Direct Utilization of U.S. Coal as Feedstock for the Manufacture of High-Value Coal Plastic Composites

DE-FE0031809 Project Update

Tuesday April 27, 2021

Create for Good.

RUSS COLLEGE OF ENGINEERING AND TECHNOLOGY

OHIO UNIVERSITY

Disclaimer

"This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof."

Project Team and Specifics

Project Specifics

- DOE Project Manager: Anthony Zinn
- Principal Investigator: Jason Trembly
- Lead Institution: Ohio University (OHIO)
- Industry Partners: CONSOL Energy and Engineered Profiles
- Consultant: Clear Skies Consulting
- National Laboratory: Pacific Northwest National Laboratory

Period of Performance

- October 1, 2019 to September 30, 2021

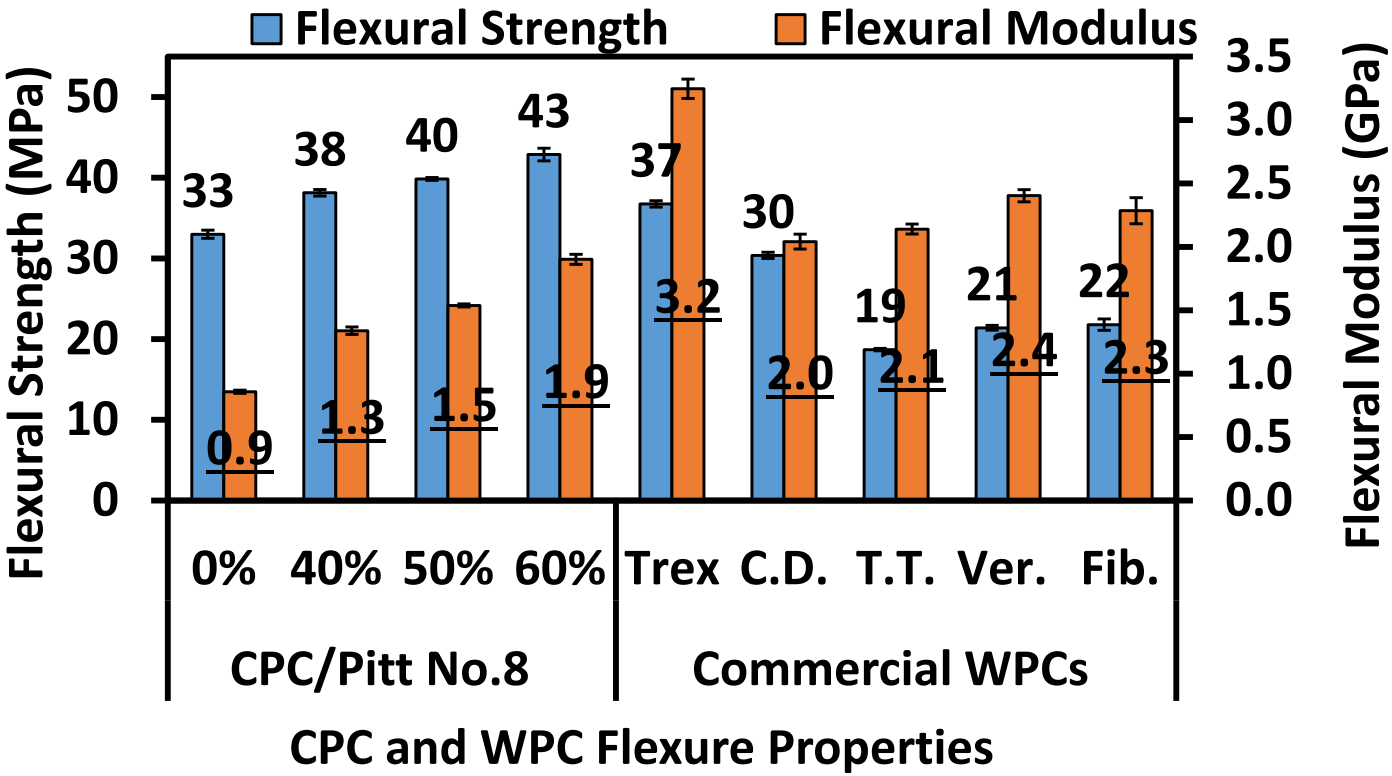
Project Budget

- Total: $2,006,578
- DOE Share: $1,500,000
- Cost Share: $506,678

Project Objectives

- Overall: Develop a coal plastic composite (CPC) formulation which is cost competitive and meets or exceeds ASTM and IBC specifications
- Phase 1
  - Demonstrate continuously manufactured CPC boards meet or exceed ASTM and IBC specifications for decking applications
  - Identify additional promising decking applications for CPC materials
- Phase 2
  - Demonstrate CPC board performance in the field
  - Identify CPC material installation methodologies
  - Identify additional non-decking applications for CPC formulations
  - Develop CPC marketing plan

