High Strength, Encapsulated, Commercially Useful Components and Particles Made from Coal Combustion Residuals

DOE Office of Fossil Energy

Award No. DE-FE0031932

NETL FECM Spring R&D Project Review Meeting

5/2/2022

Contents

Project Scope

- Protect both the environment and the health & safety of the public
- Reducing the volume of CCR disposed of in impoundments
- Increase beneficial use and advance the management of CCR

- **Innovative technology and concepts that increase beneficial utilization**
- **Innovations that improve cost and performance of CCR beneficiation**

Kynos™ Carbon Framework

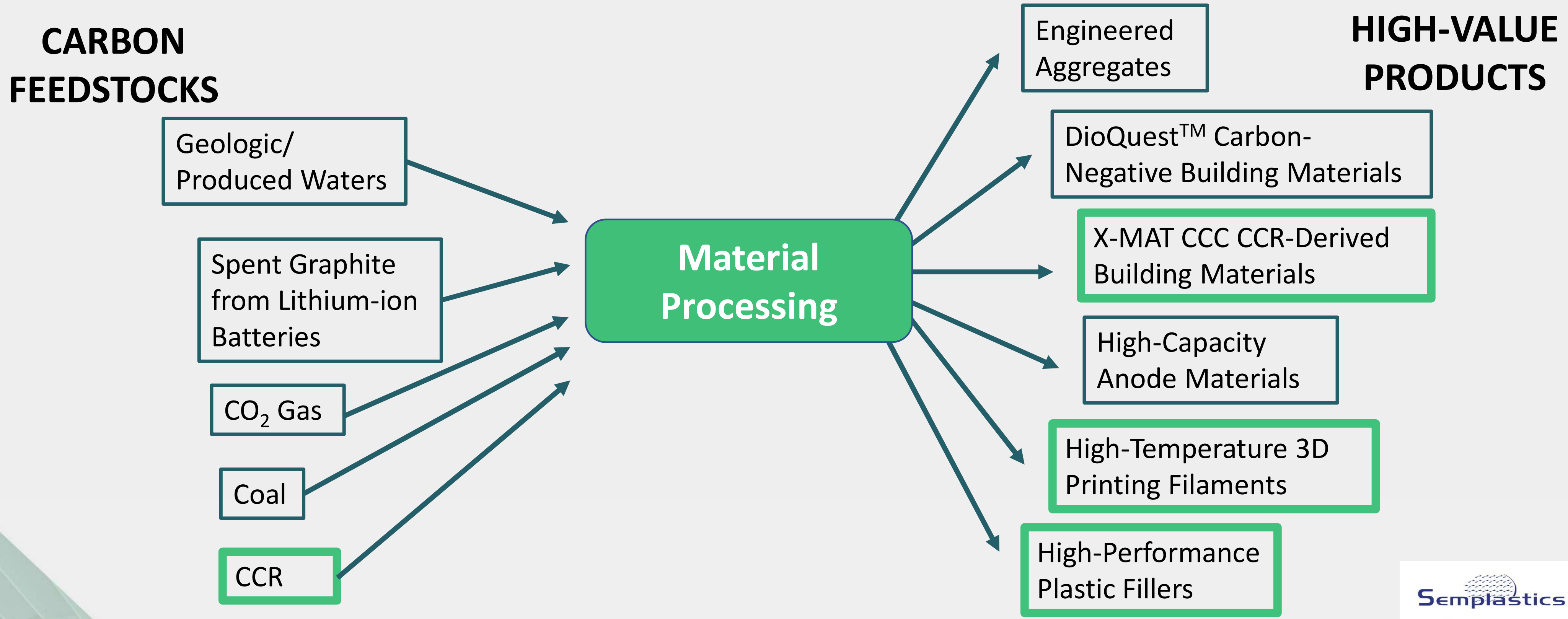
Repurposing both undervalued and waste carbon feedstocks to create valuable, customized, sustainable products.

