BABCOCK & WILCOX

RENEWABLE
ENVIRONMENTAL
THERMAL

Decarbonization Technologies for a Lower-Carbon Future

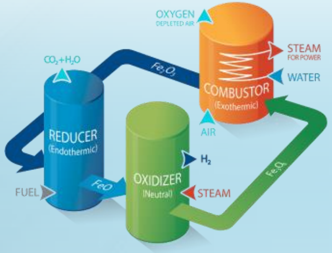
CO2 Capture, Storage & Reuse
17-18 May 2022
Copenhagen, Denmark

Brian Higgins
Director of Advanced Technologies
Babcock & Wilcox

Decarbonization Technologies are Ready

ClimateBright™
DECARBONIZATION TECHNOLOGIES

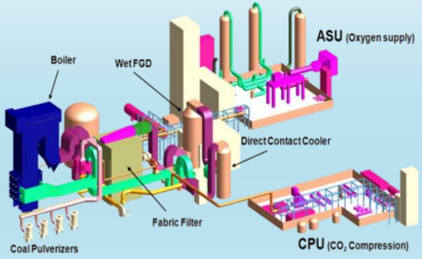
BrightLoop™
CHEMICAL LOOPING



- Jointly developed with The Ohio State University
- Can simultaneously produce hydrogen
- Pilot testing complete on both syngas and coal at 250 kW_{th} input
- Ready for scale-up to 4 x 2.5 MW_e

FUELS: Coal, pet coke, natural gas and any syngas

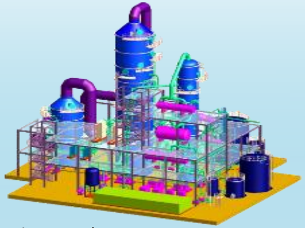
OxyBright™
OXYGEN-FUEL COMBUSTION



- Pilot-scale testing complete (30 MW_{th})
- 168 MW_e full-scale design ready

FUELS: Natural gas and solid fuels (biomass, coal)

SolveBright™
POST-COMBUSTION CARBON CAPTURE



- Pilot testing complete
- Post-combustion amine-based solvent process
- First solvent demonstrated at National Carbon Capture Center (NCCC) Southern Company's Plant Gaston
- Reference plant design ready

FUELS: Any combustion, gasification and industrial process that produces a flue gas stream with CO^2

BrightGen™
HYDROGEN COMBUSTION

- Commercially ready and currently in operation
- A combustion technology that produces no CO_2
- Can be retrofitted to fire hydrogen

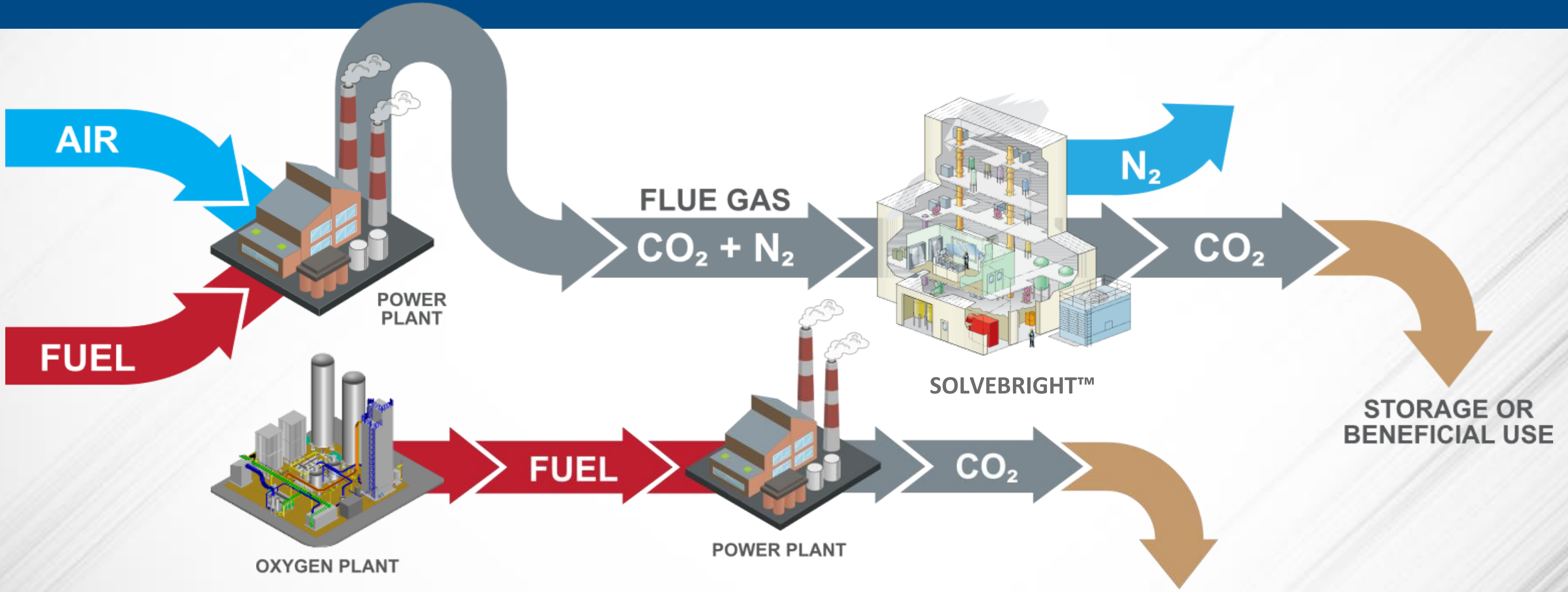
FUELS: Hydrogen, alone or in combination with natural gas, oil, or other gaseous fuels