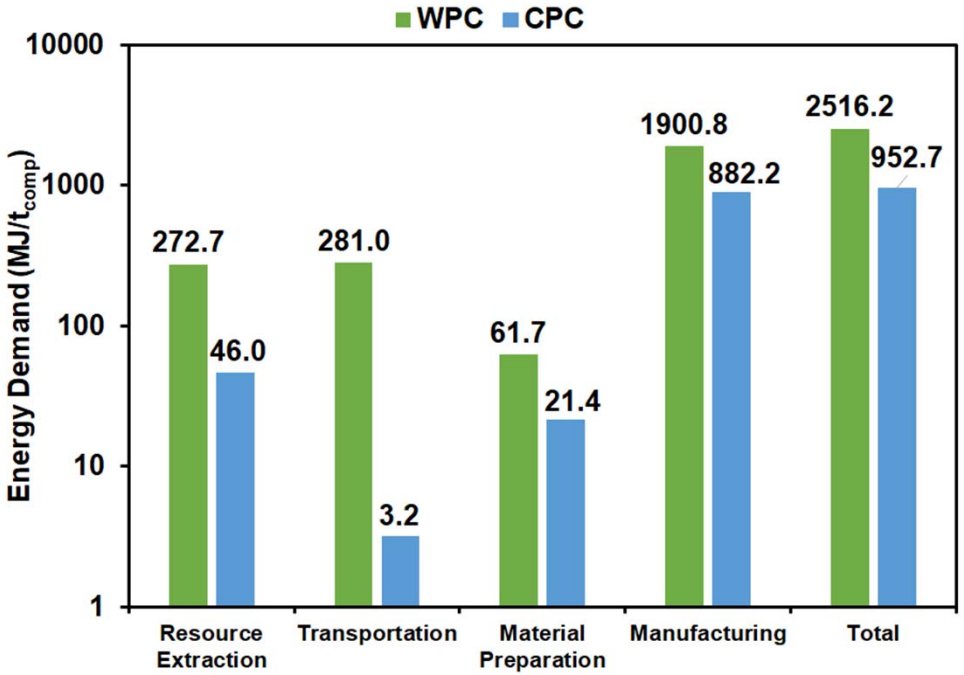
Initial Technology Status: TRL-4



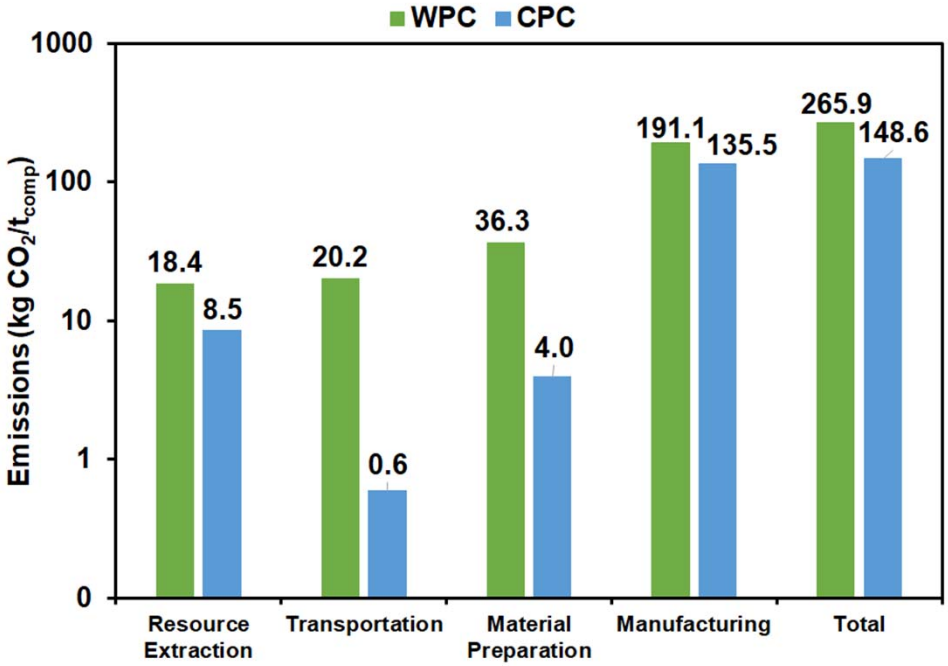
CPC and WPC Flexure Properties

Al-Majali et al., *ACS Sustainable Chem. Eng.,* 2019, 7, 19, 16870-16878.

