# Manufacture of Carbon Foam in Continuous Process at Atmospheric Pressure

DE-FE0031992

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U.S. Department of Energy
National Energy Technology Laboratory
Resource Sustainability Project Review Meeting
October 25 - 27, 2022

# Project Overview

- Funding
  - DOE $1,923,680
  - Cost Share $498,122
- Overall Project Performance Dates
  - Jan 1, 2021 – Dec 30, 2022 (extension applied for)
- Project Participants
  - CONSOL Innovations LLC (formerly CFOAM LLC)
  - CONSOL Energy Inc.
  - Touchstone Research Lab
- Project Manager: Michael Fasouletos (NETL)

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# Project Overview

- Develop continuous processing of carbon foam products made from coal at atmospheric pressure.
- Both carbon foam panels and lightweight carbon foam aggregates have been developed.

A successful outcome would:

1) significantly reduce the cost to manufacture carbon foam through reductions in capital and labor costs

2) significantly reduce the manufacturing time from weeks to hours, and

3) enable the manufacture of much larger volumes of carbon foam.

All of these features are expected to enable carbon foam to enter much larger markets and create meaningful demand for U.S. coal.

# Project Overview

| OBJECTIVE | VALIDATION OF SUCCESS |
|---|---|
| Establish a continuous manufacturing process at atmospheric pressure for carbon foam panels. | Panels must have the following characteristics:<br>• Utilize 90-100 wt% coal and contain at least 80 wt% carbon<br>• Length and width near 18 x 18".<br>• Free of cracks and large voids<br>• Density less than 50 pcf.<br>• Compressive strength > 1600 psi when normalized to 30 pcf.<br>• Flexural strength > 500 psi when normalized to 30 pcf. |
| Establish a continuous manufacturing process at atmospheric pressure for carbon foam aggregate. | Aggregate has the following characteristics:<br>• Utilize 90-100 wt% coal and contain at least 80 wt% carbon<br>• Well-formed and largely defect free.<br>• Fusing of aggregate during firing is limited to < 5%.<br>• Bulk density less than 50 pcf. |
| Create a manufacturing process that has the capability of achieving a 90% reduction in cost. | Techno-economic analyses prove a cost reduction of 90% is achievable. |

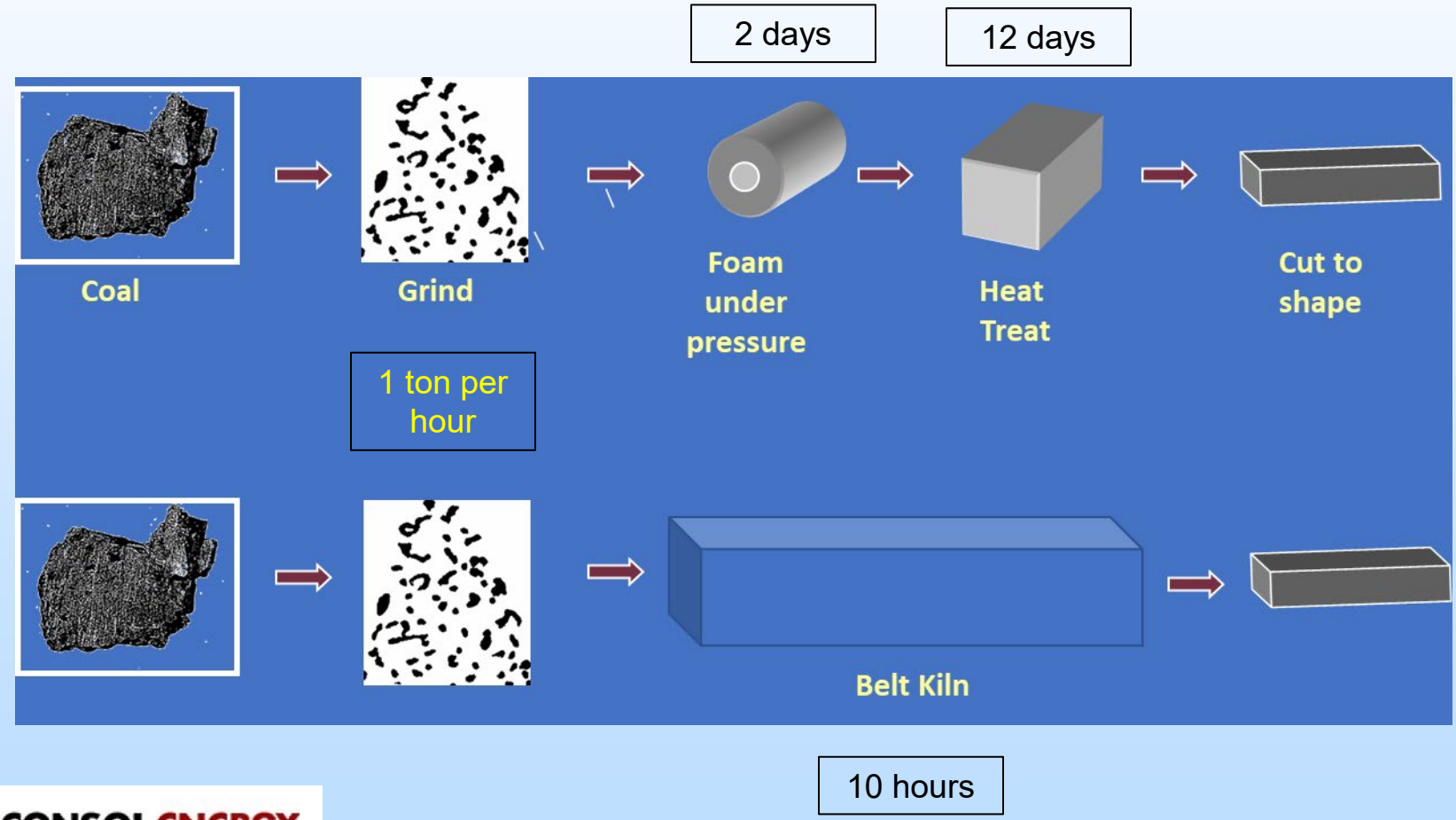
# Technology Background

**MATERIALS SCIENCE CHAIN**

Processing – Microstructure – Properties - Performance

# Technology Background

How the technology is envisioned to work in operation



# Technology Background

The fundamental science driving technology includes:

1. Choosing the starting coal chemistry
2. Influencing the stability of carbon foam through:
    a. coal preparation
    b. manipulation of thermal profile and
    c. use of additives that affect the:
        i. surface tension
        ii. viscosity of liquid phase
        iii. evolution rate of vapor phases
        iv. reaction rate of liquids

# Technology Background

Initial benchscale testing

- Panel made in batch mode at atmospheric pressure
- 34 pcf
- 636 psi

- Aggregates made in lab
- 1 – 10-mm

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# Technology Background

Economic advantages

- Continuous process reduces labor and enables automation.
- “Single piece flow” – safer than batch mode

Technical and economic challenges

- Stabilizing foam at desired density for application
- Production of large panels
- Manufacture at high speed.

