
RENEWABLE

ENVIRONMENTAL

THERMAL

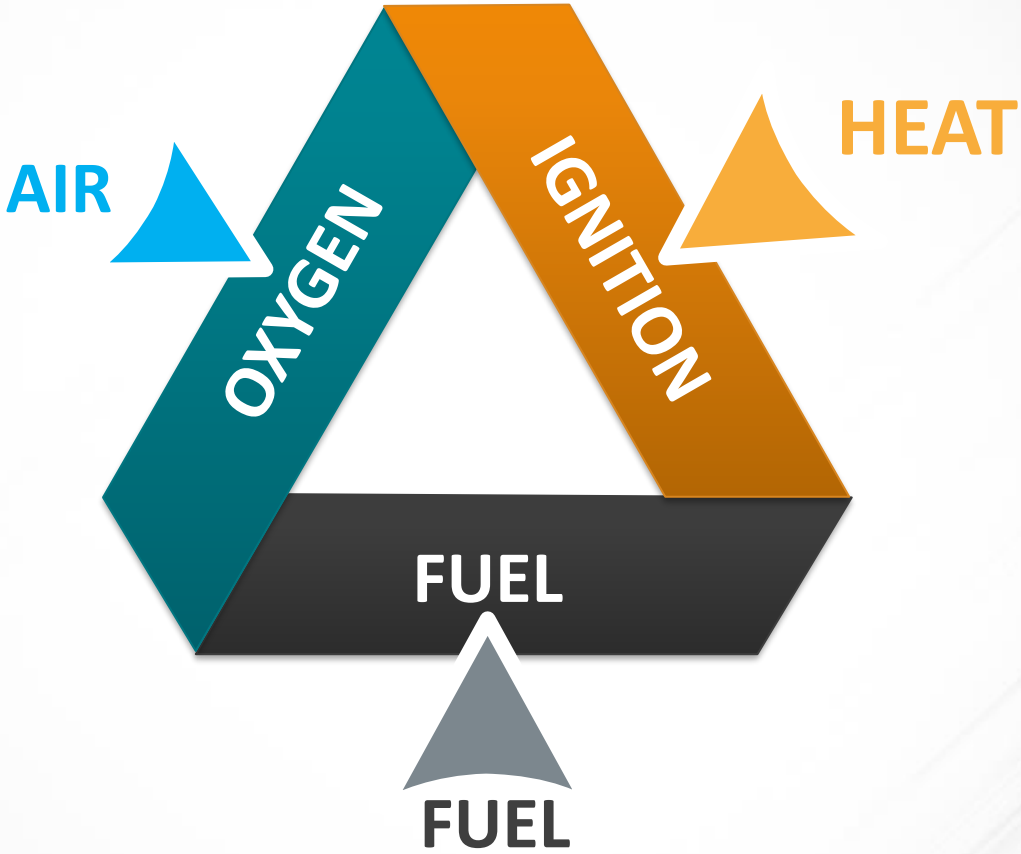
# BrightLoop™ Chemical Looping

## for Hydrogen and Steam Production with $CO_2$ Capture

# Drive to Innovate

For the foreseeable future, fossil fuels (coal, oil and natural gas) will continue to play a critical role in the world's energy supply. Continued use of these energy sources in a carbon-constrained environment will require **carbon capture use and storage (CCUS)** from power plants and industrial processes.