Initial Technology Status: LCA Results



Specific energy demand for WPC and CPC Cases.



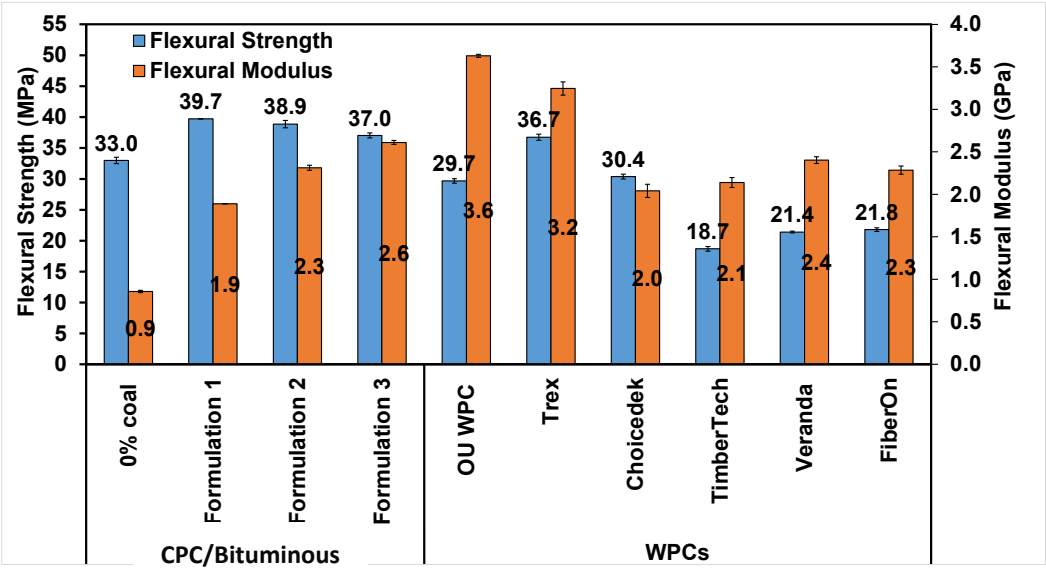
Specific emissions for WPC and CPC Cases.

- **CPC materials require 62% less energy to manufacture and generate 44% less emissions than WPCs**
- **Including HDPE adds 4800 MJ/tonne and 280 kgCO_2/tonne**

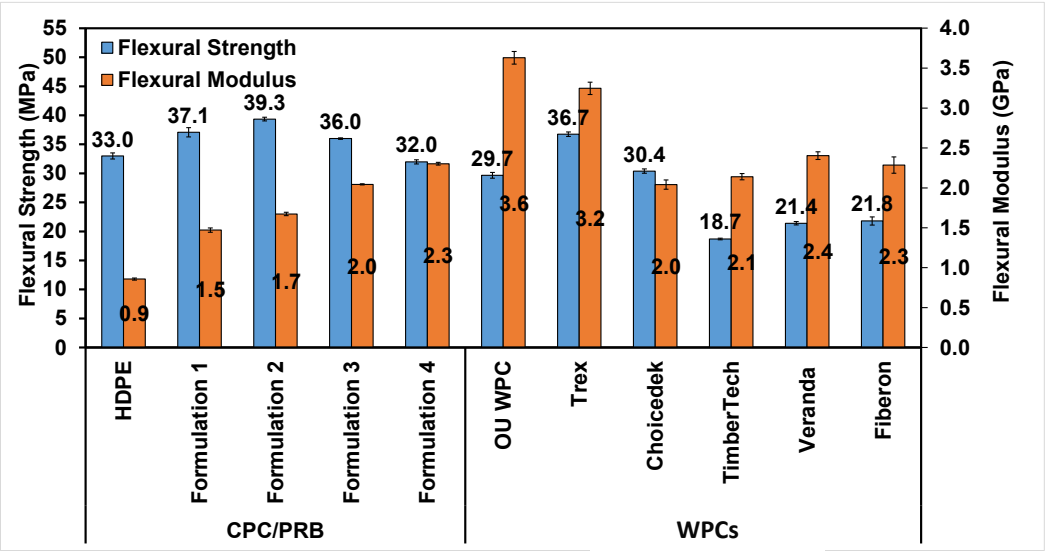
Al-Majali et al., *ACS Sustainable Chem. Eng.,* 2019, 7, 19, 16870-16878.