Site Selection

- At the coal mine.

# Technical Approach/Project Scope

Project steps

1. Assemble the kiln
2. Apply materials knowledge and conduct trials in continuous kiln using designed experiments to enable production at atmospheric pressure:

   PANELS
   - Varied thermal profile
   - Utilized different coals (high and mid volatility)
   - Varied particle size (utilized waste fines)
   - Reactive and inert additives

   AGGREGATE
   - Varied thermal profile
   - Utilized different coals (high and mid volatility)
   - Varied forming process parameters
   - Used both granulator and fluidized bed equipment

# Technical Approach/Project Scope

| Task/ Subtask | Milestone Title & Description | Planned Completion Date | Verification method |
|---|---|---|---|
| 1.1 | Safety Management Plan complete for BP 1. | 30 days after project start | A document is complete that verifies a safety review was performed and any action items have been executed. |
| 1.2 | Review of Project Management Plan | 30 days after project start | NETL Project Manager has reviewed project and approved plan. |
| 2.0 | Install and commission a used belt kiln capable of processing coal-based carbon foam products. | 5$^{th}$ month | Kiln can achieve 900C, maintain nitrogen atmosphere, and adequately combust emissions. |
| 3.1 | Develop a process capable of continuously making carbon foam panels at atmospheric pressure. | 12$^{th}$ month | Length and width near 18 x 18”<br>Free of cracks and large voids<br>Density less than 50 pcf<br>Compressive strength > 1600 psi<br>Flexural strength > 500 psi<br>(strength normalized to 30 pcf) |

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# Technical Approach/Project Scope

| Task/ Subtask | Milestone Title & Description | Planned Completion Date | Verification method |
|---|---|---|---|
| 1.1 | Safety Management Plan complete for BP 2. | 13th month | A document is complete that verifies a safety review was performed and any action items have been executed. |
| 4.0 | Install and commission equipment capable of continuously forming carbon aggregate with size ranges of 0.4-1 and 1-25-mm. | 15th month | Equipment is capable of producing aggregate at a scale of 25-50 lbs per hour in granulator and 10-lbs per hour in fluidized bed. |
| 5.1 | Develop process capable of continuously making carbon foam aggregates having size ranges of 0.4-1 and 1-25-mm. | 24th month | Well-formed, largely defect free. Aggregate fusing limited to < 5%. Bulk density less than 50 pcf |
| 6.0 | Techno-Economic Analysis complete. | 24th month | A document is complete that verifies analysis was performed and all action items have been executed. |

# Progress and Current Status

Assembled the kiln and accessories

a. Metal mesh and muffle, 24” wide, 50’ length
b. 7 heating zones (30’), 4 cooling zones (20’)
c. Thermal oxidizer
d. Nitrogen generator – atmosphere 99.97+%
e. Chiller
f. Max temperature to date, 965°C

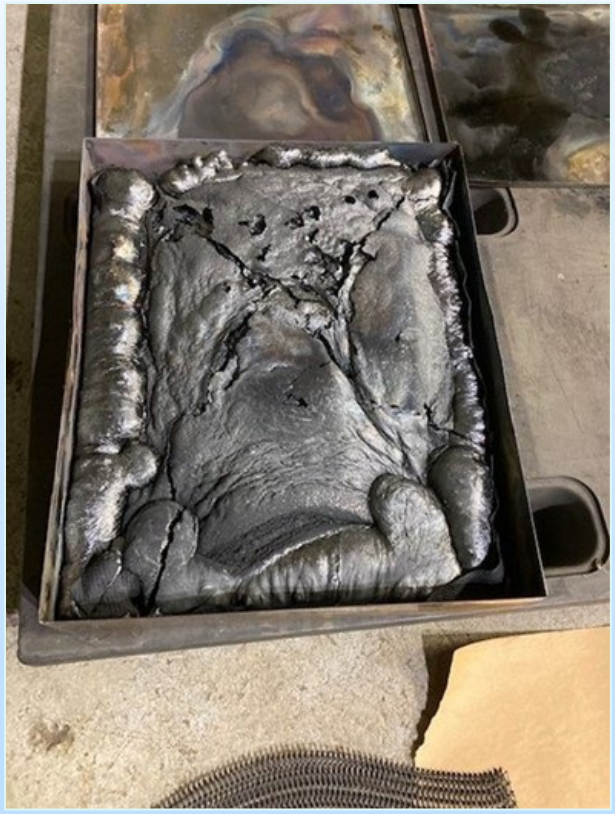
# Progress and Current Status

Drum granulator
Fluidized bed
Sweco separator

# Progress and Current Status

Trial 1, December 2021

- 20 x 24” steel pans

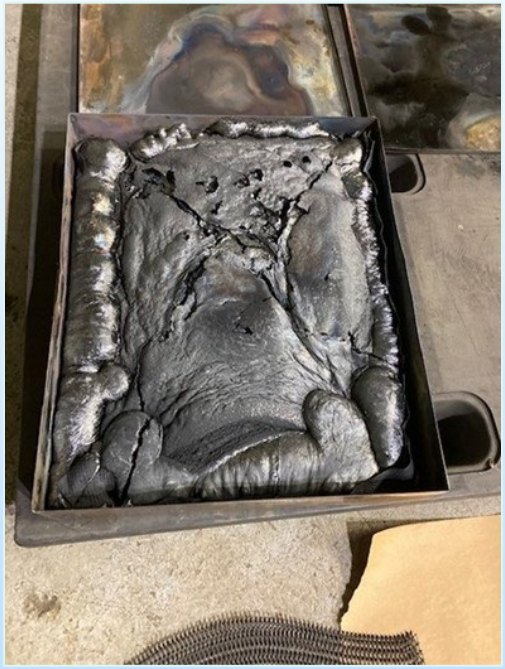


High Vol PA Coal

Mid Vol WV Coal

# Progress and Current Status

High Vol PA coal



Trial 1

Trial 24

Trial 28

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# Progress and Current Status

