PCI

Clean Energy Innovations

PRECISION COMBUSTION,INC.

COMPANY CAPABILITIES

Advanced Catalytic Reactors and Systems for the Energy and Environmental Sectors

Precision Combustion, Inc. ▪ 410 Sackett Point Road ▪ North Haven, CT 06473 ▪ 203-287-3700 ▪ pci.energy

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PRECISION COMBUSTION, INC.
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MISSION

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

VISION

We aspire to develop and commercialize world leading catalytic combustion, catalytic reaction, and sorbent 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, sorption materials and processes, and combustion including reactor design, catalyst formulation, sorbent formulation, coating processes, reactor assembly, and performance testing.

- Fuel Reformers and Fuel Processing Catalytic Reactors
- Fuel Processor Systems
- Power Generation Systems
- Burners / Oxidizers
- Air and Fuel Cleaners
- Internal Combustion & Gas Turbine Engines
- Chemicals Production
- Specialty Products and Services

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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, and located in North Haven, Connecticut, USA. Our site contains catalyst formulation, sorbent 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, sorbent module, and system design and in catalyst formulation, sorbent 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, gas and fluid filtering, chemical reaction and clean power generation.

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, COSMOS, and ChemCAD.

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TECHNOLOGIES, RESEARCH & DEVELOPMENT

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

TECHNOLOGIES

Our technological breakthroughs are reflected in PCI's Microlith® substrate used as supports for catalyst and sorbent coatings, our RCL® catalytic combustion technology, and in the more than 100 issued U.S. patents we have been awarded. Our business focus is on the commercialization of technologies developed in-house. Core technologies developed by PCI include:

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

» **RCL® catalytic combustors** for gas turbine NO_x reduction, heavy oil/methane hydrate production and soil disinfestation/remediation.

» **Specialty coatings** including frangible coatings for jet engine fueling components, catalytic coatings for chemical reactions , and sorption coatings for air and fuel clean-up.

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 appropriate procedures and processes in place 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 environmental regulations.

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MICROLITH® SUBSTRATE TECHNOLOGY

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

MICROLITH® SUBSTRATE DESIGN

Microlith® is PCI's patented substrate technology. 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.

APPLICATIONS

- Microlith® Catalyst Technology
- Microlith® Sorbent Technology

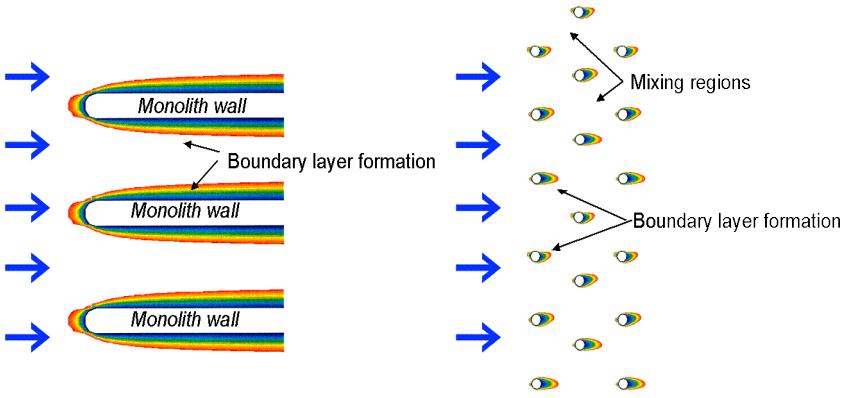
ADVANTAGES

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.



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MICROLITH® FUEL PROCESSOR SYSTEMS

Superior logistics fuel processors for HTPEM, SOFC, and other high temperature fuel cell systems

OXY-ATR System for HYCO Applications

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 liquid fuels such as diesel, JP-5 or JP-8 and biofuels and are currently sized for 0.5, 1, 2, 5, 10, 50 and 250 kilowatt fuel cell systems. 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, UAS 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

Fuel Reformer Test Cart

We put the fuel in fuel cells®

2 KWe Liquid Fuel Reformer

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MICROLITH® FUEL CELL SYSTEMS

Ultra-compact and lightweight logistics fuel reformer enabled fuel cell systems

1 kW Fuel Reformer/Fuel Cell System

MICROLITH® REFORMER ENABLED FUEL CELL SYSTEMS

PCI is developing a family of ultra-compact solid oxide 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 fuel cell stack, reformer, BOP, and User Interface 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. The company is also developing their own advanced solid oxide fuel cells for implementation in SOFC power generation and SOEC hydrogen generation systems.

APPLICATIONS

- Man-portable, mobile and stationary gensets
- Auxiliary power units (APUs) for air, sea, and ground vehicles
- Unmanned aerial system (UAS) power and propulsion systems
- Unmanned ground & surface vehicles (UGV/USV)
- 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

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MICROLITH® 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-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: Catalytic Partial Oxidizer

Energy Efficiency: > 95%
Power Range: Up to 5MWth
H2 mole % (dry): 18 -24%
Start up: < 1 minute to lightoff @5 KW_{th} with diesel

5 MWth Natural Gas CPOX

ATR: Autothermal Reformer

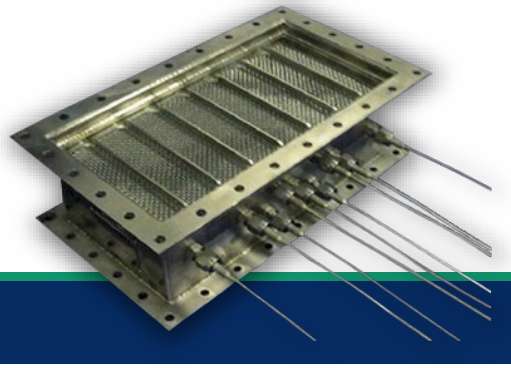
Energy Efficiency: > 80-85%
Power Range: Up to 1 MWth
H2 mole % (dry): 30 -32%
Start up: < 0.5 minute to lightoff @5 KW_{th} with diesel

