PCI
Precision Combustion, Inc.

PRECISION COMBUSTION, INC

COMPANY CAPABILITIES

Advanced Catalytic Reactors and Systems for the Energy Sector

Clean Power Solutions for the 21st Century®

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OVERVIEW

A provider of state of the art catalytic devices and systems for energy sector applications.

Overview

The use of fossil fuels for power generation is seriously limited by the increasing amount of global emissions regulations. Carbon monoxide, carbon dioxide, and nitrogen oxides are all regulated with decreasing amounts of these pollutants allowed from power generation and other processes that use oxidation and combustion. Precision Combustion, Inc. is a provider of innovative catalytic solutions to enable cleaner and more efficient use of fossil fuels for a variety of applications.

Mission

Precision Combustion, Inc. (PCI) develops, manufactures, and markets catalytic devices for clean and efficient combustion, emissions control and chemical manufacturing applications. Our focus is on two core technologies, Microlith® catalytic reactor technology for fuel reformers, fuel processors, burners, chemical reactors, sorption modules and exhaust aftertreatment and RCL® catalytic combustors for gas turbine NO_x reduction and fossil fuel production.

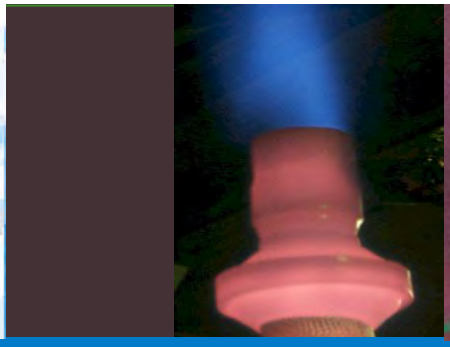
Company Vision

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

PCI has distinct competencies in the field of catalytic reaction and combustion including:

- **Reactor design**
- **Catalyst formulation**
- **Coating processes**
- **Reactor assembly**
- **Performance testing**

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COMPANY PROFILE

High value added catalytic reactor systems for combustion, environmental and chemical processing applications

Developments

Precision Combustion, Inc. (PCI) develops high value-added catalytic reactor systems for combustion, environmental and chemical processing applications. Our business focus is on the commercialization of two core technologies, 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 and our RCL® Catalytic combustors for gas turbine NOx reduction and heavy oil/methane hydrate production. All of our technologies are customized to perform within the systems of our OEM customers.

Commercialization

The company works successfully with major equipment manufacturing customers to commercialize its technologies and gain market access. Our commercial success has led to two U.S. Army SBIR Achievement Awards, two Tibbetts Small Business Innovation Research (SBIR) Model of Excellence awards, as well as being named to the Marcum Top Tech 40 in both 2010 and 2011 as one of the top 40 fastest growing technology firms in Connecticut. SBIR is a U.S. Government technology development program in which federal agencies set aside a small fraction of their R&D budgets for technology innovation competitions among small businesses. Winners keep the rights to technology developed and are encouraged to commercialize it.

Headquarters

The company is a privately held corporation, founded in 1986 and located in a modern 38,000 square foot facility in North Haven, CT, USA. The site contains catalyst formulation, coating and reactor manufacturing areas as well as multiple test rigs supported by an experienced technician and machining team.

PCI's 36 employees bring a wealth of experience from a variety of firms such as Delphi, Carrier, Hamilton, Pratt & Whitney, Sikorsky Aircraft, Sundstrand and Textron among others.