High Vol PA coal – Trial 33

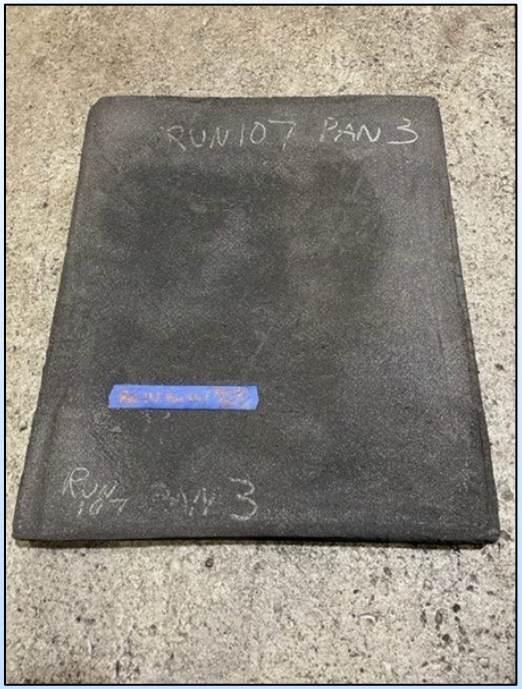
After foaming to 500C

After machining

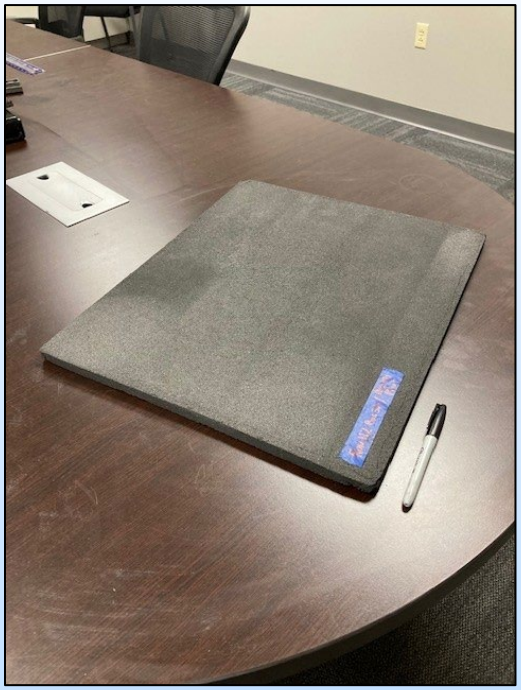
# Progress and Current Status

High Vol PA coal – Trial 107

After foaming to 500C




After carbonization to 965C



After machining

# Progress and Current Status

Mid Vol WV coal

Trial 1

Trial 37

Trial 78

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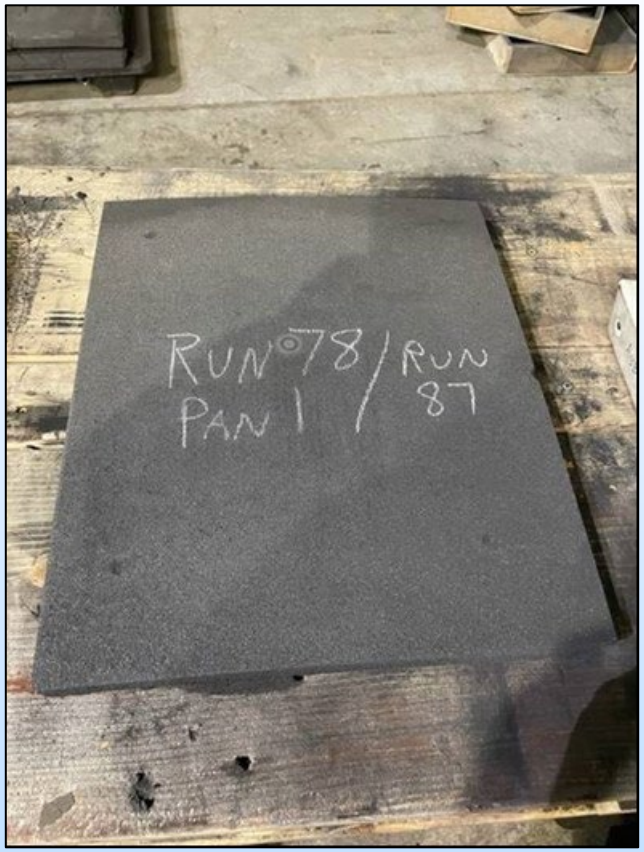
# Progress and Current Status