ATR System

CSR: Steam Reforming

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

Steam Reformer



PROX Reactor

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
- JP-5
- Gasoline
- Diesel
- Natural gas
- Propane
- Biofuels
- E-85
- Ethanol
- B-20

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PLATOON POWER GENERATOR

A compact, quiet generator that can run on many readily available fuels

500 Watt Platoon Power Generator

FAMILY OF MILITARY, MAN-PORTABLE GENERATORS

Precision Combustion, Inc. has developed portable COTS based systems proven capable of converting logistics fuel into electricity with no loss in performance or accelerated wear compared to the gasoline powered generator it is derived from. No special treatments, additives, or adjustments are needed during start up and operation. The user simply turns the unit on, waits a few moments for a green light, then draws power from the generator.

APPROACH

PCI's approach starts with commercially available engines and generators and modifies them for use with multiple fuels, including logistics fuels like JP-8.

Unlike some other technologies that atomize fuel (which allows the engine to run marginally but with accelerated wear) the PCI approach addresses the fundamental issue by raising the octane value of the fuel stream so the engine runs reliably and without risk of engine damage. This method enables seamless operation with logistics fuels or other readily available fuels like diesel and gasoline.

SPECIFICATIONS

- Power: 500 Watt
- Weight: 15 lbs
- Noise: <60dB(A)
- Voltage: 28 VDC
- Current: 18 Amp
- Start: Electric / Remote
- Dimensions: 10" x 10" x 9"

KEY FEATURES

- Lightweight (3X Specific Power vs 3kW TQG)
- Parallel Operation Up to 1kW
- Quiet
- Logistics Fueled (Jet Fuel/Diesel/Gasoline)
- Easy to Operate
- Efficient – Reduces Carry Weight
- Long Life
- Provides Power at the Tactical Edge
- Delivers Power for Field Battery Charging or Direct Output
- Right Sized for Warfighter Power Needs
- Reduces Number of Batteries Needed on Mission
- Reduces Logistic Burden and Improved Reliability

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ULTRA-COMPACT HYDROGEN-GENERATOR

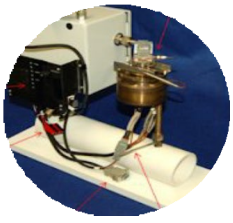
A compact and robust gasoline, diesel, or logistics fuel reformer, achieving high H_2 generation efficiency for improved fuel efficiency and reduced emissions

Ultra-Compact Hydrogen-Generator

OPERATIONAL CAPABILITIES

A 5 – 10 % net improvement in fuel economy (observed in testing) would imply savings of:

- 7 – 14 billion gallons of gasoline per year in the US
- 0.8 – 1.7 Quads of energy per year in the US
- Savings of $18 – 36 billion for the consumer per year
- Lower brake-specific NOx up to 50% reduction
- Lower brake-specific HC up to 50% reduction
- Lower brake-specific CO up to 40% reduction



TECHNICAL SUMMARY

PCI has developed a means for reforming fuels to primarily H_2 and CO directly via an ultra-compact catalytic reactor. Coking is avoided despite avoiding the need for water or steam. This is made possible by the short contact time, high surface area Microlith® substrate, with a proprietary catalyst coating developed by PCI. The stable and durable coating utilizes PCI's sulfur-tolerant catalysts.

The predominant barriers with waterless reforming are coking, low efficiency, large reactor size, high operating temperature, high parasitic losses, slow transient response and slow startup. PCI has resolved the barrier issues and demonstrated a low-cost, compact, and efficient device with robust controls for readily reforming gasoline and diesel. It is significantly superior to alternative reforming approaches (e.g. plasma reforming).

The targeted applications for this ultra-compact hydrogen generator is the automotive engine manufacturing, use in existing and new vehicles, and on-road/off-road use cases. The technology offers a significant potential impact in addressing U.S. energy efficiency, and leadership in clean energy solutions

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MICROLITH® CATALYTIC BURNER PRODUCTS

Anode Gas Oxidizer

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 CH_4, and < 0.3 ppm NOx with natural gas.

POTENTIAL APPLICATIONS

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

Stirling Engine Burner

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

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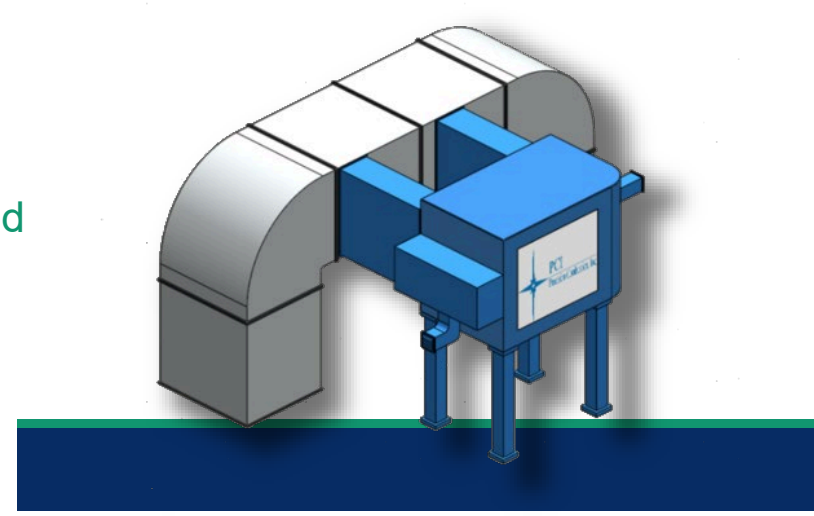
REGENERABLE MICROLITH® BUILDING AIR FILTER

Focus on control of carbon dioxide and other air pollutants in indoor settings



CO_2 Filtration System Solid Model

ADVANTAGES

» **Removes CO_2 and VOCs from indoor air:**
A combination of filtration media capable of effectively removing CO_2 and VOCs from indoor air.