Current Project Status: Flexural Properties

Bituminous Formulations



PRB Formulations



- Test performed per ASTM D790
- Bituminous formulations possess greater strength.
- All CPC formulations meet IBC specifications for decking applications.
- CPC Safety Factors: 34-46

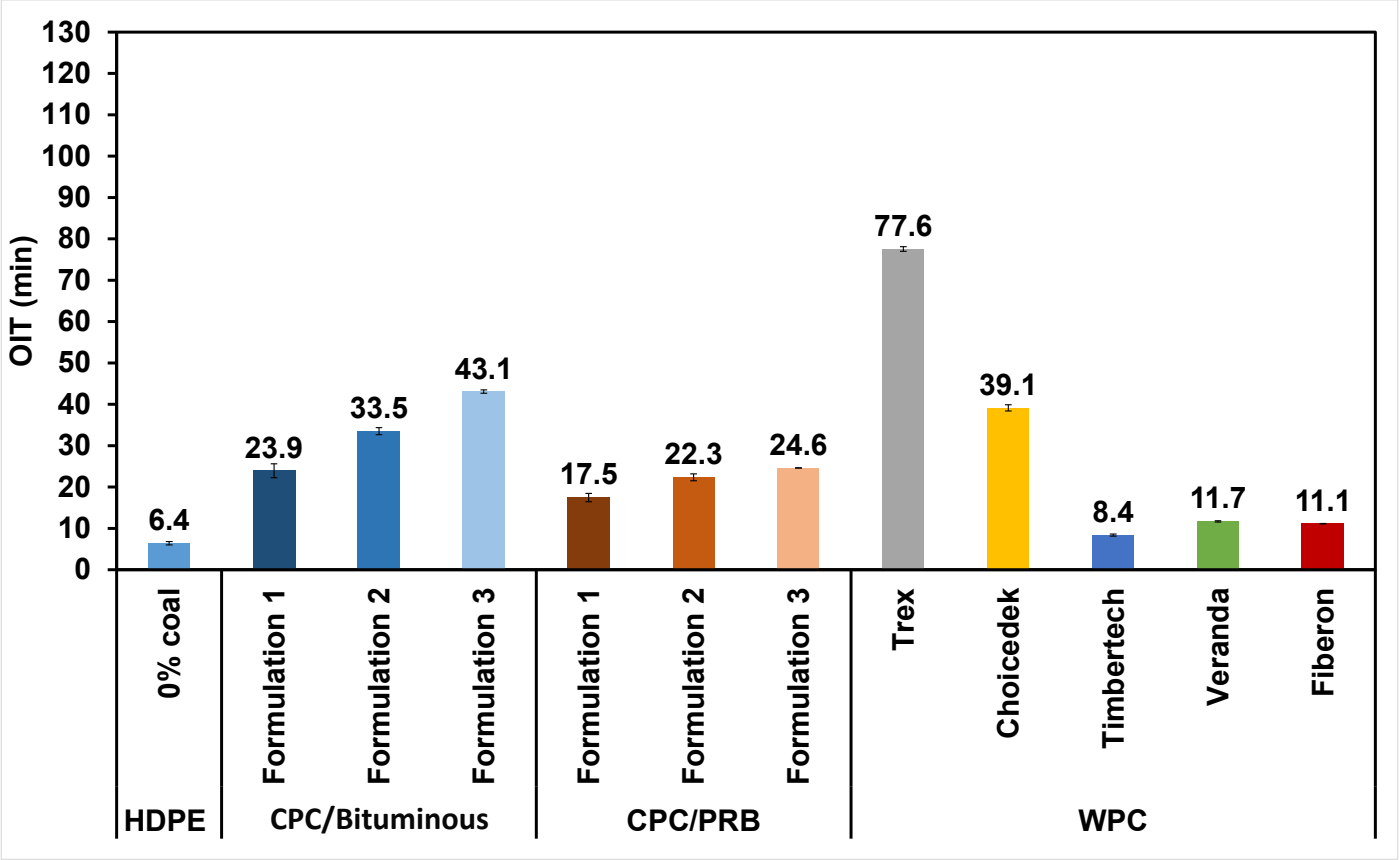
Current Project Status: Flexural Properties

International Building Code (IBC) Specifications and Composite Properties

Category	IBC Spec	P8/CPC	PRB/CPC	WPCs
>W (lbs/ft^2)	100	4047-4677	3481-4275	2034-3992
<Floor Deflection (in)	0.040	0.025-0.038	0.021-0.033	0.015-0.025
<Stair Deflection (in)	0.125	0.054-0.084	0.047-0.073	0.034-0.054

- Test performed per ASTM D790
- Bituminous formulations possess greater strength.
- All CPC formulations meet IBC specifications for decking applications.
- CPC Safety Factors: 34-46

