Advanced Catalytic Reactors and Systems for the Energy Sector
MISSION

Precision Combustion, Inc. develops, manufactures, and markets catalytic components and systems for clean and efficient combustion, power generation, emissions control, and chemical manufacturing applications.

VISION

We aspire to develop and commercialize world leading catalytic combustion and catalytic reaction technologies to enable mankind to improve its way of life while reducing and eliminating atmospheric pollutants.

CORE COMPETENCIES

Our Core Competencies are in the fields of catalytic reaction and combustion including reactor design, catalyst formulation, coating processes, reactor assembly, and performance testing.

- Fuel Reformers and Fuel Processing Catalytic Reactors
  - Fuel processor systems
  - Burners / Oxidizers
  - Air Cleaners
  - Internal Combustion & Gas Turbine Applications
  - Fossil Fuel Applications
  - Specialty Products and Services
COMPANY OVERVIEW

Highly competent technical and supporting staff focused on innovation and customer deliverables

PROFILE

Precision Combustion, Inc. is a privately held corporation, founded in 1986 is located in North Haven, Connecticut, USA. Our site contains catalyst formulation, coating, and reactor manufacturing facilities as well as multiple advanced test rigs supported by a team of experienced engineers, technicians and machinists. PCI has distinctive skills in advanced catalytic reactor and system design and in catalyst formulation, coating, and supports. Many of PCI's staff have PhD's, including in the fields of chemical and chemical reactor engineering, mechanical engineering, computational fluid dynamics, chemistry, physics and materials science. PCI has developed a world-leading expertise in the fields of catalytic combustion and catalytic reaction.

FACILITIES

» 38,000 sq ft of research and manufacturing facility
» 5,500 sq ft catalyst formulation facility
» State-of-the art in-house instruments and equipment and 13 advanced test rigs
» In-house machine shop for fabrication
» Capability for low and high pressure testing
» Computation facility with latest design and simulation software: ANSYS-FLUENT, ASPEN Engineering Suite, Labview®, SolidWorks, CFDesign, and COSMOS.

Point of Contact:

Anthony Anderson
Director, Marketing and Business Development
Precision Combustion, Inc.
410 Sackett Point Road
North Haven, CT 06473
(203) 287-3700 Ext. 290
aanderson@precision-combustion.com

Website: www.precision-combustion.com
TECHNOLOGIES

Our technological breakthroughs are reflected in PCI’s Microlith® catalytic reactor designs, the RCL® catalytic combustor, and in the more than 75 issued U.S. patents we have been awarded. Our business focus is on the commercialization of technologies developed in-house. The two core technologies developed by PCI are:

» **Microlith® catalytic reactor technology** for fuel reformer, fuel processor and fuel cell systems, portable power generation, chemical processes, adsorption systems for air cleaning, exhaust aftertreatment, and specialty applications.

» **RCL® catalytic combustors** for gas turbine NO\textsubscript{x} reduction, heavy oil/methane hydrate production and soil disinfection/remediation.

All of our technologies are customized to perform within the systems of our OEM customers. PCI creates value for our customers by applying our patented and proprietary catalytic technologies to their systems. Working with our customers, our technology and integrated design skills have provided performance benefits and reduced system costs in a compact, lightweight packages for aerospace, defense and energy applications.

PRODUCT ASSURANCE SYSTEM

PCI has in place appropriate procedures and processes to ensure quality of output to meet project objectives. Individual contributors are responsible for the quality of their output and are monitored for quality of output by their direct supervisors. PCI is committed to performing all work in compliance with applicable Federal, state, and local environment regulations.
Microlith® reactors are catalytic reactors constructed with PCI’s patented Microlith® substrate. The substrate is very thin and has short metal channels resembling screens or meshes. Microlith® reactors have low pressure drop, enabling design of a high cell density, low thermal mass device which simultaneously leads to a smaller, lighter and higher efficiency catalytic reactor. The substrate design increases mass transfer and heat transfer, allowing more rapid reactor response to gas temperatures as well as improved rates of reactant contact with the surface. The substrate is coated utilizing proprietary methods with a variety of materials including catalysts and adsorbent materials which provide a unique and superior approach to chemical reaction.

Ultra-compact: equivalent conversion and pressure drop as a monolith substrate with a 20 fold size reduction.