» **Regenerable system:**
Efficient in-situ, rapid, low power thermal regeneration through direct resistive heating of the filter media.

» **Longer lifetime:**
The filter media has been proven for extended life and thermal cycle durability.

» **Lower maintenance cost:**
Both CO_2 and VOCs filter media are regenerable, reducing filter replacement frequency over the life of the system.

» **Lower power requirements:**
Lower pressure drop (more open area vs. pellets) and more efficient filter regeneration process.

DESIGN

Precision Combustion, Inc.'s Regenerable Microlith Air Filter (RMAF) module is designed to dramatically reduce a building's energy cost by reducing its make-up air requirement without compromising indoor air quality (IAQ). The module will effectively remove contaminants such as CO_2 and VOCs from the indoor air and reuse it; minimizing the required outside air and its associated conditioning costs (heating/cooling prior to introduction in the building). The deployment of the module will maximize overall energy efficiency and will significantly reduce the operation cost of the building. The module is designed for easy integration into a building's existing HVAC system.

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MICROLITH® AIR CLEANER PRODUCTS

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

Microlith Catalytic Oxidizer

MICROLITH® AIR CLEANERS

PCI is developing air cleaning components focused on control of CO_2, humidity, Volatile Organic Compounds (VOC's), ammonia and other air pollutants. Applications include air treatment systems for spacecraft, spacesuits, 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

Trace Contaminant Adsorber

Microlith® Trace Contaminant Oxidizer

PCI's advanced Microlith®-based High Temperature Catalytic Oxidizer (HTCO) is designed for spacecraft air quality control applications, including Environmental Control and Life Support Systems (ECLSS), exploration missions, the International Space Station, and commercial spaceflight. The system delivers ≥90% methane oxidation efficiency for challenging trace contaminants, while maintaining a compact, lightweight form factor suited for mass- and volume-constrained space platforms. The latest γ-LW HTCO prototype provides a 24% weight reduction versus prior designs and incorporates an integrated recuperator with greater than 80% thermal effectiveness to reduce steady-state power consumption. With startup to 400-425°C in approximately 50-55 minutes and more than 24,000 hours of testing, the HTCO has demonstrated the durability, efficiency, and operational robustness required for long-duration missions.

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. The company is also developing Trace Contaminant Control (TCC) components for removal of ammonia within spacesuits.

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SABATIER METHANATION REACTOR

A much smaller, lighter, and more durable system offering greater energy and resource efficiency as well as longer life compared to alternatives

Sabatier Methanation Reactor

APPLICATIONS

PCI's Microlith® Sabatier reaction technology offers an ultra-compact, high efficiency catalytic reactor as a means of producing water vapor and methane from spacecraft cabin CO_2 reacted with hydrogen over a catalyst. The water can then be electrolyzed to release oxygen and hydrogen. Produced methane has the potential to be used as fuel and other in-situ resource utilization (ISRU) applications. CO_2 is obtained from astronaut respiration, and on Mars can also be obtained from the Martian atmosphere. The result is a tool for improved manned mission resource independence and reduced lift/resupply costs.

The development of PCI's Microlith® Sabatier reactor has the potential for application in future NASA missions by generating oxygen and water from spacecraft and in-situ resources. Size, weight, resource and energy efficiency, and performance durability are all key design attributes. PCI's Sabatier reactor features an ultra-compact, lightweight design while maintaining high selectivity to water and methane products.

Targeted NASA applications include ISRU architecture for future lunar base and Mars missions, both for generating life support consumables and for producing methane for fuel. In addition, non-NASA spin-off applications may be explored such as production of renewable methane, methanation for ammonia production and potentially for cleaner coal-based power production.

Non-NASA applications include the potential application as a synthetic methane generator in Power to Gas systems.

ATTRIBUTES

- **COMPACT:** Patented Microlith® technology enables compact and lightweight reactor.
- **DURABLE:** Demonstrated for 1,000 hours and multiple thermal cycles with no detectable performance degradation.
- **VERSATILE:** Can operate H_2-rich, stoichiometric, and CO_2-rich conditions, and meet equilibrium-predicted water recovery rate.
- **HIGH THROUGHPUT:** Short contact time and improved heat transfer results in greater Methane yield and generation rate.
- **RAPID RESPONSE:** Low pressure drop and thermal mass enable faster transient response and shorter start-up times.