SUSTAINABILITY =  + 

Economically Sustainable

Environmentally Sustainable

Kynos^{TM} Carbon Framework

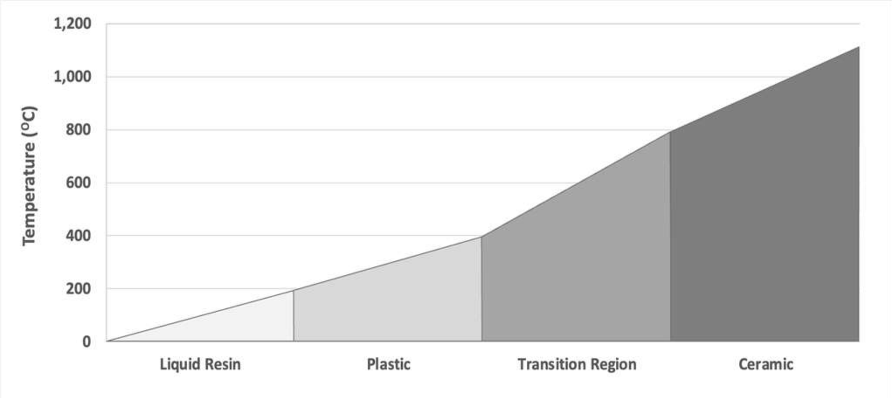


Project Objectives

1. Demonstrate ability to encapsulate CCR particles with a tailorable coating to reduce leaching of toxic elements by at least 80% over uncoated particles
2. Utilize the encapsulated CCR as a large volume filler/reinforcement to produce 9"-diameter support column prototypes with compressive strength and flexural strength 5-10X that of current concrete
3. Develop and demonstrate CCR encapsulated in a tailored, reactive resin coating as a filler for polypropylene that will increase the modulus and strength by 30-50% while reducing toughness and elongation by only 20-30% compared to traditional fillers
4. Develop initial predictive models for the behavior of CCR that reasonably predicts the effects of CCR and encapsulant composition and microstructure on mechanical properties in columns and polypropylene components

Technology Overview

- X-MAT resins
  - tunable at the Atomic Level
  - Plastic or Polymer-Derived Ceramic
- Easily manufactured plastic and ceramic composites
- Variety of particles “as-is” - CCR
- Binder for particles – no sintering needed
- Resin binds to and fully encapsulates the particle
  - ***Prevents leaching of toxic elements from CCR***
- Controllable coating thickness
- Low-cost and Scalable



Typical X-MAT Processing Cycle

Commercial Scope

- ~70 Million short tons of CCR produced in 2020
- ~41 Million tons beneficially used
- Global polyolefin (polypropylene, polyethylene, etc.) market expected to exceed 207 million tons by 2026.
  - With a 40% filler loading and 10% adoption, this could result in utilization of 8.3 million tons of CCR
- Filling with X-MAT-modified CCR results in a lower-cost, higher strength polypropylene
- X-MAT-modified CCR competitive with current plastic fillers (calcium carbonate, talc, and mica)
  - X-MAT coated CCR = $0.08-$0.16/lb
  - Commercial fillers = $0.20-$0.40/lb
- X-MAT CCR aggregates could provide significantly enhanced properties for concrete vs. current CCR use in concrete