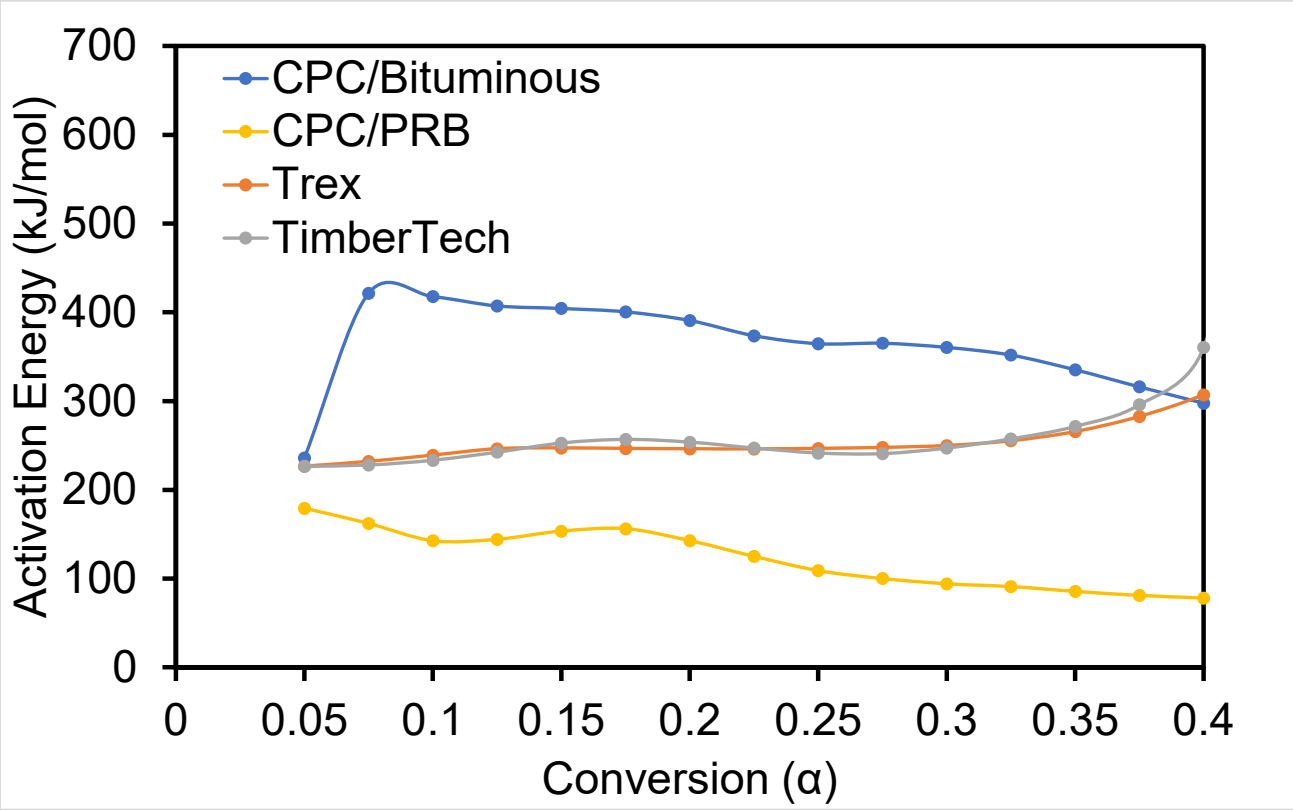
Current Project Status: Oxidation Induction Time (OIT)



- Higher OIT value indicates greater oxidation resistance.
- Determined using O_2-based isothermal DSC method.
- Bituminous formulations possess higher OIT values in comparison to PRB. formulations.
- Bituminous OIT values greater than most commercial WPCs.