Mid Vol WV coal

- Trial 78
- 47 pcf




Carbonized
and
machined

# Progress and Current Status

Use of fine waste coal

- 65-wt% high vol coal
- 35-wt% waste coal

Carbonized
and
machined

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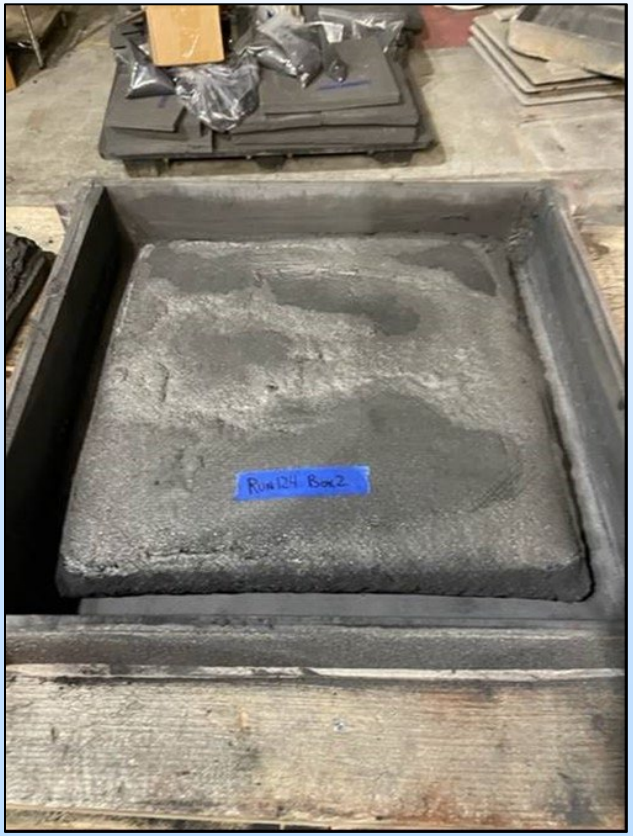
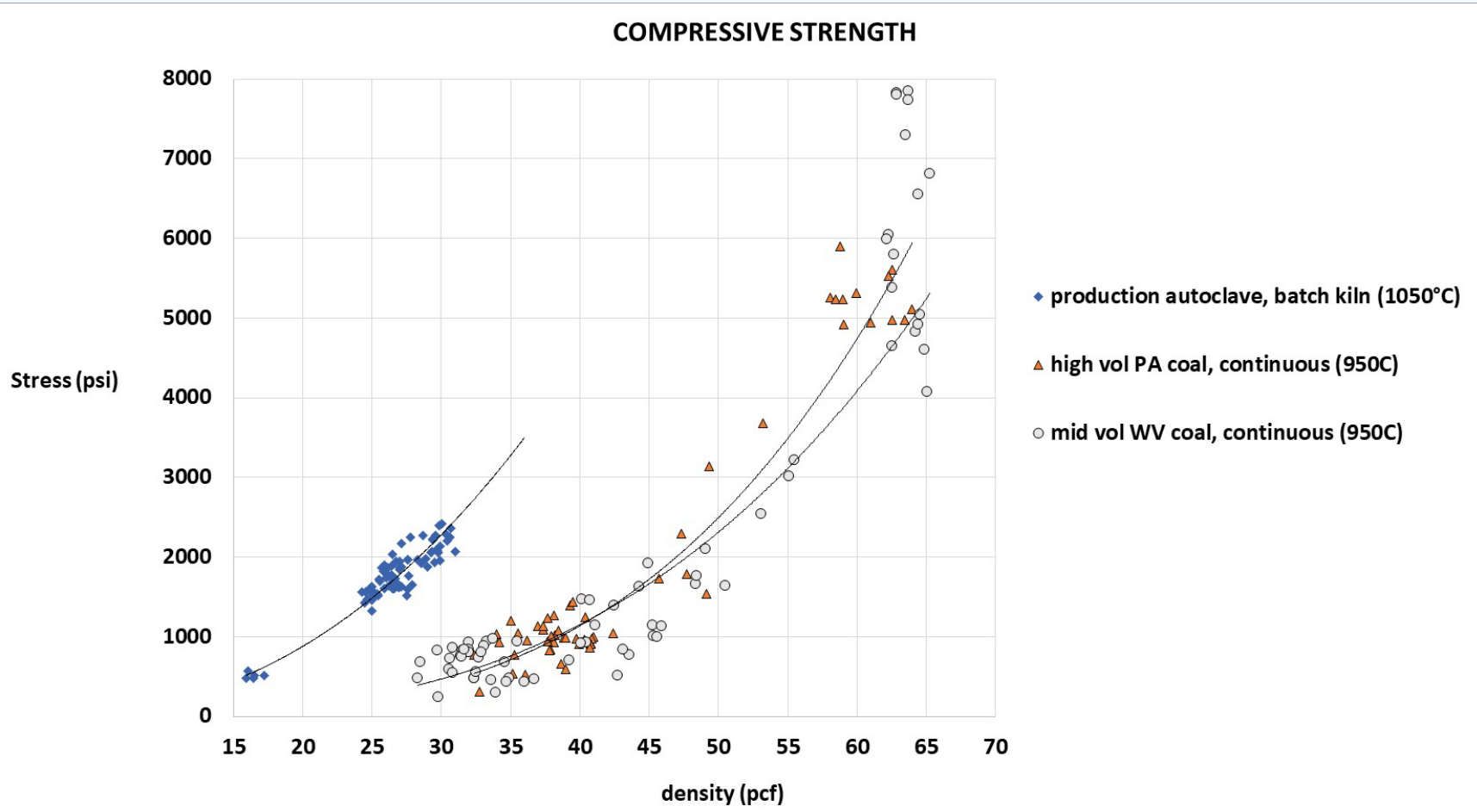
# Progress and Current Status