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X-M

R&D Progress and Accomplishments

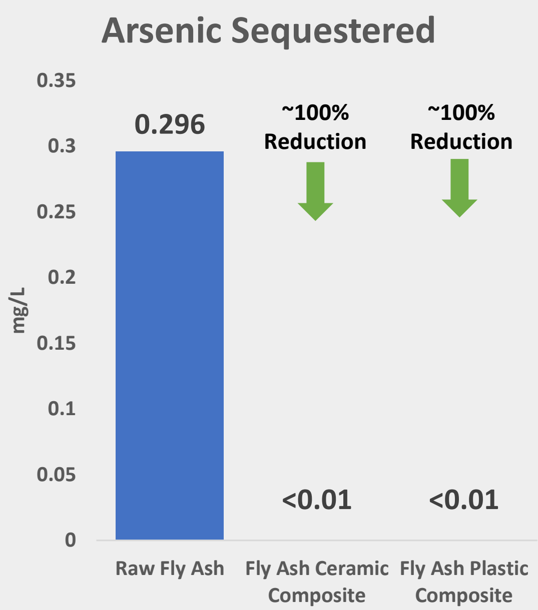
CCR Survey

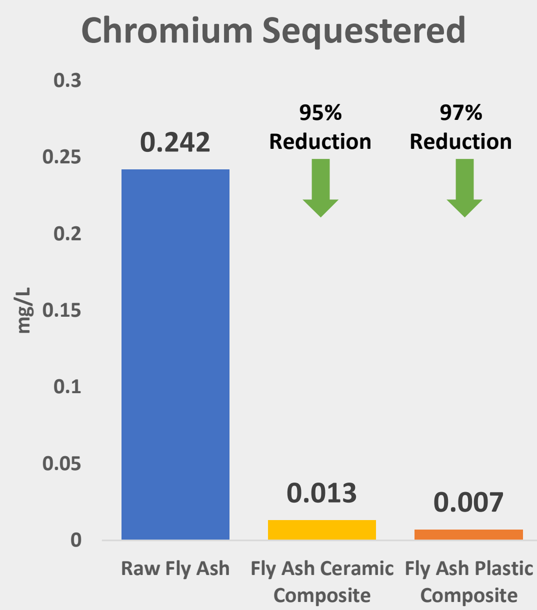
Ash ID	Source
FM-MM-fly ash	Mosser Resource Consulting
Bottom Ash 3-14-14 N001	Mosser Resource Consulting
Fly Ash 3-14-14 N002	Mosser Resource Consulting
BR-MM-Fly Ash	Mosser Resource Consulting
ME-MM-Fly Ash	Mosser Resource Consulting
ME-MM-Bottom Ash	Mosser Resource Consulting
124851 Middle Wyoming PRB Sub-Bituminous	EERC
124562 ND Lignite fly ash	EERC
124586 ND Lignite Fly Ash	EERC
Scrub Grass Fly Ash	Mosser Resource Consulting
FM Gypsum Scrubber Material	Mosser Resource Consulting
FM Fly Ash	Mosser Resource Consulting
FM Bottom Ash	Mosser Resource Consulting
American Bituminous ash	Mosser Resource Consulting
Pittsburgh Pond Fines	Mosser Resource Consulting
NA 219 Floor Northern Appalachia LK PA	Mosser Resource Consulting
#4 JLHR Pit Floor B Coal	Mosser Resource Consulting
Fly Ash from Anthracite Coal	Mosser Resource Consulting
MEA Fly Ash	Mosser Resource Consulting
FM Fly Ash Pit Coal	Mosser Resource Consulting
BRC LK Underclay	Mosser Resource Consulting
Wyoming PRB fly ash	Southern Company
Sherer Ash (26 samples)	Southern Company / Josh Dickey
Falkirk Lignite Fly Ash	EERC

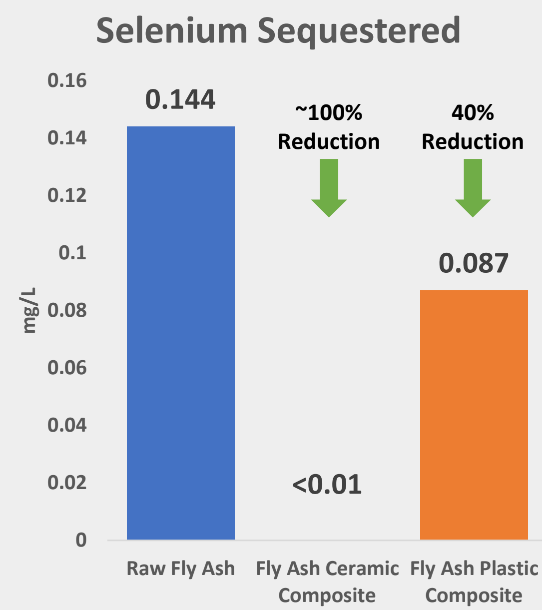
- 24 CCR sources
- Selected a ND Lignite Ash as the primary candidate in the encapsulation and leachate work due to the relatively high levels of toxic metals

Initial encapsulation trials using a "dry mixing" method. This method was used primarily for initial screening.

Leaching Results (Objective 1)







*All Materials are well below the allowable limits set by the EPA

Leach Testing carried out by UND Energy & Environmental Research Center (EERC)

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Support Columns (Objective 2)