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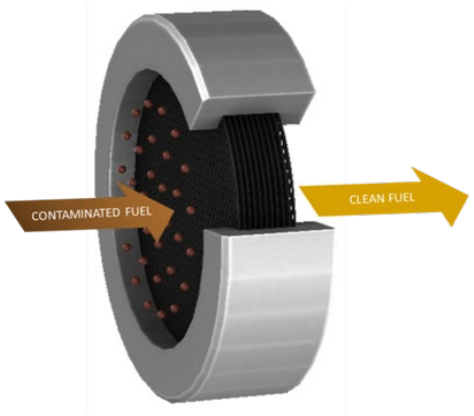
FUEL FILTERS

Control of copper ion fuel contaminants



High Efficiency Filter System

MICROLITH® FUEL FILTER

Jet fuel onboard aircraft carriers can be copper contaminated from copper-nickel alloys in piping and fittings. PCI's Microlith® Fuel Filter is designed with a modified sorbent chemically tuned to selectively attract and strongly retain dissolved copper ions, without affecting fuel additives or the fuel itself. The platform technology enables flexible design, readily integrates with the current shipboard fueling system, and meets system performance requirements.

The integration of our filter will aid the Navy in meeting and exceeding the mission performance requirements for its current and future aircraft. Removing copper contamination will let our jets fly faster, longer and with less maintenance, saving money, enhancing overmatch, and saving the lives of US Warfighters. Integration into existing fueling systems will reduce costs and extend the useful lifetimes of aircrafts and support systems.

ADVANTAGES

- Integration of the PCI fuel filter will allow carriers to deliver high quality fuel to jet aircraft
- Enables fuel to meet ASTM D5006 specification for Fuel System Icing Inhibitors
- Enables fuel to pass ASTMD3241 Thermal Oxidation Stability specification
- Enables Fuel to meet ASTM D130 Corrosion-Copper Strip specification
- Metals in Organic Matrix ICP-MS specification ITM 1051 metal ions measured at 6 ppb

APPLICATIONS

- Navy and other DoW Jets and Aircraft Carriers
- Commercial Aviation Industry that Uses Copper or Brass Piping and Fittings

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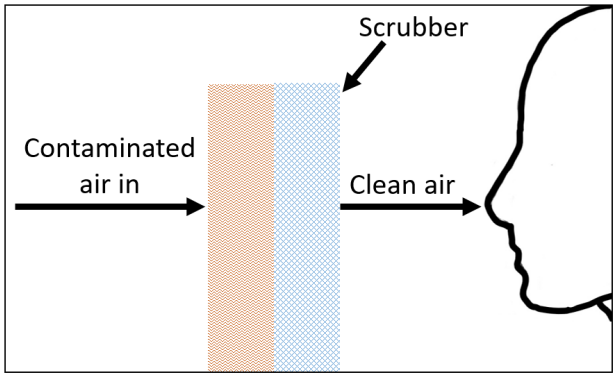
AIR FILTERS

Focus on Control of Viruses and other Disease-Causing Particles



System for Onboard Engine and Bleed Air Monitoring and Filtering

Re-VID: VIRUS IMPAIRMENT DEVICE

In the wake of the pandemic, PCI is developing a novel high surface area nanofiber catalytic scrubber and destructive filter. Such a filter could be worn as a mask and would be able to effectively capture and destroy viruses, bacteria, and fungi. The Virus Impairment Device would also be fully reusable. PCI's Technology uses a Microlith®-based catalytic scrubber for real-time filter and destruction of organics, organophosphates, Volatile Organic Compounds (VOCs), and other bleed air contaminants from the pilot air supply line in addition to killing viruses when this scrubber is used in masks.

APPLICATIONS

- Navy/Military and Commercial Aircraft OBOGS Systems
  - Specifically, F/A-18 Hornet/Super Hornet
- Personal Protective Equipment (PPE) for Contaminants and Viruses
  - License to PPE and Filtration Companies
- AFRL and NASA

FEATURES

- Provide outward and inward protective effectiveness
- Seal, such as to avoid bypass of particles
- Available in N-95/N-99/P-100 NIOSH ratings
- Compliant to wear in humiture
- Fits many different facial profile and sizes
- Destroys Pathogens
- Be able to talk without distortion
- Filters will be able to be regenerated
- Comfortable: avoids glasses fog and other annoyances

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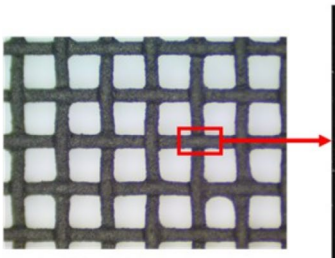
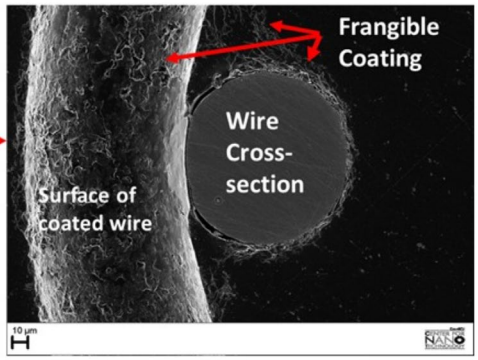
FRANGIBLE COATINGS

A frangible coating that can slough off carbonaceous deposit precursors adhering and growing onto fuel-wetted surfaces, thus preventing blockage on critical and susceptible aircraft fuel system components.



Coated last chance screen – cell opening 4.5 mm



Frangible Coating on Last Chance Screen

Fuel deposit issues currently prevent long-term fuel system operation in aircraft engines at temperatures over ~300F. Increasing heat loads, projected for advanced aircraft of the near future, will lead to higher average fuel system temperatures for both commercial and military aircraft. Formation of carbonaceous deposits can be problematic for several components of an aircraft fuel system, with "last-chance screens" and fuel injectors, which are wetted by fuel with the highest time-at-temperature exposure sufficient for coke formation. Blockage of these fuel system component passages can have serious consequences in terms of aircraft propulsion control.