Lightweight: Typically 10 times lighter than competing technologies

Fast Transient Response: typically 20 times faster than ceramic monoliths

High geometric surface area: Up to 6 times higher than competing technologies leading to higher reaction selectivity and performance advantages.
Superior logistics fuel processors for HTPEM, SOFC, and other high temperature fuel cell systems

MICROLITH® FUEL PROCESSORS

PCI has developed logistics fuel processors for SOFC, HTPEM, and other high temperature fuel cell systems. The fuel processors are designed for reforming diesel, JP-5 or JP-8 and are currently sized 1, 2, 5, 10, 50 and 250 kilowatts. The fuel processors include the fuel preparation, ATR reactor, steam generator, sulfur remover and BOP components. The initial applications targeted are tactical gensets, vehicle APUs, Navy Ship APUs, UAV and UGV propulsion, and fuel cell stack testing. PCI is also developing natural gas, biofuel and liquid hydrocarbon fuel processors to support industrial needs.

APPLICATIONS
» Fuel Cell System
» Chemical Industry
» Research & Development

KEY FEATURES
» > 85% Reforming efficiency (LHV basis)
» Projected catalyst lifetimes of thousands of hours
» Operation at low S:C ratio for reduced water needs
» No observed coke formation
» Sulfur tolerant catalyst
» Sulfur cleanup from reformate to < 1 ppm
» Pumps, blowers and controls packaged separately (with low parasitic power)
» Turn down of 5:1 demonstrated
» Start-up to steady state < 10 minutes Transient response < 2 seconds
» Cold start demonstrated at -40C
» High Power Density

We put the fuel in fuel cells®
MICROLITH® FUEL CELL SYSTEMS

Ultra-compact and light weight logistics fuel reformer enabled fuel cell systems

MICROLITH® REFORMER ENABLED FUEL CELL SYSTEMS

PCI is developing a family of ultra-compact fuel cell systems. These systems utilize Microlith® reformers to run on logistics fuels. PCI’s systems are stack agnostic and can be adapted to both SOFC and HTPEM applications. PCI’s technology is readily scalable to small and large systems. This enables PCI to design solutions for a variety of industrial and government customers.

PCI is an experienced component fabricator and system integrator, designing, producing and integrating components and subsystems such as:

» Microlith® fuel reformers/fuel processors
» Sulfur clean-up modules
» Dedicated control boards with stack, reformer, BOP, and UI integration
» Specified pumps and blowers (fuel, water, air, etc.)
» Power conditioning & electronics
» Sensors
» Water recovery systems
» Heat exchangers
» Steam generation systems
» Start-up & tail gas burners

PCI’s systems utilize an optimized system integration approach with efficient thermal management and robust controls, reducing their size and weight.

APPLICATIONS

» Man-portable, mobile and stationary gensets
» Auxiliary power units (APUs) for air, sea, and ground vehicles
» Unmanned aerial vehicle (UAV) propulsion systems
» Unmanned ground & surface vehicles (USV/UGV)
» Electric vehicle range extension

KEY FEATURES

» Water Neutral - Able to use less water (lower steam/carbon ratio)
» High quality power
» Low parasitic balance of plant components
» High Thermal integration
» Ultra-compact and light weight
» High quality & reliable reformate
» Integrated controls
» Stack agnostic

Fuel Reformer/Fuel Cell System

We put the fuel in fuel cells®
MICROLITH® FUEL REFORMING CATALYTIC REACTORS

PCI has developed several fuel reforming catalytic reactors for integration into fuel processor and fuel cell power systems for portable, mobile and stationary applications. Demonstrated fuels include: natural gas, propane, methanol, gasoline, Jet A, F-T fuels, JP-5, JP-8, JP-10, diesel and biofuels. Catalytic reactor types include: Catalytic Partial Oxidation (CPOX), Autothermal Reforming (ATR), Steam Reforming (SR) and Oxidative Steam Reforming (OSR).

CPOX:

Energy Efficiency: > 80%
Power Range: Up to 5MWth
H₂ mole % (dry): 18 - 24%
Start up: < 1 minute to lightoff @ 5 KW_th with diesel

ATR:

Energy Efficiency: > 80-85%
Power Range: Up to 1 MWth
H₂ mole % (dry): 30 - 32%
Start up: < 0.5 minute to lightoff @ 5 KW_th with diesel

CSR:

Energy Efficiency: > 80-85%
Power Range: 1 - 5 kWth
H₂ mole % (dry): 70% (3.0 Kg/day)
Start up: < 10 minute to steady state @ 1 KW_th with natural gas

MICROLITH® FUEL PROCESSING CATALYTIC REACTORS

PCI is developing Water Gas Shift and Preferential Oxidation of CO (PROX) catalytic reactors for fuel processor and fuel cell power systems which have demonstrated highly selective conversion of CO in a small package. The Water Gas Shift reactor technology reduces CO concentration in the reformate stream to ~1% in a single stage with low methanation. PCI’s PROX technology further reduces the CO concentration to below 10 ppm, typically in two stages while consuming less than 3% of the hydrogen in the reformate.

