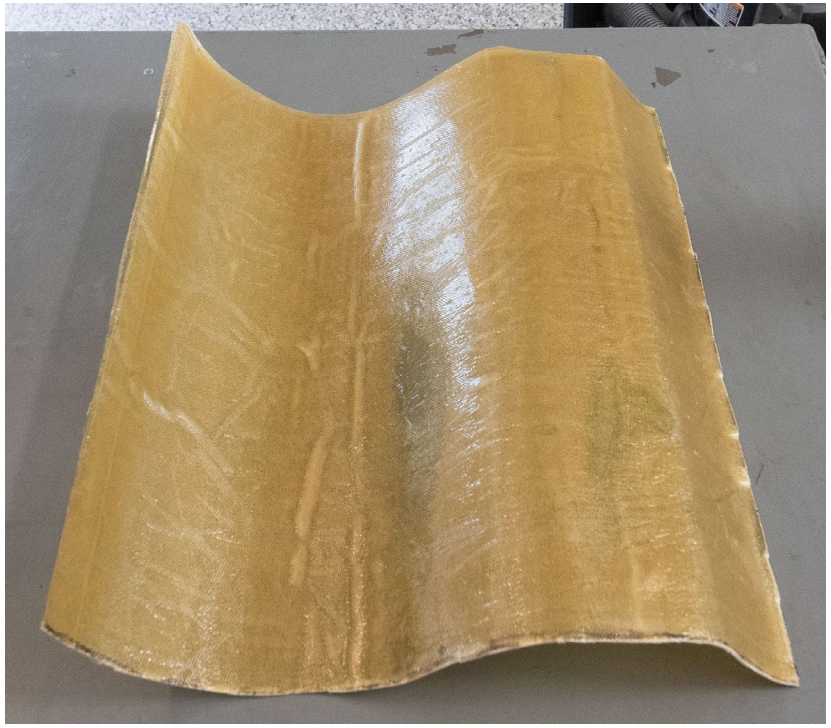
200 lb. per hour Pug Mill Extruder

Coal-Clay Tile Processing

Mold Inserts to Produce a Barrel Tile

30 Ton Platen Press

Coal-Clay Tile Processing



Fiberglass Drying/Curing Support

ve Oven

Drying/Curing Oven

Coal-Clay Tile Processing

Kiln with Retort and Support Furniture

Kiln Ready for a Pyrolysis Run

Coal-Clay Tile Processing

- Semplastics has leased and built out a prototype demonstration facility (shown below) adjacent to our Oviedo, Florida site to produce full-size barrel tiles and to produce the 10 ft × 10 ft square of tiles

Scale-Up Challenges

- **COVID-19 Supply Chain Issues**
  - Delivery times for Semplastics' kiln and retort more than doubled
- **Scaling up Polymer Production**
  - Produced **2nd** 30-gallon scale batch at toll producer with refined synthesis procedure – QA analysis indicates properties comparable to midrange of lab-scale batches
- **Barrel Tile Processing**
  - Semplastics is working to improve the drying/curing process for the barrel tiles to eliminate cracking during drying/curing – *modifying drying cycle to produce uniform drying on both sides*
  - Developing fiberglass mold inserts and steel support forms to keep the soft coal-clay tile shape during drying and curing
  - Current production rate is 2 tiles/day without inserts, need to make 6-7 tiles/day to meet program goals – *feasible with mold inserts*

Scale-Up Challenges (cont.)

- **CART must improve mold design for increased throughput**
  - CART has developed a process based on 25 lb. batches (one bag of coal) to produce 5-6 tiles per batch
  - Need to streamline tile removal from the mold – Curing oven capable of handling up to 10 tiles/day
- **Pressed Tile Firing Bottleneck**
  - Due to COVID-19 supply chain issues, CART does not have a working kiln on site to pyrolyze/fire the cured tiles
  - CART will have to ship the cured tiles to Semplastics for pyrolysis essentially doubling the number of tiles that have to be processed at Semplastics – Looking to utilize extra Semplastics furnace for pyrolysis, currently limited to 4 tiles for each 5-day cycle

Next Steps at Semplastics

Semplastics new prototype fabrication facility contains pilot scale equipment for coal-based products

- Semplastics' facility is expected to begin producing the square of molded barrel tiles by April 30, 2021
  - Plan to make low-pressure molded coal-clay barrel tiles
  - Developing fiberglass mold inserts and steel supports to hold the shape while drying and curing which will greatly improve throughput to the 6 tiles/day target rate
  - Still optimizing the drying/curing cycle and the pyrolysis cycle established that minimizes/prevents cracking – designed for up to 32 tiles per 5-6 day run cycle. Will optimize the curing/heat cycle to accommodate large numbers of tiles
- Some tiles will be sent to an accredited testing laboratory for qualification testing according to ASTM 1167

Next Steps at CART

- CART has set up the prototype production line in Bluefield, WV, which contains:
  - 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
- CART is using this equipment to:
  - Optimize the mold designs
  - Develop the curing schedules
  - Produce a square of cured pressed tiles
  - Produce tiles for ASTM 1167 testing

Expected Outcome by End of Phase II

- CART plans to demonstrate the ability to produce a full “square” (10’ × 10’) of full-size flat tiles in 20 working days and will produce a minimum of 20 cured tiles (at least 10 to be fired at Semplastics)
- CART will also 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 barrel tiles
- 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

Expected Outcome by End of Phase II (cont.)