# BrightLoop™ Chemical Looping Concept



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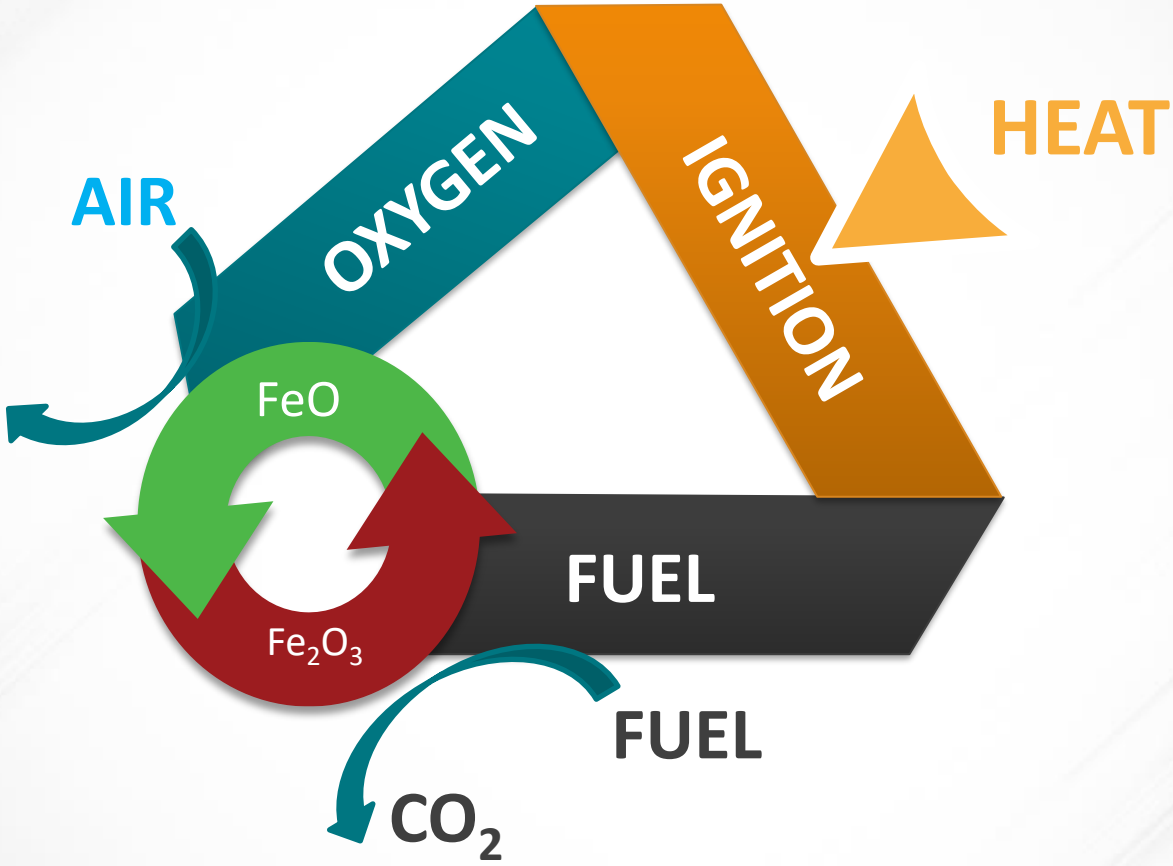
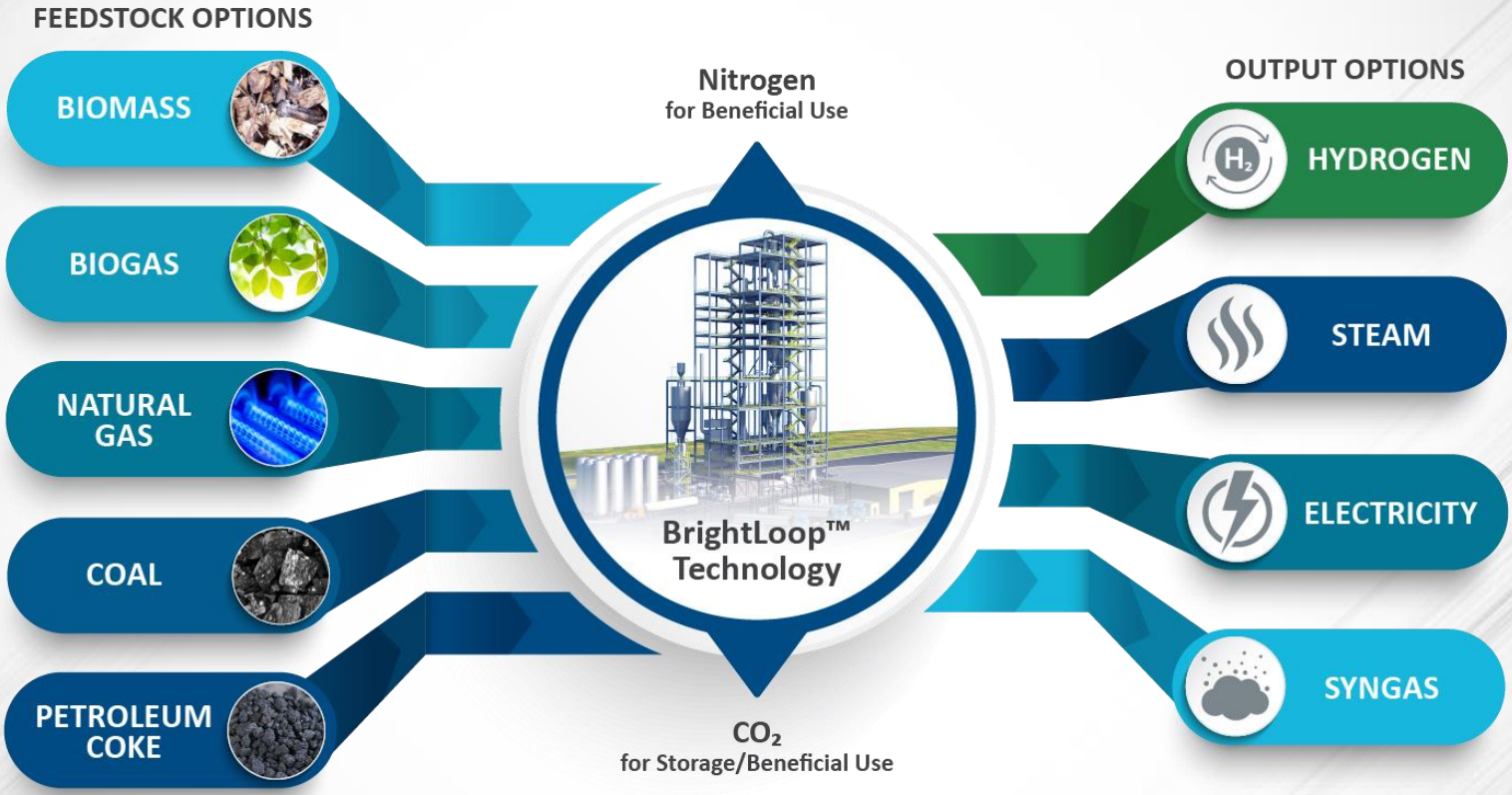
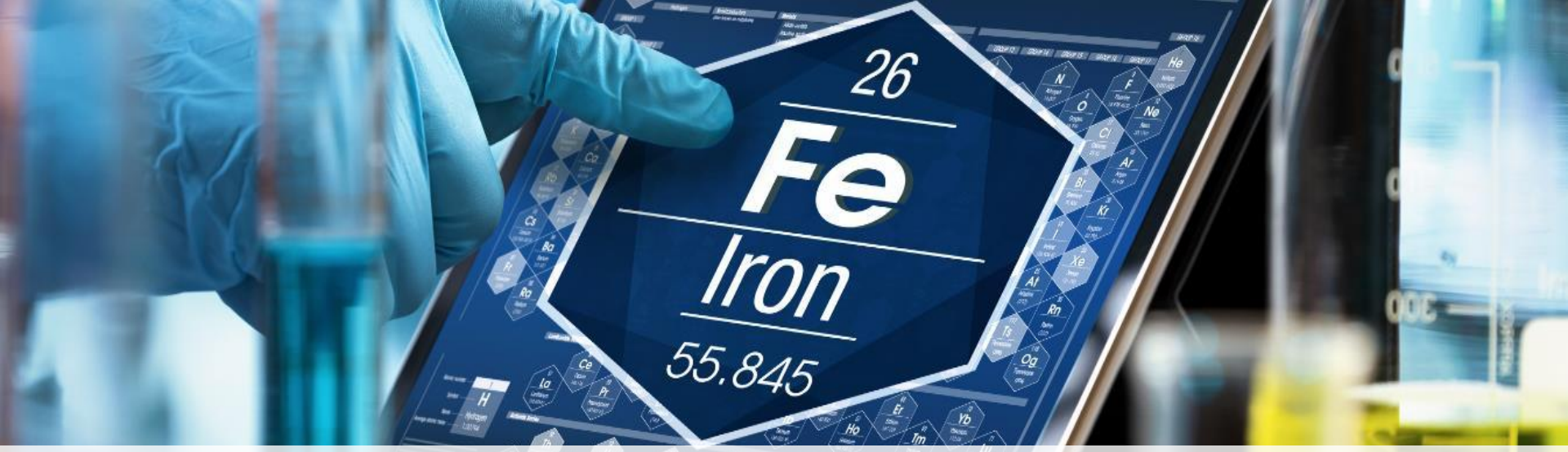


