

BRIGHTLOOP™ LOW-CARBON INTENSITY HYDROGEN PRODUCTION



SUMMARY

Babcock & Wilcox partnered with The Ohio State University to develop our BrightLoop chemical looping technology, which can use a variety of fuel stocks to produce hydrogen, syngas, steam, liquid fuel or methanol, and/or power while also producing a stream of concentrated CO₂ for sequestration and storage or other uses.

The patented BrightLoop process is based on the oxidation and reduction of an iron-based oxygen carrier particle and can produce separated streams of hydrogen and CO₂ from gas and solid fuels – including biomass, coal, waste fuels, natural gas, biogas, petroleum coke (petcoke) or others. In this process, fuel reacts with the oxygen-carrier particles in a fuel reactor, forming combustion byproducts, predominantly CO₂, while reducing the oxygen-carrier particles. The reduced oxygen-carrier particles then move to a hydrogen reactor where they react with steam to partially oxidise the particles and generate a stream of hydrogen.

The oxygen-carrier particles are then transported to an air reactor where they are regenerated with air back to their original state. The fuel and hydrogen reactors use moving bed technology while the air reactor uses fluidised-bed technology, both well-proven technologies with which B&W has extensive experience. Other emissions can be controlled using B&W's complete suite of environmental control technologies.

BENEFITS

- Hydrogen from solid fuels – can utilise a variety of solid or gaseous fuels as feedstock.
- High rate of carbon captured – inherent CO₂ isolation supports sequestration or utilisation without the expensive post combustion capture equipment and operation.
- Competitive hydrogen cost – lower levelised cost of hydrogen when compared to other hydrogen production methods.
- High quality hydrogen – production from steam produces higher quality as compared to separating hydrogen from fuel.
- Scalable for a range of applications – accommodates both large and small applications.

KEY DATA

TRL	6	Capture Rate Range (tpd)	~	Modular (Y/N)	Yes
Source CO ₂ Purity Range	~	Energy Consumption (GJ/tCO ₂)	~	Capture Efficiency (%)	~
Number of Commercial Plants	~	Number of Pilot Plants	~		
Target Industries	Oil & Gas, Refineries, Power Utilities, Iron & Steel, any medium to heavy industrial facility				

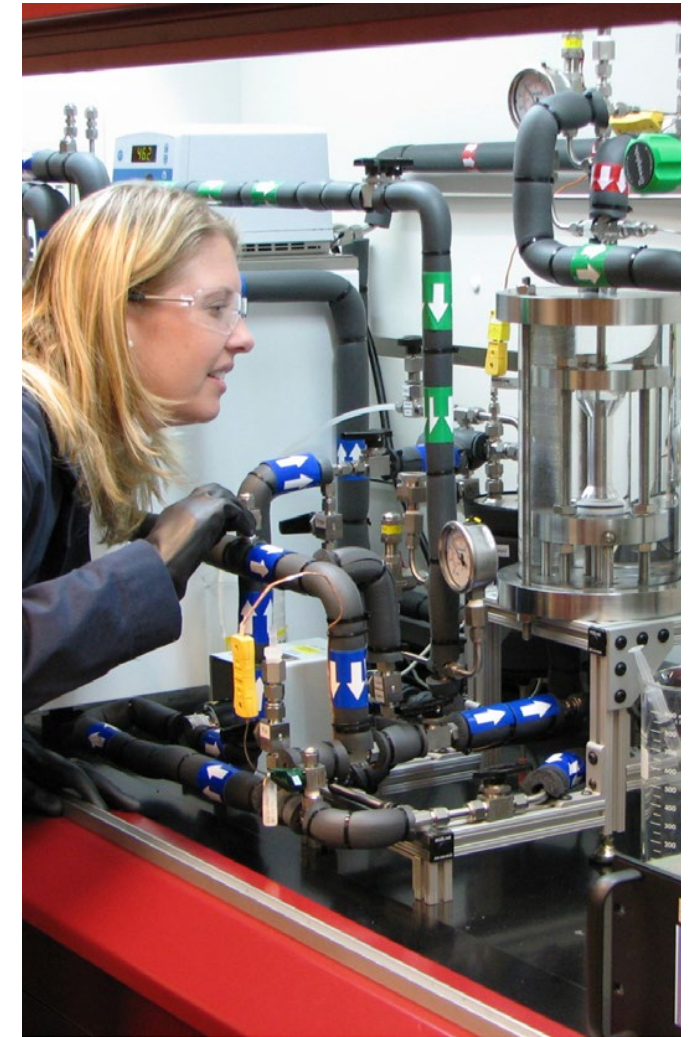
TECHNOLOGY DESCRIPTION

CLIMATEBRIGHT™ - SUITE OF REVOLUTIONARY HYDROGEN AND DECARBONISATION TECHNOLOGIES FROM BABCOCK & WILCOX (B&W)

B&W's ClimateBright™ decarbonisation technologies are designed to help customers in energy and industrial sectors aggressively combat greenhouse gas emissions and climate change. ClimateBright technologies further strengthen B&W's commitment to clean energy progress and to helping customers worldwide address the most significant environmental challenges in industrial processes and energy generation.