Single pass testing

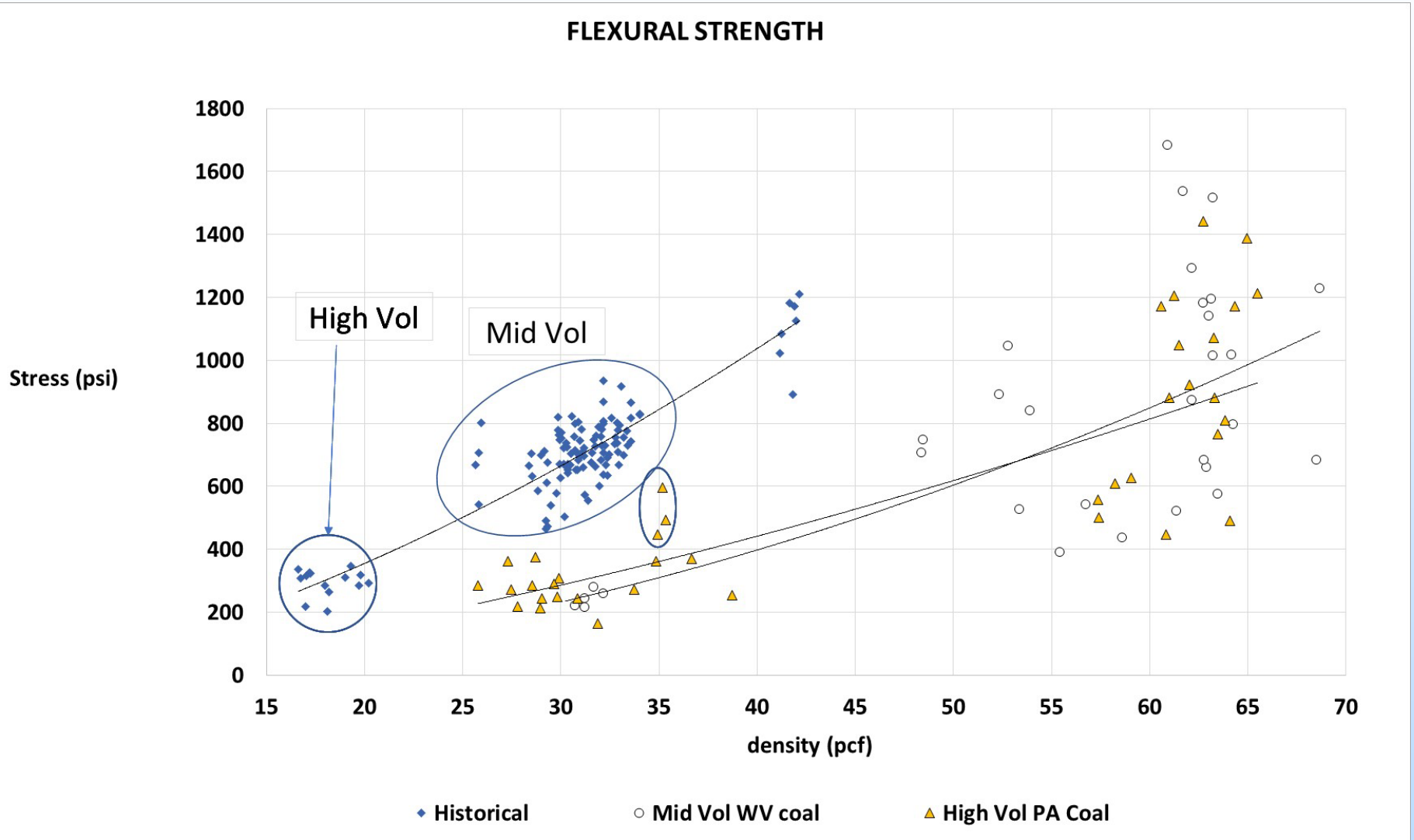
- Working to solve bowing issues



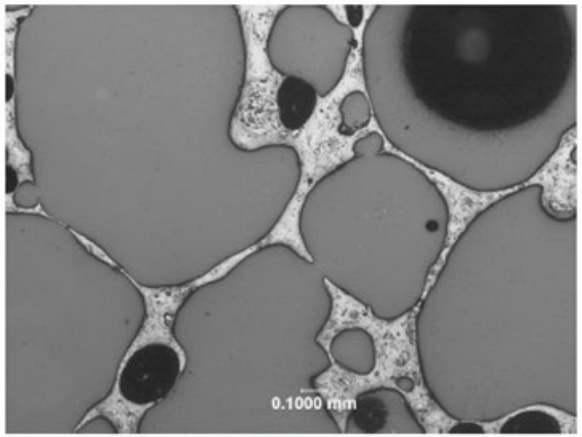
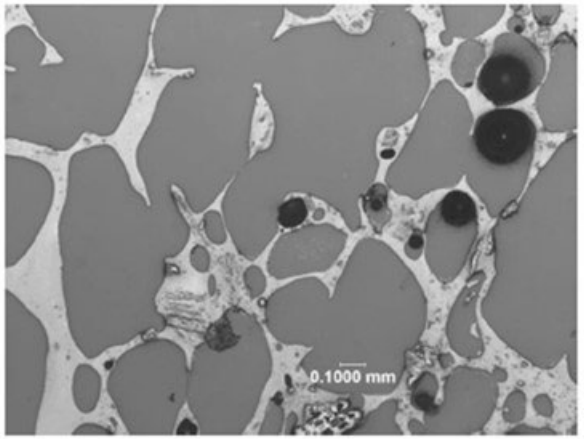
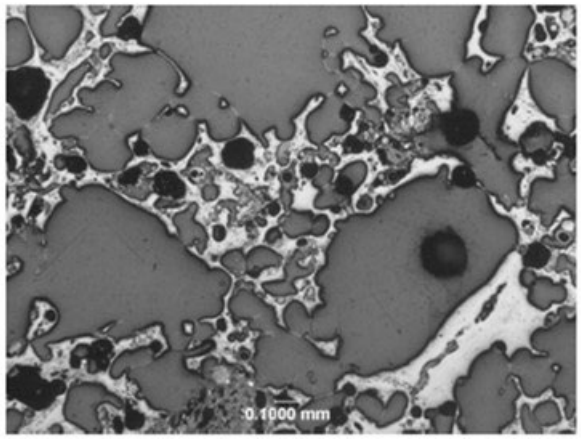
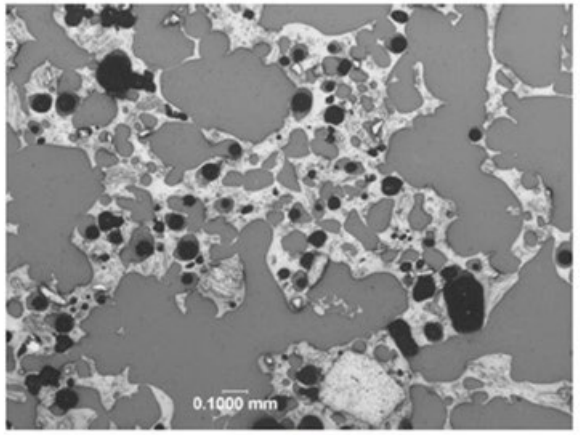
# Progress and Current Status



# Progress and Current Status



# Progress and Current Status

| | High-vol coal | Mid-vol coal |
|---|---|---|
| 400 psi |  E-X (50X) |  D-X (50X) |
| Continuous kiln |  A-Z (50X) |  B-X (50X) |

# Progress and Current Status

- Bulk densities currently averaging about 34 pcf.
- Granulator – 0.1 – 25-mm
- Fluidized bed – 0.1 – 2-mm

# Progress and Current Status

Aggregate

Bulk densities currently averaging about 34 pcf.