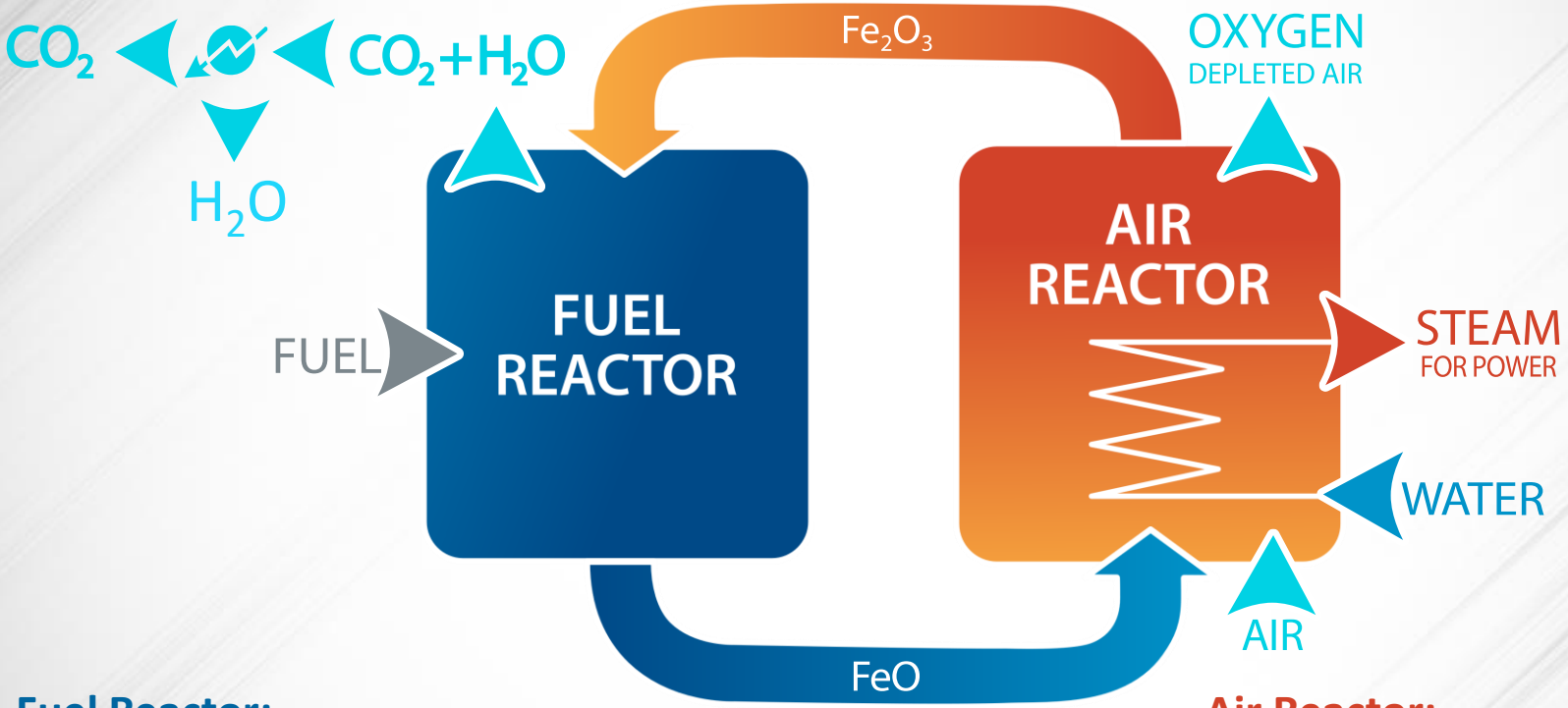
# B&W's BrightLoop™ Chemical Looping






# The Technology

# BrightLoop™ Combustion: Steam Generation

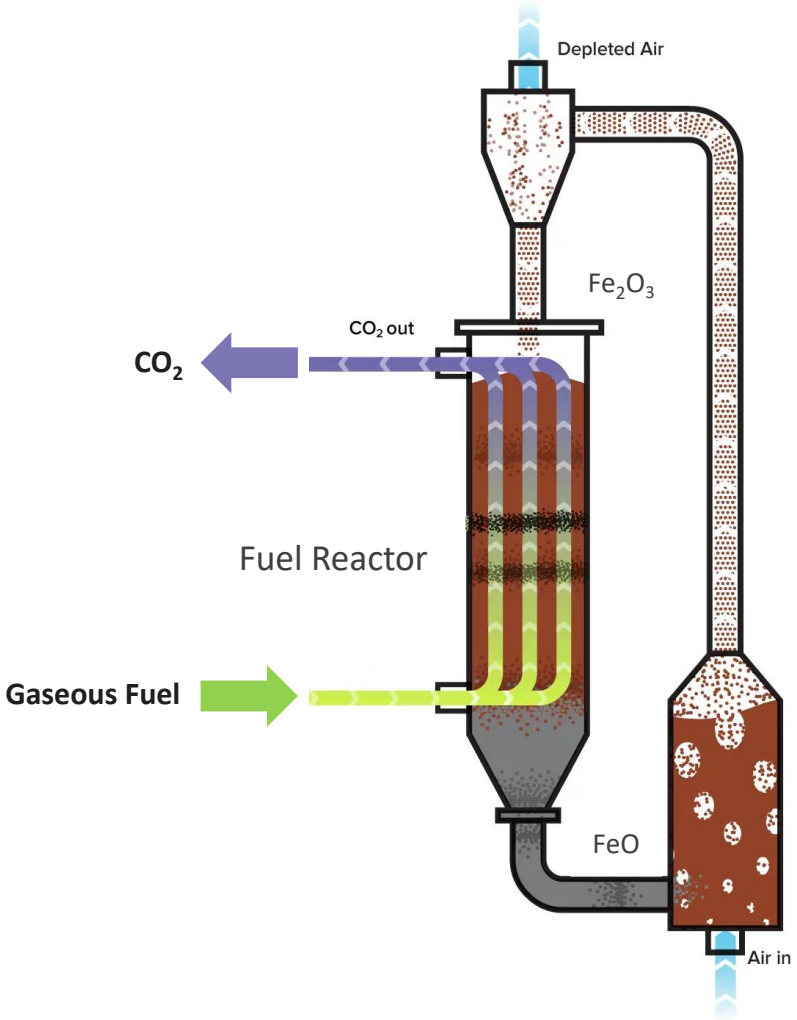



**Fuel Reactor:**

$Fuel + Fe_2O_3 \rightarrow CO_2 + H_2O + FeO$

**Air Reactor:**

$FeO + O_2 (Air) \rightarrow Fe_2O_3 + Heat$




# Steam-Only Generation

**Main reactions:**

**Fuel Reactor:** $Fuel + Fe_2O_3 \rightarrow FeO + CO_2 + H_2O$

**Air Reactor:** $Air + FeO \rightarrow Fe_2O_3 + Spent\ Air$

**Overall:** $Fuel + Air \rightarrow CO_2 + H_2O + Spent\ Air$

# BrightLoop™ Gasification: $H_2$ Generation

**Fuel Reactor:**

$Fuel + Fe_2O_3 \rightarrow CO_2 + H_2O + 2\ FeO$

**Hydrogen Reactor:**

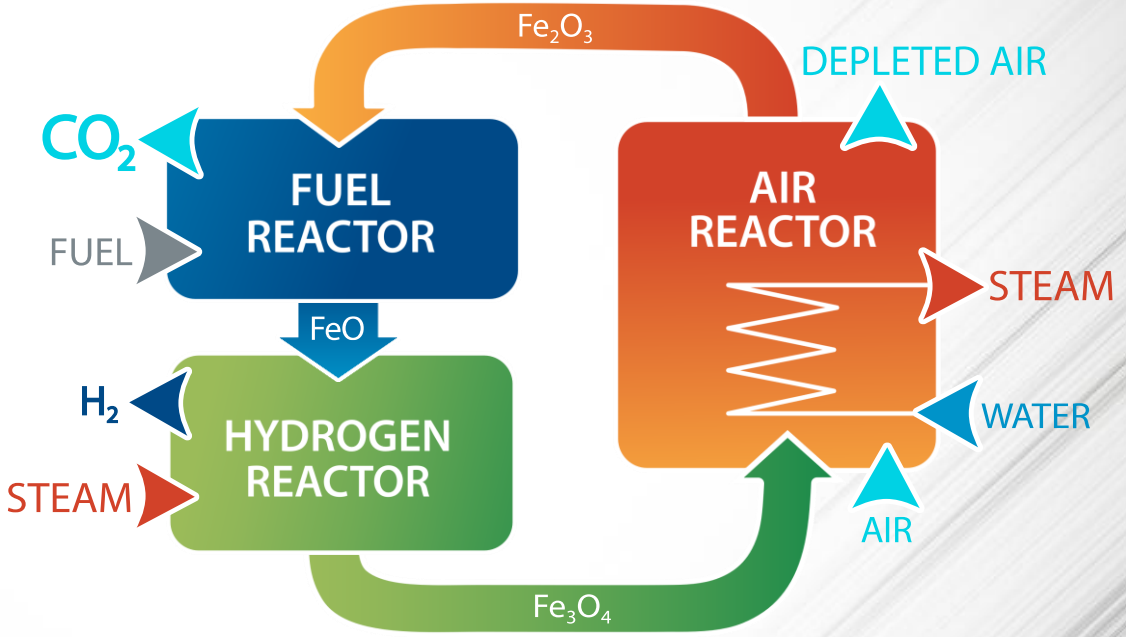
$FeO + H_2O \rightarrow Fe_3O_4 + H_2$

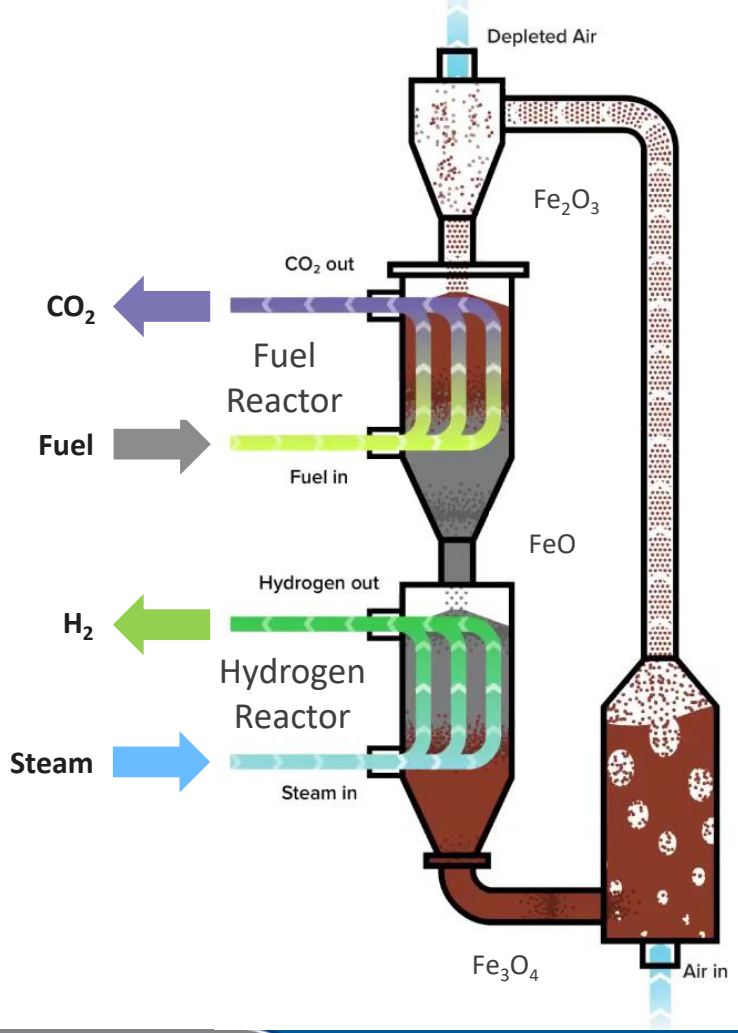
**Air Reactor:**

$Fe_3O_4 + O_2\ (Air) \rightarrow Fe_2O_3 + Heat$

**Notes:**

- $Fe_3O_4$ has lower oxidation than $Fe_2O_3$