FEATURES

- "Frangibility": Low cohesive strength of nano-layers prevents build-up by shedding adhered varnish precursors.
- Nano-scale, conformal coating
- Lubricity =/> than underlying material
- Coefficient of friction </= underlying metal
- Chemical Inertness
- Nano- to micro-meter coating thickness
- No off-gassing or other contamination

BENEFITS

- Reduced maintenance costs
- Improved reliability
- Up to a 5X increase in Mean-time Between Overhaul (MTBO) for aircraft engines compared to the baseline at 400F fuel operation

Beyond “last chance” filters, we are also evaluating coating nozzles and other small fuel passages. Application of the technology offers to reduce maintenance costs, improve reliability, and increase Mean Time Between Overhauls (MTBO) for high temperature jet engines.

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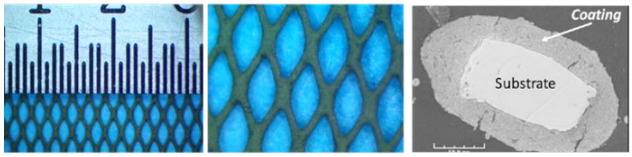
CARBON CAPTURE SYSTEM FOR DIRECT AIR APPLICATIONS

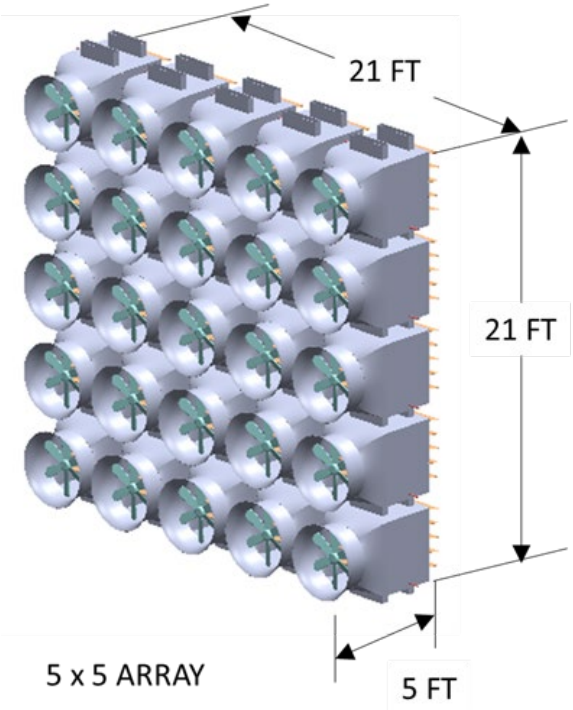
Direct Air Capture of Carbon Dioxide System Integrated with Underutilized Waste Heat Sources



Microlith mesh coated with modified MOF sorbent

TECHNICAL SUMMARY

PCI is developing a DAC system that efficiently utilizes low-carbon waste heat from sources such as geothermal to operate the unit at low cost. PCI's focus is on developing a performant CO_2 collector technology for regenerable direct air capture of CO_2 that offers significant improvement in energy costs while also reducing size, material cost and other operating costs. Our scalability and design focus towards a tight thermal integration of CO_2 collector unit with low-carbon waste heat eases integration for varied situations and with a variety of application for maximum value uses for the concentrated CO_2. Overall, PCI is demonstrating a pathway towards a new high performance solid sorbent for DAC.



SYSTEM BENEFITS

Implementation of PCI's strategy will offer:

- Energy Cost Reduction of Sustainable DAC
- Lower Energy Savings
- Reduce Carbon Emissions Globally
- Value-Added Chains of Carbon Dioxide such as Oil Recovery and Converting CO_2 to Fuels or Plastics

An array of modules operating in parallel adsorption/desorption can process 3 tonnes CO_2/day.

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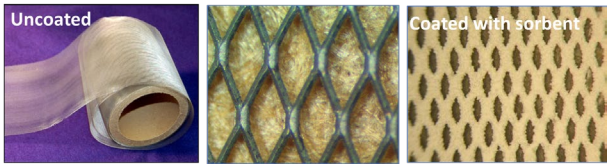
CARBON CAPTURE SYSTEM FOR POST COMBUSTION APPLICATIONS

Enabling gas separations from post combustion capture, gasification, and other industrial sources



Microlith Substrate coated with Sorbent

TECHNICAL SUMMARY

PCI's innovation is a compact, modular Post Combustion Carbon Capture System (PCCCS) utilizing high internal volume Nano sorbents, including metal organic frameworks (MOFs), for carbon capture, supported on a tailorable mesh substrate.

Our system enables low pressure drop, high volumetric utilization and high mass transfer, and is suitable for the rapid heat transfer and low temperature regeneration operating modes needed for cost-effective carbon capture. In addition, our approach to regenerable CO_2 capture eliminates close to 75% of the energy cost required for operation of methyl ethanolamine (MEA) based systems.

The primary public benefit will come from a significant improvement in the cost-efficiency of capturing CO_2 from exhaust streams, thereby reducing the costs of CO_2 capture and also encouraging its more rapid adoption due to its lower cost. Commercial applications include fossil fuel electric power plants, geological applications for fracking, cement industry, and chemical production & processing.

Microlith Adsorber

SYSTEM BENEFITS

Implementation of PCI's strategy will offer:

- High-contact area and high mass transfer rate configuration for rapid adsorption-desorption cycles at low pressure drop.
- High space velocity and lower volume than a pellet bed or monolith system.
- Full capacity utilization of advanced nanomaterials with unsurpassed properties for CO_2 capture.
- Lower energy penalty cost to the power plant through reduced operation energy requirement.
- Simplify operations by eliminating the need for steam and/or fresh solvent injection.
- Suitability for continuous upgrading as new sorbent materials are developed.
- Flexibility in application to any CO_2 -emitting industrial system.