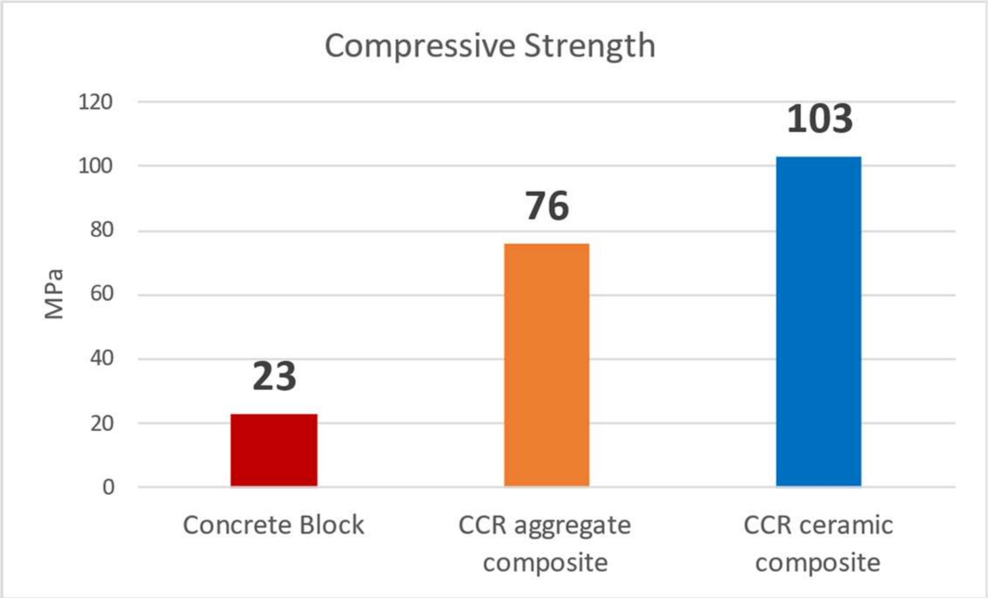
- Deliverable: 9” diameter prototype

- Bulk process to generate aggregates of resin-coated CCR particles
- Press the coated CCR aggregate into a cylindrical mold
- Cure in air @ 150-180°C
- Pyrolyze in inert gas @ 1000°C or less to convert polymer to a ceramic

Support Columns - Accomplishments

1st Solid Ceramic Aggregate Column - 3.5” X 7”

Hollow Column - 6” X 11”



Hollow Columns produced by Center for Applied Research and Technology (CART)

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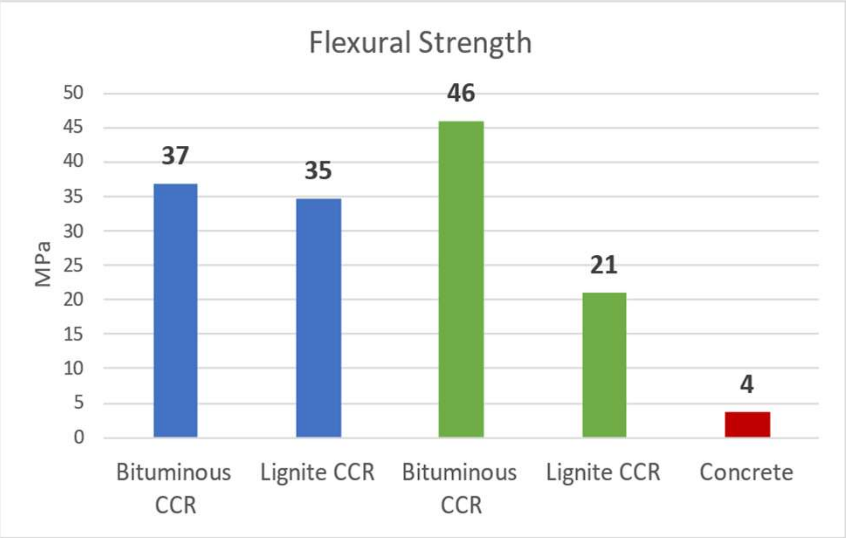
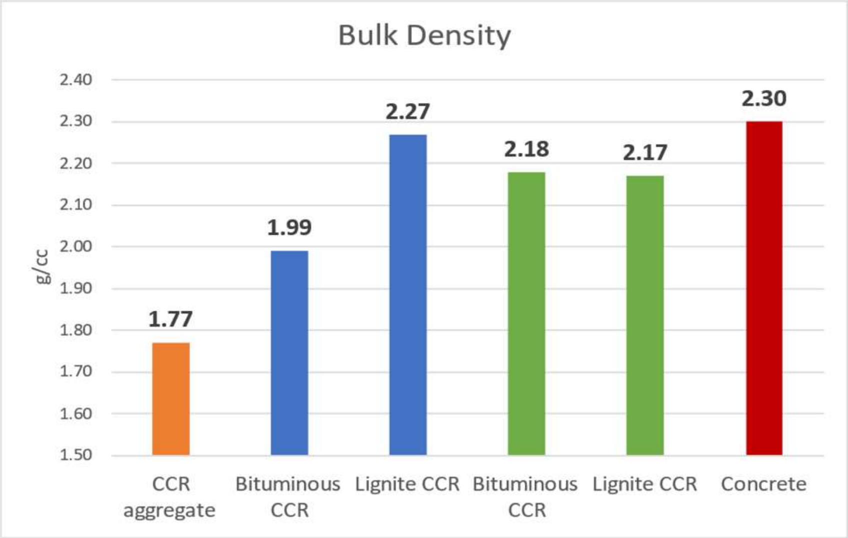
Composite Properties Comparison





Ceramic-Phase Composite

Plastic-Phase Composite

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Polypropylene Filler (Objective 3)