- Equations are not balanced






Air Reactor

# $H_2$ Generation

**Main reactions:**

**Fuel Reactor:** $C_xH_yO_z + Fe_2O_3 \rightarrow CO_2 + H_2O + FeO$

**$H_2$ Reactor:** $FeO + H_2O \rightarrow Fe_3O_4 + H_2 + Q$

**Air Reactor:** $Fe_3O_4 + O_2 \rightarrow Fe_2O_3 + Q$

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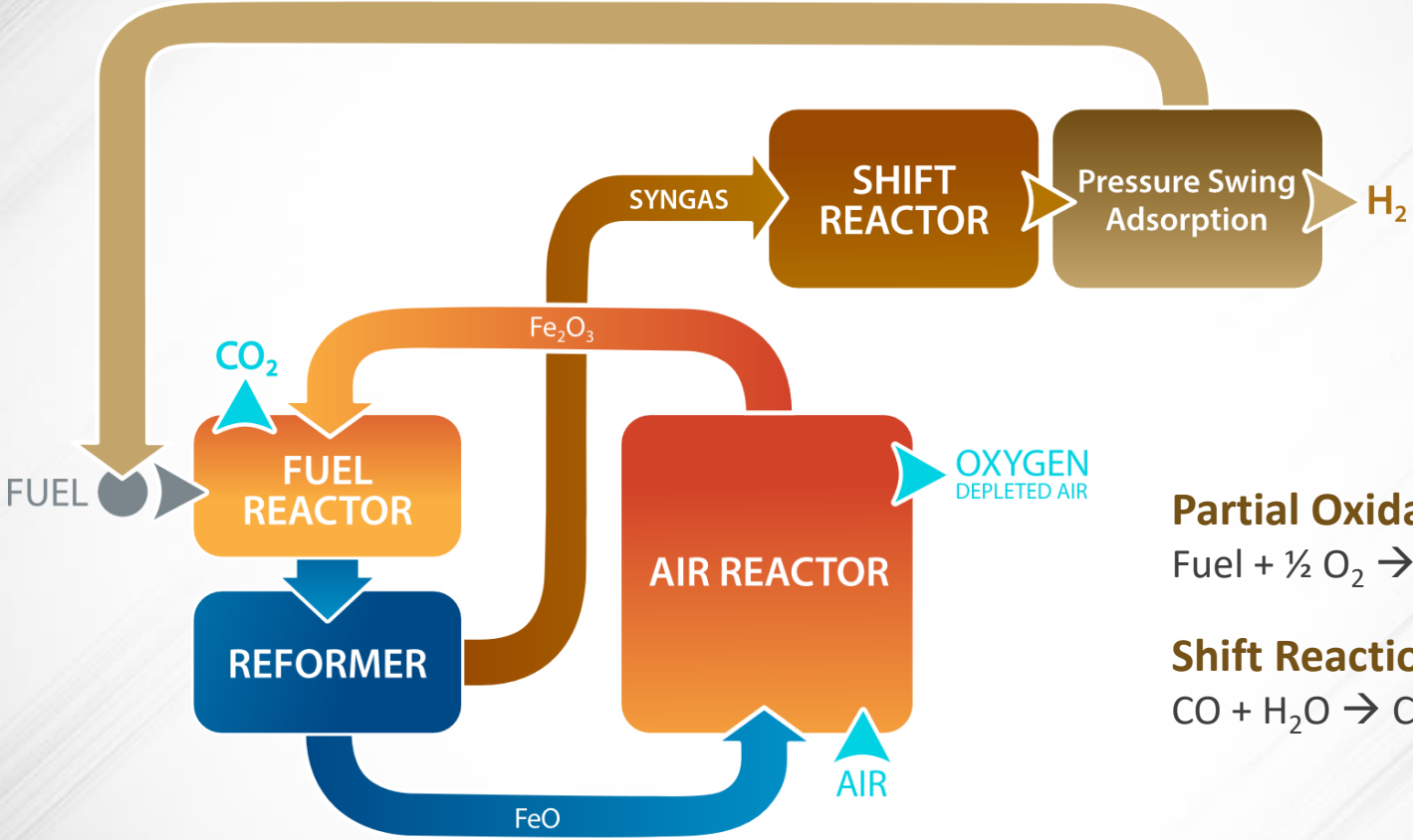
**Net Reaction:** $C_xH_yO_z + H_2O + O_2 \rightarrow CO_2 + H_2 + Q$