- CART will also demonstrate a new type of low-cost roof tile based on new coal-based aggregate filled cement
  - The technique was developed by Semplastics and will be transferred to CART for scale-up
  - These cement tiles would have the same form-factor as the pressed ceramic tiles
  - CART plans to produce a full square of *combined cement and ceramic roof tiles* by the end of the program

New Technologies and Process Improvements

- Recently developed an “Aggregate Process” that offers significant improvement over the pressed tile and extrusion technique
  - Decreases pressing pressure from current 1000 psi to as low as 75 psi
  - Decreases 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 when implemented
  - Being developed to produce other coal-filled ceramic parts such as coal bricks

New Technologies and Process Improvements (cont.)

Ceramic coated-coal based aggregate/filler developed for concrete

- A recent invention by Semplastics that has the ***potential to use millions of tons of coal***
- Coal-based ceramic aggregate or filler is a composite of coal powder and ceramic binder
- The aggregate is 60-70% coal by mass, the rest is Semplastics' low-cost ceramic forming polymer
- The mixture is simply deposited onto a tray or carrier and pyrolyzed in a reducing atmosphere to produce a rock-like material
- The chunks of coal ceramic composite are then chain-milled to form 20 micron to 5 mm size aggregate particles
- *All scrap from other roof tile manufacturing techniques can be used as aggregate* – **zero waste process**
- **The aggregate is mixed with Portland cement and water, then cast just like regular concrete**

Coal-Based Aggregate for Concrete Roof Tiles and other Applications

Ceramic coated-coal based aggregate/filler-based concrete has superior properties when compared to standard concrete:

- Compressive Strength 6000-7500 psi – 2X or more standard concrete tiles
- Flexure Strength 1500-2000 psi - 2X-3X concrete tiles
- Density 1.65 g/cc ~ 35% less than of concrete
- Cost between standard concrete and ultra-high strength concrete
- Price competitive with “precast concrete” and standard concrete roof tiles
- *Market for standard concrete roof tiles much larger than the total market for both ceramic roof tiles and slate*