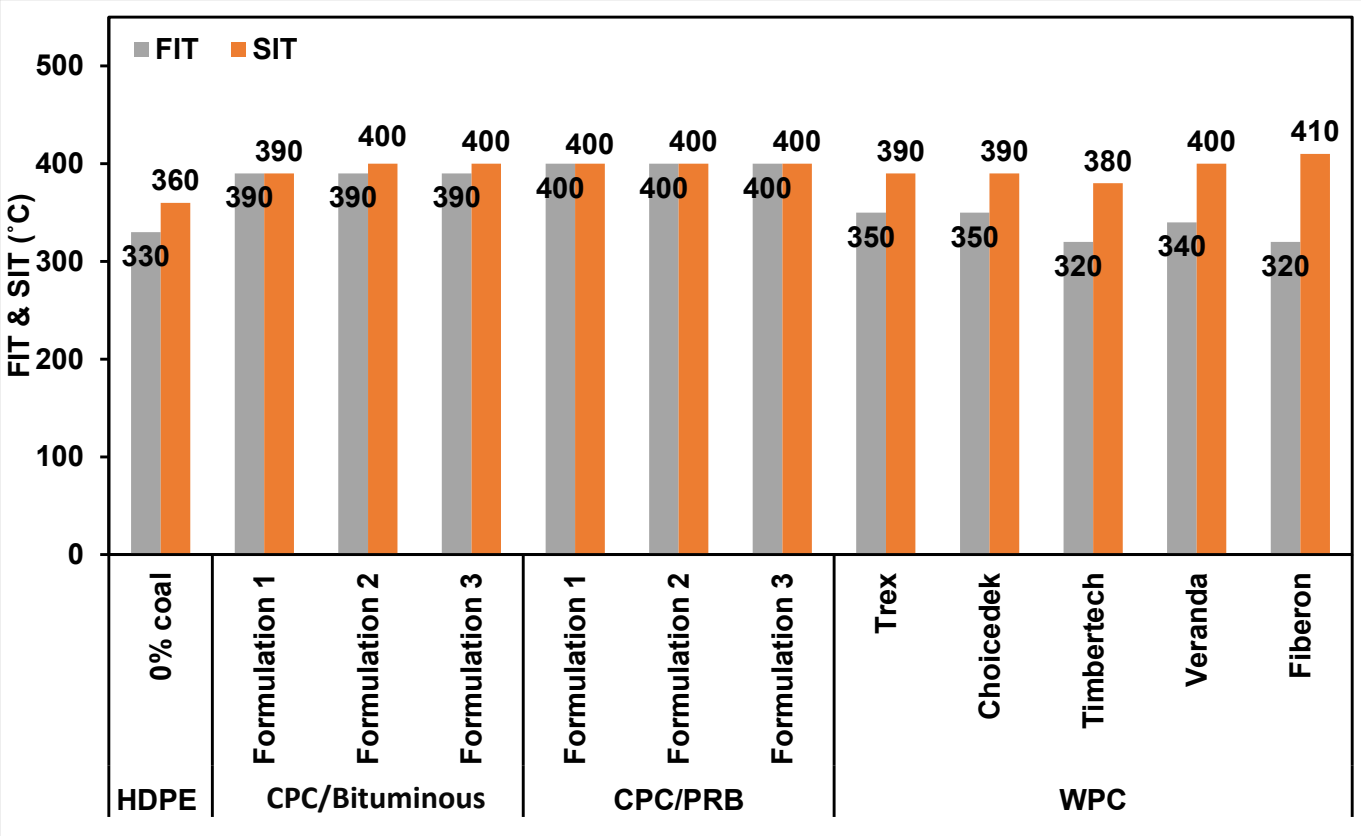
Tests performed according to ASTM D3895

Current Project Status: Oxidation Activation Energy



- Activation energy determined via isoconversional analyses in air at multiple ramp rates.
- Higher activation energy indicates more stable material.
- Results indicate bituminous CPC formulations should have longer product life than WPCs.
- PRB CPC formulations more susceptible to oxidation.