# BrightLoop™ Partial Oxidation: $H_2$ Generation



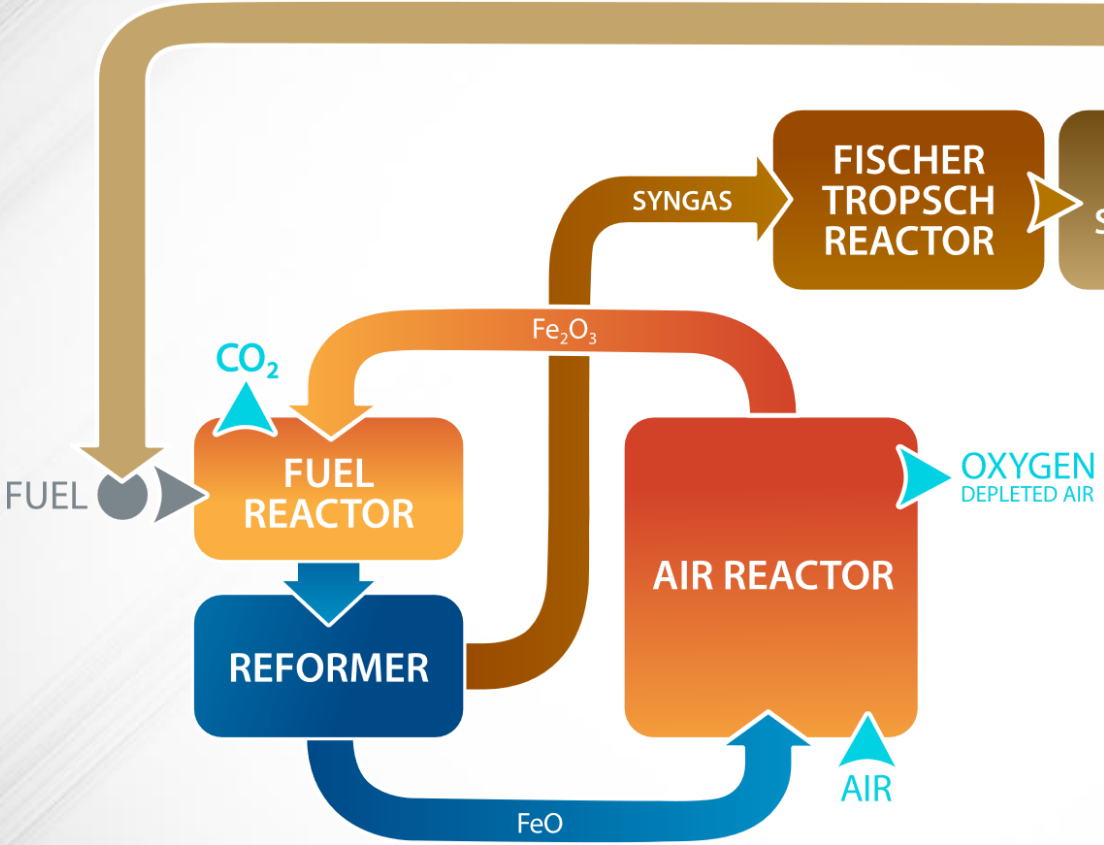

**Partial Oxidation:**

Fuel + ½ $O_2$ → CO + $H_2$

**Shift Reaction:**

CO + $H_2O$ → $CO_2$ + $H_2$

# BrightLoop™ Partial Oxidation: Liquid Fuels Generation



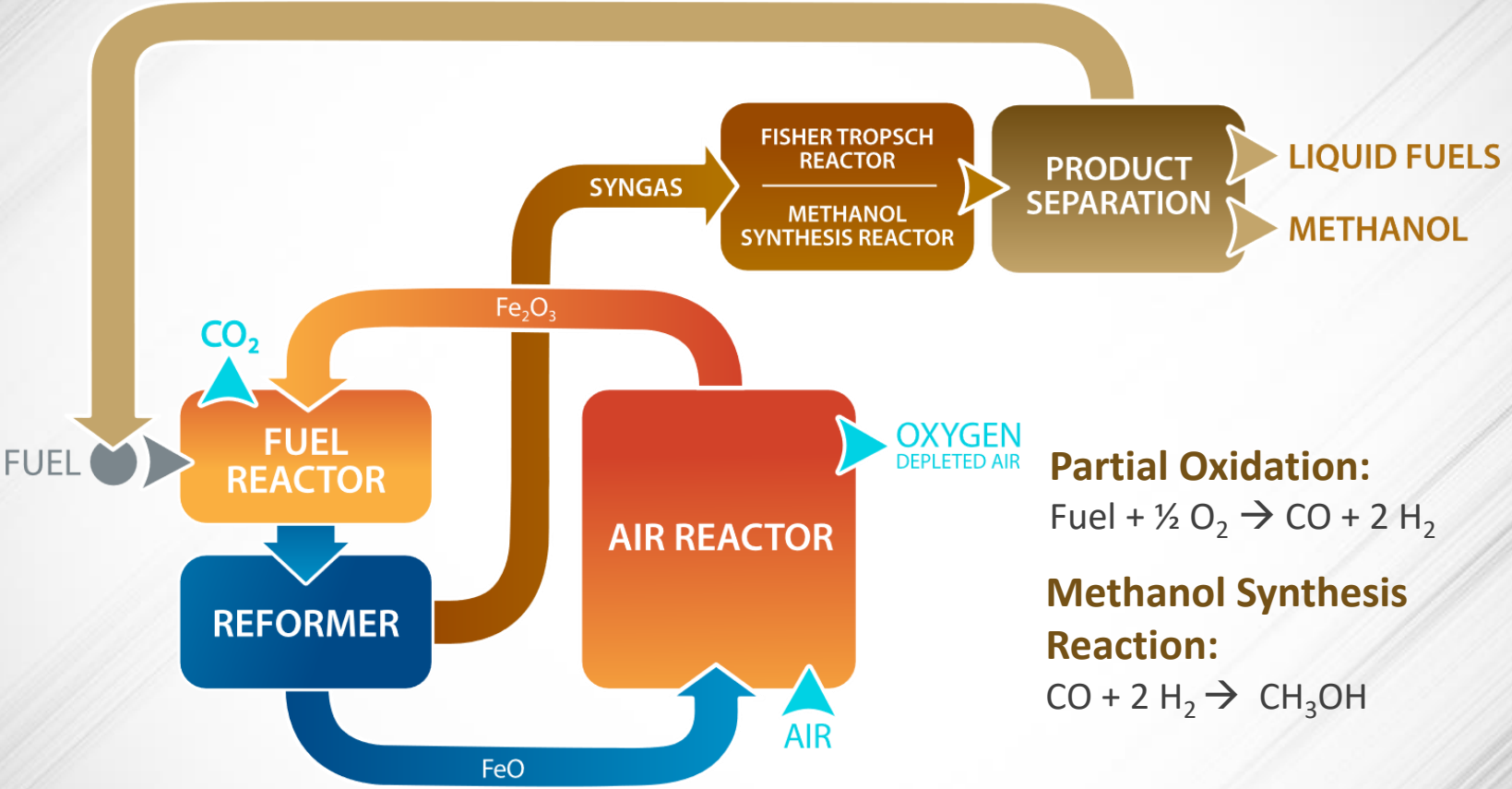

**Partial Oxidation:**

$Fuel + ½\ O_2 \rightarrow CO + 2\ H_2$

**FT Reaction:**

$CO + 2\ H_2 \rightarrow C_xH_{2x}$

# BrightLoop™ Partial Oxidation: Methanol Generation



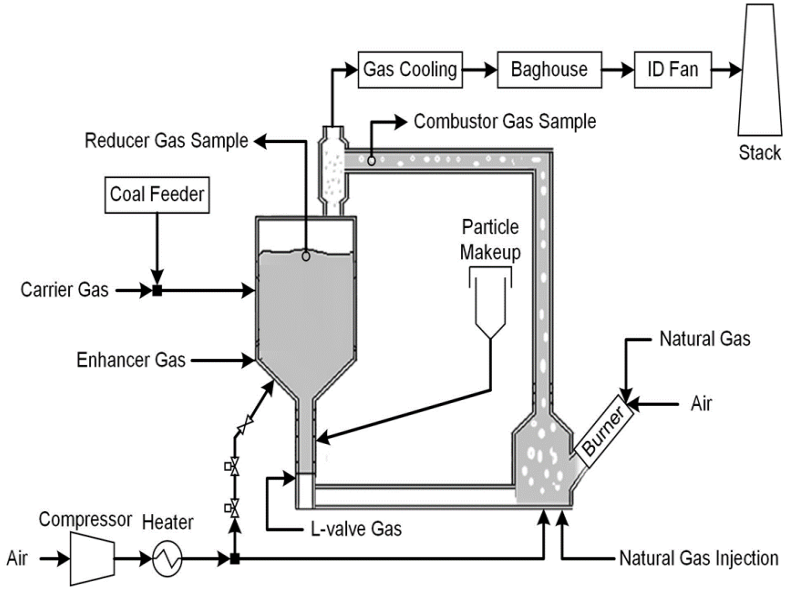