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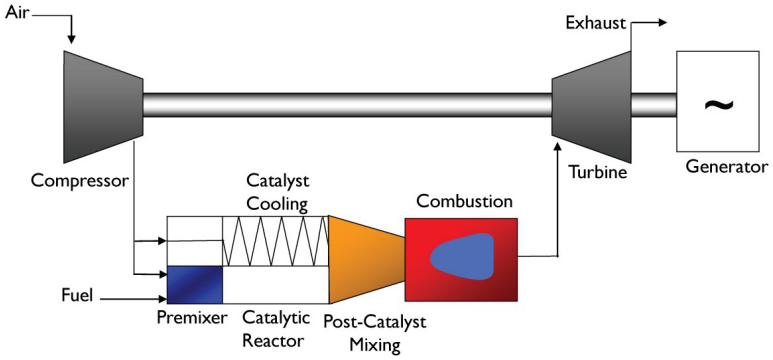
RCL® CATALYTIC COMBUSTION TECHNOLOGY

PCI's Rich Catalytic Lean burn (RCL®) technology has been demonstrated with natural gas, low BTU gas, syngas, hydrogen, and prevaporized diesel fuels

Catalytic Combustor

RCL® 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.



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 and CO output.
- 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.

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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 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 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 pre-mixed 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.

- **Compact:** Replaces the diffusion pilot in a combustor within the same working envelope
- **Low emissions:** NO_x< 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 NO_x
- **Lower Cost** 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

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

DOWNHOLE STEAM GENERATOR

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 CO_2), which are directed downhole
- Unique capability for production for permafrost, deepwell, or underwater reservoirs
- Technology has been tested in the field

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 CO_2 sequestration. PCI developed this application under a 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 CO_2 sequestration and avoids heating of the permafrost for additional energy savings.

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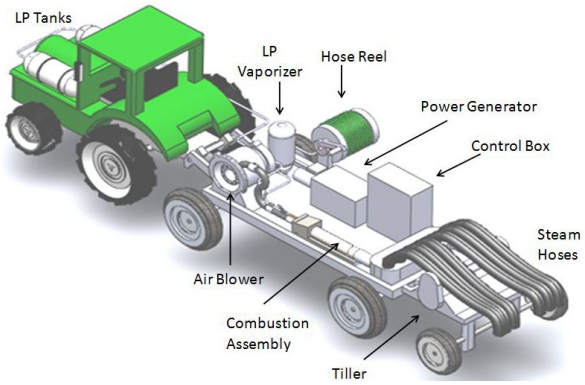
SOIL REMEDIATION & DISINFESTATION



Reducing or eliminating the addition of chemical fumigants to the soil; limiting costs of mercury removal as well as removal of non-aqueous liquids and other contaminants.

REMEDIATION

Mercury is found as a contaminant at 290 Superfund National Priority sites. Thermal treatment of this mercury and its compounds, whether above ground on removed contaminated materials or in-ground, is highly effective in removing more than 90% of mercury in place but is dependent on site-specific factors. Temperatures greater than 300°C are usually required to meet land disposal standards. Treating mercury in ground avoids the added hazards of transporting contaminant soil to a treatment facility and reduces exposure risks.

PCI is developing a direct-fire catalytically stabilized steam generation technology that offers significant energy savings compared to steam boilers. Unlike traditional boilers, PCI's technology will operate at the high temperatures between 300°C and 1000°C needed to be effective for in-situ mercury removal. Designed to be efficient for a wide range of soil porosities, water content, and locations at or below the water table, PCI's process holds potential for clean combustion with low emissions, provide extremely high rates of heat and mass injection in relatively short times and produce super-heated steam with water contents over 60%. The technology is being developed to enable close to 99% mercury removal from contaminated soils in both shallow to deep well bores.

DISINFESTATION

PCI has developed a new design for a compact, high-heat-rate catalytic combustor steam generator that can be integrated into a mobile soil sterilization system. In the USDA project, PCI coordinated with a team including university, specialty agricultural equipment, grower and soil treatment experts to develop the technology.

Soil disinfestation removes soil pathogens, pests and weeds that limit crop health and production. Chemical fumigants such as methyl bromide and chloropicrin are currently used for this purpose in open fields, especially for high value annual plants such as strawberries and other berries, as well as for other uses including commercial flowers and golf courses.

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MICROLITH® CATALYTIC CONVERTER PRODUCTS

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

LIGHTWEIGHT CATALYTIC CONVERTER

The low thermal mass is especially important for quick catalyst lightoff in order to deal with automotive cold start emissions. The PCI catalytic converter can achieve greater conversion effectiveness per unit size material, with up to 20-fold reduction in volume and weight, as well as reduction in precious metal catalyst requirements, compared to long channel monoliths.

The combination in a passive converter of faster lightoff, smaller size, lower weight, increased effectiveness and lower cost is attracting significant interest from the automotive and marine industries. Prototypes have been tested with major U.S. engine manufacturers. A two stroke application of the technology is also being developed as well as a formaldehyde oxidation catalyst for reciprocating natural gas engines. Test results conducted on a 1.9L Ford Escort, in collaboration with Ford Motor Co., demonstrated emissions reduction that exceeds the Ultra Low Emission Vehicle standards (ULEV) (SAE Technical Paper # 971023). Durability has been proven through multiple "hot vibe" tests (950oC,28g's, 100hz) and engine aging tests.