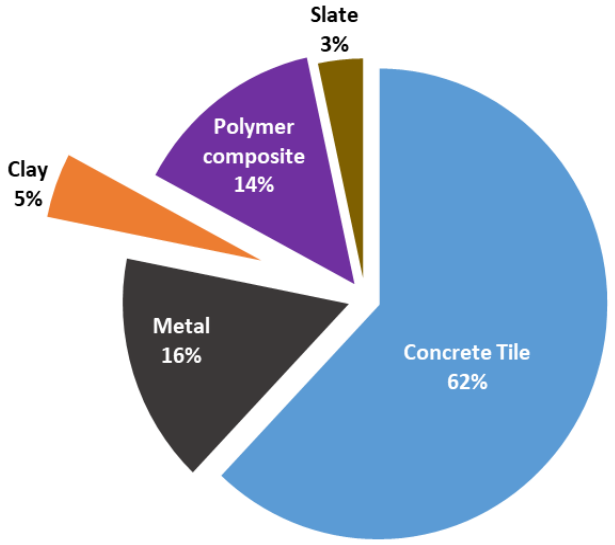
Total Available Market and Targets

High End Roof Tiles: $7.2 Billion in 2020

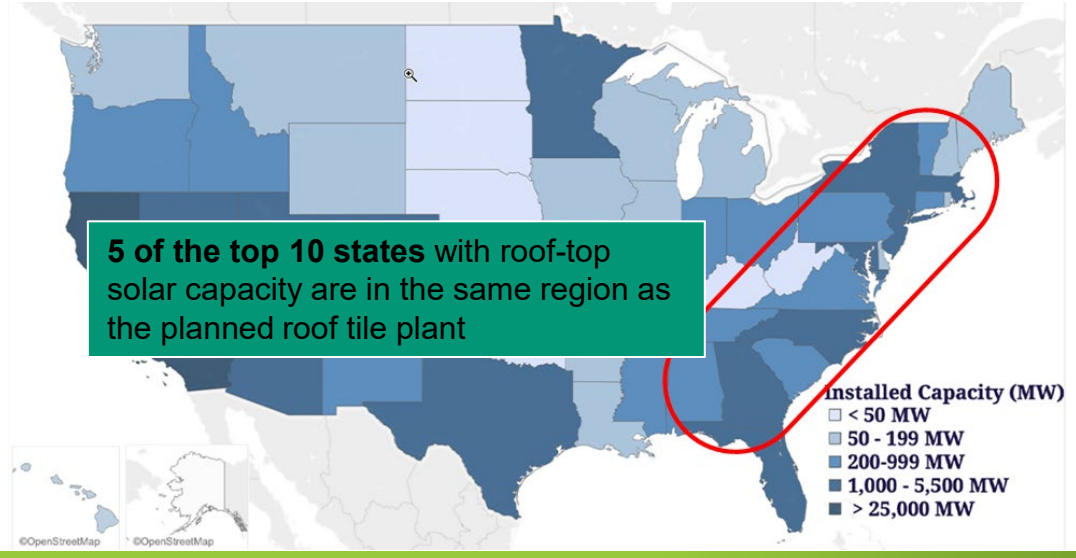
Product Type	2018	2019	2020	CAGR % 2018–2020
Concrete Tile	$ 3,793.6	$ 3,947.1	$ 4,100.5	4.0%
Metal	$ 1,043.0	$ 1,122.0	$ 1,201.0	7.3%
Clay	$ 248.0	$ 327.0	$ 406.0	27.9%
Polymer composite	$ 590.2	$ 657.6	$ 724.9	10.8%
Slate	$ 379.2	$ 568.8	$ 758.4	41.4%
Total Available Market	**$ 6,054.1**	**$ 6,622.4**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

Initial Product Replacement Target!

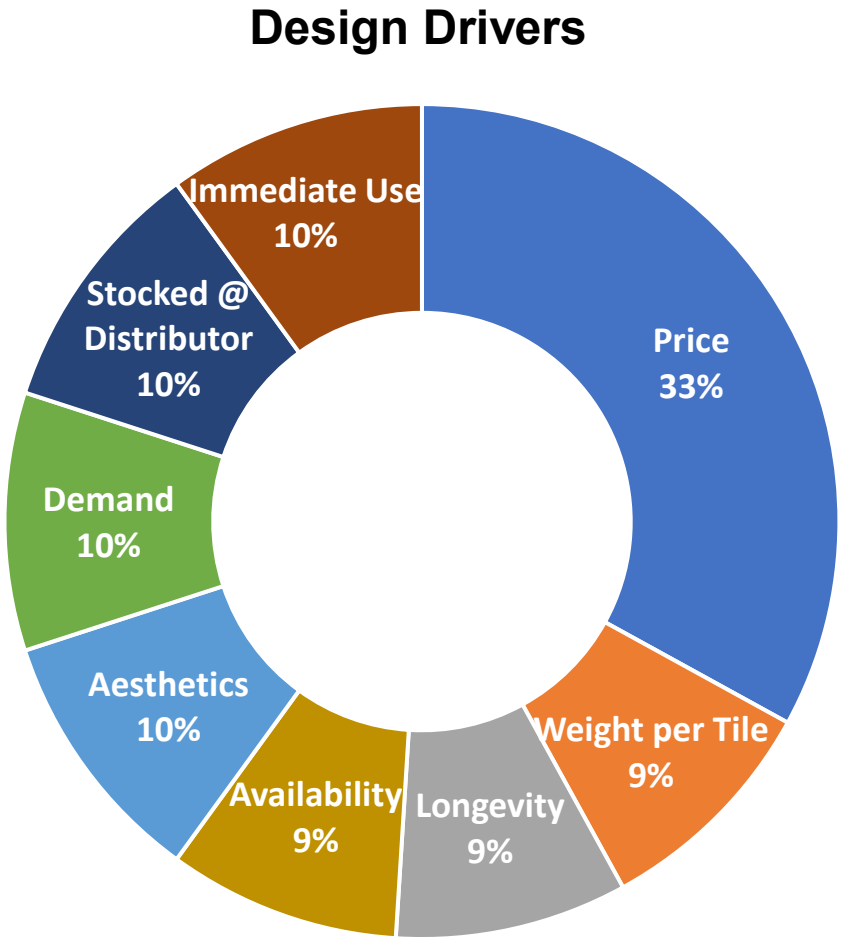
Distribution by Volume in 2018



Target Distribution Region



Commercial Products



Stage 1

Slate style (pressed)

Target price: $700/sq.

Stage 2

Villa style (extruded)

Target price: $500/sq.