- B&W is at the forefront of developing CO_2 capturing technologies
- Multiple technologies ready for commercial demonstration
- 93 active patents related to carbon capture technology
- Positioned to provide critical solutions to meet global climate goals

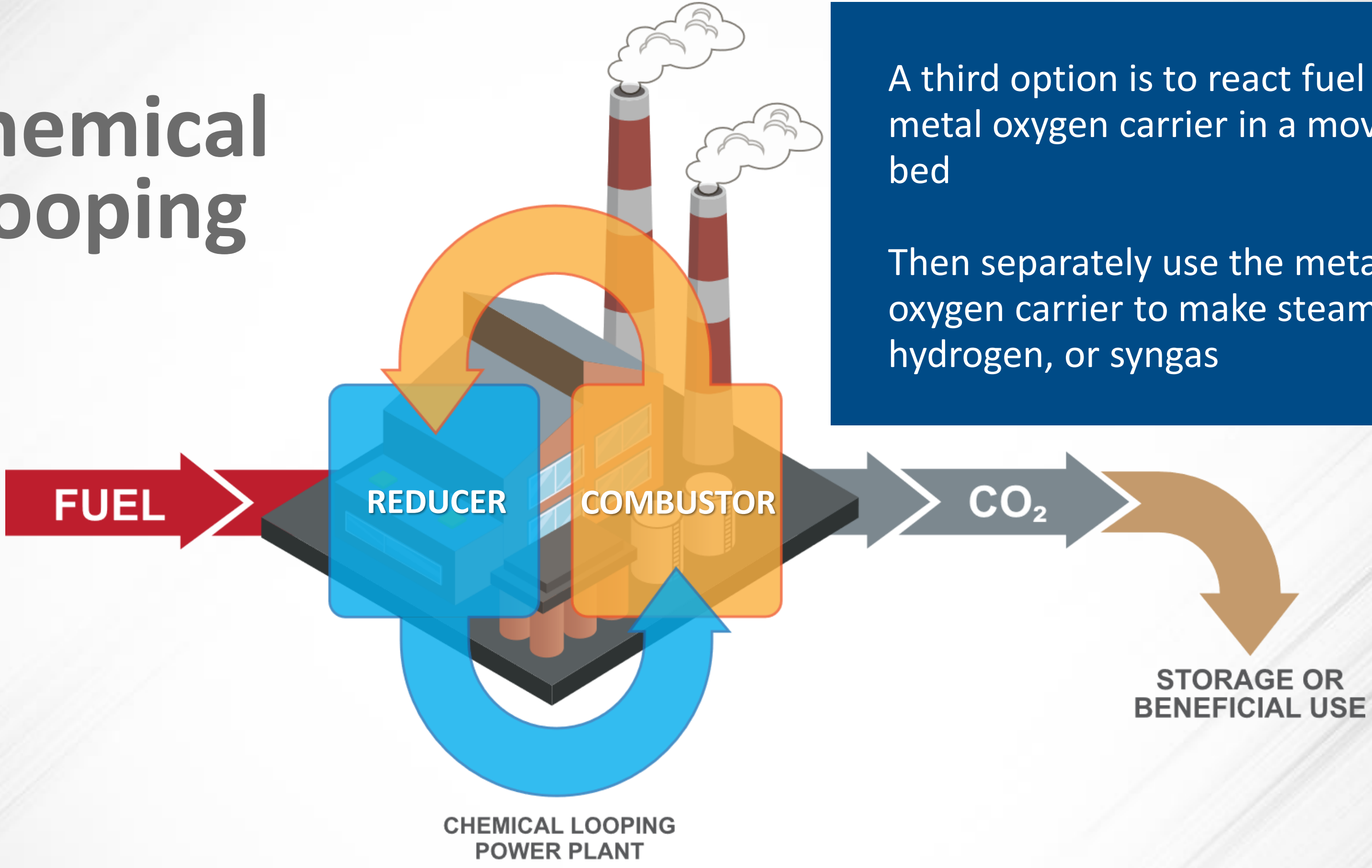
B&W has successfully tested three carbon capture technologies applicable to a wide range of gaseous and solid fuels and processes