**Partial Oxidation:**

$Fuel + ½\ O_2 \rightarrow CO + 2\ H_2$

**Methanol Synthesis Reaction:**

$CO + 2\ H_2 \rightarrow CH_3OH$


# Status of the Technology




# 250 $kW_{th}$ CDCL Pilot Test Unit

## Specifications

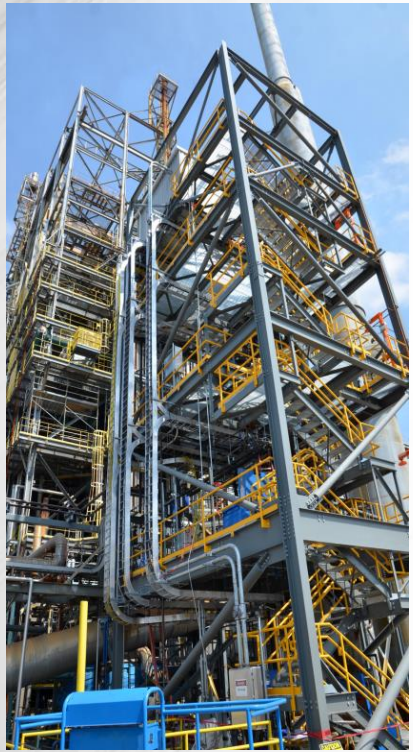
- **Materials:** Refractory-lined carbon steel
- **Max Operating Temperature:** 2012 F
- **Overall Height:** 32 ft
- **Footprint:** 10 ft x 10 ft
- **Maximum Thermal Rating:** 250 $kW_{th}$
- **Design Feed Rate:** 35 lb/hr (16 kg/hr)
- **Oxygen Carrier:** Iron based
- **Particle Diameter:** 1.5 mm