REACTOR ATTRIBUTES

» High power density > 25 kW_e/L
» High specific power > 28 kW_e/kg
» Fast start-up <30 seconds)
» Fast transient response (3-10 seconds)

FUEL FLEXIBILITY

» JP-8
» Gasoline
» Diesel
» Natural gas
» Propane
» Biofuels such as camelina oil
» E-85
» Ethanol
» B-20
Custom engineered to the specifications required by our customers

MICROLITH® CATALYTIC BURNERS

Built upon its catalytic substrate technology, PCI has several very small to medium sized catalytic burner products in development for a variety of fuels including diesel, JP-8, natural gas, biofuels, propane, methanol, ethanol, fuel cell anode exhaust, and hydrogen.

Demonstrated emissions of < 2 ppm CO, < 2 ppm CH₄, and < 0.3 ppm NOx with natural gas.

POTENTIAL APPLICATIONS

» Stirling engines
» Low NOx cook-top burners
» Thermoelectric generators
» Industrial process burners
» Portable heaters
» Thermophotovoltaic (TPV) generators
» Liquid fueled microturbines

MICROLITH® FUEL CELL SYSTEM OXIDIZERS AND BURNERS

PCI has developed, manufactured and delivered oxidizers for PEM and SOFC fuel cell systems and fuel reformers including:

» Anode gas oxidizers
» Methanol/gasoline fuel reformer start burners
» Fuel cell test stand purge burners
» Fuel cell system inerting burners
» Hydrogen recombiners

All oxidizers and burners are custom engineered to the specifications or “Fit, Form, and Function” required by our fuel cell system and fuel reformer customers. Size ranges: $100W_{th} – 300kW_{th}$

~ 10 times more lightweight
~ 20 times more compact
~ 30 times faster transient response than competing technologies
MICROLITH® AIR CLEANERS

PCI is developing air cleaning applications focused on control of Volatile Organic Compounds (VOC’s) and other air pollutants. Applications include air treatment systems for spacecraft, submarines and collective protection shelters.

ADVANTAGES

- Direct electrical heating of the conductive substrate utilizing low power
- Reduced weight and smaller size
- High energy and conversion efficiency
- Reduced maintenance and power requirements
- Improved durability for long term reliable operation

AIR CLEANING APPLICATIONS

Air cleaning applications include air treatments systems for spacecraft, submarines and other collective protection shelters.

APPLICATIONS

Microlith® Trace Contaminant Oxidizer

Advanced Microlith® based catalytic oxidizers for trace air contaminants control (TCCS) aboard the International Space Station have been provided to NASA for qualification testing, offering substantial weight savings in a compact space. Other benefits include the ability to target individual species for clean-up and ready integration with existing systems. The technology can also be paired with PCI’s Microlith® Trace Contaminant Adsorber.

These units have been tested for 16,000 hours of life and subjected to launch loads and vibration.

Microlith® Trace Contaminant Adsorber

PCI has developed specialized adsorbent technologies utilizing the regenerative capabilities of electrically-heated Microlith® substrate. These technologies are focused on adsorbing carbon dioxide, ammonia, ethanol and other Spacecraft Maximum Allowable Concentration (SMAC) compounds from cabin air replacing the activated charcoal and Li-OH beds used in current trace contaminant clean-up systems.
PCI's Rich Catalytic Lean burn (RCL®) technology has been demonstrated with natural gas, low BTU gas, syngas, hydrogen, and prevaporized diesel fuels.

**RCL® COMBUSTION**

Rich Catalytic Lean (RCL) burn catalytic combustion is PCI's patented solution for a low NOx combustor approach for gas turbines. The system uses a rich catalytic reactor with air cooling and subsequent mixing of the reactor output with the cooling air to form a lean mixture for combustion. In the process, the combustion air stream is split into two parts upstream of the catalyst. One part is mixed with all of the fuel forming a rich fuel/air mixture and contacted with the catalyst, while the second part is used to cool the catalyst. The catalyst is cooled only by primary combustion air, so that no heat is extracted from the system. The rich fuel/air stream undergoes partial fuel oxidation followed by mixing of the partially reacted fuel with the cooling stream to produce a reactive, fuel-lean mixture. This lean mixture can then be burned stably in a downstream combustion zone, with the result being lower NOx and CO emissions and greater combustion stability than with DLN/DLE technologies.