Drive to Innovate

To produce a pure stream of CO_2 for sequestration or utilization, the CO_2 must be separated
A first option is to separate the CO_2 from the flue gas after combustion
A second option is to separate oxygen from the air before combustion



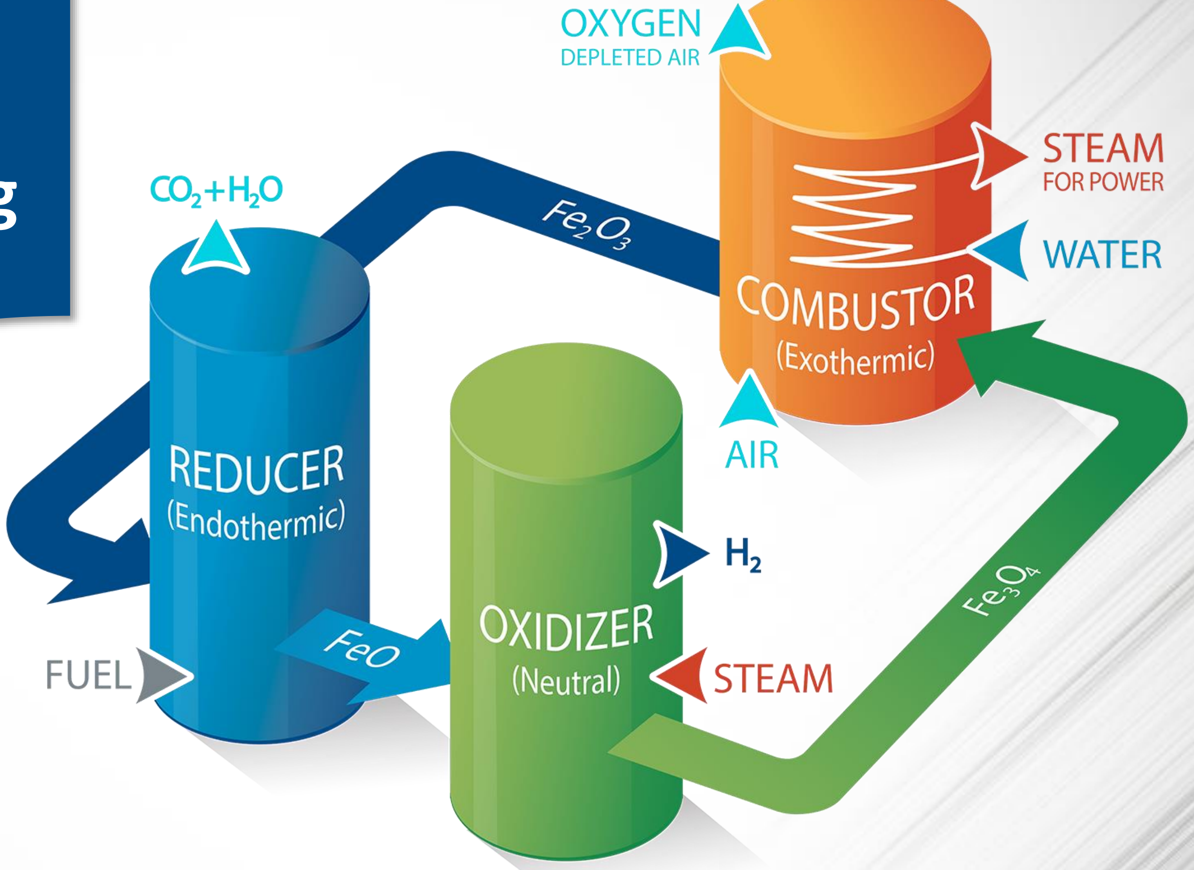
Chemical Looping



A third option is to react fuel with a metal oxygen carrier in a moving bed

Then separately use the metal oxygen carrier to make steam, hydrogen, or syngas

BrightLoop™ Chemical Looping



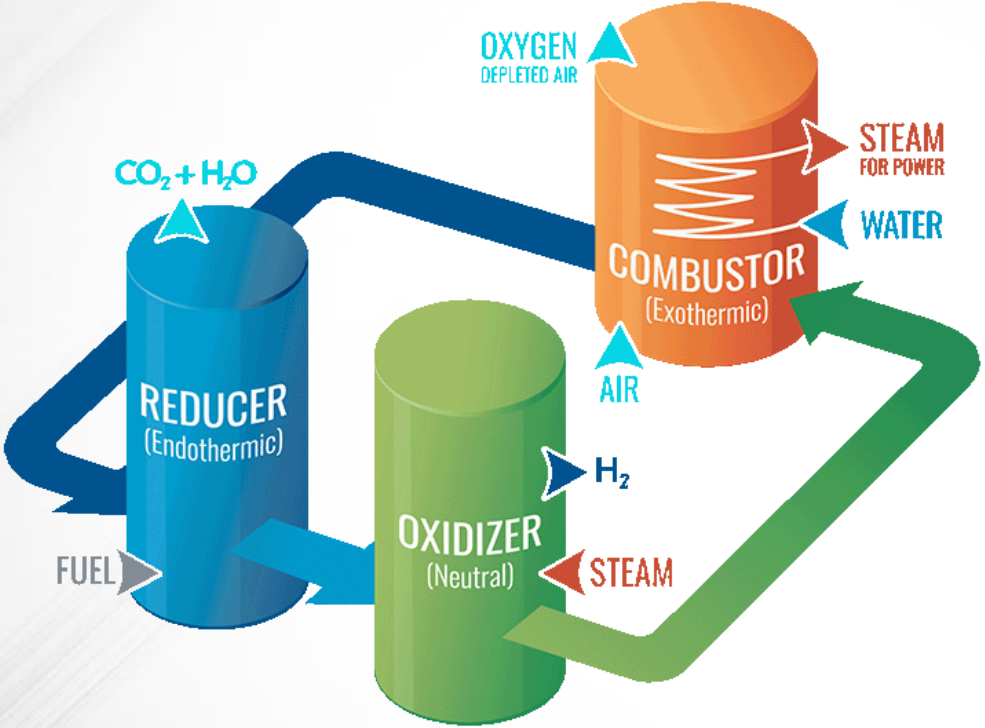
Moving Bed