# BrightLoop™

## System Plant Layout

# 250 kWth Syngas Chemical Looping (SCL) Pilot Plant

## Pilot Plant and Installed Components



**Pressure:**

- 10 bar atm

**Reducer:**

- Feed: Syngas (KBR)
- Moving Bed

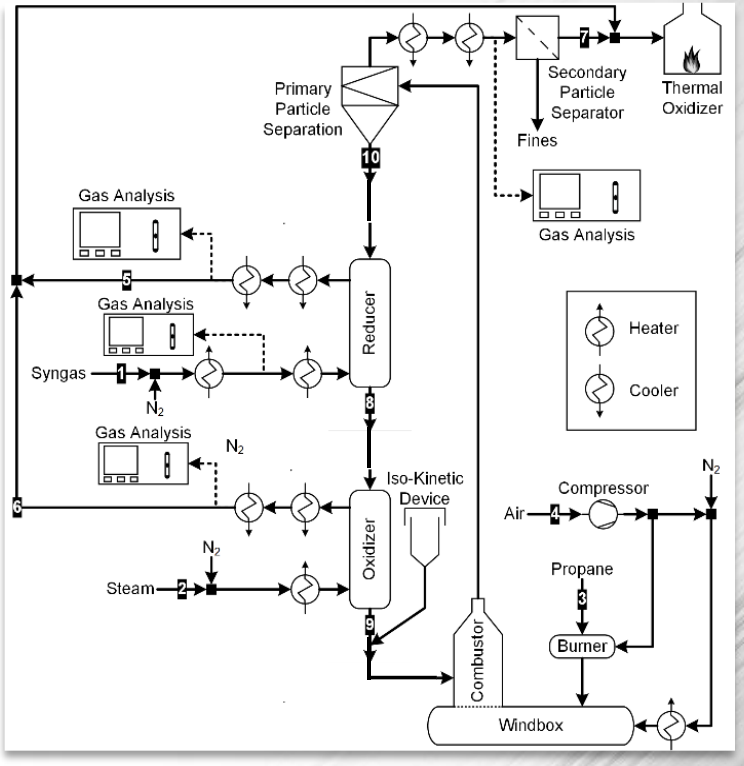
**Oxidizer:**

- Feed: Steam
- Moving Bed

**Combustor:**

- Feed: Air
- Fluidized Bed

## SCL Process Flow Diagram



# Other BrightLoop™ Applications

- Flare gas conversion to methanol
- Carbon emissions reduction in the steel industry
- Particles:
  - Thermo-chemical energy storage systems
  - Direct reduced-metal fuel cell
  - Alternative bed material in bubbling fluidized-bed boilers to reduce emissions

# BrightLoop™ Advantages

## $CO_2$ Capture

- $CO_2$ capture by design: no need for post-combustion $CO_2$ capture (amine scrubbing)
- ASU contributes to ~40% of CAPEX of $H_2$ or syngas plant
- Significant operating cost saving

## Emissions

- Contaminants report to the $CO_2$ stream
- Concentrated product streams result in more efficient and less expensive control equipment

## High Selectivity

- Moving bed design allows high purity of product from reaction equilibrium
- Compatible with $CO_2$ capture regulation

## Flexibility

- Base technology has wide range of products and applications

## Scalability

- Process maintains performance at small scale
- Not limited to ASU scales to be cost competitive

## Lower Capital Costs

- All the above advantages result in lower costs when compared to competing technologies.

# Economics

# Cost Comparison of Coal-Based Electricity Production

| | Supercritical PC No $CO_2$ Control (Base Case) ($/MWh) | Supercritical PC w/$CO_2$ Control ($/MWh) | Oxy-PC w/$CO_2$ Control ($/MWh) | Coal-DCL ($/MWh) |
|---|---|---|---|---|
| **Capital** | 39.05 | 71.75 | 62.43 | 48.21 |
| **Fixed O&M** | 9.60 | 15.41 | 14.1 | 10.74 |
| **Variable O&M** | 9.05 | 14.74 | 7.95 | 6.50 |
| **Fuel** | 11.74 | 14.73 | 15.06 | 13.35 |
| **Oxygen Carrier** | - | - | - | 3.81 |
| **Cost of Electricity (COE)** | 69.44 | 116.63 | 99.54 | 82.61 |
| **Increase in COE** | - | **68.76%** | **30.57%** | **19.53%** |

Coal: $1.4 / MMBTU

From Research Studies

# Total Equipment Cost (TEC)

| | SMR | ATR | BrightLoop Hydrogen 200 t/d (A) | BrightLoop Hydrogen 200 t/d (B) |
|---|---|---|---|---|
| ASU | | 12,870 | | |
| $H_2$ Plant | 47,592 | 71,253 | 50,213 | 50,213 |
| $H_2$ Compression | 0 | 2,223 | 15,000 | 15,000 |
| $CO_2$ Separation | 50,232 | 18,603 | | |
| $CO_2$ Compression | 15,609 | 7,488 | 12,657 | 12,657 |
| Co-Generation | 7,448 | 10,413 | | 10,673 |
| BOP | 30,195 | 23,383 | 22,192 | 22,192 |
| Total ($k) | **151,076** | **146,133** | **100,062** | **110,734** |

(A): No Electricity Production (B): With Co-Generation

# Development Plan

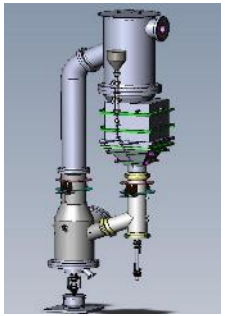
# B&W BrightLoop™ Technology Development Plan

**Laboratory**
(2.5 $kW_{th}$)

- Established particle recyclability and reactivity
- Characterized individual reactions in the reducer and combustor

**Pre Pilot**
(25 $kW_{th}$)

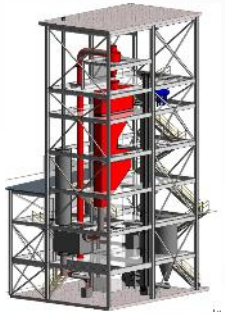
- Integrated operation reducer and combustor for more than 200 hours
- Demonstrated $CO_2$ purity capability



**Small Pilot**
(250 $kW_{th}$)

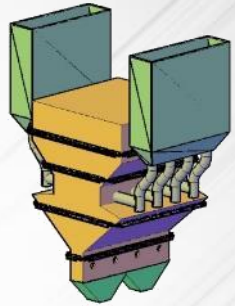
- Demonstrated adiabatic reducer operation for more than 250 hours
- Established process efficiency
- Evaluated emissions
- Demonstrated large-scale particle manufacturing
- Characterized particle attrition

**COMPLETED**



**Small Commercial**
(2.5 - 25 $MW_{th}$)

- Demonstrate long-term operation
- Demonstrate steam generation and combustor performance at a commercially scalable size
- Establish commercial-scale economics



**Commercial**
(250 $MW_{th}$)

- Demonstrate commercial operation of a single module
- Establish supply chain and fabrication methods

# B&W's Commitment

**SERVING**
**your needs**

**PRESERVING**
**resources**

**DESERVING**
**your trust**

## Thank you!

# Questions

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