ClimateBright has a wide range of clean energy solutions to drive the energy transition through carbon capture and production of hydrogen for industries including energy production, food manufacturing, steel, cement, oil and gas, pharmaceutical, petrochemical, carbon black, and pulp and paper. Our technologies build on B&W's core talents in steam generation, combustion, and flue gas treatment, and each addresses the emissions of carbon dioxide (CO₂) from the combustion of carbon-based fuels in a unique way:

- BrightLoop™ uses a chemical looping process around a ferrous oxygen carrier to separate the products of combustion of a carbon-based fuel into separate streams of CO₂ and oxygen depleted air, allowing for the capture of CO₂.
- SolveBright™ is a post-combustion capture process using regenerable solvents.
- OxyBright™ utilises nearly pure oxygen in the combustion process while purifying the flue gas stream to near pure CO₂, simplifying its capture.
- BrightGen™ eliminates/reduces the generation of CO₂ by switching to a non- or low-carbon-based fuel.
- Flue gas pre-treatment to optimise post-combustion CO₂ capture.





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SUMMARY

B&W's BrightGen hydrogen combustion solution is currently in operation in more than 60 industrial boilers around the world, including at multiple refineries and other industrial facilities and is available to customers seeking a powerful hydrogen combustion solution for utility and industrial applications where efficient, zero-carbon dioxide-emissions energy generation is a goal.

Our highly reliable utility, industrial and package boilers can be manufactured or retrofitted with BrightGen technology to safely burn hydrogen or hydrogen-blended fuels for virtually any need, including power, heating and steam generation, and for industrial applications such as refineries and petrochemical facilities.

When considering the potential for fuel switching from a solid or gaseous fuel, and integrating hydrogen into the combustion process, B&W conducts a complete evaluation of the entire boiler system. This includes all combustion equipment such as burners, burner management systems, boiler pressure parts, ignitors, flame scanners, fuel trains, and air quality control systems.

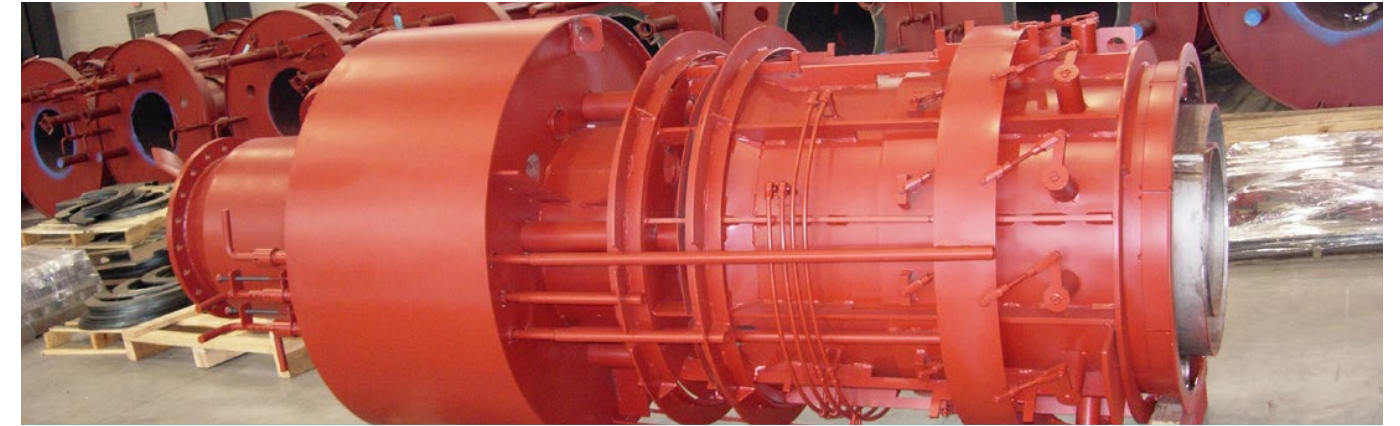
BENEFITS

- With 100% hydrogen firing, BrightGen produces no carbon dioxide (CO₂) emissions.
- BrightGen can also be fired with a blend of hydrogen and other lower-carbon gaseous fuel (such as natural gas or process off-gas) to take advantage of fuel availability and pricing to generate lower CO₂ emissions.
- The BrightGen technology can be provided with new boiler installations or as a retrofit in fuel switching applications.