$Fe_2O_3 \rightarrow FeO \rightarrow Fe_3O_4 \rightarrow$

Three Reaction Chambers

- Reducer
- Oxidizer
- Combustor

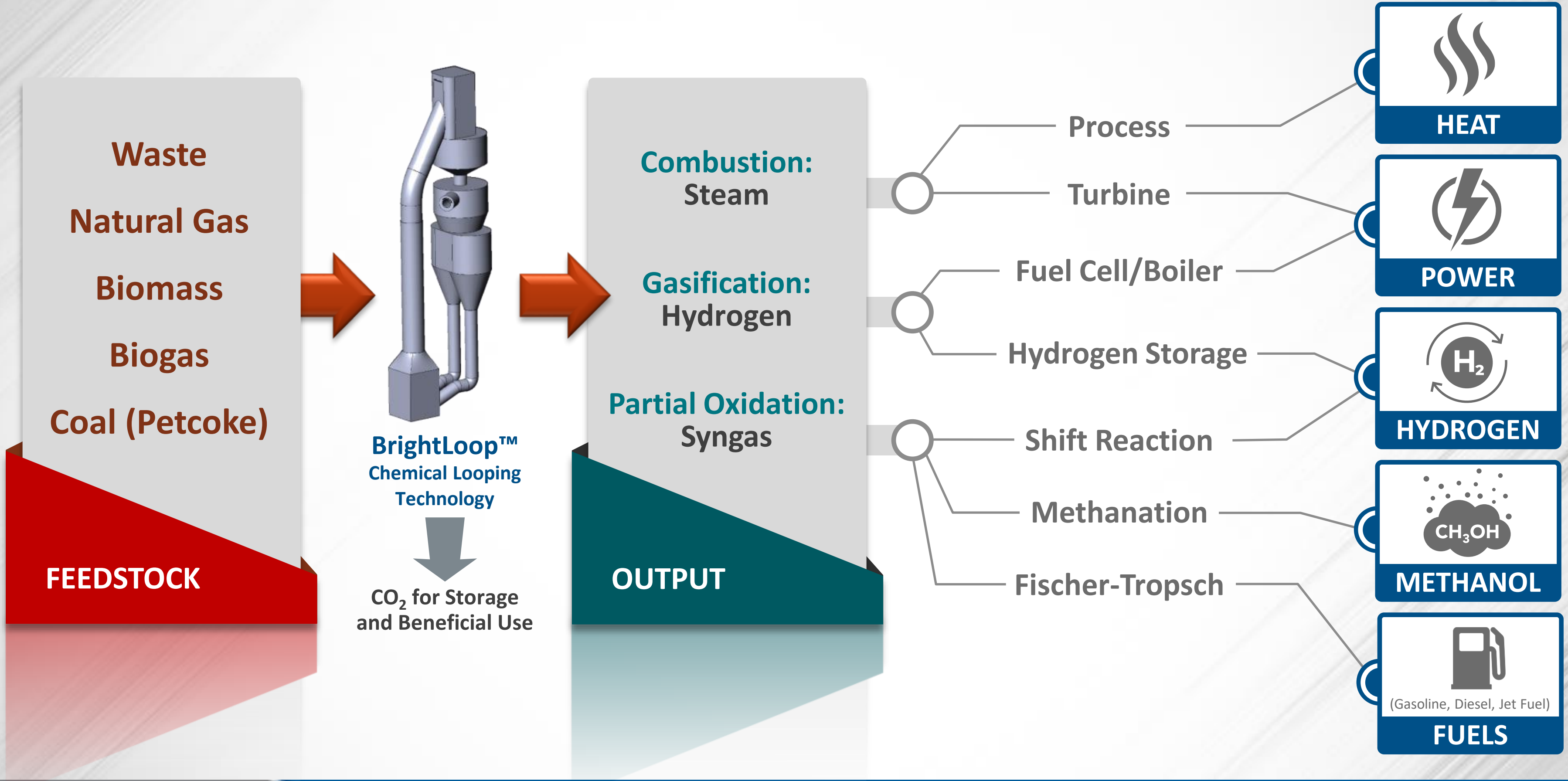
A Particle Breakthrough Made It Happen



A unique particle

- This disrupter technology allowed B&W to make the breakthrough
- Makes Chemical Looping possible for practical implementation of carbon isolation and capture

BrightLoop Chemical Looping is a Platform Technology



The Technology

BrightLoop Chemical Looping: Hydrogen Generation

Reducer:

Fuel + Fe_2O_3 → CO_2 + H_2O + 2 FeO

Oxidizer:

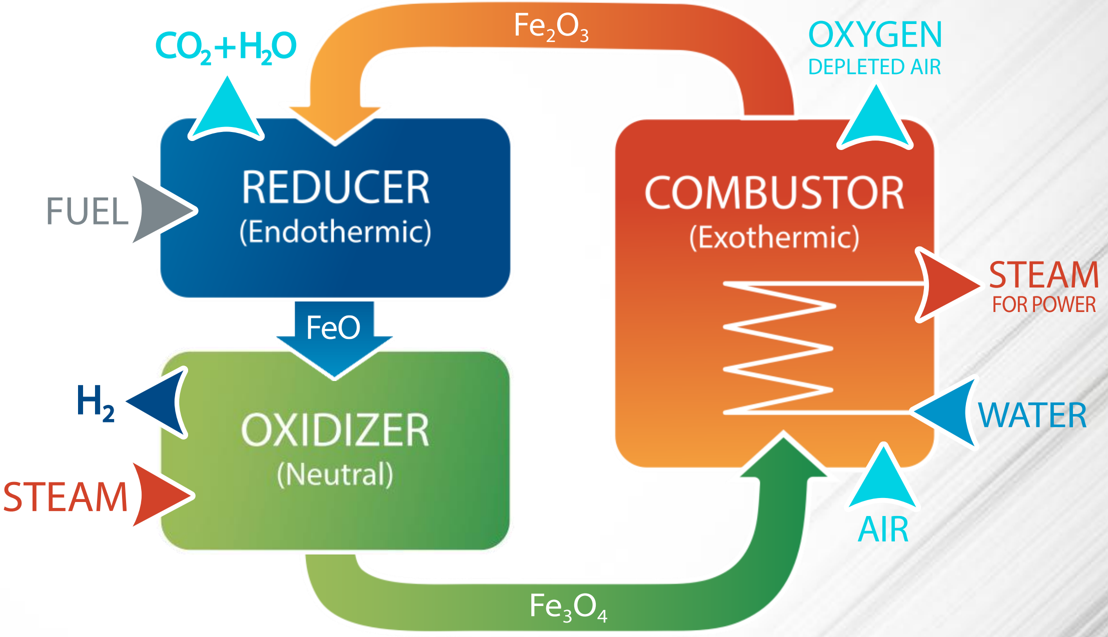
FeO + H_2O → Fe_3O_4 + H_2

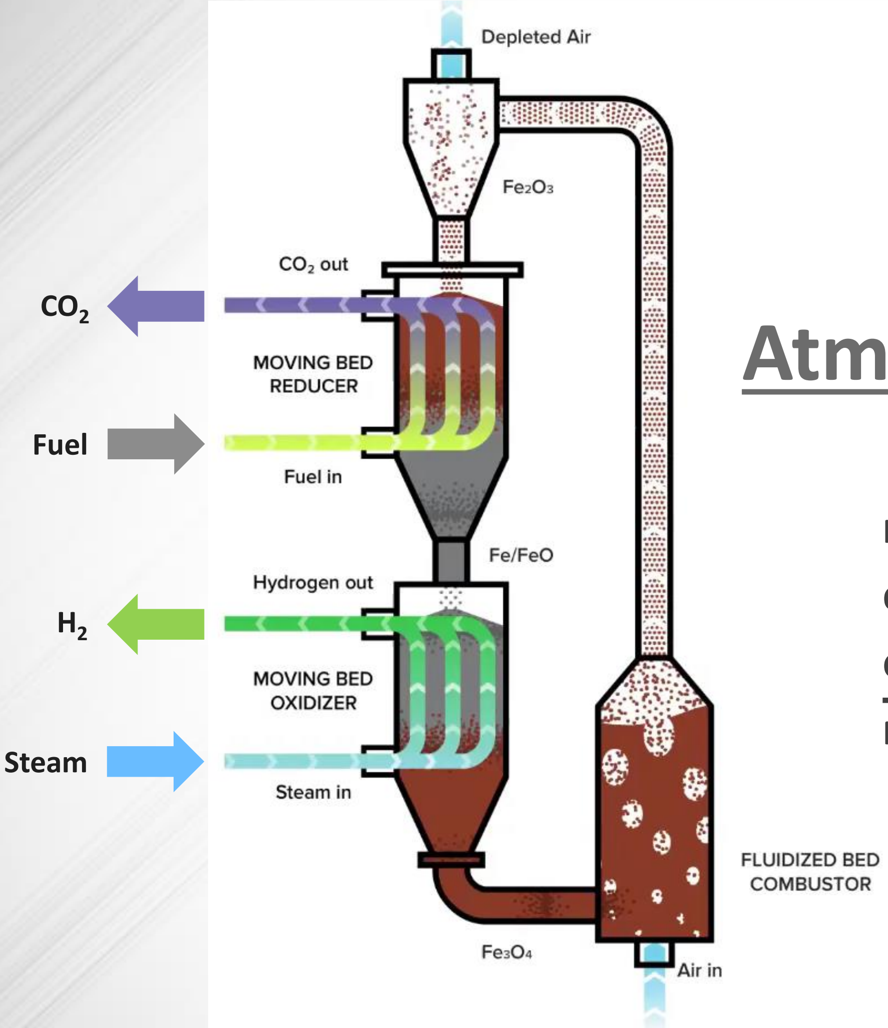
Combustor:

Fe_3O_4 + O_2 (Air) → Fe_2O_3 + Heat

Notes:

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





Atmospheric H_2 Generation

Main reactions:

Reducer: $C_xH_yO_z + Fe_2O_3 \rightarrow CO_2 + H_2O + FeO$

Oxidizer: $FeO + H_2O \rightarrow Fe_3O_4 + H_2 + Q$

Combustor: $Fe_3O_4 + O_2 \rightarrow Fe_2O_3 + Q$

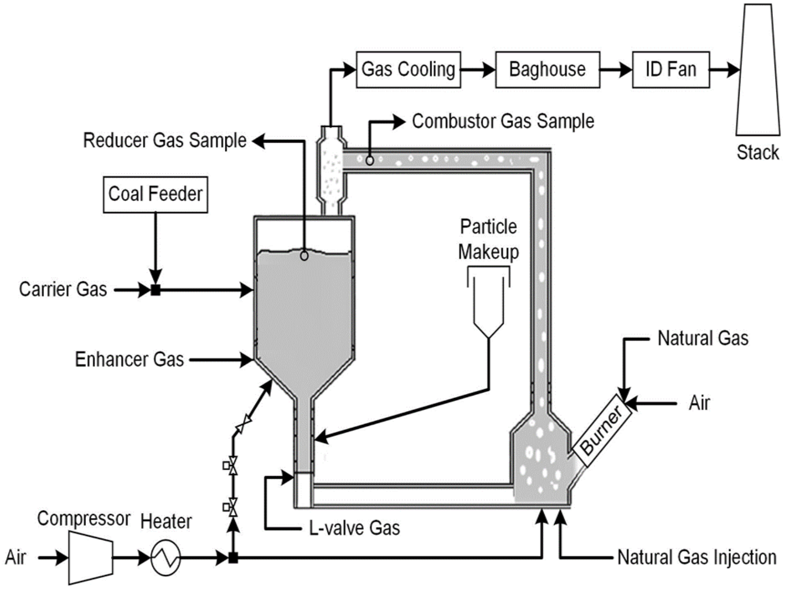
Net Reaction: $C_xH_yO_z + H_2O + O_2 \rightarrow CO_2 + H_2 + Q$