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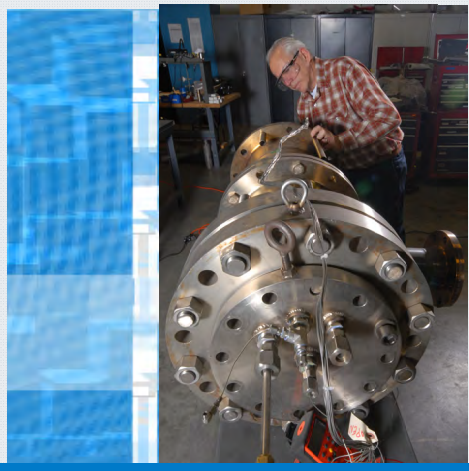

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MICROLITH® CATALYTIC REACTOR TECHNOLOGY

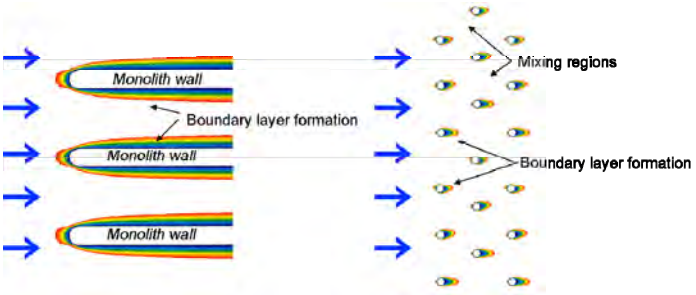
Compact, lightweight and high efficiency catalytic reactor systems offering major performance and cost advantages

Microlith® Reactor Systems

PCI has developed compact, lightweight and high efficiency catalytic reactor systems offering major performance and cost advantages compared to conventional state-of-the-art catalytic reactors. The advantages of these high heat and mass transfer reactors are derived from an ultra-short channel length substrate structure (Microlith®) combined with advanced catalyst coatings.

Design

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. Both mass transfer and heat transfer are significantly increased by the design, 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 or adsorbent materials which provide a unique and superior approach to chemical reaction.



A Superior Solution

Both mass transfer and heat transfer are significantly increased by the substrate design, allowing more rapid reactor response to gas temperatures as well as improved rates of reactant contact with the substrate surface. This provides several superior attributes, for example in oxidation reactors:

- Ultra-compact: equivalent conversion and the same pressure drop as a monolith substrate with a 20 fold size reduction.
- Lightweight: Typically 10 times lighter than competing technologies
- Fast transient response: Typically 30 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.

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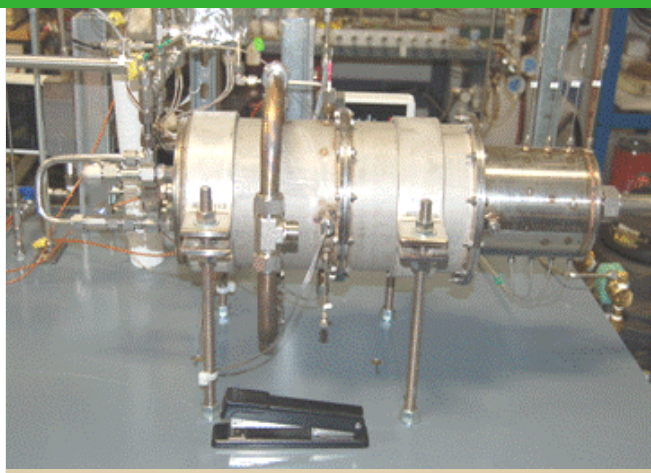
MICROLITH® FUEL PROCESSOR SYSTEMS

Superior logistics fuel processors for PEM solid oxide and molten carbonate fuel cell systems



Microlith® Compact Logistics Fuel Processors®

PCI is developing logistics fuel processors for PEM, solid oxide and molten carbonate fuel cell systems. The fuel processors are designed for reforming diesel or JP-8 and are currently sized at 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 for Army tactical genset applications and vehicle APUs and Navy Ship APUs. PCI is also developing natural gas, biofuel and liquid hydrocarbon fuel processors to support industrial needs.