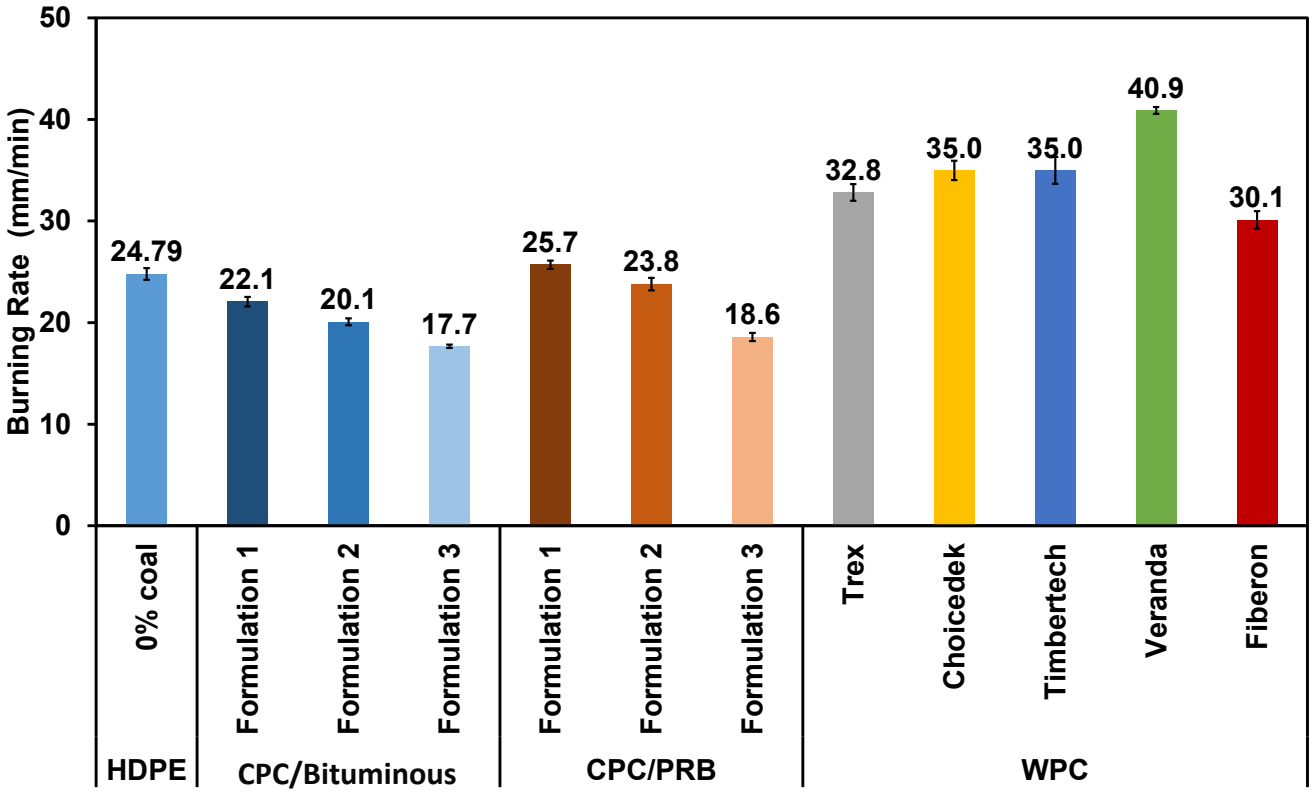
Current Project Status: Flash/Self Ignition Temperatures (FIT/SIT)



- FIT: Temperature at which volatiles ignite with external flame.
- SIT: Temperature at which material ignites in absence of flame.
- CPC formulations possess higher FIT values than WPCs.
- SIT values similar for CPCs and WPCs.

Tests performed according to ASTM D1299

Current Project Status: Rate of Burning (RoB)

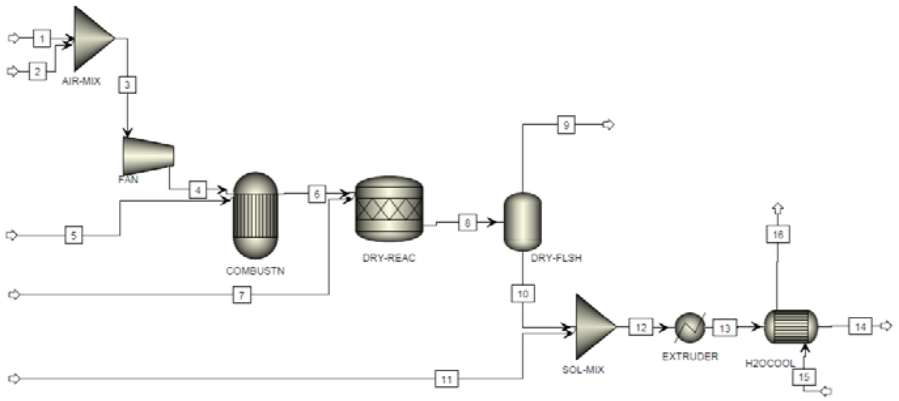


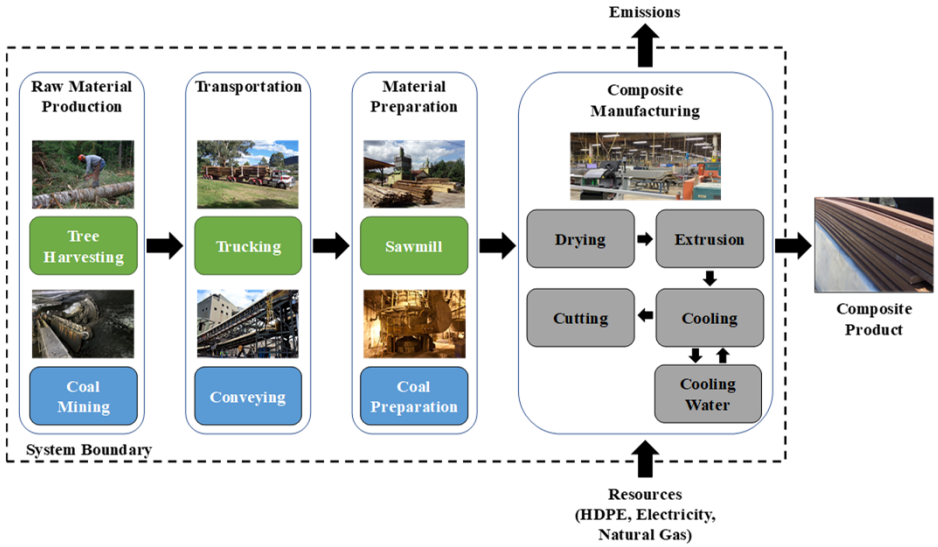
- Comparable to ASTM E84 for composite boards.
- Lower RoB value indicates less flammable material.
- CPC formulations possess significantly lower RoBs than WPC.
- Bituminous formulation RoBs slightly lower than PRB formulations.