Commercial Value Proposition

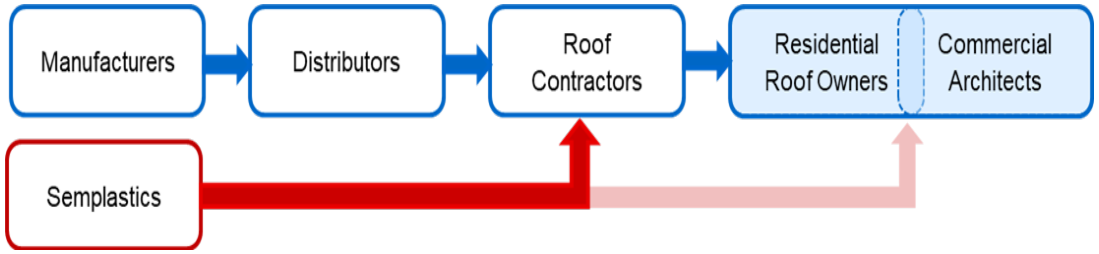
	Features	Value	Benefits
End-users (Resident Roof Owners)	Fireproof and non-combustible	Greater safety	Lower insurance costs
	High tensile and flexural strength	Low maintenance	Lower ownership costs
	Great impact resistance	Good load distribution	Minimally affected by addition of solar panels
	Low porosity	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

- **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)

Commercial Strategy and Revenues

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

Value Chain Position



Channels

Manufacturing Representatives

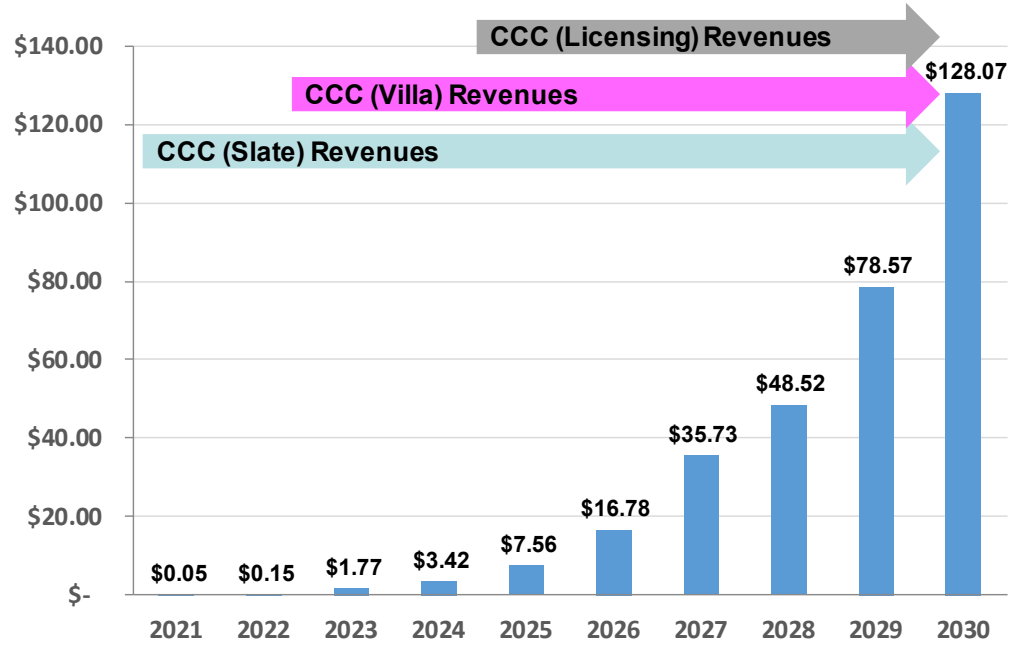
- Joe Hall Roofing
- Mad Sky

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**

Concluding Remarks

- The project has demonstrated the ability of coal-based roof tile materials to meet at least one the Strategic Fossil Energy Objectives
    - Size of addressable roof tiles market including slate, ceramic tiles and the new cement-based tiles being developed was estimated to be $5.26 Billion in 2020
    - At roughly 2.8 lbs of coal per tile the total market potential would be 9.8 billion lbs of coal per year
    - This helps address a key challenge for coal/fossil energy: how to use large amounts of coal but not rely on power generation

Concluding Remarks (cont.)

- **The Project Next Steps would include:**
  - Completing the tasks remaining in the Phase II program as discussed previously
  - Further streamlining (increasing throughput) of both the pressed tiles and the barrel tiles as the high and intermediate end of our target markets
  - Continue optimizing the ceramic-coated coal based concrete tiles as the higher volume, lower cost alternative in the larger cement tile market
  - Apply for a Phase IIB award to continue with the above as well as address roof tile market needs including:
    - Coloring the roof tiles – simplifying the process
    - Developing textured surfaces – demonstrating good replication of textures
    - Providing ways to seal/provide glossy/semi-gloss surfaces like clay tiles
    - Producing other components needed for roofs such as soffits, caps an endcaps

Questions / Discussion