**ADVANTAGES**

- The rich reactor chemistry enables operation at low temperatures.
- Lower operating temperature and rich kinetics are supportive of long catalytic surface life targeted to reach 25,000 hours.
- The Broad fuel flexibility with highly reactive fuels such as hydrogen, syngas, refinery gas, blast furnace gas, and other industrial gases.
- Simple, compact, no moving part design can fit into existing package.
- Longer material durability
- Near-zero NOx while minimizing combustion dynamics
- Long Life catalytic combustor reducing capital, operating cost and efficiency penalties of post combustion controls.
- Potential reduced O & M costs now associated with lean premix combustion dynamics.
Targeted for natural gas fueled turbines, IGCC syngas, heavy oil production, and methane recovery from hydrate formations

GAS TURBINE CATALYTIC APPLICATIONS

Precision Combustion’s gas turbine catalytic combustors are targeted for natural gas-fueled prime mover and power generation turbines from microturbine size up through 180+ MW “F”-class. PCI is also developing a version to combust hydrogen containing fuel such as IGCC syngas made from coal. In a spinoff application, PCI is developing a catalytic combustor for downhole use in heavy oil production and methane recovery from hydrate formations.

PRODUCT EMBODIMENTS

The gas turbine products are being developed in two embodiments, catalytic pilot and catalytic combustor. In the catalytic pilot, a diffusion flame pilot is removed from a DLN/DLE combustor and replaced with a catalytic pilot. Thus, the fuel that passes through the pilot is catalytically reacted reducing NOX. The catalytic combustor is a full replacement for an existing DLN/ DLE combustor. All of the fuel is reacted in the combustor with the resulting fuel air mixture being combusted downstream in a lean pre-mixed fashion.

RCL® CATALYTIC PILOT

The Rich Catalytic Lean burn (RCL®) Catalytic Pilot allows state of the art Dry Low NOx (DLN) gas turbine engines to achieve reduced NOx with high combustion stability and wide turndown.

» Compact: Replaces the diffusion pilot in a combustor within the same working envelope

» Low emissions: NOx < 5ppm

» Low acoustics (< 0.4 psi)

RCL® CATALYTIC COMBUSTOR

PCI’s Rich Catalytic Lean burn (RCL®) Catalytic Combustor offers many desirable features without an efficiency penalty across a wide turndown range such as:

» Compact: Fits within the envelope of current combustors

» Low emissions: < 3 ppm NOx

» Lower Cost than SCR systems or other methods of post-turbine NOx reduction

» High combustion stability over a wide operating range

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Precision Combustion, Inc. (PCI) has developed a catalytic combustor technology breakthrough with a downhole steam generator for oil and gas production, a tool that has been long-sought by the oil and gas production industry and that could help drive a worldwide boom in heavy oil production. PCI’s catalytic combustion technology, already developed and demonstrated for use in burning natural gas for gas turbine engines, offers to resolve key challenges that have faced prior downhole steam generators. A system built around this catalytic combustor offers the potential for key advantages compared to thermal stimulation using surface steam injection into the wellbore. These advantages include:

» Higher production and recovery from the reservoir

» 20-40% cost, energy, and water savings compared to surface steam injection

» Major air emissions savings (including of CO₂), which are directed downhole

» Unique capability for production for permafrost, deepwell, or underwater reservoirs.

HEAVY OIL PRODUCTION

A primary application for the downhole combustor technology is to improve mobility of heavy oil to aid in production. Despite plentiful reserves, heavy oil is only a small fraction of overall production. Because heavy oil requires massive amounts of heat to make it mobile/less viscous and able to be produced. Most U.S. heavy oil is currently produced by thermal stimulation using surface steam injection through the wellbore. PCI’s approach offers an improvement over surface steam injection by increasing reservoir recovery while reducing energy and water required and reducing air emissions.

METHANE HYDRATE PRODUCTION

PCI is developing its downhole catalytic combustor for generating downhole heat for efficient production of methane from its hydrate, with potential for CO₂ sequestration. PCI is developed this application under a U.S. DOE contract. Energy savings benefits are:

» Only ~ 12-15% of produced methane is consumed in the process, offering substantial energy savings.

