# High-Efficiency Post-Combustion Carbon Capture System

## primary project goal

Precision Combustion Inc. (PCI), along with its partners University of Florida and the Commonwealth Scientific and Industrial Research Organization (CSIRO) Australia, is developing a compact, modular system utilizing high-capacity metal organic framework (MOF) nanosorbents in a unique low-pressure drop system design to capture carbon dioxide ($CO_2$) from flue gas. The combination of improved sorbent geometry with a cutting-edge nanomaterial with unsurpassed properties for $CO_2$ removal that can be produced at large scale allows for a high-efficiency $CO_2$ capture unit that can be easily retrofitted to existing power plants.

## technical goals

- Optimize the sorbent to higher capacities with good selectivity toward $CO_2$, as well as resistance to humidity and contaminants.
- Optimize mesh geometry and coating process to achieve higher loadings without affecting sorbent structure at increased production capacity.
- Simulate a scaled-up plant design with steady and dynamic process and CFD modeling of the system.
- Assemble small-scale module and test with actual coal-derived flue gas to show the efficacy of the system and further refine the operating conditions.
- Integrate with DOE's CCSI software.
- Perform full-scale techno-economic modelling of $CO_2$ capture with sensitivity analysis.

## technical content

PCI is developing a post-combustion carbon capture system using high-capacity MOF nanosorbents coated on PCI's patented Microlith® mesh sorbent substrate.

MOF materials are crystalline organic-inorganic compounds formed by coordination of metal clusters or ions with organic linkers—usually bivalent or trivalent aromatic carboxylic acids or nitrogen-containing aromatics. They have extremely high surface area, high pore volume, uniform size pores, and high metal content, making them excellent candidates for selective $CO_2$ capture. The MOF materials retain $CO_2$ at up to six times the capacity of amine solutions under low pressure and high humidity conditions, and also require significantly less energy for regeneration and exhibit a lower rate of degradation due to the capture of $CO_2$ via physical adsorption rather than through chemical reaction. The modular cartridge form factor enables low-cost retrofit to existing systems. To achieve high space velocity sorption, the densified nanostructured sorbent is coated on PCI's patented mesh-based substrate, trademarked Microlith, that has higher surface area per unit volume and much higher mass transfer coefficients compared to other substrates. The the improved sorbent geometry enables decreased bed volume with equivalent effectiveness to other types of monolithic or loose packing, without pressure drop penalty. Additionally, up to 20 times higher mass and heat transfer coefficients are obtainable as compared to other sorbent systems, such

**program area:**
Point Source Carbon Capture

**ending scale:**
Bench Scale

**application:**
Post Combustion Power Generation PSC

**key technology:**
Sorbents

**project focus:**
Metal Organic Framework Nanosorbent on Microlith Substrate

**participant:**
Precision Combustion Inc.

**project number:**
SC0017221

**predecessor projects:**
N/A

**NETL project manager:**
Andrew O'Palko
andrew.opalko@netl.doe.gov

**principal investigator:**
Codruta Loebick
*Precision Combustion Inc.*
cloebick@precision-combustion.com

**partners:**
University of Florida; Commonwealth Scientific and Industrial Research Organization (CSIRO) Australia

**start date:**
02.21.2017

**percent complete:**
97%

as monoliths and pellets, due primarily to boundary layer minimization and break-up, boosting $CO_2$ removal rates with greater sorbent bed utilization and less bypass inherent to packed beds or monoliths. This sorbent manufacturing technology allows for adherent and durable MOF coatings (as well as alternative future high surface area sorbents) on the Microlith substrate. Sorbent coated on Microlith mesh is shown in Figure 1.

The process as shown in Figure 2 includes a modular capture system containing the MOF nanosorbents coated on Microlith, with adsorption at 30°C and desorption at 80°C. This capture system configuration enables low-pressure drop, high volumetric utilization, and high mass transfer, and also has a low energy of regeneration.

In Phase I, a proof-of-concept of the Microlith substrate coated with MOF sorbent was tested at laboratory scale under relevant conditions. Modeling of a scaled-up Microlith unit with thermal integration was also initiated using the U.S. Department of Energy's (DOE) Carbon Capture Simulation Initiative (CCSI) software, in collaboration with the University of Florida, and the model is being further validated in Phase II to show cost advantages over existing solvent-based systems. Phase II work focused on optimizing the sorbent and substrate properties; evaluating performance through durability testing with simulated flue gas; and producing a refined techno-economic analysis (TEA) model based on computational fluid dynamics (CFD) simulations and process modeling as well as a fully integrated economic analysis, including balance of plant components. Phase IIA work builds on the Phase II success to continue optimization of the sorbent for both higher capacity and long-term resistance to humidity and contaminants; support long-term durability testing at the National Carbon Capture Center on an automated small scale unit; and mature the technology for Phase III pilot tests.

**During Phase II, PCI:**

- Selected the (currently) best capacity commercial large-scale intent MOF and further tested it under realistic conditions and developed means for improving its stability.
- Developed means for deploying the MOF at large scale by coating it on PCI's low-pressure drop Microlith support and matured the operational map of the post-combustion carbon capture system unit in thermal swing adsorption (at 30°C) and desorption (at 80°C) to bring energy expense to 255 kilowatt-hour (kWh)/tonne of $CO_2$ recovered at the end of the Phase and utilization of materials with lower heat capacity. In comparison, a monoethanolamine (MEA) system requires more than 1,100 kilowatt-hour (kWh)/tonne due to steam injection.
- Developed a TEA showing the system can achieve the $30/tonne of $CO_2$ captured target (including compression), with $35.8/tonne projected at Phase II performance; further cost savings expected from reduction of balance of plant components; and increased efficiency to under the $30/tonne target (Phase II A target [$26/tonne], including compression).
- Developed CFD models of pilot-scale units—to be integrated with CFD package of the CCSI software.
- Assembled a small-scale MOF—Microlith unit deployed at the NCCC for initial testing with actual flue gas for model and economics validation.