Animation by The Ohio State University

Tong, A., Bayham, S., Kathe, M., Fan, L.-S. Applied Energy Journal

Thomas, T. J., Fan, L.-S., Gupta, P., Velazquez-Vargas, L.G. U.S. Patent 7,767,191.

Status of the Technology



250 kW_{th} CDCL Pilot Test Unit
(Equivalent to 0.4 ton/h Steam)

Specifications

- **Materials:** Refractory-lined carbon steel
- **Max Operating Temperature:** 1100°C
- **Overall Height:** 10 m
- **Footprint:** 3 m x 3 m
- **Thermal Rating:** 250 kW_{th}
- **Design Feed Rate:** 16 kg/h
- **Oxygen Carrier:** Iron based
- **Particle Diameter:** 1.5 mm

250 kW_{th} Syngas Chemical Looping (SCL) Pilot Plant

Pilot Plant and Installed Components

Pressure
- 10 atm

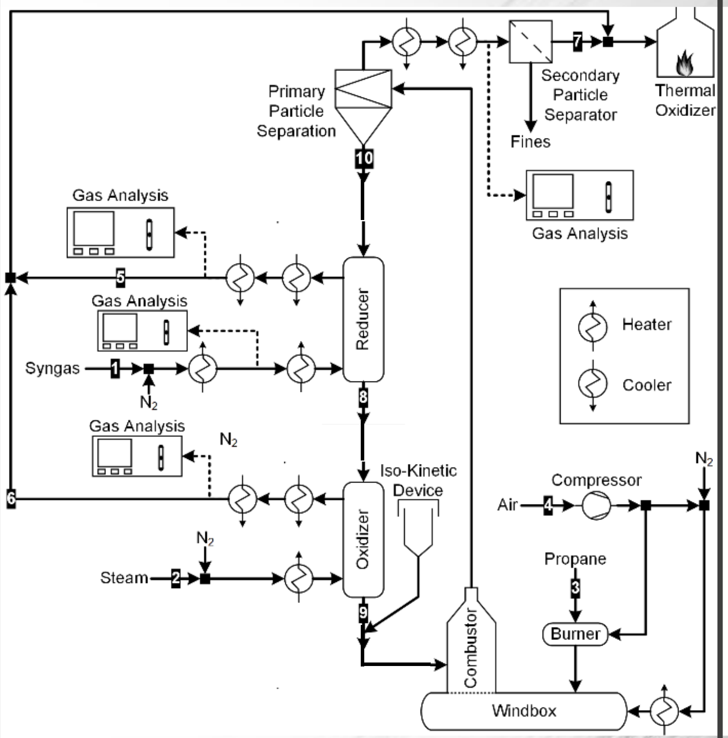
Reducer:
- Feed: Syngas (KBR)
- Moving Bed

Oxidizer:
- Feed: Steam
- Moving Bed

Combustor
- Feed: Air
- Fluidized Bed

Project led by OSU. B&W served as EPC and involved in testing and operation.