» This approach provides the potential for CO₂ sequestration and avoids heating of the permafrost for additional energy savings.
**MICROLITH® CATALYTIC CONVERTER PRODUCTS**

Microlith® technology offers multiple benefits including fast catalyst lightoff and 20-fold volume reduction.

**MICROLITH CATALYTIC CONVERTERS**

Microlith® technology offers multiple benefits for automotive and other internal combustion engine aftertreatment applications including:

- Fast catalyst lightoff
- 20-fold reduction in volume and weight, as compared to long channel monoliths
- Equivalent pressure drop per unit of conversion as compared to long channel monoliths

**APPLICATIONS**

There have been several versions of the Microlith® catalytic converter developed and demonstrated including for:

- Automotive ULEV & SULEV
- Natural gas fueled truck engines
- Natural gas fueled reciprocating engines for prime movers
- Marine two-stroke engines
- Small two-stroke engines

**ATTRIBUTES**

- Ultra-compact
- Lightweight
- Responsive to transients
PCI offers custom coating and material characterization services to meet the needs of our clients.

**COATING SERVICES**

PCI offers advanced washcoating (slurry coating) on metal and ceramic substrates and material characterization services. Substrate geometries include, but are not limited to tubes, monoliths, plates and foams.

PCI’s coating expertise includes alumina, zeolite, ceria and zirconia, precious metal deposition and other metal oxides.

PCI also has the capability to coat your substrate with a custom catalyst.

**MATERIAL CHARACTERIZATION EQUIPMENT**

- Optical Microscopy
- UV-Vis Spectrophotometer
- Quantachrome Autosorb BET instrument for multipoint BET, pore volume, pore distribution, and metal dispersion/surface area measurement. PCI has constructed special BET cells to allow measurement of these parameters for catalysts and supports coated on small parts.
- SEM/EDS for analysis of metal dispersion, particle size, morphology and chemistry of the samples.
- Brookfield Viscometer
- High Temperature Furnace/Tube Furnace
- Routine and preferred access to state-of-the-art materials characterization instrumentation through Connecticut State Colleges and Universities Center for Nanotechnology
MARKETS & CUSTOMERS

MARKETS

PRIVATE SECTOR
We work with numerous private customers, most under confidentiality.

AEROSPACE
Air cleanup
Aircraft APUs

DEFENSE
Portable power
Tactical gensets
Vehicle APUs
UAV, UUV, & UGV propulsion and power
Cook stoves
IR sources

FOSSIL FUEL PRODUCTION
Downhole heat and steam generation
Heavy oil production
Methane hydrate production

POWER GENERATION
Gas turbines
Fuel cell systems
Stirling engines
IC engine generators
Thermoelectric generators

OTHER
Contaminant clean up
Soil disinfestation/remediation
Power-to-Gas methanation
Material characterization
Coating services
Testing services

FEDERAL AND STATE AGENCIES
» Department of Defence (DoD) (Army, Navy, Air Force, DARPA, Missile Defence Agency)
» Department of Energy (DOE)
» Environment Protection Agency (EPA)
» National Aeronautics and Space Administration (NASA)
» National Science Foundation (NSF)
» United States Department of Agriculture (USDA)
» California Energy Commission

CUSTOMERS

TRANSPORTATION
Marine power
Aircraft APUs
Commercial truck APUs
Recreational vehicle APUs
Range extension
Emissions aftertreatment

POWERS GENERATION
Marine power
Aircraft APUs
Commercial truck APUs
Recreational vehicle APUs
Range extension
Emissions aftertreatment

AEROSPACE
Air cleanup
Aircraft APUs

DEFENSE
Portable power
Tactical gensets
Vehicle APUs
UAV, UUV, & UGV propulsion and power
Cook stoves
IR sources

FOSSIL FUEL PRODUCTION
Downhole heat and steam generation
Heavy oil production
Methane hydrate production

POWER GENERATION
Gas turbines
Fuel cell systems
Stirling engines
IC engine generators
Thermoelectric generators

OTHER
Contaminant clean up
Soil disinfestation/remediation
Power-to-Gas methanation
Material characterization
Coating services
Testing services

FEDERAL AND STATE AGENCIES
» Department of Defence (DoD) (Army, Navy, Air Force, DARPA, Missile Defence Agency)
» Department of Energy (DOE)
» Environment Protection Agency (EPA)
» National Aeronautics and Space Administration (NASA)
» National Science Foundation (NSF)
» United States Department of Agriculture (USDA)
» California Energy Commission

CUSTOMERS