KEY DATA

TRL	9	Capture Rate Range (tpd)	~	Modular (Y/N)	Yes
Source CO ₂ Purity Range	~	Energy Consumption (GJ/tCO ₂)	~	Capture Efficiency (%)	~
Number of Commercial Plants	60+	Number of Pilot Plants	~		
Target Industries	Oil & Gas, Refineries, Power Utilities, Iron & Steel, Pulp & Paper, any medium to heavy industrial facility				



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SUMMARY

B&W's oxy-combustion process can be used to generate steam and power using a variety of fuels, including coal, natural gas, biomass, oil, and others. In the oxy-fuel process, combustion air is replaced with nearly pure oxygen and recirculated CO₂. Nitrogen that would normally be conveyed with the air through conventional air-fuel firing is excluded and the resulting flue gas consists of nearly pure CO₂. The non-recirculated flue gas leaving the boiler is cleaned using conventional particulate and sulfur removal systems and sent to the compression purification unit (CPU) where a high-purity CO₂ stream is produced that is suitable for transportation or other uses.

Combining B&W's OxyBright technology with biomass-fired technology, such as our bubbling fluidised-bed (BFB) boiler, along with carbon capture and sequestration, energy is produced with a net-negative carbon intensity. Biomass such as forest litter, construction and demolition waste, or agricultural byproducts, can fuel our BFB boiler. BECCS (bioenergy production with carbon capture and sequestration) is a highly scalable technology and is an emerging innovative solution to decarbonise emission-intensive industries.

BENEFITS

- The combustion process produces a concentrated CO₂ stream suitable for sequestration or other beneficial uses; no post-combustion equipment is required.
- Applicable to a variety of fuel sources.
- Can be retrofitted on existing plants or designed for new steam generation installations.
- Net-negative carbon intensity when biomass is the fuel source and is combined with carbon capture and storage (BECCS).

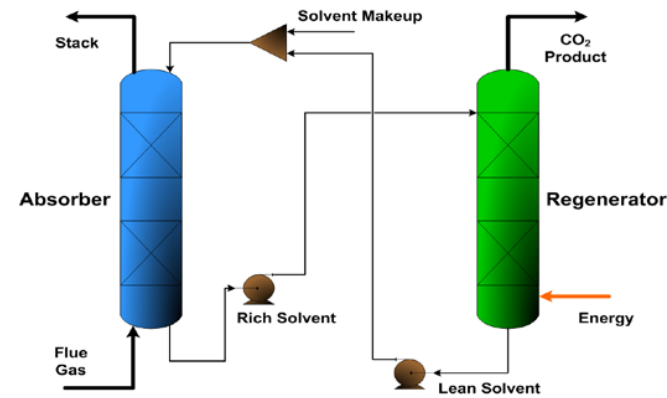
KEY PROJECTS

- B&W provided oxy-fuel technology for use with coal on the U.S. Department of Energy's FutureGen 2.0 demonstration project in Illinois, which was to be a retrofit of a 167 MW coal-fired power plant. Although construction began in 2014, the project was canceled in 2016 due to redirection of DOE funding support. B&W has continued to develop oxy-fuel technology and it is ready for full-scale commercialization and deployment.
- In March 2022, B&W announced its OxyBright and its BFB biomass boiler-fired technologies would be part of the world's largest net-negative CO₂ biomass-to-energy facility to be developed by Fidelis New Energy at the Port of Great Baton Rouge, Louisiana.

KEY DATA

TRL	8	Capture Rate Range (tpd)	~	Modular (Y/N)	No
Source CO ₂ Purity Range	~	Energy Consumption (GJ/tCO ₂)	~	Capture Efficiency (%)	~
Number of Commercial Plants	0	Number of Pilot Plants	2		
Target Industries	Utility Power, Medium to Heavy Industry, Waste/Biomass to Energy				

SOLVEBRIGHT™ POST-COMBUSTION CARBON CAPTURE



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SUMMARY

B&W's SolveBright regenerable solvent absorption technology scrubbing process came from decades of decarbonisation research and development.

The SolveBright carbon dioxide scrubbing system is a post-combustion carbon capture technology that captures CO₂ directly from flue gas in an absorber using a regenerable solvent. The CO₂-rich solvent is sent to a regenerator where it is heated, and the CO₂ is released as a concentrated stream for compression and storage or beneficial uses. The CO₂-lean solvent is then recycled to the absorber for reuse.

While B&W's solvent compared favorably with more than 100 competing solvents during our extensive testing procedures at the National Carbon Capture Center, a major advantage of the SolveBright process is solvent flexibility, which allows customisation of an optimal CAPEX and OPEX solution for each application. SolveBright can be used with a variety of solvents and we have the expertise and ability to use a wide range of potential solvents.