SCL Process Flow Diagram

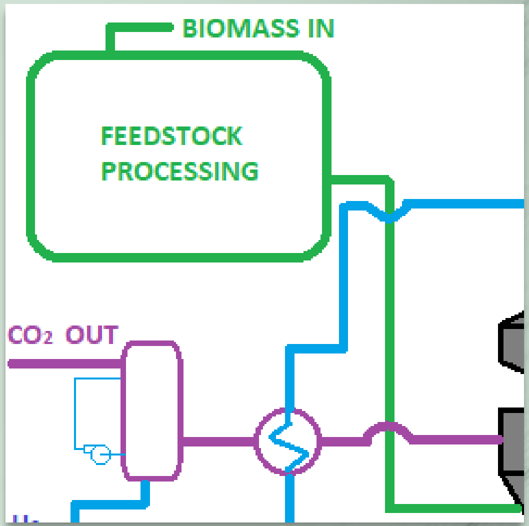


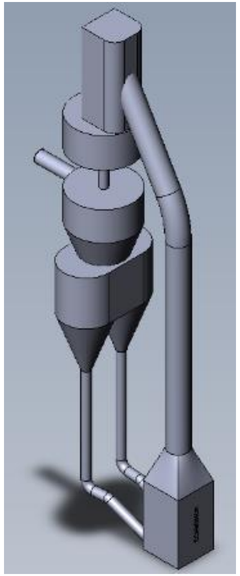
Feedstock Processing and Feeding

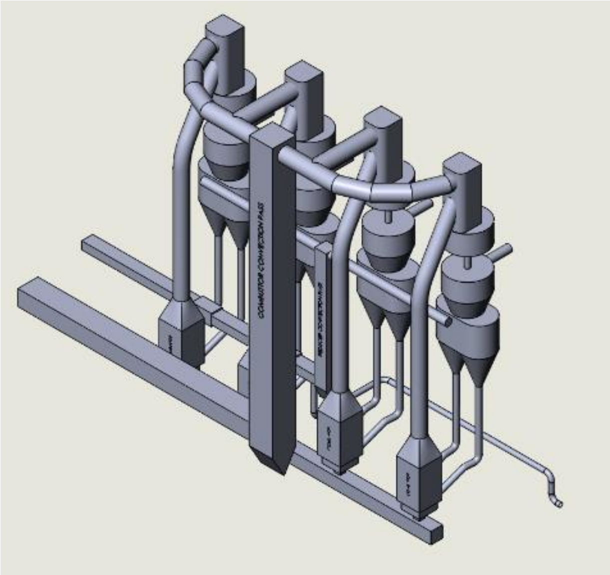
- Plant feedstock to be clean forestry waste material including potential woody industrial waste products
- BrightLoop requires fine particulate feeding (500 – 750 µm)

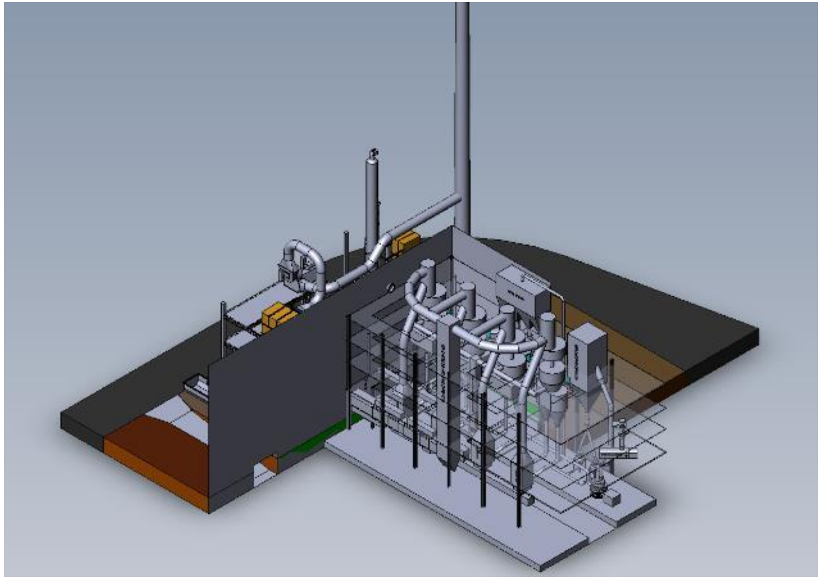
Initial Concept

- Pre-processing – screening for tramp metals and sizing
- Pyrolysis / carbonization to create a biochar and gaseous exhaust, both of which will be fed to BrightLoop 3-reactor
  - Gaseous exhaust product piped directly to 3-reactor (Reducer module)
  - Biochar to be pulverized (<300 µm) and transported via a pressurized CO_2 stream into the 3-reactor (Reducer module)









200 ton/day H_2 BrightLoop System Plant Layout

Typical Small Commercial Project

- Green Hydrogen Production
  - 15 tons/day of Hydrogen
- MSW Fuel
  - Tipping fees as revenue
- Carbon Sequestration
  - Carbon credits or 45Q (US) as revenue
- Produces carbon-negative hydrogen for $1/kg with a 5-year payback

BABCOCK & WILCOX

RENEWABLE

ENVIRONMENTAL

THERMAL

Decarbonization Technologies for a Lower-Carbon Future

QUESTIONS?

DISCLAIMER

The Babcock & Wilcox Company (B&W) assumes no liability or responsibility with respect to the use of, or for damages resulting from the use of, any information, methods, processes, or recommendations provided in this presentation. B&W expressly excludes and disclaims any and all warranties, whether expressed or implied, which might arise or apply under law or equity or custom or usage of trade, including, without limitation, any warranties of merchantability and/or fitness for a particular or intended purpose.