# Progress and Current Status

Significant accomplishments

PANELS

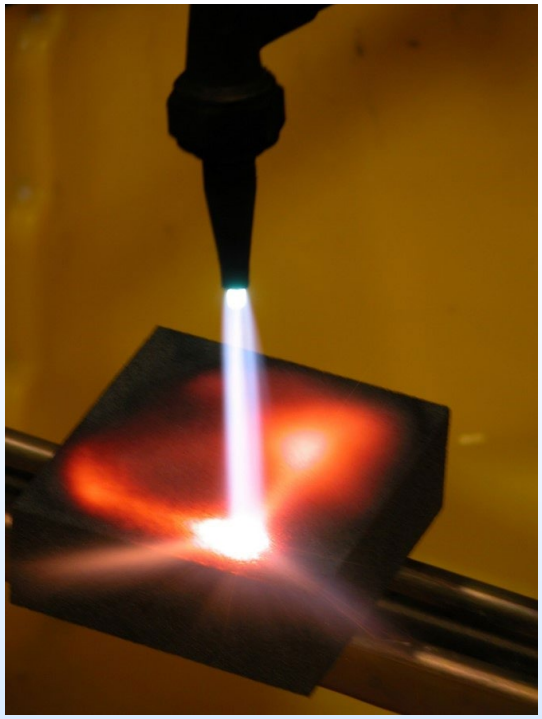
- Utilized 90-100 wt% coal and contain at least 80 wt% carbon
- Length and width near 18 x 18” achieved.
- Free of cracks and large voids achieved
- Density less than 50 pcf achieved
- Compressive strength > 1600 psi normalized to 30 pcf not achieved, *but higher strengths achieved at higher densities*.
- Flexural strength > 500 psi when normalized to 30 pcf not achieved, *but higher strengths achieved at higher densities*.

AGGREGATE

- Utilized 90-100 wt% coal and contain at least 80 wt% carbon
- Well-formed and largely defect free.
- Fusing of aggregate during firing is limited to < 5% achieved.
- Bulk density less than 50 pcf achieved.

Have moved from TRL 4 to TRL 5.

# Plans for future testing



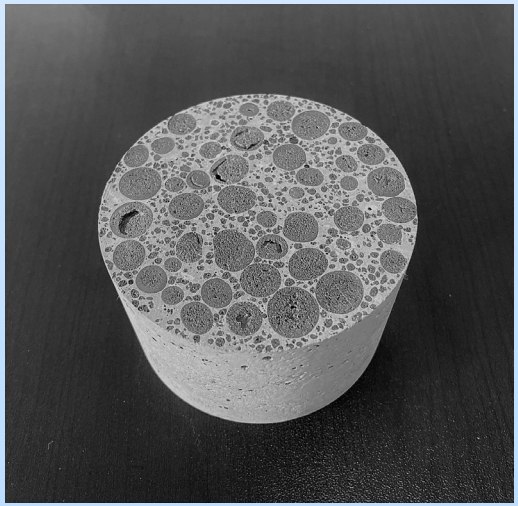
Optimize aggregate production process

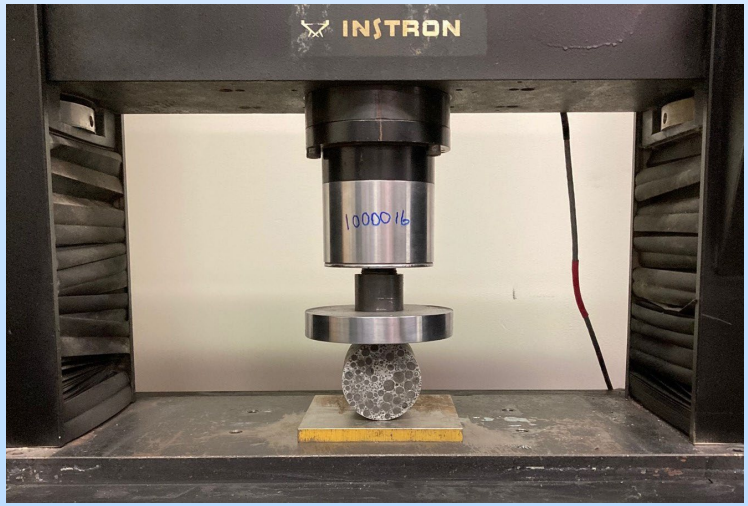
Test performance of panels

- Fire resistance
- Screw pullout
- Water migration

Test performance of aggregate

- Concrete properties
- Asphalt properties
- Refractory testing
- Proppant testing



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# Plans for future development and commercialization

- Scale-up potential will be considered after completion of TEA.
- Consider capture and utilization of off-gas for:
  - Sale as byproducts
  - Secondary heat exchange


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# Workforce Development

- Excellent training for accountant towards managing government grants.
- Student interns employed by Touchstone.

# Summary

- Thermal profile is critical for foaming and crack prevention.
  - Front end must be properly controlled to regulate foaming step.
- Additives critical for manipulating density and inhibiting cracking.
  - Small percentages of polymeric additives (0-2 wt%) aid in creating homogeneous foam and can increase density.
  - Graphite addition allows for significant increase in speed and inhibits cracking.
- Addition of coal waste fines is positive.
- Single pass through the kiln is possible.
- Compressive and flexural strength-to-weight ratios for high and mid vol coal are lower than historical, *but we can attain higher values at higher densities*.

# Summary

We can manufacture 18 x 18” lightweight carbon foam panels in a continuous process at atmospheric pressure.

We can manufacture lightweight carbon aggregate in a continuous process at atmospheric pressure with < 5% fusion.

# Acknowledgements


- Michael Fasouletos (NETL)
- Eric Shereda and Dan Connell (CONSOL Energy)
- Dwayne Morgan, Brian Gordon and Michael Spencer (Touchstone)
- CONSOL Innovations team - Brian, Doug, Bruce, Lisa, Kathy