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BENEFITS

- Solvent flexibility, allowing us to customise an optimal CAPEX and OPEX solution for each application.
- Knowledge of solvent scrubbing solutions for carbon capture since 2005; we understand the process, the equipment and the innovation behind the various type of solvents used.
- Experience across a wide range of industries with various fuels and combustion processes: from utilising waste and biomass as fuels to industries such as cement, steel, chemical, oil and gas, pulp and paper, food and beverage, and many others looking for reliable decarbonisation partners.
- Total solution support, from feasibility studies, pre-FEED and pilot unit definition, FEED studies, to full-scale plants, tailored to the customers' specific needs.

KEY DATA

TRL	8-9	Capture Rate Range (tpd)	~	Modular (Y/N)	No
Source CO ₂ Purity Range	~	Energy Consumption (GJ/tCO ₂)	~	Capture Efficiency (%)	~
Number of Commercial Plants	~	Number of Pilot Plants	~		
Target Industries	Utility Power, Medium to Heavy Industry, Waste/Biomass to Energy				



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SUMMARY

Acid gases degrade the solvents used in a post-combustion carbon capture system. B&W offers a complete suite of environmental control technologies to control sulphur dioxide (SO₂), sulphur trioxide (SO₃) – which can form aerosols and cause loss of CO₂ capture solvents – hydrogen chloride (HCl), and hydrogen fluoride (HF) in the pre-capture flue gas stream, as well as technologies for other pollutants such as metals and particulates. Nitrogen oxides (NO_x) are also detrimental for CO₂ capture solvents and can lead to hazardous degradation products in the process. CO₂ scrubbing may also improve when particulate matter is removed from the flue gas prior to the scrubbing process.

Pre-treatment of the flue gas is vital for the operation and economics of the process to result in the optimum effectiveness of the carbon capture technology. B&W has many decades of experience in emissions control solutions, pioneering technologies that have helped customers comply with stringent emissions regulations for more than 50 years.

BENEFITS

- Flue gas pre-treatment provides optimum effectiveness of the post-combustion carbon capture technology.
- Wide range of proven pre-treatment technologies to significantly reduce incoming flue gas pollutants, including sulphur oxides, particulates, nitrogen oxides, mercury and other acid gases.
- Experience with more than 2300 installations of various pollutant control technologies

KEY PROJECTS

Higher concentrations of a wide range of inlet pollutants lead to higher solvent make-up rates and higher operating costs. Since solvent is typically much more expensive than other reagents, removal of the pollutants upstream of the CO₂ absorber typically results in a reduction of overall operating costs. Our flue gas treatment installations include these impressive numbers which control a wide range of pollutants from diverse industrial segments:

- Wet flue gas desulphurisation (FGD) and wet gas scrubbers: 300+
- Dry scrubber technologies (spray dryer absorbers [SDA] and circulating dry scrubbers [CDS]): 90
- Selective catalytic reduction (SCR): 100+
- Dry sorbent injection (DSI): 35+
- Wet and dry electrostatic precipitators (ESP): 750+
- Fabric filter baghouses: 1000+
- Flue gas condensation: 35+

KEY DATA

TRL	9	Number of Commercial Plants	2300+	Modular (Y/N)	No
Target Industries	Utility Power, Waste/Biomass to Energy, Medium to Heavy Industry such as Oil & Gas, Refineries, Iron & Steel, Pulp & Paper, Cement				

TECHNOLOGY DESCRIPTION

B&W DECARBONISATION TECHNOLOGY OVERVIEW

B&W has a broad range of unique and innovative technologies and processes for carbon capture, hydrogen generation and hydrogen combustion, including:

- CO₂ Removal – Capture (OxyBright, SolveBright, BrightLoop)
- CO₂ Reduction – Efficiency improvements and fuel mixing
- CO₂ Avoidance – Replacing carbon-intensive power generation with renewables (BECCS, green steam, LDES, solar); fuel switching and combustion of hydrogen or ammonia (BrightGen, BrightLoop)
- CO₂ Reuse – Capture carbon for beneficial use (P2X [biogenic CO₂]); food & beverage use (OxyBright, SolveBright, BrightLoop)

- CO₂ Storage – Capture and store (OxyBright, SolveBright, BrightLoop)
- Low Carbon Intensity Hydrogen Generation – (BrightLoop)
- Hydrogen Combustion – (BrightGen)
- CO₂ Capture Optimisation – Flue gas pre-treatment (full suite of B&W environmental technologies)

More information on B&W's ClimateBright suite of products is available at www.babcock.com.