Tests performed according to ASTM D635

Current Project Status: TEA/LCA

- Process simulations developed to accurately assess material/energy balances for a commercial manufacturing facility.
- Sensitivity analyses underway:
  - Capacity, feedstock pricing, formulation, operating costs, etc.
- Completed TEA studies indicate CPC manufacturing possesses attractive cost savings over WPC.





Current Project Status: ASTM D7032_Flexure Tests

- ASTM D1609 used to determine flexural properties of reinforced plastic lumber.
- Board flexure strength and modulus used to determine board load and deflection values according to IBC.
- CPC board dimensions: 5.5 in by 24 in
- Load span: 16 in

CPC Boards Exceed IBC Decking Specifications for Load and Deflection

ASTM D1609 Four-point Bend Test (CPC Board Shown)

Current Project Status: ASTM D7032_Fire Rating Tests

- CPC and WPC boards manufactured and tested at certified independent testing facility

ASTM E84 Fire Ratings

Class	Flame Spread Index	Smoke Developed Index
A	0-25	0-450
B	26-75	0-450
C	76-200	0-450

ASTM E84 Test Overview

- Specimen dimensions: W: 20-24 in; L: 24 ft
- Specimen mounted to tunnel ceiling
- Parameters: Heat input: 5.3 MJ/min; Duration: 10 min

ASTM E84 Steiner Tunnel and Test

Current Project Status: ASTM D7032_Fire Rating Tests

- CPC and WPC boards manufactured and tested at certified independent testing facility

ASTM E84 Fire Ratings

Class	Flame Spread Index	Smoke Developed Index
A	0-25	0-450
B	26-75	0-450
C	76-200	0-450

CPC and WPC ASTM E84 Test Results

Observation	CPC	WPC
Ignition Time	1:20 (Min:Sec)	0:46 (Min:Sec)
Max Flame Front Advance	10.7 ft	19.5 ft
Time to Max Flame Front	7:50 (Min:Sec)	6:28 (Min:Sec)
Max Temperature	608.8 °F	1105.3 °F
Time to Max Temperature	9:59 (Min:Sec)	9:05 (Min:Sec)
Falling Ash	No	9:17 (Min:Sec)

CPC Boards Rated Class B via Independent Testing

Market Benefits & Path Forward

Market Benefits

- Lower or equivalent priced product with better properties.
- Utilizes pulverized coal or mining waste materials.
- Easily translatable manufacturing methodologies.

Technology-to-Market Path

- Results from project will provide blueprint to design, build, and operate a commercial CPC manufacturing facility.
- Additional market applications and new research areas have been identified.

Next Steps

- Finish ASTM D7032 testing
- Complete deck constructability assessment.
- Manufacture railing made from CPC.
- Perform marketing study.
- Perform environmental and occupational health studies.

Concluding Remarks

- Recent CPC technology advancements:
  - Manufacturing successfully scaled using commercial WPC manufacturing line.
  - Boards exceed IBC load and deflection specifications for decking applications.
  - Boards possess ASTM E84 Class B flammability rating according to testing at independent facility.

Acknowledgements

- CONSOL Energy: Mr. Dan Connell and Mr. Eric Shereda
- Engineered Profiles: Mr. Vick Dhanapal and Mr. Robert Heigel
- Clear Skies Consulting: Dr. Robert Statnick
- PNNL: Dr. Keerti Kappagantula and Dr. Madhu Sudhanreddy
- OHIO: Yahya Al-Majali (PhD candidate), Sam Forshey, and Dr. Damilola Daramola.


Create
for Good.
RUSS COLLEGE OF ENGINEERING AND TECHNOLOGY
Contact: trembly@ohio.edu
1804
OHIO
UNIVERSITY