Figure 1: Microlith® mesh coated with sorbent.

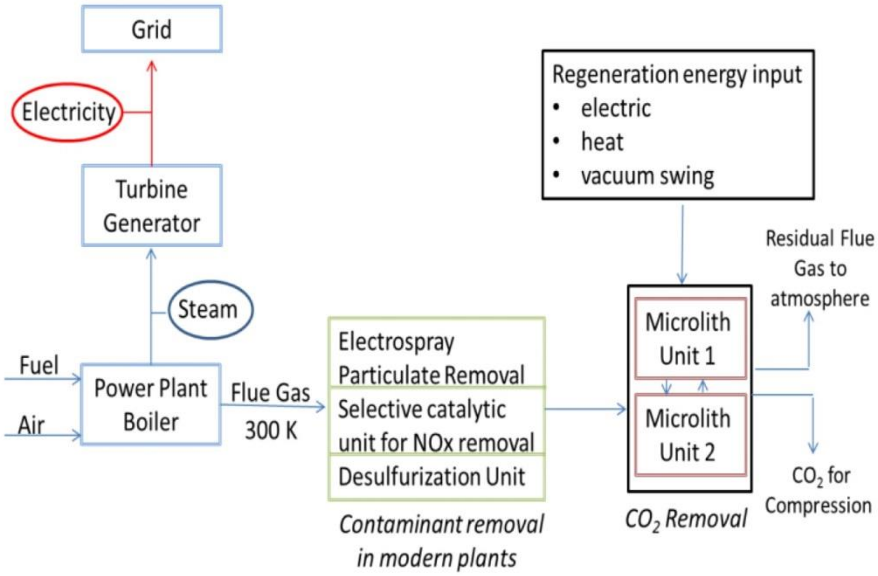


Figure 2: Process block diagram.

## technology advantages

- The MOF materials have a lower regeneration energy and a lower degradation rate due to their physical adsorption capture mechanism as opposed to chemical reaction.
  - Greatly reduces boundary layer formation, with reduced pressure drop for similarly performing post-combustion carbon capture systems (pellets or monoliths-based), resulting in process intensification with corresponding reduction in post-combustion carbon capture system volume.
  - Increased mass and heat transfer coefficients and enhanced diffusion of gas in the sorbent.
  - Immobilizing the sorbent increases its lifetime by reducing attrition.
  - Modular design flexibility (e.g., planar, radial); easily scalable.
- PCI's Microlith mesh substrate supporting the MOF material has higher surface area per unit volume and much higher mass and heat transfer coefficients, as well as low-pressure drop compared to other monolith substrates or pellets, resulting in increased $CO_2$ capture rate and reduced regeneration energy.

## R&D challenges

- Maintaining higher $CO_2$ loadings without affecting sorbent structure at increased production capacity.
- Identifying optimal sorbent to maximize capacity and selectivity.
- Achieving acceptable sorbent cost at large-scale production.
- Optimizing the material for long-term (thousands of cycles) operation in flue gas environment.

## status

In Phase II, PCI demonstrated the Microlith-based approach to carbon capture via adsorption on MOF materials. The sorbent was stable over multiple thermal cycles and showed stability to contaminants and humidity, as well as high selectivity for $CO_2$ over other components of the flue gas. The system was demonstrated to have energy-saving performance due to enhanced sorption properties, heat and mass transfer, and low-pressure drop. A TEA shows potential for achieving the DOE goal of $30/tonne of $CO_2$ captured. PCI developed a means for deploying the sorbent at large scale by coating it on Microlith support, and matured the operational map of the post-combustion carbon capture system unit in thermal swing adsorption (at 30°C) and desorption (at 70–80°C) to bring down energy expense. PCI assembled a small-scale unit deployed at the NCCC with system shakedown and installation completed.

## available reports/technical papers/presentations

Loebick, C., et al., "High-Efficiency Post Combustion Carbon Capture System," Presented at the Phase II/Phase IIA Project Review Meeting, Pittsburgh, PA, June 2020. *http://www.netl.doe.gov/projects/plp-download.aspx?id=12072&filename=High-Efficiency+Post+Combustion+Carbon+Capture+System.pdf*.

Loebick, C., et al., "High-Efficiency Post Combustion Carbon Capture System," Presented at the Phase II Project Review Meeting, Pittsburgh, PA, November 2018. *http://www.netl.doe.gov/projects/plp-download.aspx?id=12073&filename=High-Efficiency+Post+Combustion+Carbon+Capture+System+(Nov+2018).pdf*.

Loebick, C. and Weisman, J., "High-Efficiency Post Combustion Carbon Capture System," Presented at the Phase I Project Review Meeting, Pittsburgh, PA, December 2017. *http://www.netl.doe.gov/projects/plp-download.aspx?id=12074&filename=High-Efficiency+Post+Combustion+Carbon+Capture+System+(Dec+2017).pdf*.