# Thank you!

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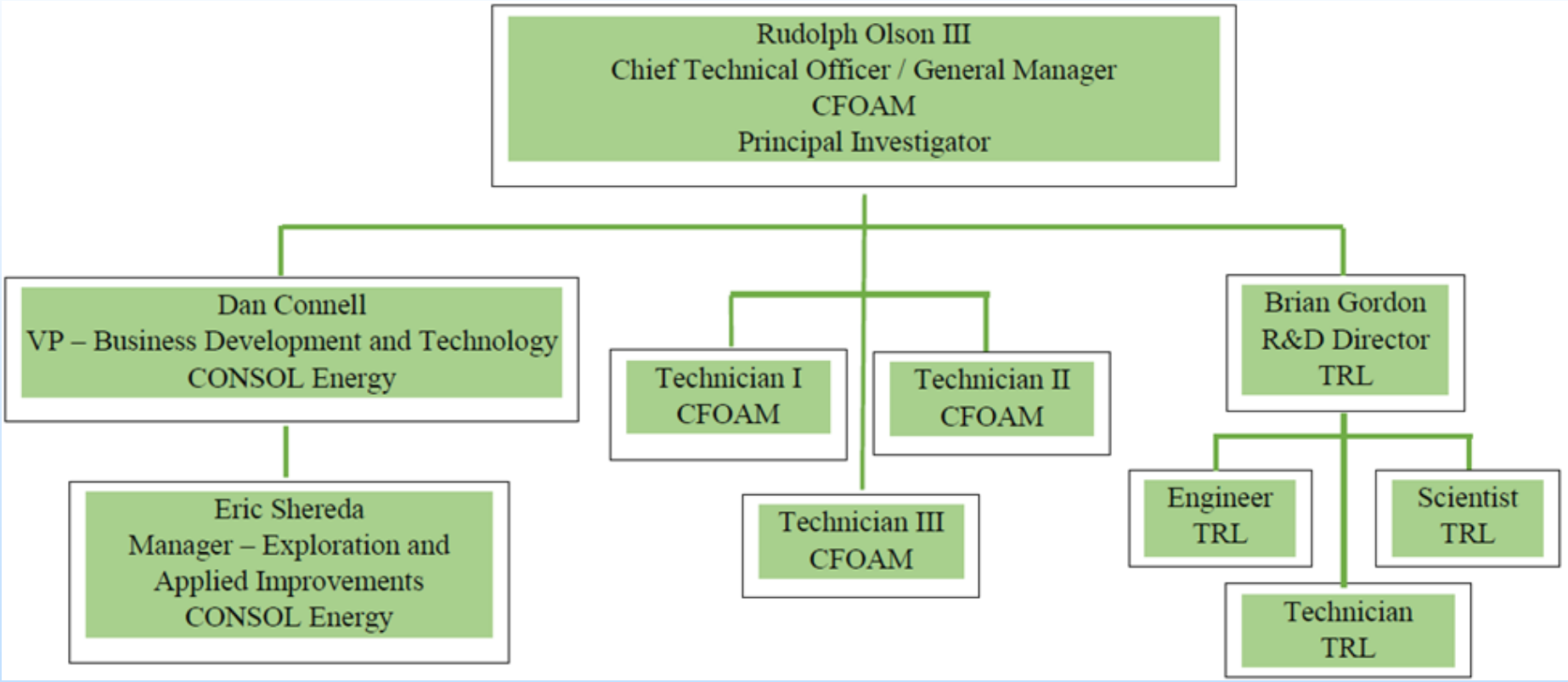
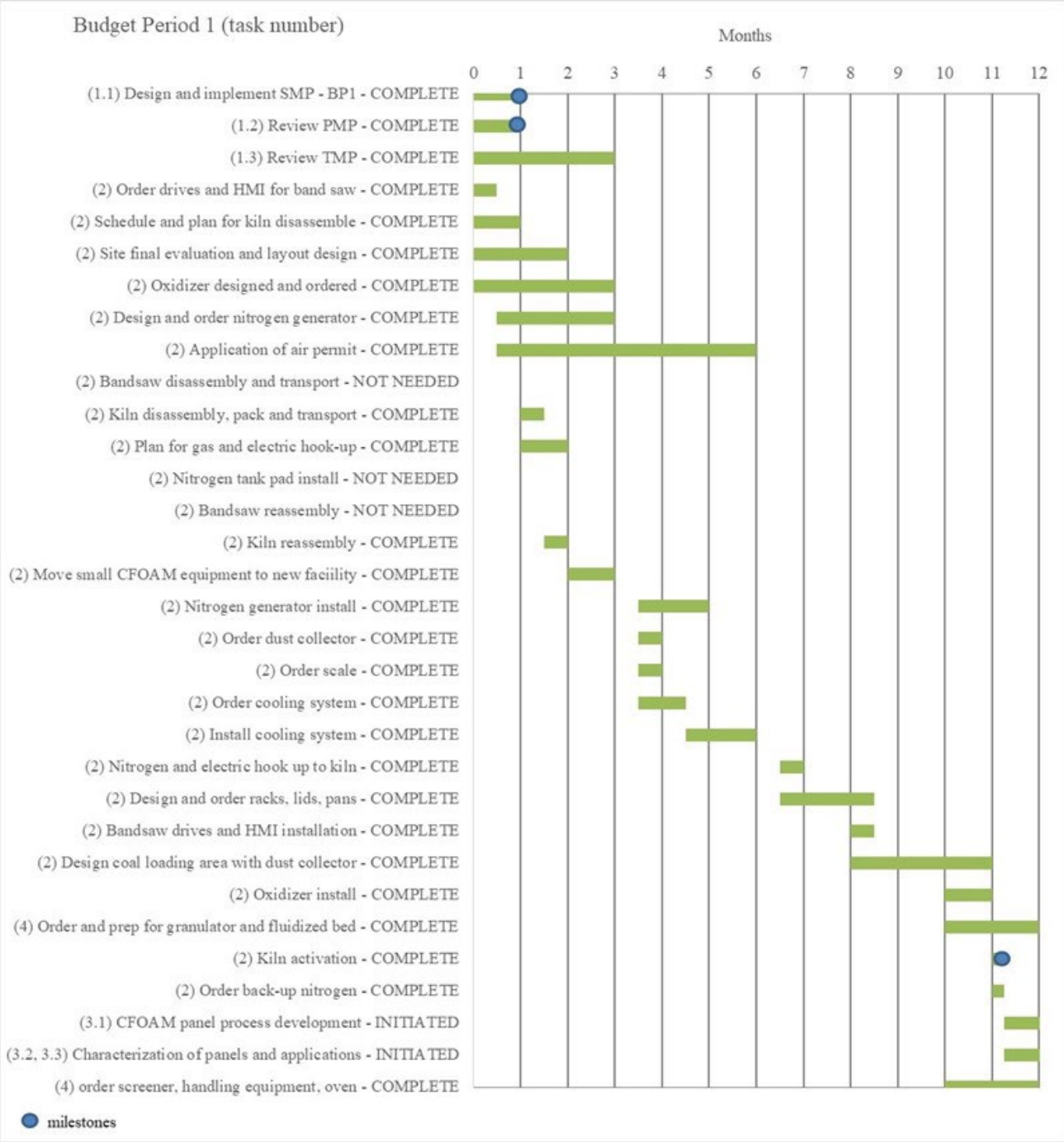
# Appendix

– These slides will not be discussed during the presentation but are mandatory.