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

BENEFITS

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

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Clean Energy Innovations

REFINERY ADVANCEMENTS

Improved still gas reforming and compact, quick-response cetane measurement tool for improved production performance.

Advanced Cetane Number Analyzer

FUEL REFORMER

This product is an ultra-compact, cost-effective and highly-efficient reformer system for on-site production of hydrogen-rich synthetic gas (syngas) from still gas/refinery gas, that can be further purified to extract high purity hydrogen via pressure swing adsorption based separation for refinery applications.

Producing hydrogen on-site from existing still gases reduces refinery need to purchase hydrogen resulting in reduced cost to the consumer as well as reduces unwanted refinery emissions.

PCI's reformer will be integrated into existing refinery plants, in particular for meeting desirable H2 to CO ratios for process selectivity improvement while simultaneously addressing DOE's objectives of cost and energy efficiency. The reformer technology is based upon PCI's proprietary high mass and heat transfer catalytic elements which has been demonstrated to be durable and superior (i.e., higher sulfur tolerant, lighter, and smaller size) to existing technologies such as pellets, monoliths, foams, and microchannels.

Fuel Reformer for Hydrogen Production

CETANE CENSOR

PCI is developing an advanced fuel quality analyzer for quickly and accurately measuring the cetane number (CN) of diesel, jet fuels, and bio-diesels. It performs a direct analysis of the fuel to provide an accurate measurement of the cetane number – as compared to inferring the CN with a cetane index methodology. This device replaces alternative measurement technologies that are expensive, time consuming and that require skilled operators. The Analyzer has a robust calibration system consistent with ASTM Standards D-613 and D-6890 process test results and is accurate on fuels containing cetane additives and cetane enhancers. The system's measurements are based on fuel combustion properties and proprietary algorithms that ensure such a high level of accuracy.

With so many advantages over conventional systems, PCI's device has wide applications in the manufacture of fuels to improve process and cost efficiencies, as well as with end-users to improve operations and maintain fuel integrity.

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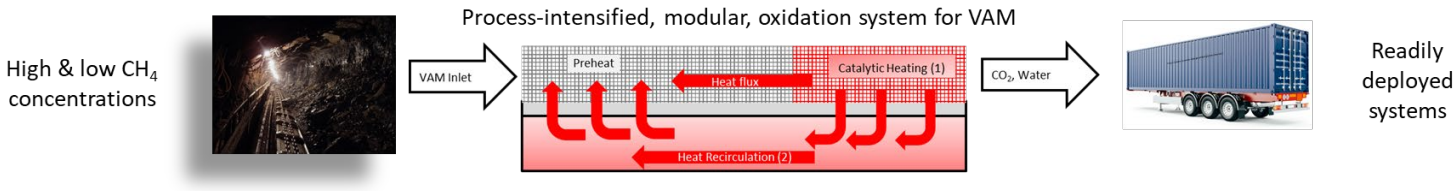
DESTRUCTIONS OF VAM USING A MODULAR CATALYTIC ELEMENT SYSTEM

Modular System for Destruction of VAM by Oxidizing Methane



TECHNICAL SUMMARY

PCI has developed a compact, modular catalytic system for abatement of ventilation air methane (VAM) from coal mine and other dilute methane air streams. The technology combines short-contact-time, low-thermal-mass Microlith® catalytic reactors for high methane destruction in a compact volume, catalyst formulations tailored for lower-temperature oxidation over a broad range of inlet methane concentrations, and a heat-recirculating architecture that captures and reuses oxidation heat to reduce supplemental energy demand. In field validation at an underground coal mine in West Virginia, PCI's trailer-mounted pilot system achieved greater than 99% methane conversion in an active ventilation stream with stable multi-thousand-hour operation. The modular, portable design supports practical deployment, scale-up, and potential carbon-credit monetization while helping operators improve methane management.

KEY FEATURES

» Greater than 99% methane conversion demonstrated in field validation

» Modular, scalable, portable system architecture

» Lower-temperature methane oxidation with durable catalyst

» Potential for carbon-credit monetization

APPLICATIONS

» Coal mining and mine ventilation systems

» Trona, potash, and other mineral mining operations

» Oil & natural gas and industrial air quality control

» Retrofit opportunities for recuperative/regenerative oxidizers

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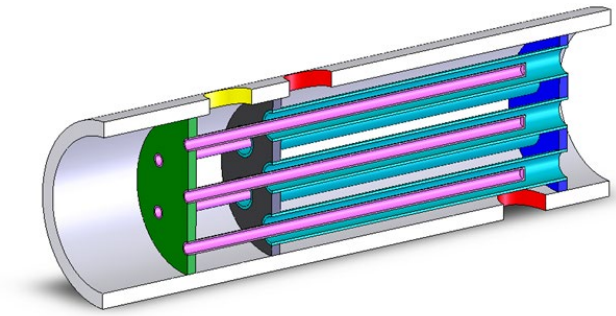
CATALYTIC REACTOR FOR LIGHT ALKANES TO OLEFINS & LIQUID FUELS

Improved reactor and catalyst for direct conversion of light alkanes into valuable products



Controlled Mass Transfer (CMT) Reactor

SYSTEM FUNCTIONALITY

PCI is developing a catalytic process to selectively convert light alkanes (C2-C4) into ethylene and other olefins, while minimizing overreaction to full combustion products. The approach leverages a Controlled Mass Transfer (CMT) reactor with improved catalysts for the oxidative dehydrogenation of ethane to ethylene, providing a pathway intended as an alternative to state-of-the-art, energy-intense steam cracking.