Attributes:

- **>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 in about <10 minutes; Transient response <2 seconds**
- **Cold start capability demonstrated at -40C**

"We put the fuel in fuel cells"

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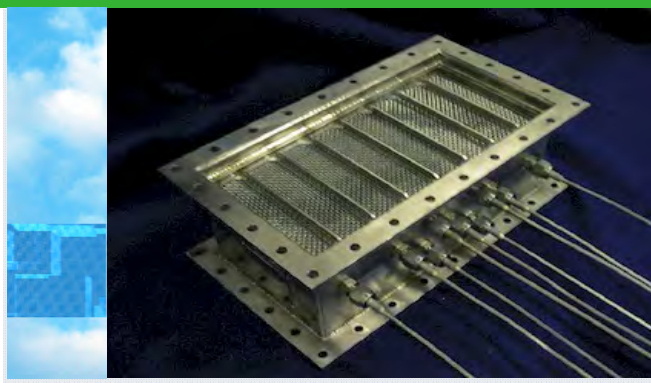
MICROLITH® FUEL REFORMER AND FUEL PROCESSING CATALYTIC REACTORS

"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-8 and diesel and biofuel. Catalytic reactor types include: Catalytic Partial Oxidation (CPOX), Autothermal Reforming (ATR), Steam Reforming (SR) and Oxidative Steam Reforming (OSR).

Fueled by natural gas, PCI's CPOX technology has demonstrated steady operation at up to 16 atm. and power densities up to 30 MW/liter. Fueled by liquid fuels, PCI's CPOX technology has demonstrated cold start-up and sulfur tolerance. PCI's ATR technology has demonstrated complete conversion of liquid fuels at low S:C ratio (~1), multi-fuel capability, and sulfur tolerance. PCI's steam reforming technology has demonstrated complete conversion of low-sulfur (up to 15 ppm) liquid fuels into high hydrogen content syngas.

Fuel Reforming Attributes

- **High power density:** ~250 kW_{th}/ℓ for liquid fuels and ~5kW_{th}/ℓ for natural gas
- **High specific power:** ~200 kW/kg for liquid fuels,
~1000 kW/kg for natural gas
- **Fast start-up** (<30 seconds)
- **Fast transient response** (~3 seconds)
- **Fuel flexibility**


Operating ATR

Designed for fuel flexibility

JP-8, Gasoline, diesel, liquid fuels. Natural gas and propane. Biofuels such as Camelina oil, E-85, ethanol and B-20

Microlith® Fuel Processing Catalytic Reactors

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

Fuel Processing Attributes:

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

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MICROLITH® CATALYTIC BURNER PRODUCTS

Custom engineered to the specifications of "Fit, Form, and Function" required for our customers

Microlith® Catalytic Burners

Built upon our catalytic substrate technology, PCI has several very small to medium sized catalytic burner products in development for a variety of fuels including natural gas, propane, butane, gasoline and JP-8. Emissions are very low. For example, a natural gas fueled version demonstrated emissions of CO<2 ppm, CH4<2 ppm and NOx<0.3 ppm.

Potential applications

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

These burners are superior to competing technologies in several ways:

- Ultra-compact: Up to 20 times smaller
- Lightweight: Typically 10 times lighter
- Fast transient response: Typically 30 times faster

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 specification or "Fit, Form, and Function" required of our fuel cell system and fuel reformer customers. Size ranges: $100W_{th}$ – $300kW_{th}$

Ultra-compact

Lightweight

Fast transient response

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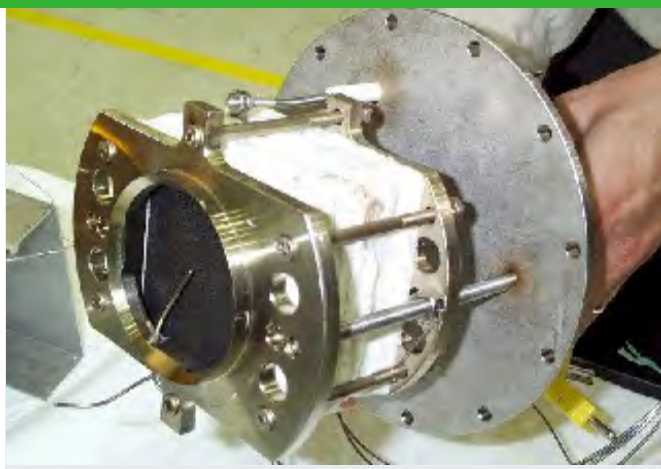
MICROLITH®
AIR CLEANER PRODUCTS