- Coat CCR in dilute solution – thin layer for minimal agglomeration
- Cure in inert gas @ 130-150°C
- Mix coated CCR with polypropylene powder/pellets
- Compounding extruder/chopper system to produce composite "pellets"
- Pellets used to produce components
  - extrusion
  - compression molding
  - injection molding

Polypropylene Filler - Accomplishments

- Coating is 2.5% to 5% by mass of total filler material
  - ~ $.08 – $0.16/lb of coated particles
- Vacuum casting used to produce initial flexure test specimens and to determine the effect of varied filler percentages in the polypropylene
- Demonstrated good bonding of the coating to the CCR and to the polypropylene
- Coating improves both the modulus and strength of filled PP vs conventional PP

50% CCR/50% Polypropylene Pellets

Polypropylene Filler - Mechanical Properties

Material	Flexural Strength (psi)	Flexural Modulus (1000 psi)	Density (g/cc)
Polypropylene	4045	250	0.93
50% X-MAT Coated CCR filled PP	4920	640	1.24

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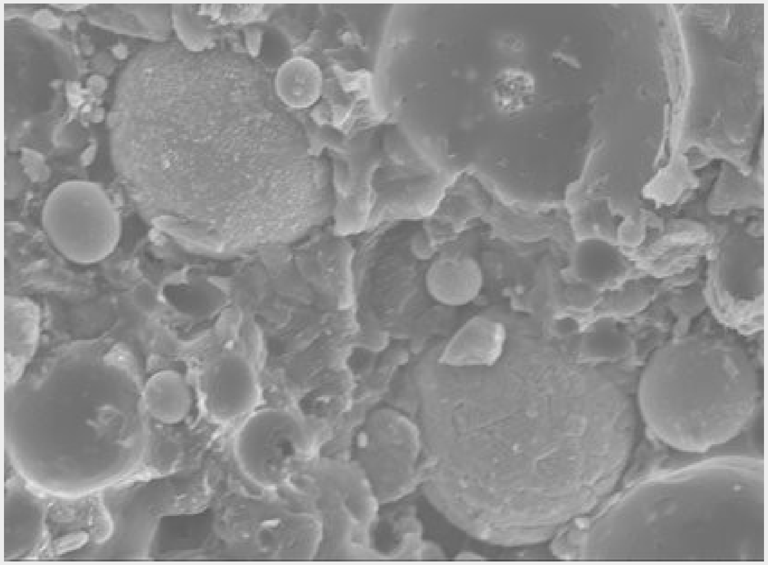
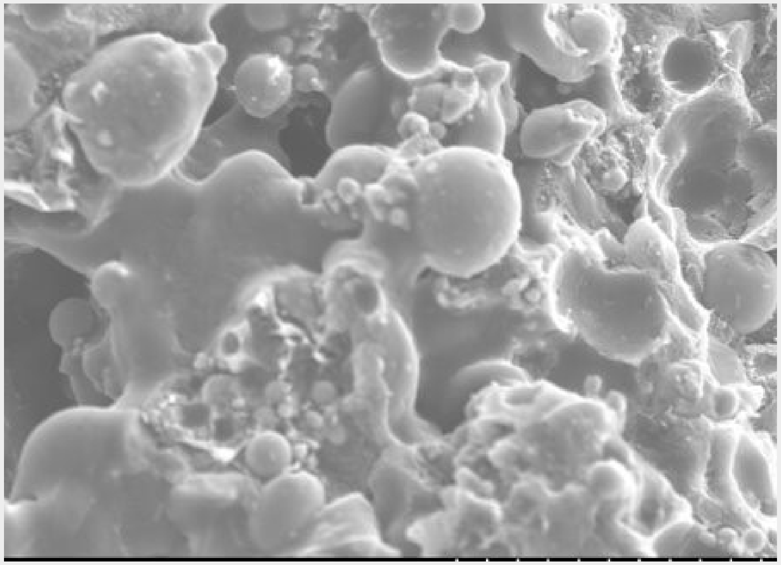
CCR-Filled Polypropylene Composites



50% Uncoated CCR in Polypropylene



50% X-MAT Coated CCR in Polypropylene

SEM imaging and materials characterization by Clemson University

Next Steps

- Scale up to 9" diameter hollow support column prototypes
- Develop interlocking column design
- Move from casting process to compression molding for polypropylene components
- Develop predictive model (Objective 4)
  - *Clemson*

- X-MAT CCR aggregates for concrete

3D-Printed Prototype of mold inserts for Interlocking Mechanism

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Thank You for Your Time

Questions / Discussion