The direct conversion approach is also positioned as a simpler path relative to indirect routes such as syngas formation followed by Fischer-Tropsch or methanol synthesis, with broader objective of enabling lower cost and lower energy conversion compatible with small scale through very large scale deployments.

GOVERNMENT & COMMERCIAL APPLICATIONS

Government/public benefits include improving energy efficiency and energy independence, reducing greenhouse gas and other emissions, and enabling utilization of stranded gas resources.

Commercial applications and partner targets include:

» Oil and chemical refineries

» Ethylene transporters

» Process plant builders/designers

BENEFITS & VALUE PROPOSITION

» Reduce energy demands for olefin production and enable operation at lower temperatures

» Reduce greenhouse gas emissions and limit carbon deposition/thermal degradation mechanisms that reduce yield

» Convert natural-gas-derived feedstocks into products that can reduce reliance on petroleum feedstocks for gasoline and other liquid fuels

» Enable value creation at remote/stranded wells and locations where gas is otherwise flared or vented

DEVELOPMENT STATUS

This work has been supported under DOE SBIR awards for “Improved Reactor and Catalyst for Light Alkanes to Olefins and Liquid Fuels.”

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REFORMATE ANALYSIS SYSTEM

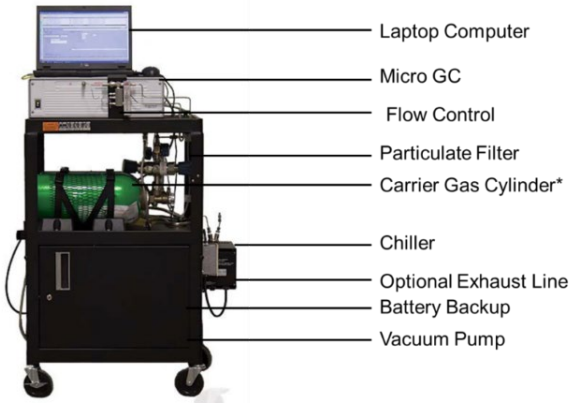
A complete portable micro GC system for use in measuring and analysing gas reformate streams

Reformate Analysis System

SYSTEM FUNCTIONALITY

PCI has created a comprehensive and easily portable analyser. Ready to operate upon delivery, the Reformate Analysis System can perform analysis of 10 permanent gases in just 90 seconds. Because of the model's portability, and thanks to a battery backup system that maintains test settings during transfer, the system can rapidly be moved between sampling sites for maximum ease of use. The self-contained setup also eliminates the need for additional carrier gas cylinders, simplifying the experience for the user. Sampling can be performed at atmospheric pressure or slightly sub-atmospheric pressure.

All of PCI's equipment used for the reformate analysis system consists of customer approved gas chromatograph and additional components under warranty from OEM's. Installation support, onsite set-up, technical support and training are also available.



ANALYSIS CAPABILITIES

- H_2 Molecular Hydrogen
- N_2 Molecular Nitrogen
- CO Carbon Monoxide
- O_2 Molecular Oxygen
- CH_4 Methane
- CO_2 Carbon Dioxide
- C_2H_4 Ethylene
- C_2H_6 Ethane
- C_3H_8 Propane
- C_3H_6 Propylene

SYSTEM COMPONENTS

- Micro GC
- Vacuum Pump
- Sample Dryer
- Flow Control
- Particulate Filter
- Mounting and Regulators for Carrier Gas Cylinders

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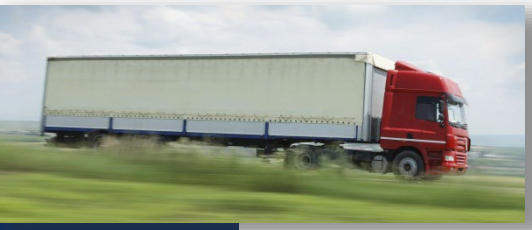
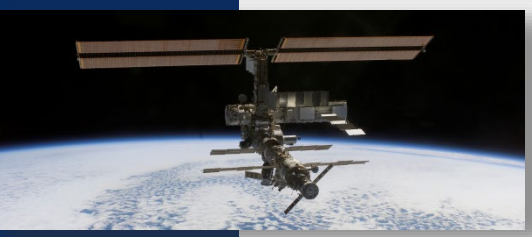
MARKETS & CUSTOMERS





MARKETS

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

AEROSPACE
Air cleanup
Power and Propulsion Systems
Aircraft APUs
Fuel Reformation and Processors

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

AGRICULTURE
Soil disinfestation
Livestock habitat ammonia reduction

DEFENSE
Portable power
Tactical gensets
Vehicle APUs
UAS, UUV, & UGV power and propulsion
Cook stoves
IR sources
Copper Contaminant Removal
Personnel air filtration
Frangible coatings of last chance screens

FOSSIL FUEL PRODUCTION/PROCESSING
Downhole heat and steam generation
Heavy oil production
Methane hydrate production
Cetane Sensor

OTHER
HYCO and hydrogen generation
Contaminant clean-up
Soil remediation
Power-to-Gas methanation
Material characterization
Alkane to Olefin Catalysis
Indoor Air Quality (IAQ) Control

CUSTOMERS

PRIVATE SECTOR

We work with numerous private customers, most under confidentiality.

FEDERAL AND STATE AGENCIES

- Department of War (DoW) (Army, Navy, Air Force, DARPA, Missile Defense Agency)
- Department of Energy (DOE), ARPA-E
- Environment Protection Agency (EPA)
- Federal Aviation Administration (FAA)
- National Aeronautics and Space Administration (NASA)
- National Science Foundation (NSF)
- United States Department of Agriculture (USDA)
- California Energy Commission

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