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



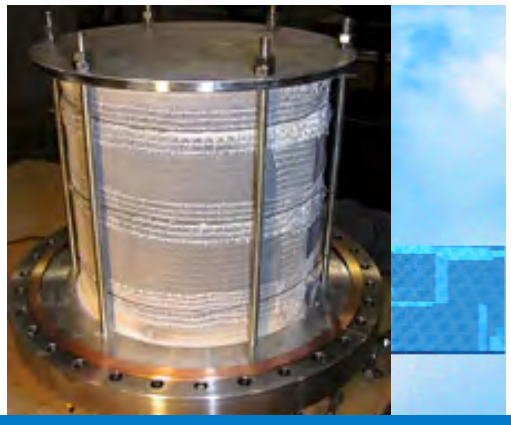
Microlith® Air Cleaners

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.

Microlith® catalytic air cleaners offer several performance benefits over alternative technologies:

- 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

The technology has been developed in two embodiments, a Trace Contaminant Oxidizer, for VOC's and CO, and a Trace Contaminant Adsorber for CO_2 and other Spacecraft Maximum Allowable Concentration (SMAC) compounds.



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 cleanup and ready integration with existing systems. The technology can also be coupled 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 is developing 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.

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RCL® CATALYTIC COMBUSTION TECHNOLOGY

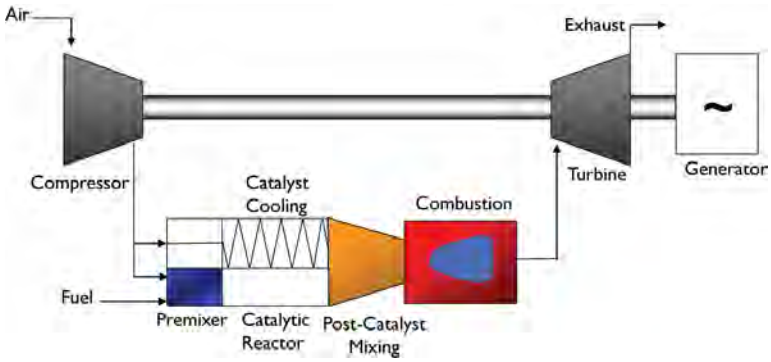
PCI's Rich Catalytic Lean burn (RCL®) Catalytic Combustor offers many desirable features with efficiency across a wide turndown range

What is RCL® Catalytic Combustion?

Rich Catalytic Lean (RCL) burn catalytic combustion is PCI's patented solution for a low NO_X 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.

A Superior Solution

RCL® catalytic combustion technology addresses multiple issues inherent in the gas turbine application. RCL® catalytic combustors have demonstrated robust operation up through F-class firing temperatures.



The rich reactor chemistry enables start-up and operation at relatively low temperature. The lower operating temperature and rich kinetics are supportive of long catalytic surface life, targeted to reach 25,000 hours. The rich reactor also leads to the catalytic reactions being controllable by available oxygen, enabling broad fuel flexibility with even highly reactive fuels such as hydrogen, syngas, refinery gas, blast furnace gas, and other industrial gases. Early autoignition is limited by the absence of oxygen in the reactor discharge and the absence of fuel in the cooling flow. A key enabling feature for retrofits is the simple, compact, no moving-part design able to fit into existing combustor packaging. The integral cooling system lowers catalyst wall temperatures resulting in longer material durability. RCL® catalytic combustors have been demonstrated with natural gas, low BTU gas, syngas, hydrogen, and prevaporized diesel fuels.