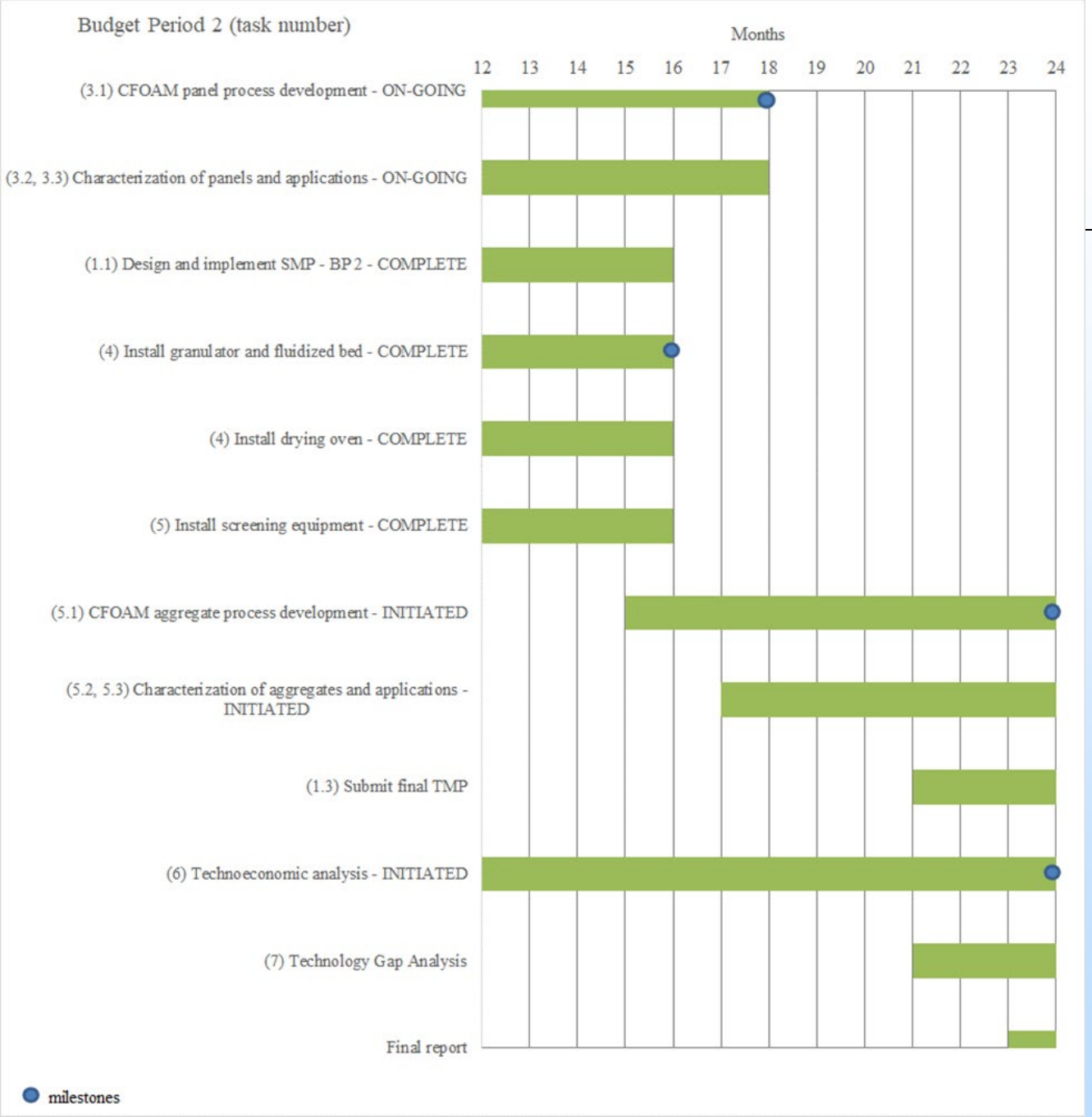
# Organization Chart



# Gantt Chart


Budget Period 1 (task number)
Months
0 1 2 3 4 5 6 7 8 9 10 11 12
(1.1) Design and implement SMP - BP1 - COMPLETE
(1.2) Review PMP - COMPLETE
(1.3) Review TMP - COMPLETE
(2) Order drives and HMI for band saw - COMPLETE
(2) Schedule and plan for kiln disassemble - COMPLETE
(2) Site final evaluation and layout design - COMPLETE
(2) Oxidizer designed and ordered - COMPLETE
(2) Design and order nitrogen generator - COMPLETE
(2) Application of air permit - COMPLETE
(2) Bandsaw disassembly and transport - NOT NEEDED
(2) Kiln disassembly, pack and transport - COMPLETE
(2) Plan for gas and electric hook-up - COMPLETE
(2) Nitrogen tank pad install - NOT NEEDED
(2) Bandsaw reassembly - NOT NEEDED
(2) Kiln reassembly - COMPLETE
(2) Move small CFOAM equipment to new faciility - COMPLETE
(2) Nitrogen generator install - COMPLETE
(2) Order dust collector - COMPLETE
(2) Order scale - COMPLETE
(2) Order cooling system - COMPLETE
(2) Install cooling system - COMPLETE
(2) Nitrogen and electric hook up to kiln - COMPLETE
(2) Design and order racks, lids, pans - COMPLETE
(2) Bandsaw drives and HMI installation - COMPLETE
(2) Design coal loading area with dust collector - COMPLETE
(2) Oxidizer install - COMPLETE
(4) Order and prep for granulator and fluidized bed - COMPLETE
(2) Kiln activation - COMPLETE
(2) Order back-up nitrogen - COMPLETE
(3.1) CFOAM panel process development - INITIATED
(3.2, 3.3) Characterization of panels and applications - INITIATED
(4) order screener, handling equipment, oven - COMPLETE
milestones

# Gantt Chart


Budget Period 2 (task number)
Months
12
13
14
15
16
17
18
19
20
21
22
23
24
(3.1) CFOAM panel process development - ON-GOING
(3.2, 3.3) Characterization of panels and applications - ON-GOING
(1.1) Design and implement SMP - BP2 - COMPLETE
(4) Install granulator and fluidized bed - COMPLETE
(4) Install drying oven - COMPLETE
(5) Install screening equipment - COMPLETE
(5.1) CFOAM aggregate process development - INITIATED
(5.2, 5.3) Characterization of aggregates and applications - INITIATED
(1.3) Submit final TMP
(6) Technoeconomic analysis - INITIATED
(7) Technology Gap Analysis
Final report
milestones