The result is a robust, long life catalytic combustor that can achieve near-zero NOx emissions while minimizing combustion dynamics. This enables combustion turbines directly achieving low single digit NOx emissions without the substantial capital, operating cost, and efficiency and ammonia penalties of post-combustion controls such as Selective Catalytic Reduction (SCR), while also offering the potential for reduced O&M costs now associated with lean premix combustion dynamics.

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GAS TURBINE PRODUCTS

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 spin-off 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 embodiment, 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 NO_x. 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 premixed fashion.

RCL® Catalytic Pilot

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

- 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 efficiency penalty across a wide turndown range such as:

- Compact: Fits within the envelope of current combustors
- Low emissions: NO_x <3 ppm
- Inexpensive: Costs less than SCR systems or other methods of post-turbine NO_x reduction
- High combustion stability over a wide operating range

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FOSSIL FUEL PRODUCTION PRODUCTS

A catalytic combustor technology offering potential for downhole steam generation for oil and gas production.

Precision Combustion, Inc. (PCI) has developed a catalytic combustor technology breakthrough that offers to fulfill the promise for 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 breakthrough, 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 generator concepts. 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 CO_2), which are directed downhole
- Unique capability for production for permafrost deepwell or underwater reservoirs.

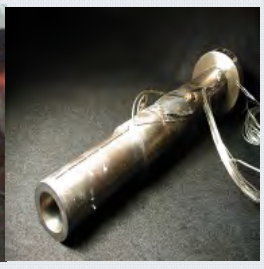
Heavy Oil Production Applications

A primary application for the downhole cobustor technology will be for improving mobility of heavy oil to aid in production. Despite plentiful reserves, heavy oil is only a small fraction of overall production. 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. This approach offers an improvement over surface steam injection by increasing reservoir recovery while reducing energy and water required and improving air emissions.

Methane Hydrate Applications

PCI is developing its downhole catalytic combustor for generating downhole heat for efficient production of methane from its hydrate, with potential for CO_2 sequestration. PCI is developing this application under a U.S. DOE contract. Among the results to date:

- An estimated 12-15% of produced methane is consumed in the process, offering substantial energy savings.
- This approach avoids heating of the permafrost while providing for potential CO_2 sequestration for added energy savings.



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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

Attributes

- Ultra-compact
- Lightweight
- Responsive to transients

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

Ultra-compact
Lightweight
Responsive to transients

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MARKETS AND CUSTOMERS

Precision Combustion, Inc. (PCI) commercializes its technologies for various markets and applications by designing and fabricating to the "Fit, Form, and Function" of our OEM customers.

PCI

- Power Generation
  - Gas turbines
  - Fuel cell systems
  - Stirling engines
  - Thermoelectric generators
- Heavy Oil Production
  - Downhole heat and steam generation
- Methane Hydrate Production
  - Downhole heat and steam generation
- Aerospace
  - Air clean-up
  - Aircraft APUs
- Defense
  - Portable power
  - Tactical gensets
  - Vehicle APUs
  - UAVs
  - Cook stoves
  - IR source

Markets & Applications

Our customers come from federal government and state agencies or commercial businesses.

Federal and State agencies

PCI typically develops its core technologies and applications utilizing Small Business Innovative Research (SBIR) contracts and grants then commercializes the developed technology by working with OEM customers.

Agencies we have contracted with include:

- California Energy Commission
- DOE
- DoD (Army, Navy, Air Force, DARPA, Missile Defense Agency)
- EPA
- NASA
- NSF

Commercial Customers

PCI typically works with our technology development and OEM customers under a mutual non-disclosure agreement. Customers we have worked with include:

- Argonne National Laboratory
- Gas Technology Institute
- McDermott Technology, Inc.
- Pratt & Whitney
- Siemens Westinghouse
- Solar Turbines
- Sunpower, Inc.
- Radiance Technologies

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COATING & MATERIAL CHARACTERIZATION

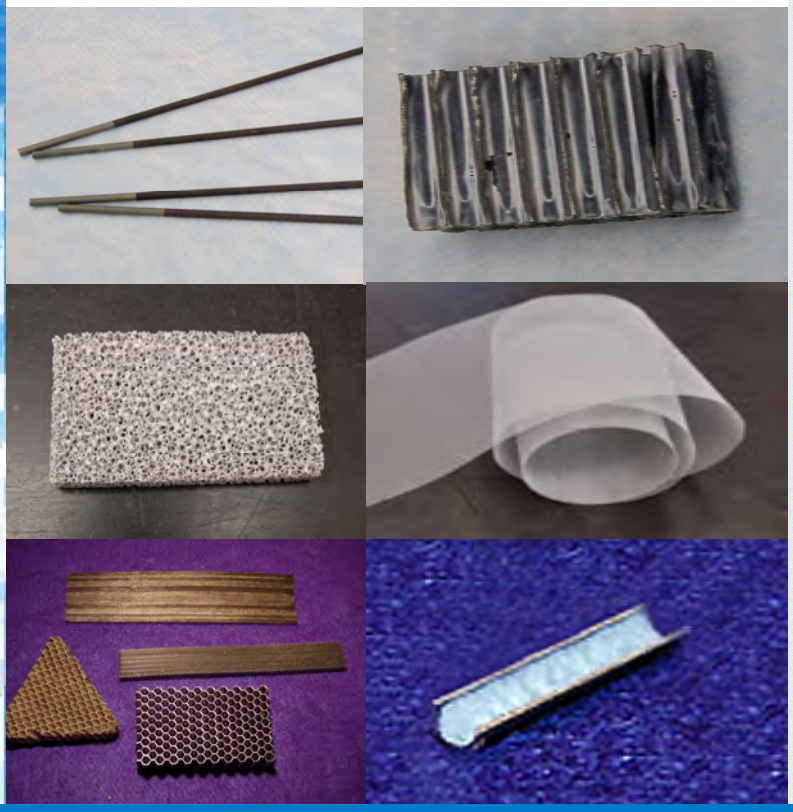
PCI offers washcoating (slurry coating) on metal and ceramic substrates and material characterization services

Material Characterization Services

PCI offers advanced washcoating (slurry coating) on metal and ceramic substrates and material characterization services. Substrate geometries include, but are by no means limited to tubes, monoliths, plates and foams.

PCI's coating expertise includes washcoating different metal oxides, including alumina, zeolite, ceria and zirconia and precious metal deposition.

We also have the capability to coat our catalysts and adsorbers on your substrates. For more information, please contact us.



Material Characterization Equipment

- Optical Microscopes
- UV-Visible Spectrophotometer
- Quantachrome Autosorb BET instrument for multipoint BET, pore volume, pore size and distribution, 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 Viscosity Meter

Material Testing Capabilities:

- Steam Aging System
- High Temperature Furnace/Tube Furnace

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CORE ADVANTAGE

PCI has distinctive skills in advanced catalytic reactor and system design and in catalyst formulation, coating and supports. Nearly 1/3 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. Our technological breakthroughs are reflected in PCI's Microlith® catalytic reactor designs, the RCL® catalytic combustor, and in the more than 65 issued U.S. patents we have been awarded.

PCI creates value for our customers by applying our patented and proprietary catalytic technologies to their engines and systems. Our Microlith® catalytic reactors offer high conversion and selectivity with rapid transient response in a distinctively compact, lightweight embodiment. Our RCL® catalytic combustors offer improved combustion stability and reduced emissions in a compact, robust assembly. Working with our customers, our technology and integrated design skills have provided performance benefits and reduced system costs in a compact, lightweight package for aerospace, defense and energy applications.

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